



**THE DIGITAL SIMULATION OF ATTACKING STRUCTURES
IN ACCORDANCE TO THE STANDARD LPS 1175 SET BY THE
LOSS PREVENTION CERTIFICATION BOARD (LPCB)**

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DECLARATION

“I, MELISSA H. AHMED, declare that this dissertation is my own work. Any section, part or phrasing of more than 20 consecutive words that is copied from any other work or publication has been clearly referenced at the point of use and also fully described in the reference section of this dissertation.”

“Signed

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ABSTRACT

Protecting critical parts of UK infrastructure resources from criminal or terrorist attack in the UK is an industrial sector which is rapidly expanding. In 2016 the UK Security sector grew by 17% and in the last five years, its turnover has doubled to £12.2 billion. There are 13 sectors of Critical National Infrastructure (CNI) that are included in the security sector, where there is a high regard for the protection of the assets within CNI. The National Infrastructure Delivery Plan, outlines details of £483 billion of investment in over 600 infrastructure projects and programmes in all sectors and spread across the UK, up to 2020-21 and beyond.

The development and successful certification of Loss Prevention Certification Board (LPCB) products, demonstrates their ability to resist physical attack for guaranteed periods of time. LPCB state that the failure rate on products submitted to them for testing is 95%, the development and testing of these new products has historically been undertaken using an iterative ‘by eye’ approach. Although this has clearly developed suitable products, the iterative approach of fabricate, test, improve, retest is inefficient and can be improved upon using digital techniques.

The aim of this thesis is to develop a new method in which to design and test new security products, so that the probability of new products passing an LPCB attack test is greatly increased through two key methods; The assimilation and interpretation of historic test data and the finite element analysis of proposed structures. This, in turn, leads to more highly engineered products that are quicker and more economical to design and develop.

A novel database that contains unique data related to the physical testing of the LPCB rated products has been proposed, created and implemented. This has shown that a saving of £10,000 could have benefitted the company on a single product with its implementation and an overall saving of £30,000 spread over a year with multiple product test regimes. This reduction in time and money spent testing individual products multiple times could also mean that the Company can have an increased capacity for the development of new products in a year. Equally a new digital workflow which is validated against a bespoke physical testing regime has been developed and implemented, which when combined with the database has led to reduced product development and increased efficiencies of product design.

This proposed methodology within the sector is unique and has generated interest from companies such as the Loss Prevention Certification Board. LPCB which is part of BRE Global, is commissioned by the BRE Trust, and wish to see the methodology rolled out across the sector.

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CHAPTER 1

1 INTRODUCTION

The demand for higher threat resistance in buildings increases at a rapid rate due to the security threats escalating around the world (Ross Technology, 2016). This was formerly a priority which was commonly found in diplomatic and military facilities but now it expands past just high-risk facilities, at critical infrastructure sites such as data centres, power generation plants and water supply facilities.

The United Kingdom's Critical National Infrastructure (CNI) is made up of thousands of networks, pipelines, roads etc. some of which are connected whilst others are isolated structures. The majority of the systems are dependent on the full functionality of one or more critical system to ensure of the delivery of services that are essential to the public (Leuven, 2011). It is noted that as people are reliant on the constant delivery of drinking water and the constant treatment of wastewater, these services need to be available 7 days a week and 24 hours a day, to ensure that communities are kept healthy and economically viable (Leuven, 2011). As water systems are vulnerable to a variety of threats, those occurring naturally and those caused by humans, growing concerns are now shifting to terrorists targeting the CNI as a substantial attack on a water system could result in widespread illness or fatalities.

Public and private organisations are pursuing to incorporate greater levels of building protection into their own physical security plans for commercial, financial and educational centres. The safety of buildings and their occupants has become a significant concern in virtually every building type since the 1995 bombings in Oklahoma City which has been exacerbated after the terrorist attacks of 2001 (Ross Technology, 2016).

This thesis focuses on the investigation and development of the digital simulation of attack testing structures and methods via physical means. These attack tests are carried out in accordance with the standards for attack testing, set up by the Loss Prevention Certification Board (LPCB).

The purpose of this thesis is to identify a more efficient method to design and test new security products, to increase the probability of them passing an LPCB attack test first time.

This will in turn lead to more highly engineered products which are both quicker and cheaper to design and develop.

The author will conduct background research into the protection of assets by physical means and provide an introduction and full breakdown of the LPCB attack testing process including the tools used and timings involved. The aim of this thesis is to replicate an LPCB attack test on a security product and independently validate the testing by another means before the LPCB testing.

1.1 AIM

The aim of this thesis is to create a design methodology that increases the likelihood of a new steel product passing a LPCB security attack at the first attempt.

1.2 OBJECTIVES

- To identify the need for the physical security of assets
- To conduct research into government standards
- To identify anti-vandal structure requirements and design approaches
- To create a literature review to provide an understanding of the current research in this field
- To determine the threats vs. security level of products
- To understand and document the LPCB testing procedure
- To determine if the properties of a material can be used to combat certain LPCB attack methodologies
- To research various methods to characterise material properties
- To conduct a variety of laboratory experiments to create a database of material properties
- To identify the possibility of creating linear models of laboratory testing using Finite Element Analysis (FEA)
- To perform stress analysis via computer simulation

- To perform displacement analysis via computer simulation
- To complete hand calculations to provide a comparison between the accuracy of the laboratory and software calculations
- To establish a design and development methodology for new products within the case study Company
- To test the proposed methodology
- To discuss the suitability of the proposed methodology and its general effectiveness, critically identifying any limitations or potential improvements.
- To conclude if there is a viable way to increase the success rate of LPCB testing prior to the commencement of actual testing
- To establish areas for further research and development

CHAPTER 2

2 MOTIVATION

The Critical Protection of National Infrastructure (CPNI) state that the threat from terrorism to the UK remains “real and serious” and considers that an attack could take place at any time (CPNI, Motivation within the Security Industry, 2012). Acts of terrorism typically vary in scale and purpose – some are intended for superficial damage, others cause public distress or aimed at drawing attention. All terrorist attacks, however, have the capacity to create mass devastation such as that caused by attacking a drinking water supply. Evidence suggests that whilst the nature of the threat is continually evolving, the environment is also developing with the introduction of new technologies, new processes, and new procedures (CPNI, Motivation within the Security Industry, 2012).

Conrath (1999) states that ‘A process is needed for determining how an attack can be carried out and with what tools, weapons and explosives.’ This links to the project that the author is carrying out in partnership with a security manufacturer called Technocover. The aim of this project is to work with the University of Salford and Technocover to create a methodology for digitally simulating attack tests. The methodology will enable predictions relating to the behaviours of future designs of products to be made, potentially reduce the amount of paid physical testing required. This will also allow Technocover to reduce not only their testing costs but also product development time and will facilitate the digital assessment of numerous attack strategies which retrospectively assess existing designs as new attack methodologies develop.

Technocover has been designing and manufacturing security access products since 1993 and achieve security certification through a 3rd party Company called the Loss Prevention Certification Board (LPCB).

In 2016, the physical security market projected to be \$67.89 billion, according to forecasts, and is expected to achieve \$126.56 billion by 2022 – this is an increase of 10.9% from 2016 to 2022 (Trent, 2017).

BRE Global (2017) state that there are over 11,500 security products and services certified by LPCB.

UK Water sets a world class standard in the approach it takes to water asset hardening (Technocover, 2018) from the upgrade of their service reservoir protection that was implemented in the late 1990's to the mature and sophisticated levels of security that are observed throughout modern infrastructure (Technocover, 2018). Technocover (2018) go on to say that there has been nothing less than a revolution in the water security product market which is dominated by LPCB certified equipment; ranging from security louvres and upstand covers to large security kiosks which are occasionally built offsite and craned into place.

Leuven (2011) explains that the most common threats to the water system can be grouped into 3 different categories.

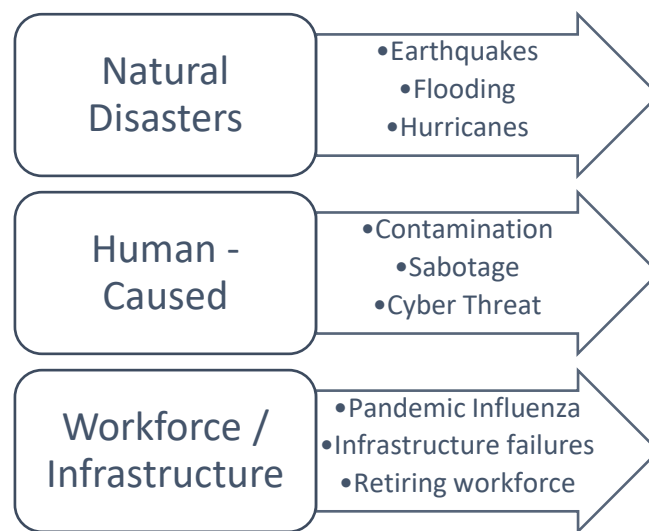


Figure 1 - Hazards and Threats¹

An additional £24 million is to be invested into counter-terrorism policing in the wake of the 2017 terror attacks (Home Office, 2017). This additional funding will be spent to reinforce protective security measures in congested places – this includes public protection from the specific threat of vehicles being used as weapons.

Miles (2017) explains that “approval to a robust security marque like LPCB (Loss Prevention Certification Board) provides an all-important assurance of physical performance”. He goes on to explain the LPCB process where security products are tested to the LPS 1175 security standard and classified according to their physical resistance to different levels of assault tools and durations of attack. LPCB provides a hierarchy of security ratings allowing specifiers to

¹ Leuven, L. J. (2011). Water/Wastewater Infrastructure Security. In R. Clark, S. Hakim, & A. (. Ostfeld, Handbook of Water and Wastewater Systems Protection (pp. 27-46). Springer Science & Business Media. Retrieved March 6, 2018, from <http://www.springer.com/978-1-4614-0188-9>

select solutions appropriate for the assessed risk of vandalism, theft, sabotage or criminal attack.

LPCB has been working in partnership with the government and industries for over 100 years, to establish the standards required to ensure that fire, security products and services perform successfully. The LPS 1175 standard sets out the testing procedures and requirements for LPCB approval and is applied to evaluate the resistance to unauthorised access proposed by various physical security products. Depending on the security level to be achieved LPCB produces physical attack tests linked to a testing time and tool category.

The costs and timescales associated with an LPCB test regime are significant and this project has exposed a gap in the test regime as it overlooks historic test results. The author explores the use of previous test data along with complex digital modelling which can be validated through real world testing, giving this project a unique and much needed relevance to the wider engineering community.

It is considered that there will be a high demand for this innovative project in the ‘security’ industry as the author aims to validate LPCB attack tests through analysis and digital simulation; this will benefit Technocover, as it increases the likelihood of new products passing the accreditation testing process first time without unnecessary over engineering.

2.1 ESTABLISHING MY CONTRIBUTION

Flint (2014) states that 95% of new products fail LPCB testing the first time they are assessed. These primary failures provide important, realistic information on how products can be made more effective through experiential testing and validation.

Collection and utilisation of the test data is valuable for a Company such as Technocover with access to vast amounts of information which could be used for the development of new products. Instead the Company relies highly on designers with tacit knowledge of LPCB testing to design new products.

Whilst this design process, which is driven by intuition, is clearly founded in practice, it is proposed that a more systematic and digitally-driven design process will likely reduce the time and costs associated with product development and ultimately align the design process to general engineering design best practice

CHAPTER 3

3 LITERATURE REVIEW

3.1 INTRODUCTION

This chapter explains the importance of physical security and sets out the reasons why it is required. Shaikh (2018) explains the two factors which affect product security: natural causes and man-made threats. Natural causes are naturally occurring phenomena such as floods, fire etc. Man-made threats are acts by malicious parties such as terrorism, vandalism and theft.

The research undertaken in this chapter explains how assets are typically assessed to establish the level of protection and security required. Various boards have created security standards and analysed the differences between them to understand and evaluate the security design process.

3.2 SECURITY

Physical security is the most vital aspect of protection. This is the use of physical controls to protect physical assets such as premises, sites, facilities and buildings. Physical security can be applied in the process of using layers which consist of physical protective measures which prevent unauthorised access, harm, or destruction of property. Physical security guards a property, plant, facility, building, office, and any or all their contents from loss or harm (Fennelly, 2013).

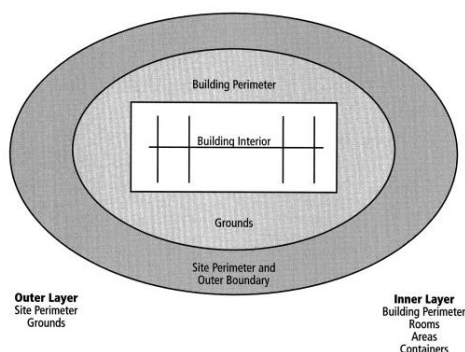


Figure 2 - Illustration of layers within a site, facility and building²

² Fennelly, L. J. (2013). Effective Physical Security (4th ed.). Butterworth-Heinemann.

Shaikh (2018) argues that there are fewer measures for physical security when compared to cyber security and that physical security is often overlooked by most organisations which tend to concentrate on the technical and administrative aspects of security.

Flint (2014) explains that criminals generally adopt an entrepreneurial approach investing more time and resources into gaining entry as the perceived returns increase. The primary function of physical security equipment is to delay an attack in order to allow detection and response in time to prevent a crime.

It is stated that 93% of large organisations and 87% of small businesses had a security breach in the last year (PWC, 2013). According to PWC, the number of security breaches in the UK continue to increase, with the rise being most noticeable for small businesses. The survey highlighted that companies are struggling to keep up to date with the security threats and implementations of cyber security.

Physical security is a set of security measures taken to ensure that access to equipment is restricted to authorised personnel, resources and other assets in a facility that these measures are laid out for (Thakkar, 2017). Organisations tend to apply a “copy and paste approach” in terms of physical security and choose to do what other organisations are doing to implement security – which typically overlooks their particularity and criticality. A risk-based security planning strategy is required to overcome this copy and paste tendency.

Over the last few years enterprises have been forced to embrace the fact that physical security and cybersecurity issues overlap (Ritchey, 2018). They also state that it is difficult to implement a converged security solution; physical and logical security systems are hard to integrate and are a costly and complex proposition.

Boon Edam Limited (2018) states that it is important to protect Company information but limiting access to a building can be just as effective in terms of the prevention of cybersecurity threats. Preventing unauthorised access to a building and the property within it can be simplified through the implementation of access products – this can act as entry deterrents. Using layering techniques when securing a building allows the integration of multiple levels of security which are typically applied sequentially from low to high. High security products such as security doors and portals as an entry solution control access to areas that demand absolute confidentiality and more common areas that must consider user movement and traffic times can incorporate lower security products.

This point is reiterated by Carney (2011), who states that several companies still treat physical and cyber security as separate systems from a device management and government agency perspective.

Carney advises companies to create appropriate security policies by

1. Understanding the level of security required
2. Identifying assets which need to be secured (physically and virtually)
3. Utilising available tools from a security and policy perspective
4. Allowing the network to handle the stresses of the tools

Fay & Patterson (2018) reference their security program as three major parts; people, process and physical security and use a chart to depict this.

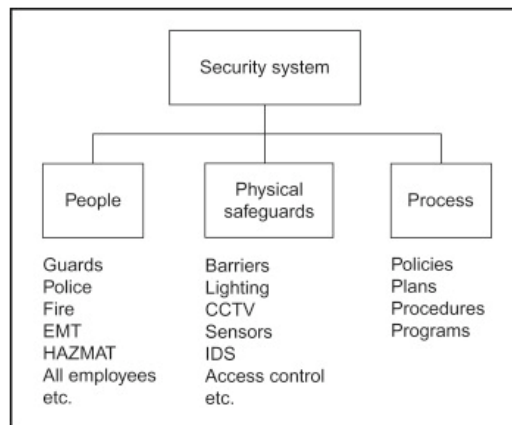


Figure 3 - The three pillars of a security program³

Threats to water security include physical attacks, cyber-attacks, damage due to natural disasters and accidents, and deliberate contamination caused by vandals and terrorists. Potential contaminants include biological, chemical, and radiological constituents that can result in illness or death in the exposed population (Jain, 2014).

Marshall, et al., (2007) explain that after the events of September 11th, a new outlook into physical security protection was ascertained for environments such as health and safety within a laboratory or a scientific research campus. They go to explain that, prior to September 11th, acts of terrorism targeted towards scientific research and testing institutions were largely sponsored by political action groups or individuals who wanted to widely publicise messages for example, relating to animal rights, environmental protection or other economic or

³ Fay, J. J., & Patterson, D. (2018). Contemporary Security Management (4th ed.).

religious crusades. Post September 11th, security programs include enhanced versions of the prior considerations, plus building hardening and chemical and biological attack protection.

There have been many terrorist attacks that have produced considerable interest among criminologists in the empirical study of violent political extremism (LaFree & Freilich, 2019). They go on to make the point that the general trajectory of research on governmental policies to counteract terrorism resembles the early years of criminology itself – this is characterised by “an amount of energy and imagination” but struggles to produce strong empirical data, sophisticated theoretical explanations and cutting-edge methods.

3.3 PROTECTING BUILDINGS

Construction sites are straightforward targets for an opportunist thief due to the high value of plant and equipment, which can lead to swift and easy profits for the successful thief (British Security Industry Association, 2012). It is added that protecting distribution systems is problematic because of the large, diffuse nature of the systems. This is due to the ease of public access (through the plumbing systems located inside buildings), and the fact that distribution systems occur downstream of treatment facilities (Jain, 2014). This makes the security of these systems a diverse and well thought out exercise.

The demand for higher threat resistance buildings increases as the security threats soar around the world (Ross Technology, 2016). Threat resistance was used mainly in diplomatic and military facilities but nowadays, this doesn't just extend to high risk facilities but to critical infrastructure such as data centres and generator plants. Both the public and private sector are seeking to integrate higher levels of building protection in their physical security plans.

Building security issues are about the detection and prevention of international threats; criminal, terrorist and other malicious acts directed towards the building and their occupants (Thiru, 2016). It is also stated that the most obvious protection is to prevent or delay an adversary from reaching a target.

Thiru (2016) explains that what is adopted for a specific building to avoid unauthorised access, delay penetration and delay time for response is generally based on the theory of a concentric layer of defence systems.

The first layer of defence can take the form of:

- Walls
- Fences
- Guard houses
- Electronic detection devices
- Surveillance cameras

The second layer of defence is between the perimeter of the site and the building envelope where it is noted that passive barriers are provided to prevent vehicle penetration. The third layer of defence is the building envelope comprising of the walls, roofs, doors and windows. This envelope must be able to withstand assaults by an intruder who has overcome the previous layers of defence and as such, there should be hardened protection – particularly to doors (Thiru, 2016). A real-life application is shown in Figure 4.

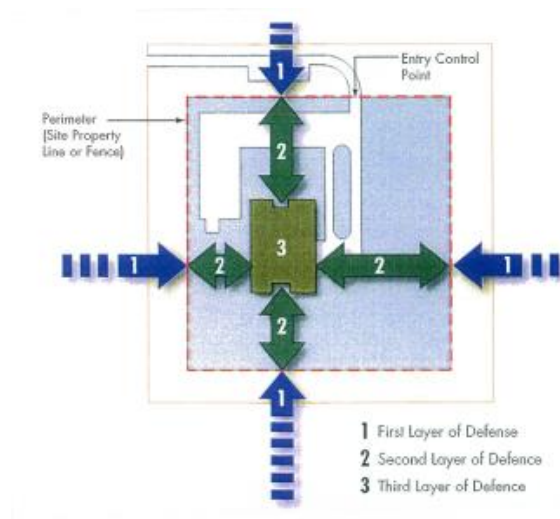


Figure 4 - Defence layers⁴

Thiru (2016) studied a few terrorist attacks and analysed the failure of the security designs to show how crucial designing a building can be in the future.

In the Oklahoma 1995 bombings, Thiru (2016) states that the first layer of defence was inadequate, and no measures were taken to provide a second layer of defence. The third layer of defence lacked redundancy in the structural system.

⁴ Thiru, S. (2016, June). Structural design for the physical security of buildings against blast. Transport Asset Standards Authority.

In the 1996 Arndale centre bomb attacks in Manchester, the first layer of defence was insufficient, no measures were taken to provide a second layer of defence and the third layer of defence was inadequate as the building envelope failed (Thiru, 2016).

Ross Technology (2016) describes the three main physical threats to building security

1. Blast threats – explosive events that can cause widespread primary and secondary damage
2. Ballistic threats – damage from projectiles fired using firearms
3. Forced entry – attack on a structure by mobs or other intruders

BLAST RESISTANCE

Ross Technology (2016) states that incendiary devices and explosives were the most common weapons used in more than 280 terrorist attacks in the United States between 2001 and 2014. Tragically these devices have also become almost commonplace in other parts of the world.

Physical testing for blast resistance can be expensive and complex requiring multiple samples and specialist equipment. To provide high levels of protection against high blast levels, all architectural features of the building must be hardened. This is accomplished by using sophisticated laminate systems in door and window systems in which the glass absorbs the energy and polycarbonate layers and coatings provide flexure and protection (Ross Technology, 2016).

There is a limited body of design documentation currently in existence containing the relevant technical data which engineers can use to design building structures with enhanced security (Thiru, 2016). As the effects of terrorist attacks are catastrophic at worst, it is prudent to incorporate measures to minimise business interruption but more importantly, that may save lives.

BALLISTIC THREATS

The ballistic threat is a projectile fired from a weapon, which results in the full or partial penetration of materials. The goal of a ballistic attack is to kill or incapacitate occupants or damage structures and equipment (Ross Technology, 2016).

Blast and ballistic methodologies were analysed to understand the differences within the physical security industry and how they compare to physical attack tests. The complexity of

blast testing is far different to the physical attack testing; instead of analysing tools blast and ballistic weapons are analysed, both of which do not share the same methodical analysis.

3.3.1 FORCED ENTRY

The technical definition of a forced-entry threat is an attack by personnel using a range of tools and methods to penetrate the protective covering of a facility. The range of motives can be as wide and as varied as the tools used: to make a statement, to obtain sensitive or valuable materials, to create damage, or to cause injury to personnel (Ross Technology, 2016). Ross Technology (2016) goes on to say that the level of protection is typically measured in terms of the delay time the product provides before an opening of defined size and/or shape is created. This delay can provide time for the destruction of documents, time for people to move to more secure locations, or time for response by local authorities.

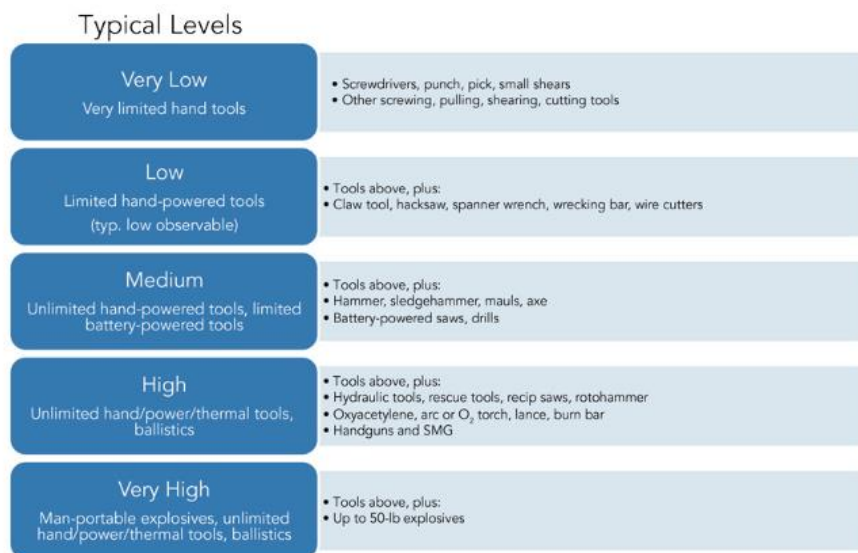


Figure 5 - Forced Entry Threat Severity Matrix⁵

The Forced Entry Threat Resistance Diagram shows the levels of protection correlated to the delay time provided until a specific-size opening is created, as required by five different major standards (Ross Technology, 2016).

⁵ Ross Technology (2016, December). Design to Protect, Fenestration systems for extreme threat resistance. Architectural Record.

Forced Entry Threat Resistance Diagram
 LEVEL OF PROTECTION (LOP):
 Delay time until specific-size opening is created

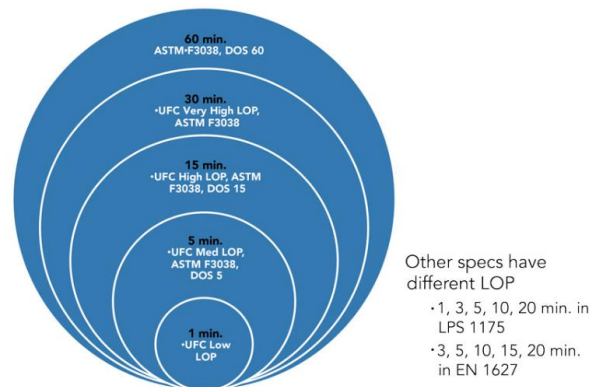


Figure 6 - Delay time⁶

3.4 DESIGN STRATEGY

Jain (2014) states that water distribution systems are inherently vulnerable to attack, given the extensive and public nature of these systems from the source to the consumer. All aspects of the water supply, treatment, and distribution system are vulnerable to attack, necessitating protection at all levels, as if any of these systems are compromised, an essential part of the water system may be eliminated.

Fennelly (2013) explain the concept maximum security and that physical barriers, alarm systems, guard forces, and various other parts of a security system do not independently achieve maximum security. The parts of the system cannot realise the overall aim unless they are joined in the right proportions (Fennelly, 2013).

Hutter (2016) states that a ‘layered approach’ is the best strategy to defend an organisation’s assets. This is due to an attacker finding it harder to reach their goal when there are many layers that need to be bypassed to access a resource. Security professionals that have physical security in mind, are concerned about the physical entrance of a building or environment and what damage may be caused. Oriyano (2017) agrees, adding that by using the approach “Defence in depth” by adopting multiple security controls, it is more difficult for attackers to gain access to valuable Company resources.

⁶Thiru, S. (2016, June). Structural design for the physical security of buildings against blast. Transport Asset Standards Authority.

Contemporary approaches to security and security zoning must also contemplate the presence of threats, which can be shown against information technology infrastructures once physical access has been acquired within a security zone (Coole, Corkill, & Woodward, 2012). They add that, Security in Depth for an organisation or facility is the sum of all security layers, physical and logical which stand between an adversary and a protected target and is therefore separate rather than synonymous to, Defence in Depth.

Fennelly (2013) created a breakdown of security levels to address confusion around the lack of standards surrounding physical security. He believes that individuals are deluded about the protection that they are providing themselves.

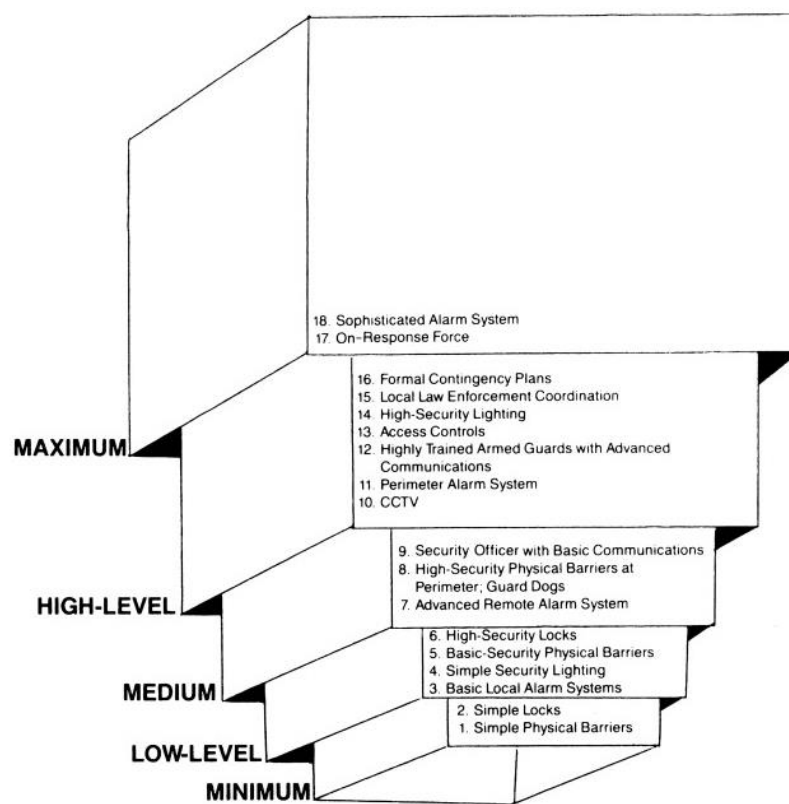


Figure 7 - The levels of physical security⁷

He then goes on to break down the components into 4 categories; impede, detect, assess and neutralize (Fennelly, 2013).

Looking at the components to impede, the physical barriers refer to the building envelope and perimeter which are the two most outer layers of a protection system. This section focuses on delaying attackers from penetrating the building, which is achieved by investing in locks and

⁷Fennelly, L. J. (2013). Effective Physical Security (4th ed.). Butterworth-Heinemann.

access controls. Additional support in the form of security personnel, manning levels and security training would reduce the risk of gaining unauthorised access into a building.

Physical Barriers	Locks
Perimeter fence	Perimeter fence
High-security doors	Openings
High-security windows	Designated doors
Vault	
Security Force	Access Controls
Manning levels	Protected areas
Training	Vital areas
	Equipment

Figure 8 - Components to Impede⁸

The components required for assessing are broken down into three categories; lighting, communications and CCTV.

Lighting	Communications	CCTV
Perimeter	On-site	Perimeter
Protected areas	Off-site	Protected areas
Vital areas		Vital areas

Figure 9 - Components to Assess⁸

Fennelly (2013) designed a way to choose components to make up the maximum-security system and develop a design-reference threat which, in his opinion, is the most cost-effective design strategy.

⁸ Fennelly, L. J. (2013). Effective Physical Security (4th ed.). Butterworth-Heinemann.

Security Force	Response Force	LLEA Coordination
Manning levels	Manning levels	Contingency planning
Training	Training	Training drills
Equipment	Equipment	

Figure 10 - Components to Neutralise⁹

3.5 ATTACK TESTING

An investigation into the different forms of physical attack testing was undertaken to understand the market and potential variants. All the known standards have been evaluated to identify the most effective physical attack standard to comply with such that the security products designed can withstand the most up to date methods of physical attack.

3.5.1 CPNI

CPNI evaluates security products for the Critical National Infrastructure and the Government, which is undertaken by test houses. Following completion of the testing and an assessment of the results, successful products are awarded a grading which can be either a class or protection (CPNI, 2016). The products assessed are for use in high security environments and the testing reflects this. The two classes of products which are classified as CPNI rated are explained in more detail below.

CLASS

This class rating is given to a product with characteristics that defend against surreptitious attack – i.e. gaining access to classified materials for nefarious reasons without leaving a trace of the attack. The importance of a CLASS product is detection, compromise or tamper indication as it is possible to have a product with a class rating but not being able to provide any protection against forcible attack (CPNI, 2016).

CPNI (2016) explains the numerous ways in which to achieve a Class rating:

- Make a product capable of auditing its use
- Make an anti-tamper product
- Design a long-standing (in terms of attack time) product
- High level detection or performance

⁹ Fennelly, L. J. (2013). Effective Physical Security (4th ed.). Butterworth-Heinemann.

The class grades are described below by CPNI (2016) but state that the grades are not for public knowledge, so companies are not allowed to publicise their class rating or indicate that a product has been assigned one.

- Class 1 – LOWEST
- Class 2
- Class 3
- Class 4 – HIGHEST

PROTECTION

CPNI (2016) explains that the PROTECTION level of a product demonstrates resistance to forced attack based on a perceived skill of an attacker and time to resist the attack. These products will try and prevent terrorist attacks which seek to defeat the product and gain entry. There are three levels of protection; base, enhanced and high and the emphasis is mainly on delaying an attack.

The differences between both levels are shown in Figure 11.

	CLASS	PROTECTION
Speed	May be slow Could take many months (but not necessarily)	As fast as possible
Key principle	Detection	Delay
	Possibly NO delay	Speed of response is important

Figure 11 - Comparison of class and protection levels¹⁰

CPNI (2016) explains that the focus of these levels is to use both to layer the security; class level products keep things in (defending against espionage attacks) and protection level products keep people out (defending against terrorist attacks). The required solution is found by combining the two.

3.5.2 EN 1627/28/29/30 STANDARD

There are two aspects to the burglar-resistance performance of construction products; their normal resistance to forced operations and their ability to remain fixed to the building (The British Standards Institute, 2015). With EN 1627 the methodology tests the integrity of the products by aiming to lever open the specimen or make an accessible opening by targeting

¹⁰ CPNI. (2016). The CPNI Product Rating System. Crown.

identified weak and vulnerable areas of the specimen within the resistance time and total test time for the resistance class.

It is classed as a failed test if an opening of the sizes below can be created (The British Standards Institute, 2015).

- E1 – Rectangular 400mm \pm 2mm x 250mm \pm 2mm
- E2 – Ellipse 400mm \pm 2mm x 300mm \pm 2mm
- E3 – Circle of diameter 350mm \pm 2mm

3.5.2.1 TOOL ANALYSIS

The tool analysis provides a breakdown of the anticipated methods of attack and resistance class against the tools specified in the tool category.

A1 TOOL CATEGORY

This tool category is in reference to the casual burglar attempting to gain entry using small and simple tools and physical violence – this could be kicking, tearing out and lifting. Typically for this tool category, the burglar attempts to take advantage of opportunities and has no knowledge of the level of resistance offered by the construction of the product but is concerned about the times and noise involved in the attack.

		Tool No.
1	Multiple slip joint gripping pliers; maximum length 260 mm	1.1
1	Screwdriver; Flat blade, total length (260 ± 20) mm, shaft diameter of (8 ± 2.2) mm and blade width (10 ± 1.2) mm	1.2
1	Set of small screwdrivers; maximum length 250 mm, maximum shaft diameter 8 mm. Typical blade forms as shown in Figure A.1.	1.3
	Hexagonal allen keys; maximum length 120 mm. Blade forms as shown in Figure A.1.	1.4
	Spanners; maximum length 180 mm	1.5
1	Pliers; maximum length 200 mm. Typical plier forms are shown in Figure A.1.	1.6
1	Tweezer	1.7
1	Knife; maximum length of blade 120 mm, thickness of blade max. 3 mm. The blade shall not be serrated.	1.8
1	Torch	1.9
	Hooks; Various shapes and sizes, maximum diameter 4 mm. Hooks may be shaped with relevant tool-set.	1.10
	Steel wire; Various diameters up to a maximum diameter of 4 mm.	1.11
		Tool No.
	including steel and electrical wire. No restriction on length.	
	Adhesive tape	1.12
	String; Various diameters and types, including rope, cord and laundry line. The material shall not be elasticated. No restriction on length.	1.13
1	Rubber hammer; Hardness (90 ± 10) shore; head weight (100 ± 20) g, total weight (145 ± 20) g, length (260 ± 20) mm	1.14
1	Universal lock key; including cabinet lock and profile cylinder functions. Typical keys are shown in Figure A.1.	1.15

Figure 12 - A1 Tool Category¹¹

A2 TOOL CATEGORY

Simple tools are used in this category excluding mechanical drilling. In this type of attack the burglar intends to take low risks and typically has no understanding of the level of protection associated with the product.

	Tool set A1 plus the following	Tool No.
1	1 Screwdriver; Flat blade, length (365 ± 25) mm, blade width (16 ± 2.2) mm	2.1
1	1 Pipe wrench; length (240 ± 20) mm	2.2
2	Plastic wedges; length (200 ± 25) mm, width (80 ± 10) mm, height (40 ± 5) mm	2.3
2	Wood wedges; length (200 ± 25) mm, width (80 ± 10) mm, height (40 ± 5) mm	2.4
1	Compass saw; with two bimetal or HSS blades, total length (310 ± 25) mm	2.5
1	Pad saw; with two bimetal or HSS blades, total length (310 ± 25) mm	2.6
1	Hacksaw, with two bimetal or HSS blades, blade length (330 ± 30) mm	2.7
1	Steel extension tube, length (500 ± 5) mm, outer diameter (30 ± 0.5) mm, maximum wall thickness (3 ± 0.3) mm	2.8

Figure 13 - A2 Tool Category¹²

¹¹ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

¹² The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

A3 TOOL CATEGORY

The use of a crowbar increases the forces that can be used to attack the product and the drilling tool allows the burglar to attack the locking device, making the associated risks for the burglar medium risk.

	Tool set A2 plus the following	Tool No.
1	Screwdriver; Flat blade, length (365 ± 25) mm, blade width (16 ± 2,2) mm	3.1
1	Crowbar; length (700 ± 20) mm	3.2
1	Locksmiths hammer; head weight (200 ± 20) g, length (300 ± 20) mm	3.3
1	Set of pin punches; diameters between 3 mm and 10 mm	3.4
1	Hand drill; maximum length 355 mm	3.5
1	Set of drill-bits; HSS or HS/CO parallel shank twist drills (jobber), Ø 1,0 mm to Ø 6 mm in steps of 0,5 mm. Only one drill bit of each diameter may be used.	3.6

Figure 14 - A3 Tool Category¹³

A4 TOOL CATEGORY

This tool category refers to a practised burglar, and incorporates tools such as a heavy hammer, axe, chisels and a portable battery powered drill which increases the number of attack methods. The reward from this kind of attack is reasonable with increased risks taken by the burglar.

	Tool set A3 plus the following	Tool No.
1	Club hammer; length (300 ± 25) mm , head weight (1,25 ± 0,1) kg	4.1
1	Cold chisel; length (250 ± 25) mm, blade width (30 ± 5) mm	4.2
1	Wood chisel; length (350 ± 25) mm, blade width (30 ± 5) mm	4.3
2	Plate shears; left cutting and right cutting, length (260 ± 25) mm	4.4
1	Axe; length (350 ± 25) mm, head weight (800 ± 30) g	4.5
1	Bolt-cutter; length (460 ± 50) mm	4.6
1	1 Cordless drilling machine; Without percussion action, with two nominal 14.4 V battery packs (up to 3,2 Ah each)	4.7
1	Set of drill-bits; HSS or HS/CO parallel shank twist drills (jobber), Ø 1.0 mm to Ø 13 mm in steps of 0,5 mm. Only one drill bit of each diameter may be used.	4.7.1

Figure 15 - A4 Tool Category¹⁴

¹³ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

¹⁴ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

A5 TOOL CATEGORY

This tool category is associated with attacks by an experienced burglar using electric tools especially the angle grinder which increases the range of attacks used to penetrate the product. This attacker is prepared to take a high risk and typically has no regard for the noise level associated with the attack.

	Tool set A4 plus the following	Tool No.
1	Electric drill; nominal 650 W \pm 10 %, with percussion action	5.1
1	Set of drill-bits; HSS or HS/CO parallel shank twist drills (jobber), \varnothing 1.0 mm to \varnothing 13 mm in steps of 0.5 mm. The maximum number of drill bits is not restricted.	5.1.1
1	Set of drill-bits; carbide tips parallel shank twist drills (jobber), \varnothing 3,0 mm to \varnothing 13 mm in steps of 1,0 mm. Maximum of two drill bits of each diameter may be used.	5.1.2
1	Set of core drills; HSS, HS/CO, carbide, \varnothing 50 mm max	5.1.3
1	Electric sabre saw; nominal 1 100 W \pm 10 %	5.2
5	Saw blades; bimetal	5.2.1
1	Electric jig saw; nominal 650 W \pm 10 %	5.3
5	Saw blades; bi-metal	5.3.1
1	Angle grinder; nominal 1 100 W \pm 10 %	5.4
3	Discs; nominal \varnothing 125 mm, thickness 2,5 mm (for steel or stone excluding diamond)	5.4.1

Figure 16 - A5 Tool Category¹⁵

A6 TOOL CATEGORY

This last tool category is the highest one and is associated with experienced burglars due to the high level of risk associated with the attack. The tools in this category are capable of being operated by a single person, are very effective and have a high level of performance.

	Tool set A5 plus the following	Tool No.
1	Electric drill; Nominal 1050 W \pm 10 %, with percussion action	6.1
1	Angle grinder; Nominal 2300 W \pm 10 %, disc diameter max 230 mm	6.2
4	Discs; \varnothing 230 mm maxi, thickness 3,0 mm (for steel or stone excluding diamond)	6.2.1
1	Spalling hammer; length (800 \pm 50) mm, head weight (3,5 \pm 0,25) kg	6.3
2	Steel wedges; length (200 \pm 10) mm, width (80 \pm 10) mm, height (40 \pm 5) mm	6.4

Figure 17 - A6 Tool Category¹⁶

¹⁵ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

¹⁶ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

3.5.2.2 STATIC LOADING

The static loading tables for the relevant resistance classes are shown below.

	Resistance class (RC)											
	1, 2			3			4			5, 6		
	Test load	Gap gauge	Pressure pad	Test load	Gap gauge	Pressure pad	Test load	Gap gauge	Pressure pad	Test load	Gap gauge	Pressure pad
Loading points	kN	Type	kN	Type	Type	kN	Type	Type	kN	Type	Type	
F1 Corner of infilling	3	B	1	6	B ¹	1	10	B	1	15	B	1
F2 Leaf and casement corners	1,5	B	1 or 2	3	B	1 or 2	6	B	1 or 2	10	B	1 or 2
F3 Locking Points	3	A	1 or 2	6	A	1 or 2	10	A	1 or 2	15	A	1 or 2
F3.a Group 1 ^a products Locking Points (additional loadings)	1,5	A	–	–	–	–	–	–	–	–	–	–
F3 Group 2 products Lift up (additional loadings)	3	A	1 or 2	6	A	1 or 2	10	A	1 or 2	15	A	1 or 2

^a Resistance class 1 product only.

Figure 18 - Static load for Group 1 and Group 2 products¹⁷

	Resistance class (RC)											
	1, 2			3			4			5, 6		
	Test load	Limiting value	Pressure pad	Test load	Limiting value	Pressure pad	Test load	Limiting value	Pressure pad	Test load	Limiting value	Pressure pad
Loading points	kN	mm	Type	kN	mm	Type	kN	mm	Type	kN	mm	Type
F1.1 Guide rail deflection test	3	30 ^a	4	6	30 ^a	4	10	30 ^a	4	15	30 ^a	4
F3 Curtain lift test	3	C ^c	1 or 2	6	C ^c	1 or 2	10	C ^c	1 or 2	15	C ^c	1 or 2
F2 Lath engagement test	1,5	10	1 or 2	3	10	1 or 2	6	10	1 or 2	10	10	1 or 2
F1 Static test on guide rail and curtain	3	10 ^b	3	6	10 ^b	3	10	10 ^b	3	15	10 ^b	3

^a Maximum allowable deflection of the loaded leg of the guide rail is 30°. The determination of the angle is described in EN 1623.
^b Minimum depth of penetration under static load.
^c Checked by means of gap gauge type C.

Figure 19 - Static loading for Group 3 products¹⁸

¹⁷ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

¹⁸ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

	Resistance class (RC)											
	1, 2			3			4			5, 6		
	Test Load	Gap gauge	Pressure pad	Test Load	Gap gauge	Pressure pad	Test Load	Gap gauge	Pressure pad	Test Load	Gap gauge	Pressure pad
Loading points	kN	mm	Type	kN	mm	Type	kN	mm	Type	kN	mm	Type
F2.1 Between two fixing points	1,5	D	5	3	D	5	6	D	5	10	D	5
F2.2 Loading between two junction points	1,5	D	5	3	D	5	6	D	5	10	D	5
F3 Locking points	3	D	1 or 2	6	D	1 or 2	10	D	1 or 2	15	D	1 or 2
F3.1 Fixing point between grille and masonry	3	D	5	6	D	5	10	D	5	15	D	5
F1 Static test on guide rail and curtain or two adjacent grille bars at a junction point	3	D	5	6	D	5	10	D	5	15	D	5
F1.1 Guide rail deflection test load	3	30 ^a	4	6	30 ^a	4	10	30 ^a	4	15	30 ^a	4
F3.2 Curtain lift test	3	D	1 or 2	6	D	1 or 2	10	D	1 or 2	15	D	1 or 2
F2.3 Drawing the grille curtain out of the guide rail	1,5	D	1 or 2	3	D	1 or 2	6	D	1 or 2	10	D	1 or 2

^a Maximum allowable deflection of the loaded leg of the guide rail is 30°. The determination of the angle is described in [EN 1623](#).

Figure 20 - Static loading for Group 4 products¹⁹

3.5.2.3 DYNAMIC LOADING

The dynamic loading table is shown in Figure 21.

Resistance class (RC)	Mass of the impactor kg	Drop height mm
1	50	450
2	50	450
3	50	750
4 - 6	no dynamic test is required	

Figure 21 - Drop height for dynamic test²⁰

3.5.2.4 RESISTANCE CLASSES

The breakdown of resistance classes for the EN standard is shown in Table 1. This explains the resistance from a casual burglar to a terrorist who has no regard for noise or damage when gaining entry.

¹⁹ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

²⁰ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

Table 1 - Resistance Class Table²¹

Resistance class	Anticipated method and attempts to gaining entry
1	The casual burglar attempts to gain entry using small simple tools and physical violence e.g. kicking, shoulder charging, lifting up, tearing out. The burglar typically attempts to take advantage of opportunities, has no specific information on the level of resistance offered by the construction product and is concerned with both time and noise. No specific knowledge of the likely rewards is anticipated and the level of risk the burglar is willing to take is low.
2	The casual burglar additionally attempts to gain entry using simple tools e.g. screwdriver, pliers, wedge and in the case or grilles and exposed hinges the use of small handsaws. Mechanical drilling tools are not associated with this level of burglar as a result of the use of drill resistant cylinders. The burglar typically attempts to take advantage of opportunities, has little knowledge of the likely level of resistance and is concerned with both time and noise. No specific knowledge of the likely rewards is anticipated and the level of risk the burglar is willing to take is low.
3	The burglar attempts to gain entry using a crow bar, an additional screwdriver and hand tools such as a small hammer, pin punches and a mechanical drilling tool. With the use of the crow bar the burglar has the opportunity to apply increased forces. With the drilling tool the burglar is able to attacked vulnerable locking devices. The burglar typically attempts to take advantage of opportunities, has some knowledge of the likely level of resistance and is concerned with both time and noise. No specific knowledge of the likely rewards is anticipated and level of risk the burglar is willing to take is medium.
4	The practised burglar uses in addition, a heavy hammer, axe, chisels and a portable battery powered drill. The heavy hammer, axe and drill give the burglar an increased number of attack methods. The burglar anticipates a reasonable reward and is likely to be resolute in his efforts to gain entry. He is also less concerned with the level of noise he produces and is prepared to take a greater risk.
5	The experienced burglar uses in addition electric tools e.g. drills, jig- and sabre saw, and an angle grinder with a disc of max. 125 mm diameter. The use of the angle grinder further expands the range of attack methods likely to be successful. The burglar anticipates a reasonable reward, is resolute in his efforts to gain entry and is well organised. He also has little concerned for the level of noise he generates and is prepared to take a high level of risk.
6	The experienced burglar uses in addition spalling hammer, powerful electric tools, e.g. drills, jig- and sabre saw, and an angle grinder with a disc of max. 230 mm diameter. The tools are capable of being operated by a single person, have a high level of performance and are potentially very effective. The burglar anticipates a good level of reward, is resolute in his efforts to gain entry and is very well organised. He also has no concerned for the level of noise he generates and is prepared to take a high level of risk.

RESISTANCE CLASSES 1 TO 3

The British Standards Institute (2011) explain that Classes 1, 2 and 3 deliver the levels of attack which are generally associated with a casual or opportunist burglar. These attacks are the result of an opportunist who attacks with no regard to the reward that success may bring. The level of force used is therefore not excessive and the tools used are more common (hand tools and levers). This kind of burglaries is likely to avoid noise and unnecessary risk. As risk is associated with time, the time period spent attempting to gain entry is limited and this kind of attack on a high-level resistance structure would often result in an aborted attack.

RESISTANCE CLASSES 4 TO 6

The British Standards Institute (2011) states that resistance classes 4, 5 and 6 are related to more experienced burglars with a greater knowledge of the likely reward that success may

²¹ The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

bring. It is also noted that noise and time are both not issues for this type of attacker. The tools included in this resistance class are powerful, single-operator power tools and there is a high likelihood that organised criminals are involved.

TOOLS SETS AND RESISTANCE TIMES

Figure 22 shows the resistance times and maximum test times of tool sets within the resistance classes.

Resistance class (RC)	Tool set (see EN 1630: 2011, Clause 7)	Resistance time min	Maximum total test time min
1	A1	–	–
2	A2	3	15
3	A3	5	20
4	A4	10	30
5	A5	15	40
6	A6	20	50

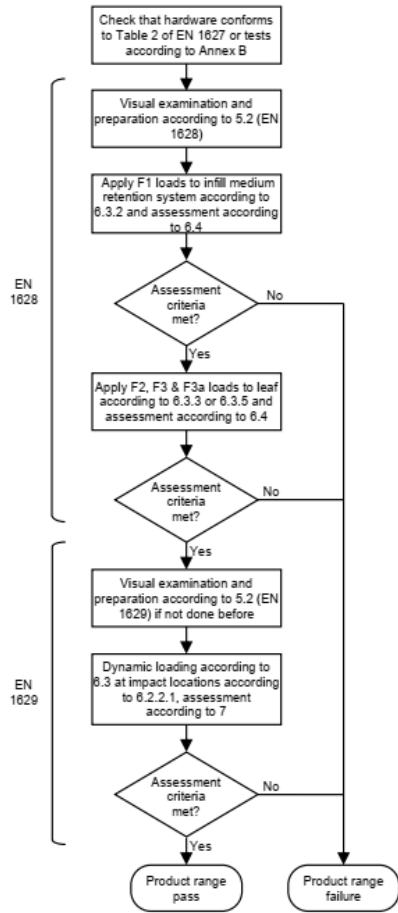
Figure 22 - Tool Sets and Resistance Times²²

3.5.2.5 PROCEDURE FOR TESTING AND CLASSIFICATION

The testing procedure for the methodology detailing the pre-tests and main tests is shown in Figure 23. The test methodologies are broken down into resistance classes ranging from (low) R1 to (high) R4+.

²² The British Standards Institute. (2011). BS EN 1627:2011 Pedestrian doorsets, windows, curtain walling, grilles and shutters. Burglar resistance. Requirements and classification. BSI Standards Limited.

EN 1627 – EN 1630 – RC 1



EN 1627 – EN 1630 – RC 2 and 3

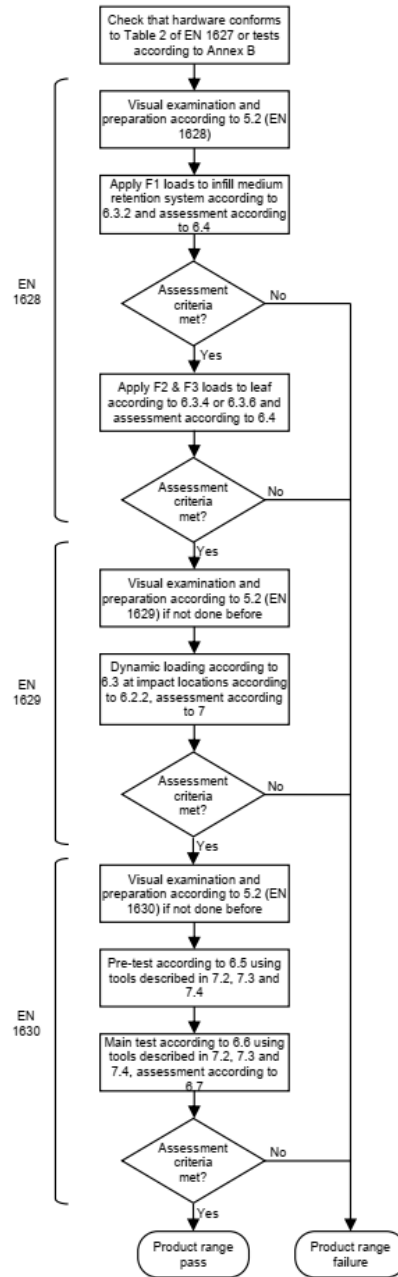


Figure 23 - Testing and classification for burglar resisting elements²³

²³ Secured by Design, U. (2013). Interpretive document for BS EN 1627 to 1630 Draft Issue 67.0. ACPO.

EN 1627 – EN 1630 – RC 4+

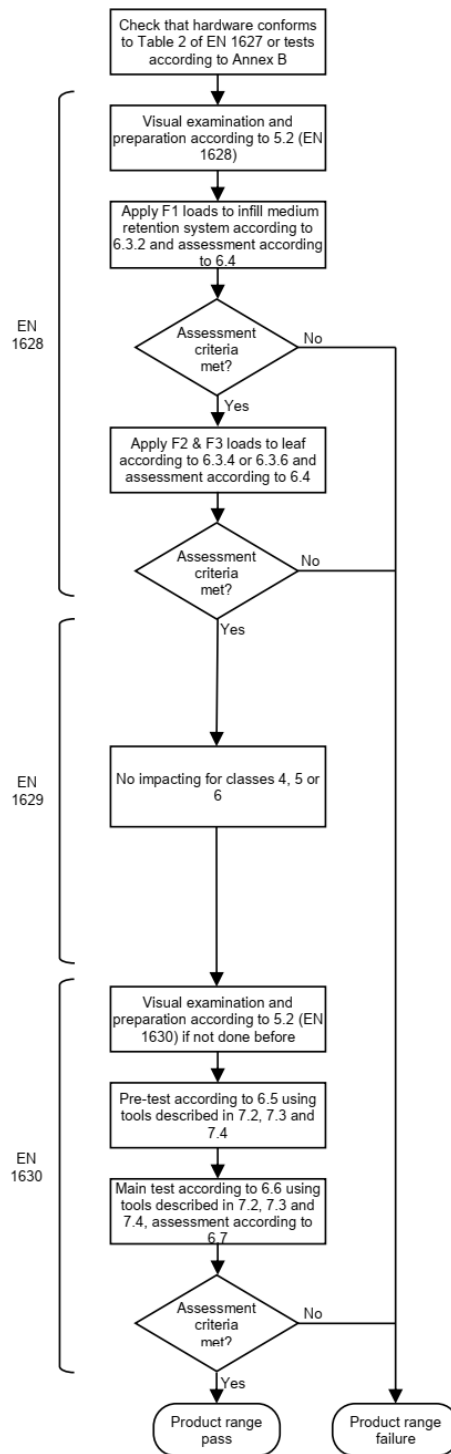


Figure 24 - RC4+ Test Methodology²⁴

²⁴ Secured by Design, U. (2013). Interpretive document for BS EN 1627 to 1630 Draft Issue 67.0. ACPO.

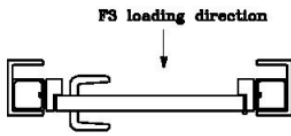
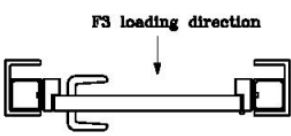
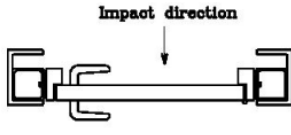
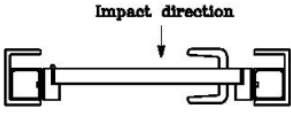
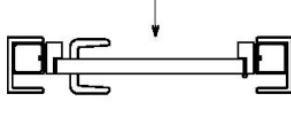
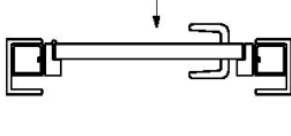
	Inward opening Group 1 products	Outward opening Group 1 products
Installation for EN 1628 tests		
Installation for EN 1629 tests		
Installation for EN 1630 tests		

Figure 25 - Orientation of test specimen within test rig²⁵

3.6 BRE & LPCB

The Loss Prevention Certification Board (LPCB) is part of the Building Research Establishment (BRE) group and is a UK-based organisation which is responsible for technical approvals and testing of products under Building Regulations, Construction Products Directive and other European legislation (Plant, 2017).

The BRE Group is an international, multi-disciplinary building science organisation which overall mission is to improve the built environment through research and knowledge generation and their application. BRE Global limited is an independent third-party certification board for fire, security and sustainable products and services (BRE Global, RJF2945 Revision 0.7, 2018). They are a custodian of several world-leading brands including

- LPCB for the certification of fire and security products and services
- BREEAM for the world's leading environmental assessment method for buildings

²⁵ Secured by Design, U. (2013). Interpretive document for BS EN 1627 to 1630 Draft Issue 67.0. ACPO.

- SABRE for security assessment and certification schemes for buildings, infrastructure and managed space

Plant (2017) states that the requirements to prevent incursions on airside areas increase as terror threats continue to rise globally. He explains that sadly the world is one where our security measures are never going to decrease, and it would be a mistake not to increase them in line with requirements and review new and existing physical perimeter products.

3.6.1 LPS 1175 STANDARD

LPS 1175 was first published over 25 years ago with the intention of providing UK insurers with a means to verify the delay to forced entry provided by physical security equipment. The standard has since become widely used by regulators and specifiers around the world. It is predominantly used to address current and emerging threats of manual forced entry which are faced across a variety of sectors and situations. The standard covers a broad scope of tools and attack methods in use by criminals, terrorists and other hostile actors wishing to access a protected asset or space (BRE Global, RJF2945 Revision 0.7, 2018).

LPS 1175 is continually being reviewed and adapted to address developing and emerging threats due to the increasingly effective scope of tools available to hostile actors and the diverse range of entry methods which may be employed. This has resulted in the standard being reissued several times since its first publication and means that it continues to provide an effective way of measuring a product's resistance to manual forced entry (BRE Global, RJF2945 Revision 0.7, 2018).

Management (2016) explain the differences in the physical security standard (LPS 1175) compared to other standards.

- Can be applied to all layers of protection from the perimeter to the core
- Considers the whole product or system in a holistic manner
- Assumes the intruder is willing to make noise while attempting entry on the basis they are likely to assume they have already been detected
- Is free to access and download
- Is an approval standard; requiring claims of compliance to be supported by third party approval. That approval involves a programme of surveillance audits.

The criteria listed above ensure that the factors affecting a product's performance, such as its design and quality, do not change in a detrimental way.

BRE Global (2018) states that 95% of products that are submitted to LPCB for physical testing fail to achieve their manufacturer's target security rating. By obtaining approval to the LPS 1175 standard, the manufacturer can demonstrate the product's resistance to manual attack and their investment in achieving and maintaining a product capable of delivering that level of protection.

Historically, standards for forced entry protection used around the world have well-defined performance classification systems. These assume that there is a linear relationship between the size and scope of tools, and the duration and severity of the attacks by hostile actors who are willing to successfully complete an attack based on their perceived reward (BRE Global, RJF2945 Revision 0.7, 2018).

However, it has been increasingly evident that a hostile actor's tool choice depends not only on their perceived value (in terms of return on investment in conducting the attack) but also on the environment in which they plan to conduct their attack and how quickly they wish to complete the attack (due to their perception of the likely response and other risks presented) (BRE Global, RJF2945 Revision 0.7, 2018).

3.6.2 CLASSIFICATION

The LPS 1175 standard details the tool category and maximum working and test times for each security rating. The standard specifies eight grades of security based on the tools likely to be used by a criminal and attack times (BRE Global, LPS 1175: Issue 7.2, 2014).

Table 2 – Security rating requirements for each manual intervention attack test²⁶

Security rating classification	Tool category	Maximum working time (minutes)	Maximum test duration (minutes)
1	A	1	10
2	B	3	15
3	C	5	20
4	D	10	30
5	D+	10	30
6	E	10	30
7	F	10	30
8	G	20	60

3.6.3 TOOLS

Table 3 details how the LPS 1175 standard breaks down the tools available to test attackers into 8 categories which increase in range and potency from tweezers in category A to an oxyacetylene cutting kit in category G. This broad range of tools aligns to the intended attacker and their level of experience. Due this vast range each security level has prescribed tool categories available during the attack test process, the higher the security rating the higher the tool category.

Table 3 - Tool Category Aim's²⁶

Tool Category	Description
A	The tools of this category are selected to simulate an opportunist attack by bodily physical force and by stealth using minimal tools.
B	This tool category provides a more determined opportunist attack by bodily physical force and tools with a higher mechanical advantage.
C	This tool category provides a more determined opportunist attack by bodily physical force and tools with a higher mechanical advantage.
D	This tool category is for experienced attempts at forced entry.

²⁶ BRE Global. (2014). LPS 1175: Issue 7.2. *Loss Prevention Standard*.

D+	This tool category is for experienced attempts at forced entry.
E	This tool category provides a professional means of attempting forced entry into higher value storage areas generally after penetrating the facade. Although the tool category incorporates mains powered tools, this serves to cover those risks where the criminal may use tools of powers greater than those permitted in tool kit D, including battery powered, petrol driven and mains powered up to that possible with the tools specified in this tool kit
F	This tool category is an enhancement of category E. Although the tool category incorporates mains powered tools, this serves to cover those risks where the criminal may use tools of powers greater than those permitted in tool kit D, including battery powered, petrol driven, and mains powered up to that possible with the tools specified in this tool kit.
G	This tool category provides extreme means of attempting forced entry into higher value storage areas before resorting to the use of vehicles, firearms or explosives

3.7 CHANGE IN LPS 1175 STANDARD

LPCB is in the process of issuing a new revision of the LPS 1175 standard named Issue 8. BRE Global (2018) states that the new revision defines a new performance classification system which recognises the increasingly diverse relationships between the tools a hostile actor is likely to use and the time they are likely to spend completing their attack. It also factors in the nature of the facility that is being targeted and the reason why it is being targeted.

Instead of the typical relationship (which is relatively linear between tools and attack duration), Issue 8 defines a matrix style classification system formed of two characters

- The category of tools a product is designed to resist (from A to H)
- The minimum delay in minutes that a product achieved when evaluated using tools from the selected tool category (1, 3, 5, 10, 15 or 20)

The benefits of this standard change is that it recognises that hostile actors may not be willing to conduct attacks for as long as defined in the LPS 1175 and EN 1627 standards and enables specifiers to select products according to the delay they present to attackers using tools from that particular category (BRE Global, RJF2945 Revision 0.7, 2018). This allows specifiers to construct defensive layers using tools selected from the tool category deemed to reflect the threat providing a known delay against entry attempts.

3.8 DOORSETS

Doorsets are an essential part of physical security which is frequently required for various functions as stated below (CPNI, 2018).

- Controlling access for authorised personnel
- Permitting an appropriate flow of people or materials etc.
- Working in conjunction with intruder detection systems to detect unauthorised access
- Providing a barrier to delay the progress of an adversary
- Providing protection from specific threats; blast or ballistic
- Providing protection from fire or smoke ingress
- Providing a means of escape in an emergency

CPNI (2018) explain that security doors are considered to be a system comprising of a door leaf, door furniture, locking hardware, door frame, frame fixings and a supporting structure. They also maintain the necessity to define the security requirements for each door, and whether it is protecting against blast, ballistic, manual forced entry or surreptitious entry. In such cases it is usually possible to fulfil multiple requirements.

3.8.1 INCREASING SECURITY OF DOOR

Flint (2014) explains that at a time of heightened terrorist threat, specifiers of security premises are turning to security products which are independently certificated to provide a guarantee that they are fit for purpose. He reminds us of the need for constant vigilance and states that it is easy to reduce the element of luck when protecting against terrorism and crimes by using well-proven mechanisms to help specify and execute effective security protection. These include the use of security systems and products that have been assessed independently and certificated using recognised standards as LPS 1175 (BRE Global, 2015).

BRE Global (2015) explain that the LPS 1175 standard considers a product’s resistance to forced entry in terms of the size and availability of the tools likely to be used, their concealability and power used to attack it and the time the intruders may be prepared to spend on the attack.


 <p>HIGH RISK</p> <p>LOW RISK</p>	LPS 1175 SR 8	Products certified to this standard provide 20 minutes of resistance to extreme means of attempting forced entry into higher value storage areas.
	LPS 1175 SR 7	Products certified to these standards provide 10 minutes of resistance to professional means of attempting forced entry into higher value storage areas using a wide range of tools including mains powered tools.
	LPS 1175 SR 6	
	LPS 1175 SR 5	Products certified to these standards resist experienced attempts at forced entry using a wide range of tools including battery powered tools lasting up to 10 minutes (SR4 and SR5) or 5 minutes (SR3).
	LPS 1175 SR 4	
	LPS 1175 SR 3	
	LPS 1175 SR 2	Products certified to this standard provide 3 minutes of resistance to determined attack by an opportunist burglar using a range of techniques including those that involve creation of noise.
	LPS 1175 SR 1	Products certified to this standard provide 1 minute of resistance to opportunist attempts at entry using a range of techniques including those that create noise such as those involving breaking glass.

Figure 26 - Security rating to LPS 1175 Issue 7²⁷

Figure 26 shows the breakdown of the security levels in the standard. This standard differs from the European standard for physical security EN 1627, which assumes criminals will use stealth and have little knowledge of the products that they are targeting. Due to this, Flint (2014) states that many products that are approved to EN 1627 fail to provide enough delay to attacks relating to when the intruder is willing to make noise.

3.8.2 WEAK POINTS OF DOOR

A door in the physical security industry is employed to provide a barrier at the point of entry or exit. In maximum security, the door’s function is to be impenetrable and offer the maximum delay time before penetration by extraordinary means (use of cutting tools and some explosives) (Fennelly, 2013). Within the fabric of an enclosure or building, the rigid nature of the enclosure itself is generally robust, and it is straightforward to increase its resistance to attack, however due to the requirement for doors to open and close, they frequently present a weak point.

Doors have always been one of the weakest points in most structures, mainly due to the requirement for convenient human access (Anderson & Dover, 2003).

²⁷ BRE Global. (2015). LPS 1175 – Requirements and testing procedures for the LPCB approval and listing of intruder resistant building components, strongpoints, security enclosures and free-standing barriers.

Mueller & Moen (2016) state that it is common to see roller shutter doors failing either by unhinging or excessive jamb deformation when subjected to wind damage. Fennelly (2013) adds that the weakest part of a door system is the latching component and provisions need to be made to ensure the locking devices are internally locking.

Ross Technology (2016) sets out the features of different materials typically used in the attack tests. Glazing is designed to resist forced entry and generally includes layers of glass and thermoplastic materials such as polycarbonate and acrylic. It has been determined that products with a higher amount of plastics are usually more resistant to blunt tool attacks and glass provides resistance to sawing and cutting actions. Glass is commonly used in buildings due to aesthetics as it is transparent, light, scratch-resistant and enables vision. (Ross Technology, 2016).

	Blast	Ballistic	Forced Entry
Glazing	<ul style="list-style-type: none"> • Glass and poly good • High reaction forces for glass • Design affected by LOP 	<ul style="list-style-type: none"> • A lot of glass layers • Thin poly or film on safe side • Multi-shot or multi-temp requirements 	<ul style="list-style-type: none"> • A lot of poly layers • Tool selection important
Components	<ul style="list-style-type: none"> • Need to transfer loads • FEA analysis required for high loads • Watch rebound effects 	<ul style="list-style-type: none"> • Harder materials perform differently than softer • Gap protection may be required 	<ul style="list-style-type: none"> • Tool selection drives material selection • Watch brittle/hard materials

Figure 27 - Combined Threat Resistance Chart²⁸

Figure 27 shows the general approach to selecting design features and requirements to provide a combined threat resistance. The objective is to define levels of protection precisely and work towards a more realistic and achievable target of combined resistance to provide effective protection for buildings against attacks (Ross Technology, 2016).

3.9 SUMMARY OF STANDARDS

Flint (2004) explains that identifying physical security products such as doors, windows etc. which are fit for purpose and undertaking associated compliance audits is not straightforward. He explains that the main reason is because security performance is not yet a mandated requirement in construction regulations. As such, manufacturers can make voluntary

²⁸ Ross Technology (2016, December). Design to Protect, Fenestration systems for extreme threat resistance. Architectural Record.

declarations of security performance against standards such as LPS 1175, PAS 24 and EN 1627.

EN 1627 has “eased barriers to EU trade in security products” but Flint explains that this isn’t a solution to assess risks as it is crucial that facility managers fully understand the performance assurances behind the standard in order to consider if the perceived threats are being addressed (Flint, 2014).

Flint (2014) explains that both EN 1627 and LPS 1175 recognise a similar magnitude of delay but beyond this, there are differences in testing requirements and testing regimes that define performance classifications.

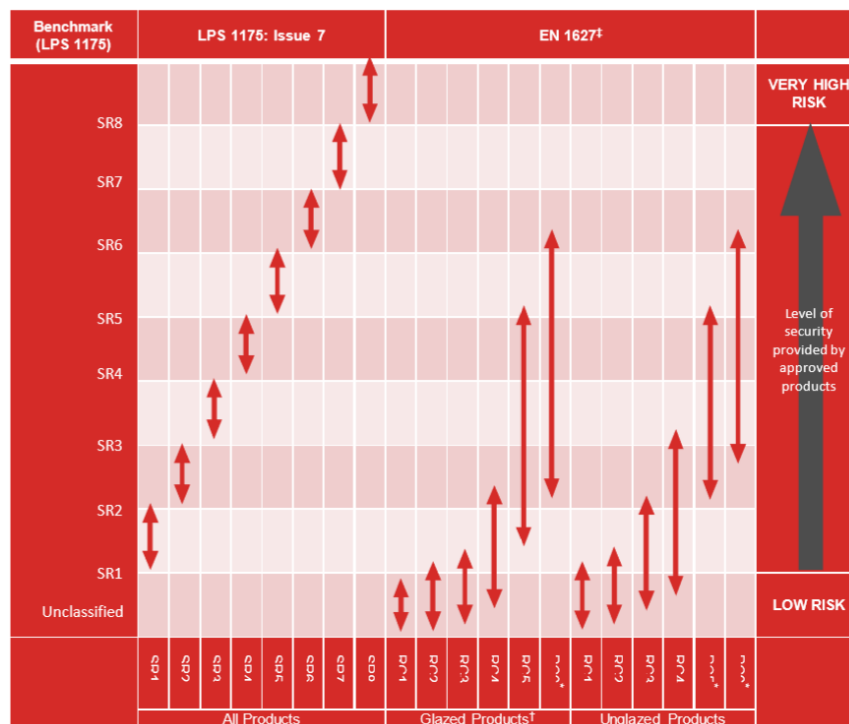


Figure 28 - Comparison of LPS 1175: Issue 7 vs EN 1627²⁹

According to Flint (2014) the differences in standards has a significant impact on the suitability of the products that are approved to each standard in different threat environments. EN 1627 is based on attackers being physically bigger in size and therefore needing to make a larger hole with an associated increase in the delay time – this goes against LPS 1175 as they have a set size of hole which needs to be created for a product to fail the test. This is based on an elliptical test block sized at 400 x 225mm.

²⁹ Flint, R. (2014). Security by numbers: The art of specifying effective physical security. CIPRE Expo.

The scope of test tools in EN 1627 and LPS 1175 also varies considerably; EN 1627 references tools dating back to the late 1980's and 1990's whilst LPS 1175 undergoes a periodic evaluation of tools with cooperation from the government and police, to ensure that they reflect the tools available to criminals in the future and near future (Flint, 2014). A clear comparison of the tools from both standards are explained in Figure 29. EN 1627 does not include basic hand tools such as a claw hammer, common battery tools such as 18V drills and reciprocating saws whilst LPS 1175 does.



Standard	LPS 1175	EN 1627
Rating/Class	SR3	RC3
Working Time	5 minutes	
Total Test Time	20 minutes	
Tools	As earlier, plus: 	As earlier, plus: 

Figure 29 - Comparison of EN 1627 vs LPS 1175³⁰

3.10 SUMMARY

By analysing the standards relating to physical attacks; it is clear that there are similarities between CPNI, BS EN 1627-30 and LPCB. However, in the author's opinion the LPCB standard incorporates a more physical approach in mimicking an attack. It is very difficult to obtain information regarding CPNI's test methodology, as it is not disclosed to the public. The British standards have a more theoretical approach when compared to LPCB in terms of measurement of static and dynamic loads, but a significant benefit of complying with either CPNI or LPCB standards is the formal approval certificate that is awarded to the tested product upon passing the relevant tests. LPCB does not quantify the amount of force being applied instead using a physical attack approach.

In the author's opinion LPCB is more transparent compared to CPNI because the standard is published and is readily accessible. However, this brings with it associated risks as it could be used to expose potential vulnerabilities to experienced attackers with knowledge of LPCB standards. It is on this basis that the test methodology for this project has been created. A

³⁰ Flint, R. (2014). Security by numbers: The art of specifying effective physical security. CIPRE Expo.

benefit that CPNI has over LPCB is that as there are no published standards, it is harder to expose vulnerabilities in the same way as can be done with LPCB.

The main shortcoming of EN 1627, as highlighted by Flint (2014), is that an organisation can conduct testing and evaluation services compliant with EN 1627 but is not legally required to corroborate compliance claims. As a result, there isn't a central body responsible for assessing the quality and consistency of testing in terms of its conformity with its test criteria or policing misleading claims of compliance with the standard.

Flint (2014) emphasised that products being tested to the LPS 1175 standard required approval by a single organisation working to the "test ethos and quality standards of BRE Global". Flint goes on to say that using security products approved by recognised third parties to appropriate standards ensures the products used provide a reliable delay and helps mitigate the risk of forced entry (Flint, 2014).

In the author's opinion the most ideal solution would be to include aspects of the British Standards in the pre-testing which can then be developed into factory testing and to finish with LPCB testing.

This would serve the dual purpose of reducing overall costs of the LPCB testing and increasing the likelihood of the product passing an LPCB test first time. LPCB state that they have high levels of failure testing with a 95% failure rate for new products overall (BRE Global, 2018). With a single test day at LPCB costing £2,500, increasing the first-time success rate for testing can lead to significant testing cost savings.

In pre-testing the aim would be to implement methods to test the structural integrity of the product, which would increase the engineering knowledge at the Company and the understanding of attack tests typically completed by LPCB. This would lead to a reduction in LPCB costs and result in fewer test days needing to be booked. Going forward investigations can be carried out into how test days at LPCB can be further reduced by producing methodologies and tests to evaluate the structural integrity of the products and a retrospective analysis into historic LPCB testing data. It is noted that it is not possible to eliminate LPCB testing completely; in order to gain security certification from LPCB, a minimal amount of LPCB testing will still be required.

Chapter 4 analyses historical data from previous LPCB testing regimes and provides a mechanism to analyse and manipulate the test data for use in the design of new products.

CHAPTER 4

4 BACKWARDS FACING HISTORICAL DATA

4.1 INTRODUCTION

The previous chapter explains the reasoning behind the author's choice of LPCB as the testing body for physical attack testing. It has previously been stated that LPCB has a high-test failure rate of 95%.

This shows how difficult it is to achieve an LPCB certified product as LPCB try and keep up to date with modern perpetrators by updating and evolving their standards and attack methods. To quantify the success of a new material, composite or product, is difficult often comprising of an approach to fabricate a test sample, send it for testing, improve/remake the sample, retest the sample.

There are several factors that potentially contribute to this high-test failure rate:

- a lack of awareness of how a product and its components behave under attack
- a lack of understanding of LPCB test attack strategies
- inadequate preliminary testing
- difficulty in accessing and manipulating historic test data

The author has identified a niche in the industry for a procedure which reduces the amount of LPCB testing by creating a methodology that incorporates tools and tests to evaluate the structural integrity of a product prior to the LPCB testing.

This section uses the research compiled and evaluated in previous chapters to analyse the processes in place to complete LPCB testing. This begins with an analysis of how security products are currently designed and tested based on the design methodology in operation at Technocover.

4.2 THE CURRENT LPCB PROCESS

The flowchart in Figure 30 shows the typical LPCB procedure, from a manufacturer's perspective.

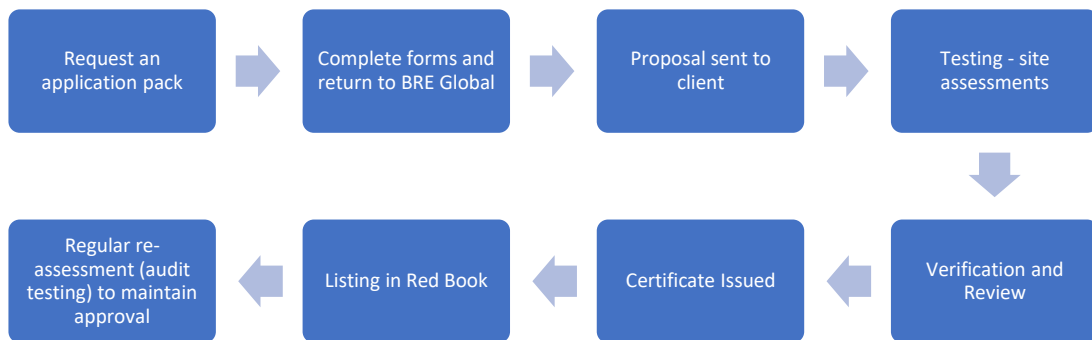


Figure 30 - LPCB Certification Procedure³¹

4.3 UNDERSTANDING THE CURRENT LPCB PROCESS IN PRACTISE

The author has worked in partnership with Technocover to understand the current LPCB process, and appreciate the LPCB design procedure from a specific manufacturer's perspective. Technocover was chosen as they state that over 25 years, they have gained a reputation as the UK's leading supplier of certified physical security galvanised steel access products (Security News Desk, 2016).

The Physical Security Certification Scheme Manager at LPCB commented on Technocover, stating that they have an impressive portfolio of products and that LPS 1175 is a difficult standard to achieve certification for due to the high failure rate of products submitted to test. Due to the extensive scope of products approved by LPS 1175, he says it's a testament to the design and engineering excellence and robust quality systems (Technocover, 2013).

The author acknowledges that this view, which dates back more than 5 years, would have been applicable to Technocover's limited product range at the time. However due to the rapidly advancing techniques in engineering, the increased number of products manufactured by Technocover and the benefit of possessing a significant amount of their own test data, this

³¹ RedBookLive. (2018, December 01). Certification. Retrieved from Red Book Live: <https://www.redbooklive.com/page.jsp?id=92>

would give them a greater advantage over other manufacturers if they were able to successfully utilise it.

Red Book Live is an online database created by LPCB which lists all the companies that are LPCB approved and details the type, security level, size restrictions etc. of LPCB approved products. On performing a search of the security protection products using Red Book Live, it has been ascertained that Technocover is the leading Company in the LPCB security market, having 12% of the overall listings detailing various security protection products that are LPCB approved.

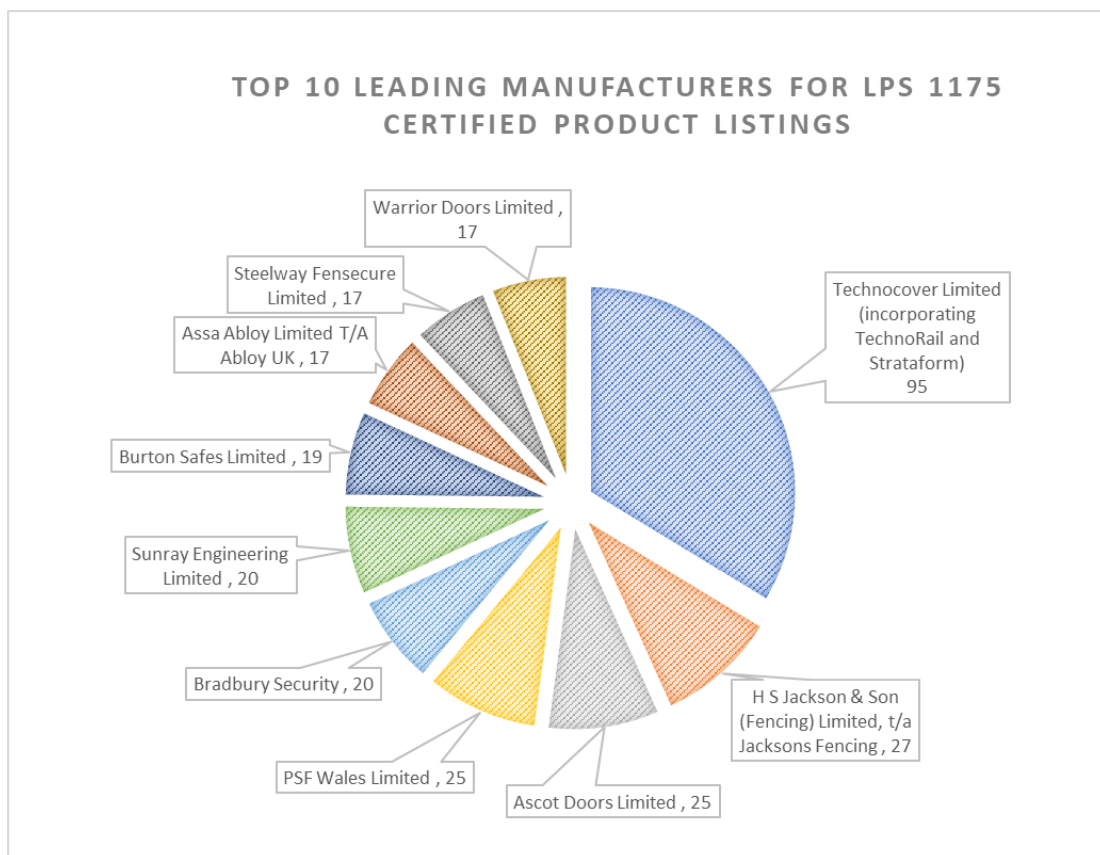


Figure 31 - Top 10 Leading Manufacturers for Security Protection Products related to Steel (LPCB Approved)

There are 100 manufacturers with LPS 1175 certified products. By completing an analysis of all the security protection products listed under Red Book Live the author was able to identify the Top 10 leading manufacturers with products certified to the LPS 1175 standard.

The top manufacturer was identified as Technocover with 96 of their products across 10 different product types having achieved LPS 1175 certification, equating to 12% of the LPS 1175 listings on Red Book Live as previously stated. After Technocover, the next listed manufacturer with the highest number of LPS 1175 approved security products is H S Jackson

& Son Fencing Limited with 27 products across 2 different product types (3% of the LPS 1175 listings on Red Book Live). Technocover has a vast amount of historic data gained from all the previously completed testing regimes at LPCB, it is considered that Technocover has the broadest knowledge of the testing process.

With the greatest number of products with LPS 1175 certification in the market, Technocover can use the new design methodology to design new products more efficiently by using their historic data to their advantage instead of repeating tests that have been previously completed, bringing about savings in LPCB testing costs.

To evaluate the design process of an LPCB product by Technocover, analysis into how a product is designed and tested took place to understand if there was any way to increase the certainty of passing an LPCB testing regime.

As stated by Richard Flint, he explains that Technocover has a vast number of different products that are approved by LPS 1175 (Technocover, 2013). This is a great benefit for Technocover, and the historic data can be used to look up previous testing data to predict attack test times.

The design process shows the procedure for creating a new product, creating a standard product or modification of an existing product. As LPCB products are tested to a high standard, the requirements of testing a product state that a product is certified within limits, such as minimum and maximum sizes, which must be obeyed. Any kind of modification to the product is subject to approval from LPCB which could possibly lead to a requirement for the product to be re-tested.

The current LPCB procedure is detailed in Figure 32.

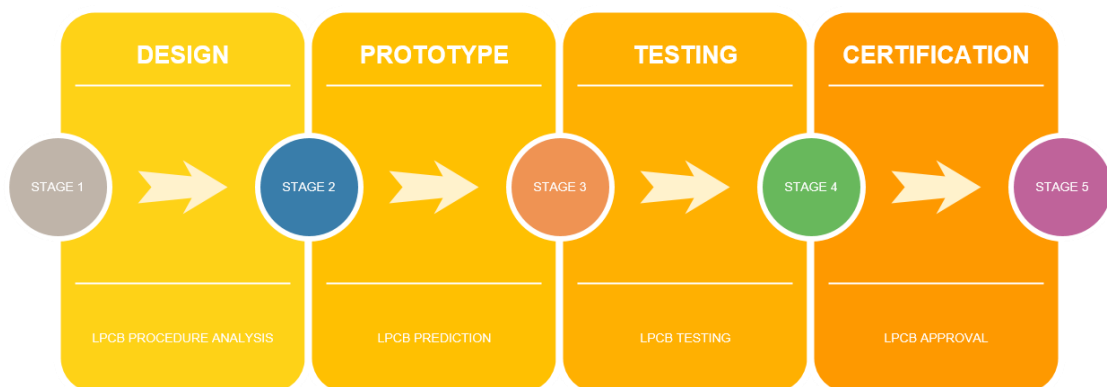


Figure 32 - LPCB Process

The current design process (Figure 33) has been taken from Technocover’s Integrated Management System which is the backbone of their quality system, set up to ensure compliance with ISO 9001 and ISO 14001, making it of high importance to the Company.

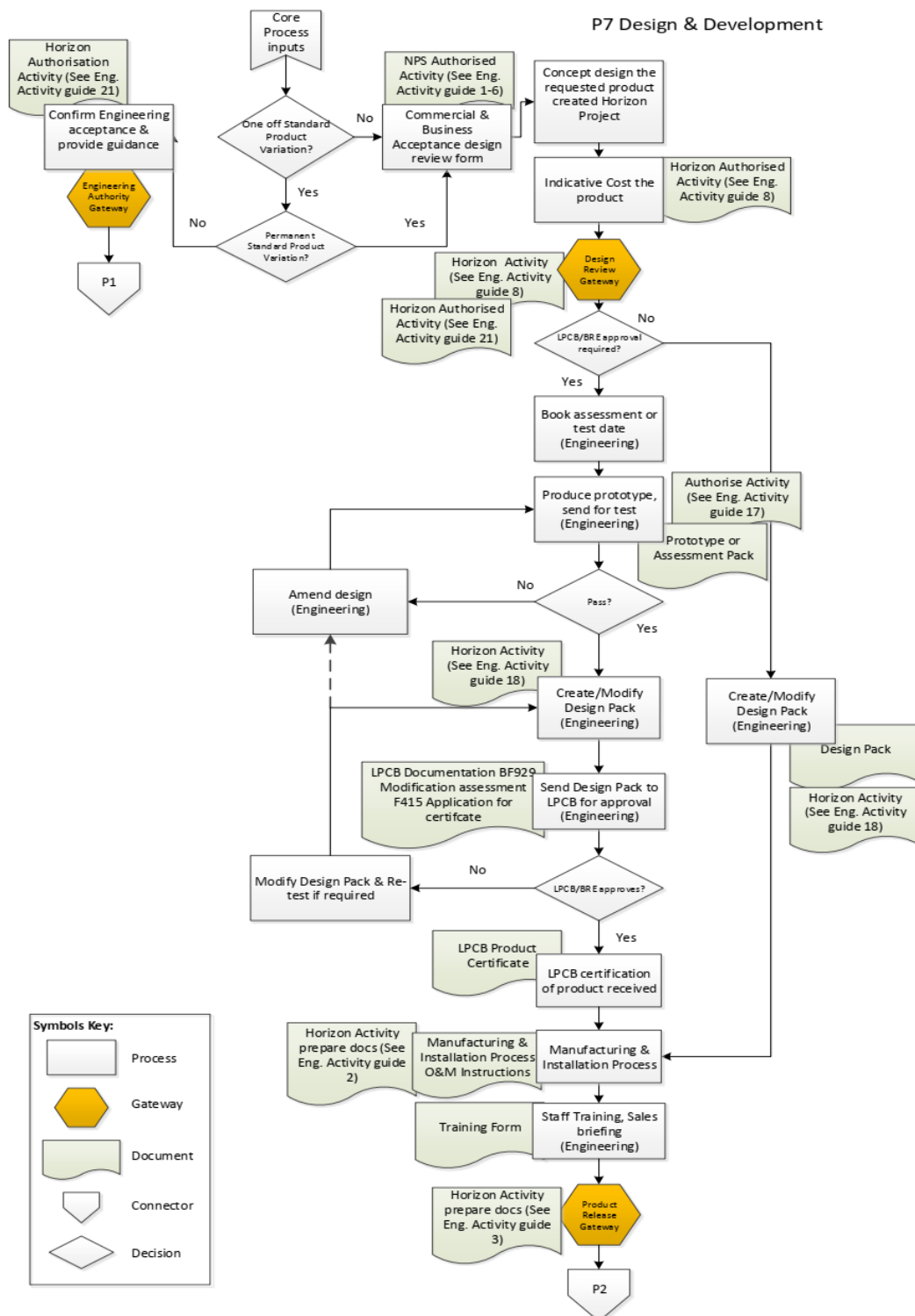


Figure 33 - Current LPCB Process³²

³² Taken from Technocover’s IMS System (2019)

4.4 TOOL ANALYSIS

To understand the LPCB attack tests, analysis into the tools used to attack products was undertaken. This was to identify the methodologies used with the tools to gain access into a security product.

Tools for forced entry attacks can be categorised into hand, power, thermal and explosive (Conrath, Krauthammer, Marchand, & Mlakar, 1999). It is assumed that all tools are portable by two persons and the tool types can be grouped by the severity of the threat they pose to a facility.

1. Very low severity level – limited hand tools
2. Low severity level – optimal hand tools
3. Medium severity level – optimal hand tools, limited power and thermal tools
4. High severity level – optimal hand and power tools, limited thermal tools and explosives
5. Very high severity level – optimal hand, power and thermal tools and explosives

This tool category breakdown explained by Conrath, Krauthammer, Marchand, & Mlakar (1999) is highly comparable to LPCB's tool category and security level categorisation as they have the same overall severity levels with LPCB breaking down their tool category further to link to the attack time. This is because it is considered that if the attack time is low, an attacker is less prepared corresponding more to an opportunist attack as opposed to a highly trained planned attack associated with the higher security levels.

A comprehensive analysis was undertaken on the LPS 1175 tools and tool categories to understand the specifications of the LPCB test attackers. The tools are categorised in tool categories which range from A to H – depending on the revision of the LPS 1175 standard being referenced. These tool categories refer to a security level and a delay time that a product needs to protect to.

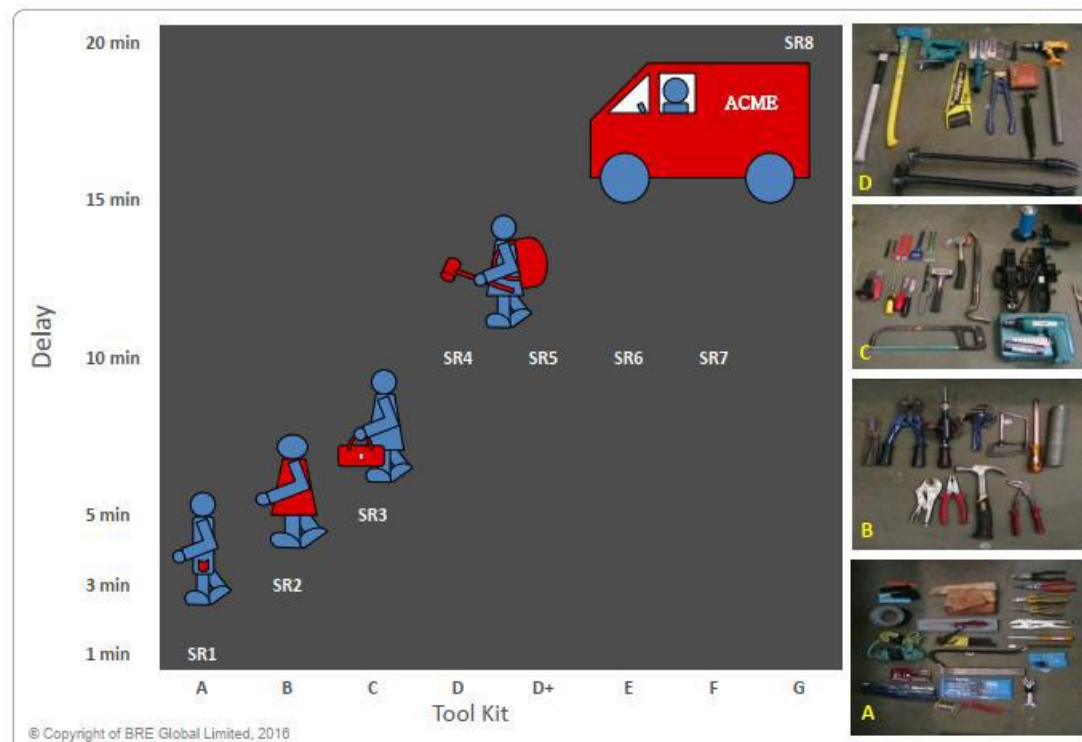


Figure 34 - Delay and tool kit comparison³³

As seen in Figure 34, the greater the delay time, the higher more complex the tool kit. A greater range of more advanced tools can be used for an extended period and therefore, the higher the security level gets. This is because at higher security levels, there are greater risks associated with the level of attack as it involves a more prepared attacker with more powerful tools that will be used to attempt access. Therefore, the higher security levels have more powerful tools used to attack the products with at a greater attack time / delay period time to be attacked with.

A study into the types of tools provides an understanding into how tools are manipulated to gain entry into a product and examines the different types of tools that can be used.

Initially, the tools can be categorised as follows:

- Cutting
- Power
- Lever
- Impact
- Manipulation

³³ BRE Global Limited. (2016). Dawn of the matrix, the future of the physical security standards. Richard Flint. LPCB.

- Temperature

In comparison with the breakdown of the tools above, a broader categorisation is provided in Structural Design for Physical Security (Conrath, Krauthammer, Marchand, & Mlakar, 1999):

- Hand tools
- Power tools
- Thermal tools
- Explosives

The difference is that the category for the hand tools encompasses impact, prying, sawing, drilling, screwing, pulling, shearing and cutting tools (Conrath, Krauthammer, Marchand, & Mlakar, 1999). It was considered that when analysis of the LPCB testing tools, the categories cutting, impact, lever and manipulation are important when analysing the attack testing and should be broken down and analysed as individual attack categories.

The LPCB breakdown categories encompass all the tools in the LPS 1175 standard and the breakdown provides a complete understanding of the functionality of these tools in attack tests. Cutting tools are used to cut through or make insertions into materials/composites in preparation for removal. Power tools are used to mechanically remove material whilst Levering tools are used to ‘lever’ materials to gain entry into the next layers of the composite or into the actual product by the displacement of the material(s). Impact tools use force to impact the product being examined to deform the material. Manipulation tools are the most diverse type of tools as they can be used for a variety of attacks. Temperature tools use either heat or the cold to change the material properties to facilitate easier access.

CUTTING

The majority tools of this type were in the D tool category and it was noticed that there was an 23% increase in this categorisation of tools from Issue 5 to Issue 7. This was expected as the tools are more advanced and heavy duty to reflect the higher security ratings being tested to.

POWER

64% of the power tools such as the power drills in this category are from the low to high risk security levels B-D+. There has been a slight increase in the power tools from comparison of the Issue 5, Issue 6 and Issue 7 tool kit. This reflects the improvement in tools available on the

market and how much more accessible they are. The most common used tools in this category are the power drills and the drill bits.

Conrath, Krauthammer, Marchand, & Mlakar (1999) explain that it is assumed in this category that the aggressor has all types of power tools available to them and is skilled in using them for a target. It is assumed that because of this, the aggressor will select an optimal combination to minimise the penetration time.

LEVER

27% of the tools from this category have come from the tool category D and there has been a slight increase in tools from this category from Issue 5 – Issue 6 – Issue 7.

IMPACT

Many of the tools from this category are included in the low – medium attack tool category range and the number of tools in this category have been increased.

MANIPULATION

85% of these tools are in tool category A – the lowest tool category. This is expected as the manipulation tools are most commonly used after a product/material has already sliced or punched open with a tool from a higher category. There has been a slight increase of these manipulation tools from Issue 5 to Issue 7, showing their worth to the attackers and how the test methods and thinking involved has advanced. They are no longer just using brute force to break into every single product put in front of them for testing.

TEMPERATURE

Most of the tools (57%) in this category are from Tool Category C and the amount of tool in this category have more than doubled from the previous revisions of LPS 1175.

Thermal tools generate heat for the cutting of steel or other materials. It is known that these tools are generally heavier than either hand or power tools due to the weight of the material that is consumed during the heat generation (Conrath, Krauthammer, Marchand, & Mlakar, 1999).

4.4.1.1 TOOL CATEGORY MATRIX

Following a review of the tools available to LPCB, the tool categories referenced by Issues 5, 6 & 7 of the LPS 1175 standard were compiled into a matrix. This matrix enabled the author to analyse the difference in tools and how they have changed with each update of the LPS 1175 standard. As the tools and tool categories differ for each revision of the standard, it was important to understand the changes so that the different LPCB reports could be compared.

BRE Global (2018), states that specifiers are faced with the fact that criminals continue to have access to increasingly effective tools and a broader knowledge of attack techniques, which is why the LPS 1175 standard is periodically revised and new products require testing against the most updated revision of the standard.

Analysis was used to compare the different tool categories in each standard. A table was created that specified the standard and the tool categories.

Table 4 - Revision of LPS 1175³⁴

ISSUE OF STANDARD	TOOL CATEGORY
5	A
5	B
5	C
5	D
5	E
5	F
6	A
6	B
6	C
6	D
6	D+
6	E
6	F
6	G
7	A
7	B
7	C
7	D
7	D+
7	E
7	F
7	G

³⁴ BRE Global. (2014). LPS 1175: Issue 7.2. Loss Prevention Standard.

4.4.1.2 CHANGE IN REVISION

The characterisation of tool categories between Issue 5 and Issue 6 identifies the introduction of the D+ tool category in the later Issue. The main differences between the D and D+ tool category is the variation in power tools (12V and 18V tools). The emergence of 18V tools as a readily available product and their use as a forced entry tool of choice, prompted certain regulatory authorities to request LPCB to replace the 12V tools with 18V tools. However, if confirmed, this change would invalidate all SR4 rated products which would then need to be retested with more powerful tools with no guarantee they would pass. The 18V tools weren't deemed to be sufficient for the (higher) E classification and consequently LPCB created an intermediate tool category between D and E named D+ which integrated the 18V tools and tool categories E and F were realigned to use the D+ tool category instead of D.

From Issue 7 to Issue 8, a new tool category H is added – this addition is to address the high-end threats identified to sectors (particularly nuclear) as well as the longer delays required (20 minutes).

Looking at Table 5 and Table 6, analysis into the changes between tool category and revision of the LPS 1175 standard was undertaken. The tool categories were given a colour and if there is a colour in the tool row, it means that it is in that certain tool category and the higher categories subsequently.

A	B	C	D	D+	E	F	G
Orange	Green	Blue	Yellow	Purple	Light Blue	Yellow	Red

Figure 35 - Key to the LPCB Category Table

Table 5 - Breakdown of LPCB Tool Categories

TOOL	ISSUE 5						ISSUE 6							ISSUE 7								
	A	B	C	D	E	F	A	B	C	D	D+	E	F	G	A	B	C	D	D+	E	F	G
>50 mm diameter Hole Saw																						
10 mm Carbide jobber drill bit																						
10 mm HSCO jobber drill bit																						
10 mm HSS jobber drill bit																						
1100 W Circular Saw with 3 cutting blades																						
1100 W Disc Grinder with 3 Cutting discs																						
12 V d.c. Jigsaw with 3 (HSCO/Carbide/HSS) blades																						
12 V Disc grinder plus 3 cutting discs																						
12 V drill																						
14 mm screwdriver																						
18 V d.c. Circular saw (cordless) with 3 blades																						
18 V d.c. Jigsaw with 3 Carbide blades																						
18 V d.c. Jigsaw with 3 HSCO blades																						
18 V d.c. Jigsaw with 3 HSS blades																						
18 V d.c. Reciprocating saw with 3 Carbide blades																						
18 V d.c. Reciprocating saw with 3 HSCO blades																						
18 V d.c. Reciprocating saw with 3 HSS blades																						
18 V Disc grinder plus 3 cutting discs																						
18 V drill																						
1900 W breaker																						
2 Wood boring spade bits																						
2000 W Drill																						
2000 W Reciprocating Saw																						
2100 W Circular Saw with 3 cutting blades																						
2300 W Disc Grinder with 3 Cutting discs																						
38 mm Tube																						
50 mm diameter Hole saw																						
5kW Cut-off Stihl Saw with 3 blades																						
5No. 13 mm Carbide jobber drill bit																						
5No. 13 mm Carbide long series drill bit																						
5No. 13 mm HSCO jobber drill bit																						
5No. 13 mm HSCO long series drill bit																						
5No. 13 mm HSS jobber drill bit																						
5No. 13 mm HSS long series drill bit																						
5No. 20 mm Carbide jobber drill bit																						
5No. 20 mm HSCO jobber drill bit																						
5No. 20 mm HSS jobber drill bit																						
6 mm Carbide jobber drill bit																						
6 mm HSCO jobber drill bit																						
6 mm HSS jobber drill bit																						
6.5 mm Screwdriver																						
7 mm screwdriver																						
7.2 V drill																						
75 mm Tube - 1500 mm long																						
75 mm Tube - 1000 mm long																						
75 mm Tube - 500 mm long																						
750 W Drill																						
750 W Reciprocating Saw with 3 Carbide blades																						
750 W Reciprocating Saw with 3 HSCO blades																						
750 W Reciprocating Saw with 3 HSS blades																						
Adhesive Tape																						
A-tool lock puller																						
Axe																						
Bolt cutter - 350 mm long																						
Bolt cutter - 400 mm long																						
Bolt cutter - 500 mm long																						
Brick Bolster																						
Cable Cutter																						
Claw hammer																						
Cold chisel																						
Concrete chainsaw 2 stroke																						
Crowbar																						
Diamond core drill bit																						
Enforcer - 450 mm long																						
Enforcer - 600 mm long																						

Table 6 - Breakdown of LPCB Tool Categories Part 2

TOOL	ISSUE 5						ISSUE 6							ISSUE 7								
	A	B	C	D	E	F	A	B	C	D	D+	E	F	G	A	B	C	D	D+	E	F	G
Felling / fire axe																						
Fishing line																						
Flexible plastic coupon																						
Fluorocarbon based freeze spray																						
Gas torch																						
General purpose saw																						
Giasmaster saw																						
Glass cutter																						
Hacksaw plus 2 HSS blades																						
Hammer																						
Hand drill																						
Hexagon wrench																						
Hooks																						
Hooligan bar - 760 mm long																						
Hooligan bar - 910 mm long																						
Hydraulic head and toe jack																						
Junior hacksaw plus 2 HSS blades																						
Knife																						
K-tool lock remover																						
Lever																						
Metal plate shears																						
Multiple slip joint pliers																						
Oxyacetylene "Saffire Portapak" cutting kit - 50l																						
Oxyacetylene "Saffire Portapak" cutting kit - 250l																						
Pad saw plus 2 HSS blades																						
Pinch bar																						
Pipe wrench																						
Plastic wedges																						
Plate shears																						
Pliers - 200 mm long																						
Pliers - 250 mm long																						
Pneumatic impact tool																						
Punches																						
Rope																						
Scissor jack																						
Sledgehammer - 3kg																						
Sledgehammer - 6kg																						
Soft Body Impactor																						
Socket / screwdriver set																						
Spanner																						
Steel wedges																						
Traction screws																						
Tweezers																						
WD40																						
Wire																						
Wood chisels																						
Wood wedges																						

The major benefit of the tool matrix is that it allows the user to easily identify the difference in tools, tool categories and revisions of the LPS 1175 standard. The user can track how tools have moved between tool categories following the implementation of a new Issue of LPS 1175.

The tool matrix will be most beneficial when new revisions of the standards are released, allowing the differences to be easily compared to identify the effects it has on historic test data. The matrix also illustrates the vast range of tools LPCB have at their disposal to decide upon their attack methods with the tools they can use.

4.5 BREAKDOWN OF ATTACK CATEGORIES

The breakdown of the attack categories used by LPCB follow the same principal categories that were created for the analysis of tools. An analysis into the attack categories was

undertaken to understand the typical methodologies that are followed by the LPCB attackers to break into the product being tested.

- Cutting – these tools are used to make incisions in a material, in preparation for it to be removed by other means.
- Power – these tools are used to mechanically remove material. The power element of the tool aids the removal, making it increasingly more likely to be achieved within a short period of time when compared to tools from the cutting category. There has been an increase in the number of power tools in line with the accessibility and development of tools available for purchase.
- Lever – these tools are used to displace the material to gain entry or access into the product that is being tested. Physical force is exerted on these tools by the attack tester to make them more effective.
- Impact – these tools use physical force to deform the material/composite.
- Manipulation – these tools are sometimes used in conjunction with other tool categories to achieve attack objectives. Typically, these tools are readily accessible to the public. Using a real-life LPCB test scenario an example would be fishing the panic bar on a doorset where holes are created on either side of the panic bar via power tools enabling a wire to be fed through the top hole and out of the bottom hole. The wire is then pulled until the force on the panic bar is strong enough for the lock to disengage and the door to open.
- Temperature – these tools focus on the use of temperature to manipulate the material properties in the LPCB test. These tools are typically found in the higher tool categories due to their size and the experience required to use them and the associated risks involved in these kinds of attacks.

Knowing the typical methods used by the attackers during the LPCB testing allowed for a standard list to be identified and created. This allows searches to be carried out on attack tests from the historic data, enabling the user to identify the methods that have been used in previous tests.

By trying to understand the testing methodology that LPCB follow, predicting how the product will behave when following the same procedure will increase the certainty of how the product will perform in the testing.

4.6 FAILURE MECHANISMS

The product is deemed to have failed the LPCB attack test if the attackers are able to gain body access into the product within the time limit available to them. Body access is determined by enabling an elliptical test block sized at 400 x 225 mm, to be passed through any opening created during the test.

To gain this access it isn't as simple as the test attackers attempting to create a hole or opening in one face of the product big enough to fit this test block through. Many products are secured by ancillary products such as padlocks and high security locking systems. If these are not well protected, they can be compromised, allowing full access into the product. For example, creating a handhole within a wall structure complete with a door can allow the attackers to reach the internal locking system. The attackers can then use the tools at their disposal to create an extended arm to manipulate the locking system. Dis-engaging the locking system opens the door allowing the attacker to walk through into the structure. If accomplished within the time limit, the product fails the test.

This analytical approach adopted for attack testing by experienced testers means the design process for new products involves a lot of second-guessing and the application of experience to anticipate the methods used to gain access to the product.

By analysing LPCB testing videos from previous test regimes, a breakdown into the failure mechanisms was created, and how these failures can come to happen.

The common failure mechanisms were compiled from historic LPCB testing data and listed below from completing searches to find the most common objectives failing. These are based on the success of the approach taken during the actual testing at LPCB.

- Hand hole
- Levering
- Coupon
- Fishing
- Drilling
- Cutting
- Impact
- Shear

4.6.1 LPCB TESTING

It has been ascertained that LPCB testing analyses the effectiveness of the product when being attacked with certain tools within a specific time limit as specified within the standard. What the tests do not include is physical test data such as the displacement of the door or the time taken to move it a certain distance. This kind of physical data can be manipulated and used in separate testing or simulations to mimic physical testing. It is noted by Conrath, Krauthammer, Marchand, & Mlakar (1999) that there is no expectation that this will prevent failure in all cases, but it is important to formulate designs in which failures can be localised and isolated.

Historic physical attack data is specific to the product, its composite and how it is manufactured, which differs for each manufacturer. However, an analysis into the methods of attack completed for Technocover's products will highlight their design weaknesses and analysis into attack methodologies completed by the LPCB attackers on Technocover's products. A methodology was created that focused on not just Technocover's products but had the ability to broaden and be used by any manufacturer of security products.

A review of the previous LPCB testing was completed to identify the current approaches and strategies of the LPCB attack testers.

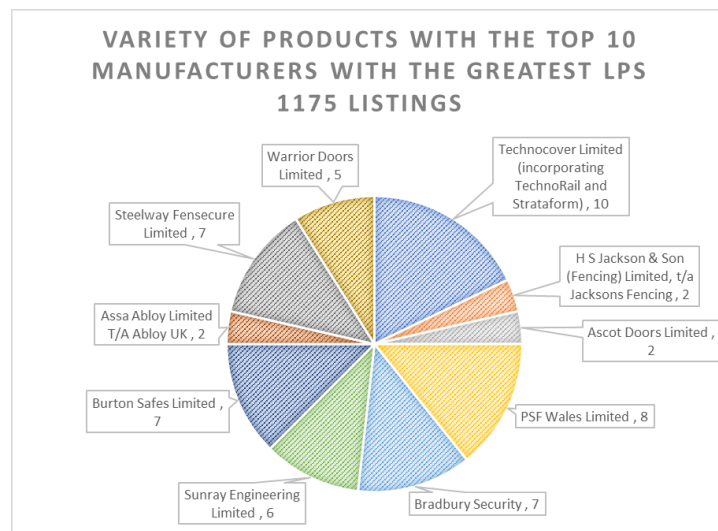


Figure 36 - Variety of products with the Top 10 manufacturers with the greatest LPS 1175 Listings

IMPACT

Figure 37 is an extract from a historic LPCB test video and shows the LPCB attackers impacting a roof panel using a sledge hammer. The sledge hammer is classified under the

impact tool category and it is being used to hit the roof panel in order to deform the material. The aim is to use sufficient force to change the material behaviour in order to distort it.



Figure 37 - Impact testing on roof panel at LPCB

Figure 38 shows a test being carried out on the frame of a cover using a sledge hammer and axe. The attacker uses the sledge hammer to impact against the axe, in an attempt to shear the fixings which, secure the cover to the structure.



Figure 38 - Impact testing on Cover Frame at LPCB

Figure 39 depicts an attacker using a lump hammer to try to impact the glazing panel from the door structure. This would enable hand access through the door to facilitate manipulation of the internal locking system.



Figure 39 - Impact testing on glazing at LPCB

CUTTING

In Figure 40 the attacker is attempting to cut a material using cutting tools in preparation for it to be removed. The material is being cut using a combination of a lump hammer and chisel, to create a triangular shaped cut sized at 90x90mm which can then be removed or repositioned using levering or impact tools. This creates a 'hand hole' in the product allowing the attacker easier access to the secure side of the product.



Figure 40 - Coupon creation at LPCB



Figure 41- Leading edge attack at LPCB

LEVERING

The aim of this test is to apply sufficient force to displace the material/composite. In the still shown in Figure 42, the attacker is using a crowbar between the two door leaves in an attempt to lever the door open by displacing the door enough to disengage the door latch. To get to this stage of the attack, the gap between the two door leaves has been increased using wedges. The attacker will hammer wedges between the edges of both door leaves, starting at the base of the frame and working their way up to the locking latch, increasing the gap until it is large enough to insert a crow bar. As the gap increases the force which needs to be applied by the attackers reduces.

This highlights that during a door test regime, the lock disengaging is the most fundamental part of this kind of attack. As the latch is a crucial component of the door and what secures the door leaf to the frame, it is crucial to make this as strong as it can be.



Figure 42- Lever Test at LPCB

4.6.2 DISPLACEMENT

By watching the video, it is possible to set up testing to mimic the displacement of the door leaf to disengage the lock latch. By linking this kind of LPCB attack test to fundamental theories within structural engineering, the Company can devise a method to test this kind of attack prior to conducting LPCB testing.

When analysing the lock engagement, depending on the locks, the door would always be required to move a specific amount in order to disengage the lock. This is because the lock demonstrates elastic behaviour by moving back and forth without deforming. By using this information, the initial notes would be to prevent the door latch from moving more than that amount.

INCREMENTAL

After analysing the LPCB test, it is considered that monitoring the displacement data of a few reference points on a doorset being tested, would allow for a greater understanding of how the product would behave under attack. The attack method undertaken by LPCB caused an incremental deformation of the channel attached to the doorset called the Anti Jemmy Angle. This was attacked from the bottom and more force was gradually applied to deform this angle. After periods of 1, 3 and 5 minutes, the LPCB test was halted and to record the displacement from 3 reference points.

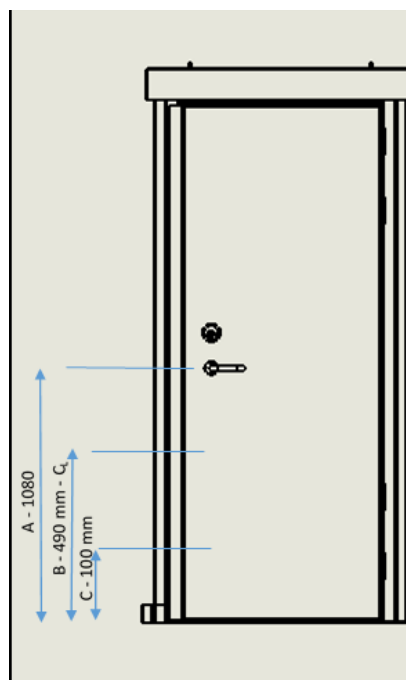


Figure 43 - Displacement Analysis at LPCB

The data collected from the LPCB testing was highly beneficial in validating the results of the software modelling. By having known markers of how far a point in the doorset has displaced by, a comparison can then be created in the form of a model to be analysed using FEA. Determining the biggest and smallest size of the wedges will allow an approximation of the maximum displacement to be gained from using the wedges.

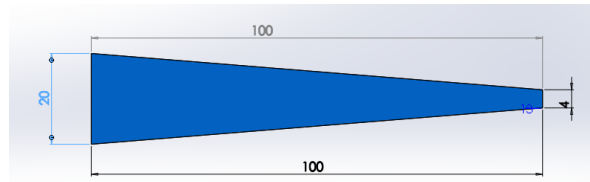


Figure 44 - Biggest wedge in LPCB tool kit

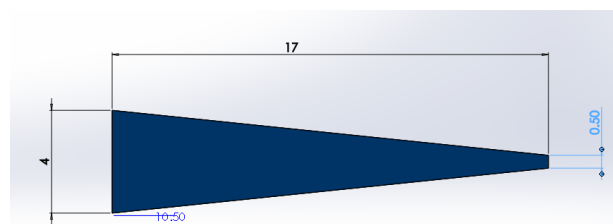


Figure 45 - Smallest wedge in LPCB tool kit

4.7 ANALYSIS OF LPCB TESTING

One of the challenges during the design stage of new LPCB products is deciding what material to use and where to place it within the structure to stop one of the many attack methods LPCB have at their disposal. The Company uses indicative test days at LPCB to influence their choice of material and product assembly when designing a complete product for testing. These individual days cost £2,500 each for the attack testing itself, excluding the material and labour costs to produce samples for testing. A full breakdown of a typical indicative test day can be seen in Table 7.

Table 7 - LPCB initial costs

<u>Process</u>	<u>Cost</u>
Material to manufacture test rig	£75
Labour to manufacture test rig	£150
Design Time	£90
Test sample sections	£150
Travel & Subsidence (2 people)	£610
LPCB test day	£2500
Total	£3575

During the indicative testing various materials are used, which are placed in different positions in relation to the ‘Attack Face’. A variety of LPCB attack methods are then carried out and their performance is recorded in varying positions. This provides the designers with a good base from which to start when choosing how the product will be manufactured and the position of materials to withstand LPCB attacks.

4.7.1 IMPROVEMENTS IN THE LPCB DESIGN TESTING PROCEDURE

Technocover has the greatest number of LPS 1175 security products listed in Redbook Live. For the Company to make use of the vast amount of historic data that has been collected over the years; a database will be created to store and link the data to facilitate searches to look up and manipulate the data for future product development.

Implementing a database will provide the ability to search through historic test data quickly and efficiently. This data is important because it allows the user to identify the failures of a product and easily look back at historic testing to examine subsequent changes and possible improvements to the product. This would save the Company both time and money, as LPCB

testing would not be required for products/materials that have failed in the past. It will also help to identify solutions for new designs by stipulating precise requirements such as drill resistance for a set period of time. This can be achieved by specifying a time and searching through the materials to find a potential solution.

The limitations of the database are that it can only produce test data for historic tests; as not every single test is completed on every material in use, there will be identified gaps in the data for which historic test data does not exist. Also, when undergoing attack tests on certain composites, it is not viable to attain a time for the attack action for every material in the composite. This will reduce the amount of data available for predictions of potential composites via a Composite Builder. A way to overcome this would be to identify gaps in the database and book LPCB testing to test all the gaps identified. This aim of this process is not to eliminate the LPCB testing altogether, as certain aspects of a product will always require testing or some sort of modification to obtain LPCB certification. The aim is to reduce the amount of testing by creating processes and increased prototype evaluations before taking the product for LPCB testing. This will allow the Company to increase its confidence in a product faring well in an LPCB test.

By applying the historical data available when designing a new product, a product can be predicted to a certain degree, depending on whether the materials have been tested before and there is sufficient data to evaluate the product. As a result, it is possible to integrate the application of the historical data with physical modelling. This includes the simplification of the structural behaviour of the product, analysis of the materials, evaluation of the model designed as a 3D assembly and an investigation of the structural integrity of the product by using FEA and material engineering knowledge. Both concepts would not be as effective when used independently of each other because they are separate tools that interlink. Historical data can create a conceptual design which can be analysed via FEA to give an overall confidence of the structural integrity of the product.

By recording future tests, an evaluation of the testing can take place which would benefit the Company as it would allow the failure of the product being tested to be scrutinised and analysed.

4.7.1.1 PRODUCT MATRIX

A product matrix was constructed to show all the products tested and their level of security, the Issue of the security rating, minimum and maximum sizes etc. This was provided as a

general reference document, allowing gaps in the product range to be identified with the long-term aim of creating a pool of design solutions for existing products at common security levels.

Product	Issue	Level	Tool Category	Maximum working time (min)	Maximum test duration (min)	Fire rated	Fire resistance (Integrity)
Upstand Access Cover	7	2	B	3	15	0	0
Upstand Access Cover	7	3	C	5	20	0	0
Upstand Access Cover	7	4	D	10	30	0	0
Flush Fitting Access Cover	7	2	B	3	15	0	0
Flush Fitting Access Cover	7	3	C	5	20	0	0
Flush Fitting Access Cover	7	4	D	10	30	0	0
CB1	7	2	B	3	15	0	0
CB1	7	3	C	5	20	0	0
CB1	7	4	D	10	30	0	0
CB2	7	2	B	3	15	0	0
CB2	7	3	C	5	20	0	0
CB2	7	4	D	10	30	0	0
WMC	7	2	B	3	15	0	0
WMC	7	3	C	5	20	0	0
WMC	7	4	D	10	30	0	0
SCS Cage System	7	3	C	5	20	0	0
SCS Cage System	7	4	D	10	30	0	0
SCS Mesh Panels	7	3	C	5	20	0	0
SCS Mesh Panels	7	4	D	10	30	0	0
SCS Gates	7	3	C	5	20	0	0
SCS Gates	7	4	D	10	30	0	0
Padlockable Doors	7	2	B	3	15	0	0
Padlockable Doors	7	3	C	5	20	0	0
Padlockable Doors	7	4	D	10	30	0	0
Sentinel Doors	7	3	C	5	20	0	0
Sentinel Doors	7	4	D	10	30	1	0
Sentinel Doors	7	5	D+	10	30	1	0
Sentinel 2 Doors	7	2	B	3	15	0	0
Sentinel 2 Doors	7	3	C	5	20	0	0
Window Bars	7	3	C	5	20	0	0
Window Bars	7	4	D	10	30	0	0
Louvre Vents	7	3	C	5	20	0	0
Louvre Vents	7	4	D	10	30	0	0
Louvre Vents	7	6	E	10	30	0	0
Cylinder Clamps	7	6	E	10	30	0	0
Upstand Access Cover	5	4	D	10	30	0	0
Flush Fitting Access Cover	5	3	C	5	20	0	0
Single leaf doors	5	4	D	10	30	0	0
Twin Leaf doors	5	4	D	10	30	0	0
Full Location Apparatus Case	5	3	C	5	20	0	0
Half Location Apparatus Case	5	3	C	5	20	0	0
Full Location Apparatus Case	5	4	D	10	30	0	0
Half Location Apparatus Case	5	4	D	10	30	0	0
WMC	5	3	C	5	20	0	0
WMC	5	4	D	10	30	0	0
CB1	5	3	C	5	20	0	0
CB1	5	4	D	10	30	0	0
CB2	5	3	C	5	20	0	0
CB2	5	4	D	10	30	0	0
DS1/LS3	5	3	C	5	20	0	0
DS2/LS3	5	3	C	5	20	0	0
Ultrasecure Cylinder Clamp	6	2	B	3	15	0	0
Sentinel UltraSecure	6	3	C	5	20	0	120
Sentinel UltraSecure	6	3	C	5	20	0	240
Sentinel UltraSecure	6	4	D	10	30	0	120
Sentinel UltraSecure	6	4	D	10	30	0	240
Louvre Vents	6	5	D+	10	30	0	0

Table 8 - Product Matrix

4.7.1.2 PRODUCT SPECIFICATION SHEET

A product specification spreadsheet was designed to link the LPCB testing to the security products and to access the vast amount of LPCB test data held by the Company. This provides a breakdown of the different types of products, security levels, LPCB data (such as LPCB certificate and test details), heights and widths and the standards the products adhere to.

The specification spreadsheet was designed based on the product matrix and provides a snapshot of the products and their details in terms of LPCB standards. It can be used as a reference document for the Company and can also be given to specifiers in the industry to allow them to specify a product that complies with the regulations and requirements of Technocover’s products.

Product Type & General Info				LPCB Data								Doorset Height					
Product code	Product Trade Name	Product Type	Assembly drawing reference	LPCB Accredited	LPS 1175 Issue Status	Security Rating	Tool Category	Maximum working time	Maximum test duration (min)	Certificate Link	LPCB Certification No.	Issue Number	LPCB Certification Date	Minimum structural opening height (mm)	Maximum structural opening height (mm)	Minimum structural opening width (mm)	Maximum structural opening width (mm)
DS1/SLT2	Single leaf outward opening hinged security doorset	Sentinel Lite 2	DS1-SLT-GA-001	✓	7	2	B	3	15	450f-07	450#13	7	21/11/17	1300	2410	500	1200
DS2/SLT2	Double leaf outward opening hinged security doorset	Sentinel Lite 2	DS2-SLT-GA-001	✓	7	2	B	3	15	450f-07	450#14	7	21/11/17	1300	2410	1200	2300
DS1/SEN3	Single leaf outward opening hinged security doorset	Sentinel Ultrasecure	SEE LPCB PACK	✓	7	3	C	5	20	450f-07	450#01	7	21/11/17	1800	2350	750	1200
DS1/SEN3	Single leaf outward opening hinged security doorset	Sentinel Ultrasecure	SEE LPCB PACK	✓	7	3	C	5	20	450f-07	450#07	7	21/11/17	1210	2350	750	1200
DS2/SEN3	Double leaf outward opening hinged security doorset	Sentinel Ultrasecure	SEE LPCB PACK	✓	7	3	C	5	20	450f-07	450#02	7	21/11/17	1800	2350	1200	2185
DS2/SEN3	Double leaf outward opening hinged security doorset	Sentinel Ultrasecure	SEE LPCB PACK	✓	7	3	C	5	20	450f-07	450#08	7	21/11/17	1210	2350	1200	2350
	Single leaf outward opening hinged security doorset																

Figure 46 - Product Specification Sheet (Part 1)

Product Type & General Info				Accessories						Standards Adhered to			
Product code	Product Trade Name	Product Type	Assembly drawing reference	Upper louvre vent (200mm x 220mm)	Lower louvre vent (200mm x 220mm)	Sentinel Lite Upper louvre vent (188mm x 288mm)	Sentinel Lite 'SR2' Vision Panel (visible area 190mm x 290mm)	Sentinel Lite 'SR3' Vision Panel (visible area 190mm x 290mm)	Sentinel 'SR3' Vision Panel (visible area 190mm x 290mm)	Sentinel 'SR4' Vision Panel (visible area 190mm x 290mm)	LPS 1175	LPS 1075	BS EN ISO 1461
DS1/SLT2	Single leaf outward opening hinged security doorset	Sentinel Lite 2	DS1-SLT-GA-001			✓	✓				✓		✓
DS2/SLT2	Double leaf outward opening hinged security doorset	Sentinel Lite 2	DS2-SLT-GA-001			✓	✓				✓		✓
DS1/SEN3	Single leaf outward opening hinged security doorset	Sentinel Ultrasecure	SEE LPCB PACK	✓	✓				✓		✓		✓
DS1/SEN3	Single leaf outward opening hinged security doorset	Sentinel Ultrasecure	SEE LPCB PACK	✓	✓				✓		✓		✓
DS2/SEN3	Double leaf outward opening hinged security doorset	Sentinel Ultrasecure	SEE LPCB PACK	✓	✓				✓		✓		✓
DS2/SEN3	Double leaf outward opening hinged security doorset	Sentinel Ultrasecure	SEE LPCB PACK	✓	✓				✓		✓		✓

Figure 47 - Product Specification Sheet (Part 2)

4.7.1.3 DOOR COMPOSITION TABLE

An analysis of the composites used in the Sentinel Lite doorsets was undertaken to understand the type of composites that are currently used and how they differ when the security level and zone within the door leaf changes. This provided an insight into how the composites were typically made up and how they would have to be replicated in the database.

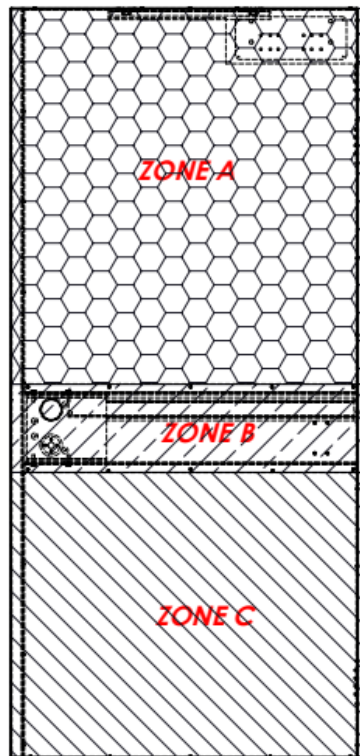


Figure 48 - Breakdown of Doorset

Zone A is the section of the door leaf which spans from the top of the centre channel to the very top of the door leaf. This will vary in size (height and width) on every doorset. The primary aim of the LPCB attackers is to create a handhold to reach the internal locking system, or to create a hole to feed a wire through; this varies depending on the locking system.

Door Type	Level	Solenoïd	Panic Bar	Zone A		
				Layer 1	Layer 2	Layer 3
Sentinel Lite	2	N	N	25mm Celotex	2No. 2mm Spacers	25mm Celotex
Sentinel Lite	2	Y	Y	12mm LDPE	2.5mm Stainless Steel	40mm Celotex
Sentinel Lite	3	N	N	12mm LDPE	0.9mm Zintec & 2No. 2mm Spacers	35mm Celotex
Sentinel Lite	3	Y	Y	2.5mm Stainless Steel	35mm Celotex	3mm spacer, 7mm Avertic Armour '6+2', 3mm spacer

Figure 49 - Door Composition Zone A

For the SR2 security doorset, layers 1 and 3 are 25mm Celotex which is a type of foil faced insulation board. This is primarily used because of its thermal properties which benefit the doors. For LPCB testing purposes, this material is placed within the category of a delay material. The product has a foam like structure which is easily cut, but it takes time to do this and remove it from within the door. Layer 2 is made up of spacers which offer no security purpose but space the infill materials to keep the door leaf the same thickness throughout.

For the SR3 security doorsets, in layer 1 the Celotex board is replaced with a sheet of 12mm LDPE board and a sheet of 0.9mm Zintec is added to layer 2. These materials are stronger than Celotex making them much more difficult to cut and remove. This also reflects the difference in tools available when the test is for a level 3 security rating. The additional layer of 0.9mm pre-galvanised steel helps to stop a drill attack, as it is an additional layer of steel to breach within the centre of the door leaf.

When the doorset has a panic escape locking system, there is also a major difference in the materials required in this zone. This is to delay and stop the attackers from creating a hole in the doorset above the panic bar allowing them to feed a wire through and fish the panic bar.

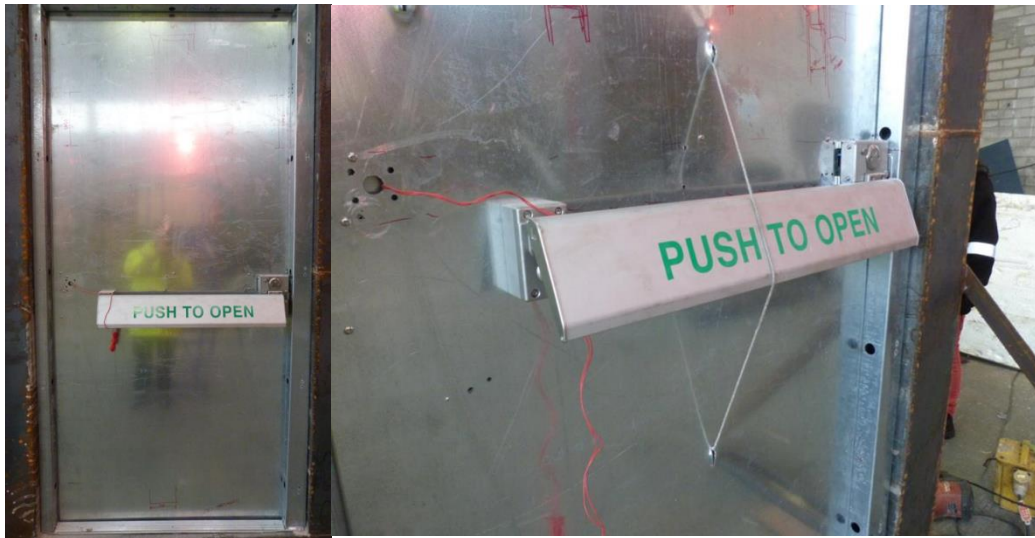


Figure 50 - LPCB attempting a fishing technique to overcome the panic bar

The SR2 doorset requires a sheet of 2.5mm stainless steel within layer 2 and the Celotex in layer 1 is replaced with 12mm LDPE board, to stop the attackers from impacting a hole through the door. The SR3 door requires a specialist anti cut Avertic armour material to stop the drill attack in layer 3 and the 12mm LDPE in layer 1 is replaced with 2.5mm stainless steel.

Door Type	Level	Solenoid	Panic Bar	Zone B		
				Layer 1	Layer 2	Layer 3
Sentinel Lite	2	N	N	25mm Celotex	N/A	25mm Celotex
Sentinel Lite	2	Y	Y	25mm Celotex	N/A	25mm Celotex
Sentinel Lite	3	N	N	35mm Celotex	N/A	12mm LDPE
Sentinel Lite	3	Y	Y	35mm Celotex	4.5mm D2	12mm LDPE

Figure 51 - Door Composition Zone B

Zone B is the section of the door leaf which spans from the edge of the locking system, through the centre channel up to the edge of the door leaf. This will vary in size (width) on every doorset. The primary aim of the LPCB attackers is to create a handhole, through which they can reach and retract the locking system.

For the SR2 security doorset, layers 1 and 3 are made up from Celotex boarding. As stated above this is used as a delay material, with the main strength coming from the inner and outer

2mm pre-galvanised skins of the doorset. Layer 2 is left void as the composition will pass all level 2 tests.

For the SR3 security doorsets, the layer 3 Celotex material is replaced with a sheet of 12mm LDPE boarding. The LDPE is much harder to cut and remove, this makes it difficult for the LPCB attackers to drill, cut and remove and make a handhold in the door. Layer 2 only has a material added when a locking system featuring a solenoid lock is used. This material is used to protect the cables which run from the lock, through the centre channel and out through the hinge side of the door leaf. To stop the attackers drilling the door and gaining access a layer of 4.5mm D2 plate is used which stops all drill attacks.

Door Type	Level	Solenoid	Panic Bar	Zone C		
				Layer 1	Layer 2	Layer 3
Sentinel Lite	2	N	N	25mm Celotex	N/A	25mm Celotex
Sentinel Lite	2	Y	Y	25mm Celotex	N/A	25mm Celotex
Sentinel Lite	3	N	N	12mm LDPE	N/A	40mm Celotex
Sentinel Lite	3	Y	Y	12mm LDPE	N/A	40mm Celotex

Figure 52 - Door Composition Zone C

Zone C is the section of the door leaf which spans from the edge of the base of the centre channel up to the base of the door leaf. This will vary in size (width) on every doorset. The primary aim of the LPCB attackers here is to create a handhole, through which they can reach and retract the locking system or to create a hole big enough for body access.

For the SR2 security doorset, layers 1 and 3 are made from the Celotex boarding. This is used within the other zones of the door. For the SR3 security doorset, layer 1 is a section of 12mm LDPE board and layer 3 is a section of the Celotex board. For both security levels layer 2 is left empty as there is no need for any additional material. For all the zones above the door has an inner and outer skin in which all the composites are housed. These skins are manufactured from 2mm pre-galvanised sheet and provide additional security for the door leaf.

4.8 LPCB DATABASE

After analysing all the previous LPCB test reports, it was determined that there was a vast amount of data that was not being used by the Company especially from testing where a product had failed. The failed tests can be analysed to understand why the product had failed, when it had failed and how close it was to passing the test. To do this, all the test report data had to be in a format which facilitated searches to look up data.

There are currently 46 LPCB reports representing different products which have been tested for Issue 5, 6 and 7 of the LPCB standard - LPS 1175. The data of the reports would have to be synonymous to create the relevant metadata tags. The database was constructed in such a way that it could be searched, and information could be easily extracted. It also has the capacity to visualise the gaps in data through effective data visualisation. The data will allow cross referencing where specific materials and thicknesses have overcome certain engineering challenges to allow bottom up driven design and help prevent the overengineering of products.

Initially the LPCB reports were analysed to identify the metadata tags used to categorise the data in the database.

Figure 53 is a typical representation of a breakdown of a LPCB report.

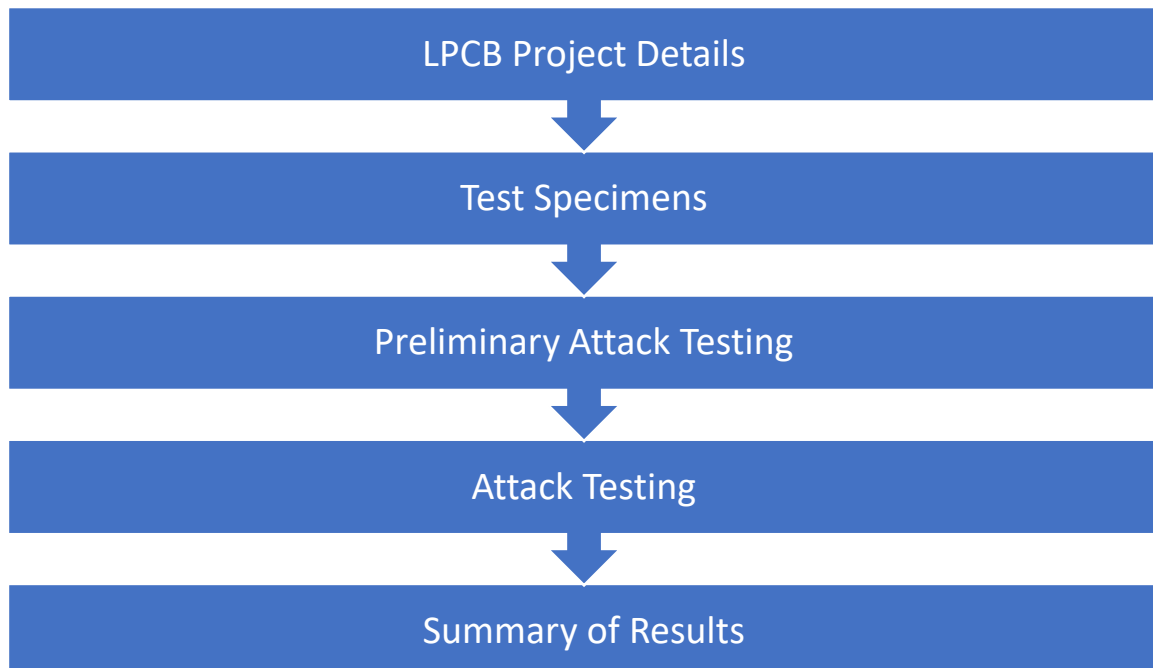


Figure 53 - LPCB report breakdown

This was discovered to be too complicated for categorisation in the database due to the amount of data contained in each category and their relationships.

This was then refined to provide a more detailed breakdown which encompasses and highlights the most relevant categories.

Table 9 - LPCB test data breakdown

LPCB Project Details	Test Specimens	Attack Testing Details	Attack Testing Breakdown	Summary of Results
<ul style="list-style-type: none"> •Product Name •Issue Standard •Target Security Level •Date 	<ul style="list-style-type: none"> •Specimen name •Material breakdown •Composite •Number of layers 	<ul style="list-style-type: none"> •Objective •Tool Category •Locked Condition •Test Specimen •Target security level 	<ul style="list-style-type: none"> •Attack Actions •Number of Steps •Tools used •Attack time breakdown 	<ul style="list-style-type: none"> •Security Level Achieved •Comments from LPCB •Observations

An understanding of the searches required by the end user was essential to ensure that the database was designed with the ability to perform them. It was identified that the following searches were required:

- Tool Category
- Composite
- Fixings
- Objective
- Test Result
- Time Restraint
- Product
- Material
- Tool
- Attack Action

After creating the tables explained above, it was apparent that all the data captured from the reports produced by LPCB was relational meaning that the data is connected to each other.

4.8.1 CREATION OF DATABASE

As there were more than 40 test reports to compile, research was undertaken to understand how to compile a large amount of data and to identify the most appropriate software to use.

Both databases and spreadsheets are critical components in the infrastructure of software which is designed to manage large amounts of data (Augen, 2011). Databases serve as information repositories as a lot of data can be stored and tend to grow over time as more information is required. However, Augen (2011), states that spreadsheets are the best choice for managing a single table of numerical information. Due to the recent increased capacity in Microsoft Excel, it is an excellent complement to a large database infrastructure (Augen, 2011). Cervesato (2013) compares a relational spreadsheet to a relational database and states that the primary focus for relational spreadsheets is to provide the means to rearrange tabular information. A relational database isolates the physical layout of the data into abstract relations (Cervesato, 2013).

It is highlighted by O'Donnell (2008) that spreadsheets have limited specification of data types for columns which only extend to formatting rules (O'Donnell, 2008). They are also limited to the growth of the data exponentially and to only one single user using it at one time. If a relational database is created, data types for all columns can be specified and there is no limit to how many rows can be added into the database. Display and layout features are irrelevant in a relational database. Another benefit would be that databases are created to allow for multiple users simultaneously (O'Donnell, 2008).

Based on the research into the differences between spreadsheets and databases, it was determined that creating a database would be the most beneficial method for the manipulation of the historic data.

Figure 54 is a breakdown of structural types of database management systems evaluated by Panwar (2019).

- Hierarchical databases

This system is alike a tree structure and collects all the records together as a record type. However, the disadvantage of this system is being able to have only one parent and relationship

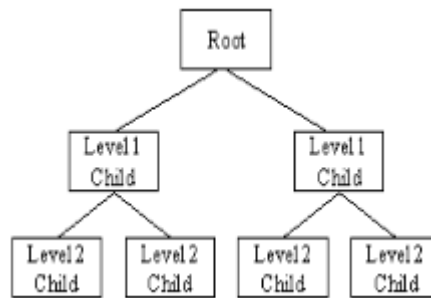


Figure 54 - Hierarchical Database³⁵

- Network databases

These are mainly used on large digital computers and uses a tree-like hierarchy.

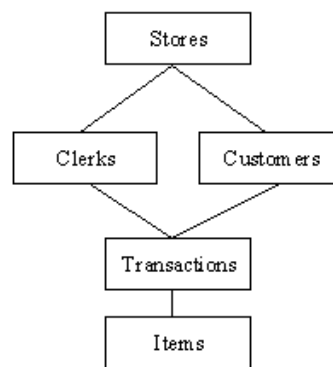


Figure 55 - Network Database³⁶

- Relational databases

The advantage of using this kind of database is modifying data entries without affecting the entire body.

³⁵ Panwar, A. (2019, January 18). Types of Database Management Systems. C# Corner.

³⁶ Panwar, A. (2019, January 18). Types of Database Management Systems. C# Corner.

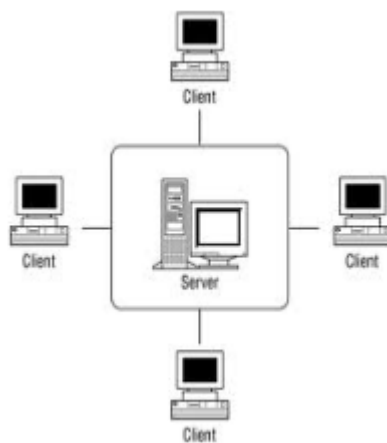


Figure 56 - Relational Database³⁷

- Object-orientated databases

These are broken down in to 2 elements detailing the type of data and methods of the data. This method is generally more expensive to develop and more complicated to create.

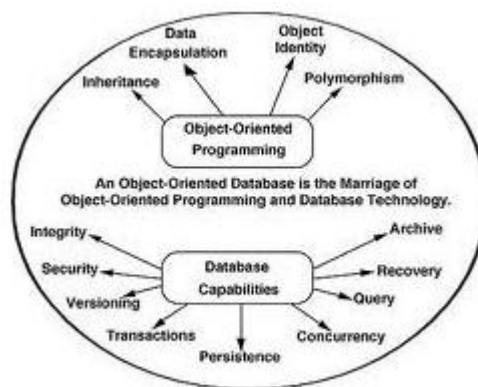


Figure 57 - Object-orientated Database³⁸

Following the research, it was identified that the best method to use would be a relational database. This was backed up by O'Donnell (2008) who states that a relational database provides a way to store large amounts of data in tables that are related to one another or are independent of one another. It is also a way to ensure data integrity to formalise relationships among data. It is also a way to extend the database when there is new data to be input or if there are new ways to operate the data (O'Donnell, 2008). The relational database would allow the tables to reference each other whilst allowing it to be modified and for more data to be entered without affecting the core structure.

³⁷ Panwar, A. (2019, January 18). Types of Database Management Systems. C# Corner.

³⁸ Panwar, A. (2019, January 18). Types of Database Management Systems. C# Corner.

4.8.1.1 MICROSOFT ACCESS

The database was created using Microsoft Access and the tables were designed to ensure that all the required searches could be completed. Consistency between data types was very important when linking similar field names together so if for example a test time was not in the same field type as a different test time, integration between the two could not occur.

It was decided that the data would be stored within the tables detailed below. Some of the tables were set up to specify individual parts of the test such as tools, objectives etc., whereas other tables were set up to be relational. The benefit of this structure is that the interface allows additions to the tools list and the objective list enabling data to be entered whilst maintaining the correct relationships.

- **Action Test**
This table details the breakdown of the attack test. This includes and links fields such as tools, layers, composites, materials, working times, running times, action and test results etc. This table allows the examination of all the attack test breakdowns.
- **Actions**
This details the attack actions, the project number and the total number of stages of an attack test.
- **Actions/Tools**
This table is used to specify the breakdown of the tools, quantity of the tools and the attack action where they are used.
- **Attack Actions**
An attack action is a single objective undertaken in a test with an aim of completing many attack actions in the hope of achieving the overall objective for the product to pass the security tests.
- **Attack Products**
This is the categorisation of the type of product designed and tested.
- **Attack Tests**
This refers to the single tests carried out in the testing by LPCB. This would have an overall objective and have a maximum working time for every test which took place, linking to the maximum overall test duration – which links to the security level the product is aiming to achieve.

- Composites

This is a list of all the composites that have been used in the LPCB tests. The composites would be made up from varying different materials in a set order. This would be beneficial as a list to the designers of the products, to see what composites have been tested and how they reacted when compared with similar materials tested.
- Database Categories

This category collates the data together such as the LPCB Security Tests, Blast, Ballistic, Fire and Acoustics.
- Layers

The layers refer to the layers that the materials are in the composite with the inner layer being the layer on the inside of a product and the outer layer being the attack face of the product.
- Materials

These are the materials used in the LPCB testing and include any of the materials that make up the composites and specimens.
- Objectives

These are the overall objectives that LPCB test to and is the aim of every single attack test.
- Product Descriptions

This describes the typical type of products tested by LPCB but designed by the Company.
- Product Name

This is extracted from the test reports given by LPCB. This is typically the name given by the Company who designs the products and would be what they are proposing to call the product once certification is achieved, and it is released into the market place.
- Project Number

The project number given by LPCB, for each testing regime. This links to their test reports.
- Specimen Table

This list explained the specimen numbers given to specimens by LPCB. Each item presented to LPCB for testing will be assigned a specimen number, so that each attack test carried out can be linked to a specific specimen.
- Tool Categories

This is a list of tool categories (A-H), applicable to the test regime.

- Tool Category Breakdown

This was a table linking the tool categories, revisions and the maximum working time.

- Tools

This was a list of all the tools included; the tool name, revision and tool category.

All the tables were created on Microsoft Access and were linked together by specifying their relationships – typically the relationships were one to many or many to one. The relationship table taken from the Microsoft Access is shown in Figure 58.

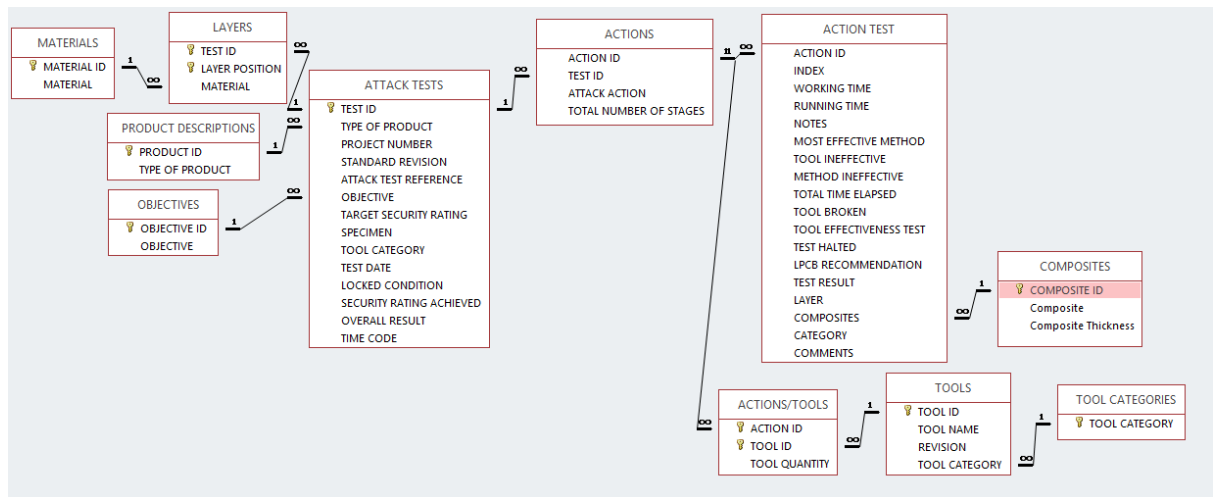


Figure 58 - Relationship table of LPCB Database

The available searches in the database are listed below.

- Tool Category Database

This allows the user to search for a specific tool category and the Issue of the standard applicable at the time of testing. From here all the tests carried out can be seen along with what material/product is used and if the product passed or failed.

- Composite Database

This allows the user to search for composite structures that have been used by the Company in the past. You can then see what tests have been carried out on them, at what security level and what Issue of the standard.

- Fixings Database

This allows the user to search for what fixings have been tested. The time they took to break and with what tools. This can help when specifying how many fixings and what type will be required to secure the new product.

- Objective breakdown

This allows the user to search for a set test objective, such as drill 8mm hole. You can then see what products/materials/composites have been tested where they have tried to create an 8mm hole.

- Test Result

This allows the users to search for tests which have either resulted in a pass, pass with a lower security rating or a fail. This can save new tests being carried out which have already been done.

- Time Restraint

This allows a certain time restraint to be inputted. From here you can filter the results to find materials which have withstood a certain attack for this required period. This can help with the selection of materials when designing new products.

- Product Search

This allows the user to search for specific products, and filter what attack tests have been carried out on them.

- Material Search

This allows the user to search for specific materials, and filter what attack tests have been carried out on them.

- Tool Search

This allows the user to search for specific tools which the attacker can use. This will detail what security rating was being tested for, and what attack method was being used.

- Attack Action Search

This allows the user to search for specific attack actions that have previously been carried out by LPCB. The results can again be filtered to suit the new product that is being designed.

By creating the searches explained, it allows the Company to easily manipulate the data that will be stored in the database and to integrate the database more straightforwardly into the design process - as the tool will greatly aid the designer by giving them knowledge of the historic testing.

4.8.2 DATABASE INTERFACE

A user interface was designed to facilitate easy manipulation of the data by automatically populating the pertinent fields based on the entered data. This enables a user to input the details from a complete test report without the need to link specific tables together.

4.8.2.1 NAVIGATION FORM

The navigation form is accessed by clicking on the Navigation bar on the left of the screen and clicking the form 'Navigation Form'.

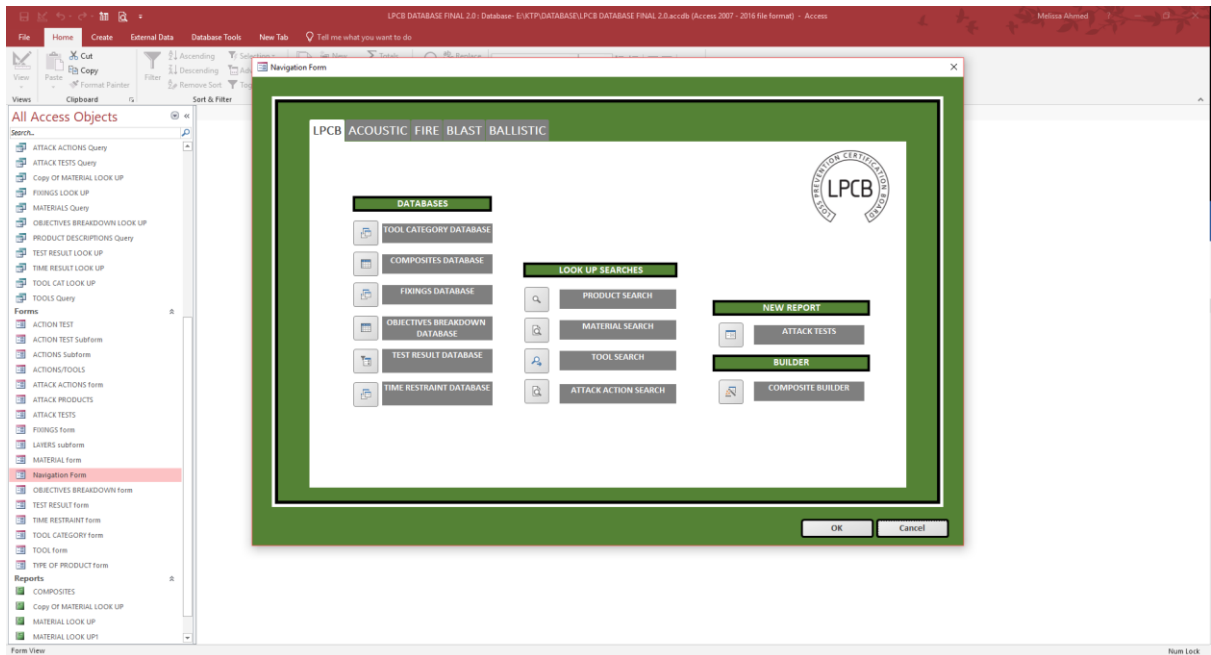


Figure 59 - Database Navigation

The navigation form provides users with an interface from which they can enter data or search the database. It also provides access to the Composite Builder which facilitates the manipulation of data.

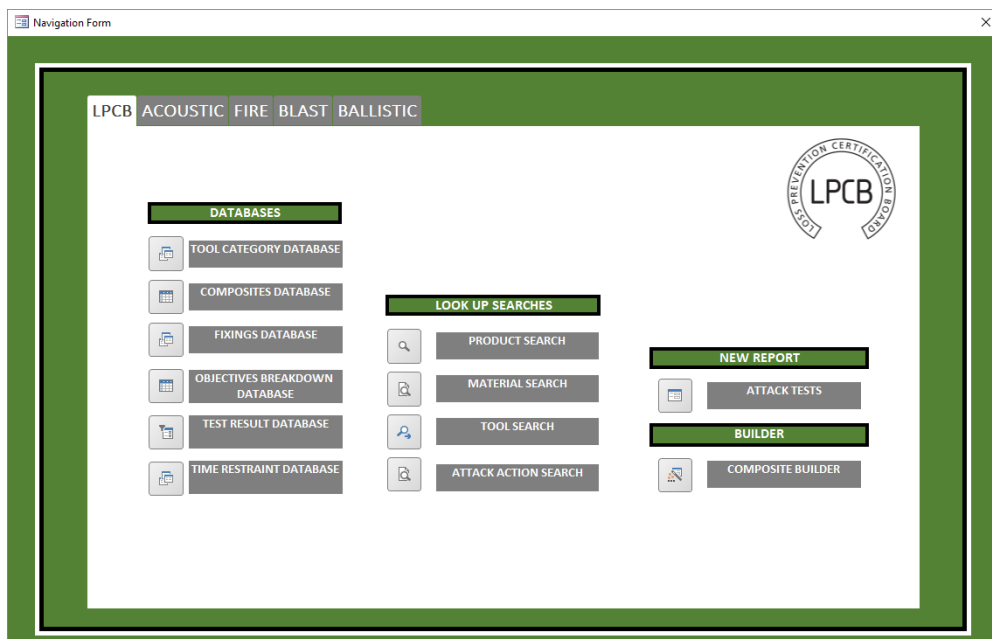


Figure 60 - Navigation Form

LOOK UP SEARCHES

This section of the navigation page facilitates searching through the database for products, materials, tools etc. Every search is linked to a query in the Microsoft Access Navigation pane.

DATABASES

This section of the navigation page analyses the data in the various databases.

COMPOSITE BUILDER

The Composite Builder is an Excel sheet which allows users to input times and materials to predict the time taken to theoretically attack the composite created; this will be used for composites that haven't previously been tested by LPCB.

NEW REPORT

This section allows a user to easily input new reports into the database. Data is entered into forms which create records in the database; these will subsequently be available to look up searches.

4.8.2.2 COMPOSITE BUILDER

The Composite Builder can be used to theoretically design a new product composite from the outer layer through to the inner layer. An objective and attack action can be set and the times from previous tests will be used to populate the column on the right-hand side of the table in Figure 28. From this a prediction can be made for the length of time the new product/material composite could withstand a set attack action, before any actual physical testing is completed. This tool will eliminate the need for provisional indicative test days. This document will be used alongside the database to create composites and note down the test times for the individual materials used.

All materials with data held could then be grouped together to calculate a predicted time for LPCB to attack the composite, to see if the product was likely to withstand the allotted amount of time set by LPCB.

This is finalised before the composite is taken to LPCB to be tested to ensure that testing was necessary to be completed – if there is historic data for the exact composite, a new LPCB test doesn't need to be done. Checks to see if it would have been possible for there to have been

enough historic test data to be able to mitigate some (if not all) of the testing undertaken by LPCB.

NUMBER	LAYER	MATERIAL	OBJECTIVE	ATTACK ACTION	TOOL CATEGORY	TIME (HH:MM:SS)
1	OUTER	MILD STEEL			6A	00:10:00
2	2ND					00:10:00
3	3RD					00:10:00
4	4TH					00:10:00
5	5TH					00:10:00
6	6TH					00:10:00
7	7TH					00:10:00
8	8TH					00:10:00
9	9TH					00:10:00
10	INNER					00:10:00
TOTAL TIME						01:40:00

Figure 61 - LPCB Composite Builder Prediction

The design engineers at the company can fill in the material section on the left-hand side of the table from outer to inner skin of the new product. They can then evaluate the designs capability to resist attack tests using the LPCB database to fill in the objective and attack action columns. These will have times linked to them dependant on the security level and tool category, which will tell you if the proposed product can pass the set test.

4.9 USING THE DATABASE

The test result search allows the users to filter the database for tests which have either resulted in a pass, pass with a lower security rating or a fail. This can save new tests being carried out which have already been done.

The test result function allows the user to search through all existing test data to calculate the pass rate of all products sent for testing by LPCB. From the data it was found that Technocover had a failure rate of 71% for all products they had submitted for testing. This was above the industry standard of 95% claimed by LPCB. The database will also show the attack action which has caused the most failures for Technocover products over the years and determine the areas that the company need to improve testing. This will vary dependant on the product and will highlight where certain products require strengthening. The failure rates for all types of products submitted to LPCB for testing are detailed:

- Failure rate of doors = 69%
- Failure rate of access covers = 68%
- Failure rate of flush covers = 70%

- Failure rate of buildings = 56%
- Failure rate of mesh = 87%

4.9.1 VALIDATION

The composite database was created to allow the user to search for composite structures that have been used by the company in the past. It will show what tests have been carried out on them, at what security level and what issue of the standard.

The most recent product tested and certified by the company was their latest range of doorsets, the sentinel lite range. This style of doorset was a new thinking process for the company with them moving away from fully welded assemblies made up from mild steel, which is post galvanised to bolted connections with pre-galvanised components. Because of this the company carried out numerous indicative test days at LPCB to determine the layers of composites required to resist drill and cutting attacks. These test days cost £2500 a day, increasing the overall certification scheme by thousands.

With this composite builder that has been produced, these indicative days could have been reduced or even eliminated altogether. The composite builder uses the previous data held by the company to theoretically build a composite of materials to manufacture the product from. This builder allocates time next to the materials dependant on the test carried out and gives a predicted time resistance for composite.

A material search was completed to obtain the effectiveness of the D2 plate in terms of stopping drill attacks. The database was used to conduct a search into all previous tests which have involved the material. The first step was to search the database for the material and filter the results to only show tests which have involved drill attacks.

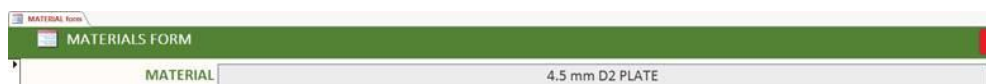


Figure 62 - Database material search result

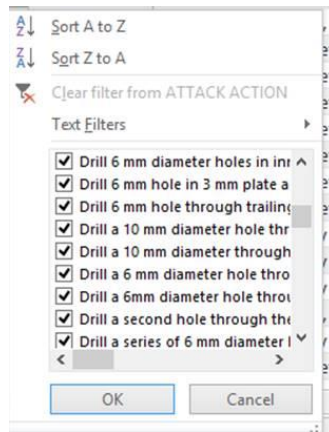


Figure 63 - Database filter

From this the quickest time in which LPCB have drilled through a section of D2 plate was found to be as below:

- 6mm hole with carbide drill bits: 3minutes 13 seconds (four drill bits used)
- 8mm hole with carbide drill bits: 6 minutes 39 seconds (five drill bits used)
- 10mm hole with carbide drill bits: 5 minutes 57 seconds (6 drill bits used)

These were all conducted with category D tools, whilst aiming to gain an SR4 rated product. These times can now be linked to the hardness values gained from the lab testing to calculate expected drill times for new potential materials, and to assess they're capability compared to the D2 plate.

4.9.2 PROPOSE WORKFLOW

It was understood that for certain tests and product types, the objectives and attack test methods are very similar. The database can group together the typical objectives to improve the ease of searching. By selecting the product that was tested, all the objectives that were completed in historic testing were found.

This provides the user with knowledge on what tests will be completed dependant on the type of product being designed, giving an insight into where the product needs strengthening to stop certain attack methods. By searching for different objectives, the primary failure mechanisms are shown through the evaluation of the testing shown on the database. This will highlight where products of the same type have been weak in the past and where extra time needs to be spent during the design stage.

Various actions are analysed in this investigation to identify possible routes that LPCB would use to test this product with the aim of breaking into it. This allows for a more accurate prediction of how LPCB will attack the product, dependant on its type and the materials used to construct it.

This study analyses the tools and the product type depending on the security level or the tool category of the product. Filters allow analysis of the most common tools used on the product to be grouped together. This will show the most popular tools used by LPCB on the Company's products and shows how different materials/composites have resulted in the attack tests with these tools. The tools are linked to the relevant tool category and Issue of the LPCB standard. This is useful as new products being designed for testing will be to the latest Issue of the standard. Historic testing may have tools listed in lower categories than they are currently.

4.9.3 COMPOSITE BUILDER

With the completion of all the studies above, a composite builder can be created to predict the time taken for LPCB to complete attack testing on a product designed from a set list of materials. The materials are sorted in layers from outer to inner and times from the database listed next to each material to build up an overall resistance to the attack method chosen. This was created using Microsoft Excel and was linked to the database. This builder can be completed by the user when researching through the historic data in the database. This is a very useful tool that collates the data from the database, to allow the designer to evaluate different materials in one spreadsheet. This can cut weeks from the design process as the engineer will have a guide as to which materials to use to construct the new product.

4.9.4 IMPROVEMENTS IN THE LPCB TESTING PROCEDURE

After creating the database, it was highlighted that for the database to work efficiently and at its best, the database would have to be synonymous on the typical phrases used for the objectives, attack actions, tools etc. to make the searches more effective.

Another way to improve the data obtained from LPCB is to continue a test after a product has passed a test to see how long it takes to fail. This will give the Company more accurate results and can use the failed test data to improve the product.

It has proven effective to understand how a product is failing in terms of different tests but sometimes it isn't possible to see unless it is measured. When undergoing lever tests, by

measuring the displacements at the time intervals relevant to the tool category restrictions, a controlled measure of how the product is failing is shown.

4.10 SUMMARY

The approach to the Company's procedure to the LPCB testing followed a typical process in which a sample is fabricated, tested, revised and re-tested. This process was perceived to be highly inefficient and has been improved upon by using modern innovative digital techniques.

For the most recent product that was tested and certified by the company, the Sentinel Lite Doors, three indicative test days were carried out. These all had a similar cost to what is shown in Table 7 and have added an additional £10,000 to the current LPCB design and testing process.

A unique database has been created which compiles all the test data held from previous test regimes presented in a searchable format. The product designer can use this to search for a material and establish how it will react to a certain attack methodology, as they would do during an indicative test day.

The database also contains data from previous tests - which gives an indication of the time for which a product can withstand a certain attack method. The use of this database will remove the need for multiple indicative test days and based on figures previously provided, has the potential to save the company around £10,000 per product being developed. As well as the money saved from cutting out the indicative testing, the company would also save time and resources. This time would be derived from not having to wait for test windows where LPCB are available to carry out multiple tests, as the likelihood of only requiring one test would be greatly improved. The time saved can be put towards developing new products within the year potentially increasing the new product average from 3 per year up to 4.

Searches have also been carried out to test the search facilities in the database to check the accuracy of the database and the ease of use. Using the searches and look up functions on the database, it is easy to identify the missing tests for specific materials. Identifying the gaps in the material LPCB testing database is crucial for making the Composite Builder more accurate as the more data that is put in the database, the more accurate the database will be able to predict the test times. An analysis of the gaps in the database knowledge could be undertaken and a test day can be completed on gaining data for the database.

The database has proven very valuable already as it has been included in the LPCB testing procedure in January in the padlock assessment testing project. By searching through the database and its historic records, LPCB could reference previous testing and consequently eliminate the need to carry out any further physical testing. This is evidence that if the database was used in partnership with LPCB, then certain attack tests could use historic data instead of being re-tested, therefore saving the company money and resources as the testing time and costs would be reduced.

The database was used to calculate the failure rate of Technocover based on the test data from previous test attacks which amounts to 71%, which is 24% better than the LPCB stated average of 95%. This demonstrates that Technocover is passing more tests than the average manufacturer which could be credited to the experience gained by the high number of tests that have been performed improving knowledge and understanding of the test methodology. The author anticipates that the use of the database will further improve this first-time success rate, making it more straightforward and quicker to gain pertinent information from previous test regimes.

CHAPTER 5

5 MATERIAL BEHAVIOUR

5.1 INTRODUCTION

With the aim of investigating if there is a way to mimic physical attack tests undertaken by LPCB, it was first relevant to understand the behaviours of materials in the products – this is identifying the point where a material will break, how hard it is, the strength of the material etc. If it is known at what point a material will break, preventions can take place to stop it from reaching these points through re-designing.

Every piece of material purchased through a supplier is given a material datasheet which states an overview of the mechanical, chemical, thermal and physical properties of that specific material. If the knowledge of different material properties can be studied and understood, it will be simple to compare different materials through this method which can in turn reduce the number of material tests completed at LPCB – this will save the company money and reduce the time taken to develop a product. It can be explored if material properties can be related to the physical attack tests at LPCB.

The materials used at Technocover was compiled into a Material Inventory list.

Analysing the material datasheets of the current materials used at Technocover, the most frequent properties stated are compiled below:

- Minimum yield strength
- Minimum tensile strength
- Maximum tensile strength
- Minimum energy required when impact tested
- Chemical composition

Investigations into the different material properties stated on datasheets was subsequently completed to understand if it was necessary to obtain further testing on materials.

By identifying material properties such as breaking points, tensile strength, hardness etc., allows for comparisons between different materials strengths at the very initial stages of the design process as it gives an understanding of for example the amount of stress needed to prevent reaching, to allow the material to be in its elastic state. Designing the structure using a minimum value of tensile strength, the probability of failure decreases.

Investigating and recognising the behaviours of the materials will increase the chances of preventing an attack on an LPCB product. This is due to the knowledge of the breaking points of the materials and strengthening the materials accordingly, with the aim of increasing the chances of overcoming an LPCB attack or reducing the LPCB attack time and costs by eliminating indicative material testing at LPCB, where material testing has taken place at LPCB previously.

5.2 INVESTIGATING MATERIAL PROPERTIES

A study into the types of materials and their properties was undertaken. Investigations into different types of materials was undertaken to understand the properties of them and how they can be applied to this research project.

After inspecting the material datasheets, a study into the different types of materials was completed to categorise the different material types and compile typical material properties. This allows a basic understanding of the behaviour of different types of materials and how they typically react – this will have an influence on how a product will be designed right from the initial stages of the design process.

The material properties are a crucial part of the design process as a specific material can be chosen based on its properties to stop certain LPCB attack tests such as drill resistance. Selecting a suitable material based on its properties at the initial design stage of the process can save time and resource such as indicative material testing at LPCB.

5.2.1 TYPES OF MATERIALS

Materials are categorised into four categories; natural materials, manufactured materials, new materials and old materials (Seward, 2014). Natural materials contain materials such as stone and timber and have been used for centuries as building materials however, as they are natural, they often contain defects and aren't appropriate for use in the large-scale engineering. Manufactured materials are material such as steel and aluminium alloy which are produced under controlled factory conditions, which produces a more consistent material.

New materials refer to fibre reinforced composites which are highly manufactured but haven't been in existence as long as materials such as steel to understand the material properties completely, making this material have a high material safety factor. Old materials such as cast iron and wrought iron are less commonly used as stronger and cheaper alternatives exist (Seward, 2014).

Beer, Johnston, Jr, & DeWolf (2004), states that stress-strain diagrams vary with materials. However, identifying common characteristics are possible when analysing types of materials by looking at their stress-strain diagrams (Beer, Johnston, Jr, & DeWolf, 2004). However, Prasad & Nair (2009) categorise the materials into three different categories; metals and alloys, polymers and ceramics. They compare their typical properties and applications. Materials are subjected to many manufacturing processes to produce the desired shape and to ensure that the design stipulated physical and mechanical properties and dimensional tolerances are followed (Prasad & Nair, 2009). Figure 64 shows the properties and engineering applications of various materials.

Materials	Properties	Application
Metals and alloys (ferrous and non-ferrous)	Good thermal and electrical conductivity, high strength and stiffness, ductility, malleability, hot and cold workability, weldability	Fabrication of structural components and assemblies for general engineering as well as high-tech application in such areas as aerospace, aircrafts, automobiles, railways, atomic reactor vessels, electrical and thermal conductors, offshore and deep sea exploration
Polymers (includes a variety of materials like rubber, plastics and adhesives)	Light weight, corrosion resistance, low strength and stiffness, electrical insulation, low coefficient of friction, poor resistance to high temperature	Structural and decorative items, paints, adhesives, car tyres and doors, home appliances, trash bags, potholders, wire insulation, computer chips, packing materials
Ceramics (inorganic non-metallic materials, constituents of which are bonded together by covalent or ionic bonds)	Low density, good temperature and corrosion resistance, high melting temperature, brittleness, abrasive, piezo-electric properties, good optical properties	High temperature applications, fabrication of transparent windows, pottery making, abrasives

Figure 64 - Properties and Applications of Materials³⁹

DUCTILE MATERIALS

Beer, Johnston, Jr, & DeWolf (2004) explain that typically, ductile materials are comprised of structural steels and alloys of other metals. Metals are a structure of atoms which are held together by metallic bonds and because of this, when the material is subject to small stresses the atoms roll over each other to new positions without breaking the metallic bond. Therefore,

³⁹ Prasad, J., & Nair, C. K. (2009). Non-Destructive Test and Evaluation of Materials. Tata McGraw-Hill Education.

they are typically a ductile material which can withstand large deformation before failure. Some of the ductile materials include copper, aluminium, gold etc. (Raj & Ramasamy, 1983).

The ductile materials identified at Technocover were the stainless steel and mild steel sheets. They can be used effectively in LPCB products in areas where a great amount of force is applied, as the ductility will allow for the material to bend and flex until it undergoes strain hardening and fractures.

Due to this knowledge, materials can be strategically placed to utilise their material properties to obtain the most effective product to resist an LPCB attack test. These products would be the most vulnerable when they are used on their own as they are vulnerable to the attack tests which involve the cutting tools.

BRITTLE MATERIALS

Typical brittle materials comprise of cast iron, glass and stone (Beer, Johnston, Jr, & DeWolf, 2004). The main characteristic of a brittle material is to rupture without any notice prior change in the rate of elongation. Due to this, the materials ultimate strength and breaking strength are the same value. Comparison of the material property strain shows that it is considerably smaller for brittle materials, compared to ductile materials. No necking is exhibited in these types of materials and the rupture typically occurs along the surface, perpendicular to the load. Normal stresses are the primary responsibility for the failure of brittle materials (Beer, Johnston, Jr, & DeWolf, 2004).

It is said that most of ceramic materials are brittle which is because of the measurable plastic work failure being negligible as they tend to fail without warning (Creyke, Sainsbury, & Morrell, 1982).

The brittle material observed at Technocover was the Bohler K110 D2 plate which had been hardened before use. This hardening increases the number of grain boundaries there are within the material structure. The grain boundaries are areas within the material structure, where atoms are no longer in good contact with each other. Because of this, the material tends to fracture at grain boundaries, therefore the hardening process makes the material stronger by increasing the hardness value but in turn this makes the material act brittle. This material would be effective when being used inside a casing/shell to delay the attackers from penetrating the further layers due to its high hardness value.

Technocover primarily use this material to stop the attackers from drilling through and penetrating to a key component of the product. The D2 plate must be positioned so that it cannot be attacked with a tool from the cutting category, due to its brittle material structure and likelihood of fracturing.

5.2.2 STRENGTH AND STIFFNESS

Raj & Ramasamy (1983) explain that the strength of a material is determined by the maximum stress that a material can withstand prior to failure. This is an important property to consider whilst determining what material to use in the design of a new product, as it will be subjected to high stress levels whilst being bent and levered open during the attack tests and must withstand these forces for a set period of time. By being able to identify the strength and the breaking point of the material, a design can be completed by trying to keep the material behaving in the elastic region when under attack.

It is necessary to keep the material within its elastic range when undergoing analysis of materials for this project. This is because the material becomes non-linear (plastic) after passing the elastic range and the aim of the project is to stop the material from deforming.

Another property to look for is the stiffness of the material being chosen. Stiffness is a property of a material that enables the material to withstand high stress without large deformations – this depends on the material's elastic properties (Raj & Ramasamy, 1983). Again, this will help determine the correct material to utilise its properties abilities to overcome some of the attack tests its subjected to such as bending of the material when making a coupon.

Both material properties can be investigated in a tensile test (Seward, 2014), the tensile test when completed can allow the research and comparison of the tolerances of the material data sheets provided.

5.2.3 STRESS AND STRAIN

Robert Hooke described the concept of stress in 1660, that is well-known throughout the engineering field. By understanding the stress and strength of materials it allows engineers to design products that are safe to be used in their working conditions and understand the types of typical materials - such as ductile and brittle materials shown in Figure 65. When the stress exceeds the strength of a part, it fails. This principle must be taken into account when selecting the right material to manufacture new products.

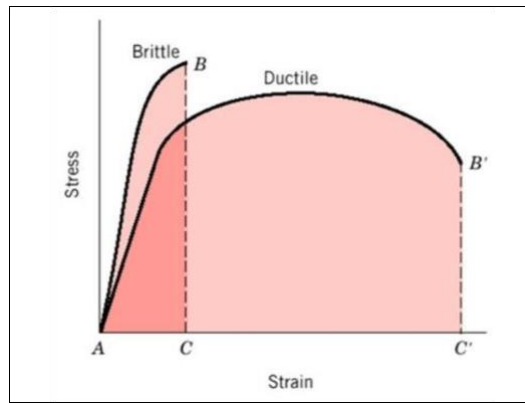


Figure 65 - Schematic stress-strain curve showing typical ductile & brittle behaviour⁴⁰

Numerous mechanical properties of materials are determined from tests which some give relationships between stresses and strains (Erik, 2012). Stresses are a calculation of the load applied on a certain cross-sectional area of a sample and give a stress value at that point.

$$\text{Stress} \left(\frac{N}{\text{mm}^2} \right) = \frac{\text{Load (N)}}{\text{Cross - sectional Area (mm}^2\text{)}}$$

Equation 1 - Stress

These stresses are a measure of how much force a sample experiences per unit area and the ability of that specific material to withstand stress before failure. This figure will be different for every material and is a value that can be compared whilst carrying out a material comparison.

If by applying a stress, the material stretches or lengthens, it is called a tensile stress. This is likely to occur whilst the products are subjected to levering and bending tests. However, if the material is compressed, it is called a compressive stress. This will typically be found when the products are impacted with hammers. If the material is sheared under the stress it is named a shearing stress (Erik, 2012). This will be found where cutting tools such as chisels, and axes are used.

⁴⁰ Madias, J., Wright, M., Behr, G., & Valladares, V. (2017). Analysis of international standards on concrete reinforcing steel bar. 72° Congresso Anual da ABM.

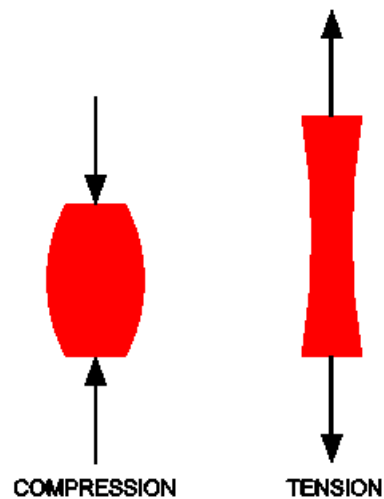


Figure 66 - Compression and Tension⁴¹

Erik (2012) explains that tensile and compressive stresses always act at right angles to the area being considered. However, shearing stresses are always in the plane of the area being considered (at right angles to compressive or tensile stresses). (Erik, 2012).

STRAIN

Strain is a measurement of how an object reacts to stress; a percentage change in the shape of the sample.

$$\text{Strain} = \frac{\text{New Length} - \text{Original Length (mm)}}{\text{Original Length (mm)}}$$

Equation 2 – Strain

When a material is deformed, and the stress is relieved, the material will go back to its original shape if it is observing elastic behaviour. This means that the material has only elastically deformed, like a rubber band.

Percentage reduction of area, as a measure of ductility, has the disadvantage that for very ductile materials it is often difficult to measure the final cross-sectional area at fracture – this is particularly true of sheet specimens (Davis, 2004).

⁴¹ Erik, O. (2012). Machinery's Handbook 29th Edition. Industrial Press.

It is said that stress-strain relationships are used to develop the theoretical parametric relationships between strain, bending moment, tensile modulus, width and height (as shown in Equation 3) (Szaroletta & Denton, 2002).

$$\varepsilon = \frac{6M}{Ebh^2}$$

Equation 3 - Strain relationship

ELASTICITY

Elasticity is the property of a material, when the material is under stress, it recovers to its original shape after removing the external load (Raj & Ramasamy, 1983). Hannah & Hillier (1962) contribute to this by adding that a material is elastic if it is extended by a load and it returns to its original length when unloaded (Hannah & Hillier, 1962). It is known that there are many materials such as iron, brass, copper etc. that are elastic if they are not overloaded.

A material is to be stressed within the elastic region when the working stress doesn't exceed the elastic limit (which is the same as the proportional limit for steel) (Erik, 2012).

Raj & Ramasamy (1983) explain that materials such as steel, copper and aluminium etc. can be grouped as these materials can be categorised as being perfectly elastic (within certain limits of deformation) – they regain to their original shape completely. For every material, there is a critical value of load named the elastic limit which highlights the point at the partial breakdown of elasticity, where loading after this point will lead to permanent deformation (Raj & Ramasamy, 1983).

Davis (2004) describes elastic deformation as when a solid material is subjected to small stresses, the bonds between the atoms are stretched and when the stress is removed, the bonds relax, and the material returns to its original shape (Davis, 2004). By being able to identify the elastic range of materials, the design of a product can appreciate these parameters to understand the strength of the product being designed.

HOOKE'S LAW

Hooke's law is defined as when the stress induced in a material is proportional to the strain within the elastic limit, which is applicable for both tension and compression (Raj & Ramasamy, 1983). They go on to say that this law is valid within certain limits of stress for

most ferrous alloys and with enough accuracy to other materials such as timber, concrete and non-ferrous alloys.

STRESS-STRAIN DIAGRAM

Stress-strain curves are an extremely important graphical measure of a material's mechanical properties however, they vary due to the type of material. Ductile materials can undergo substantial geometry change during testing (Roylance, 2001). The change in geometry is documented by the strain on the graph – the greater the value of strain, the greater the deformation of the material sample.

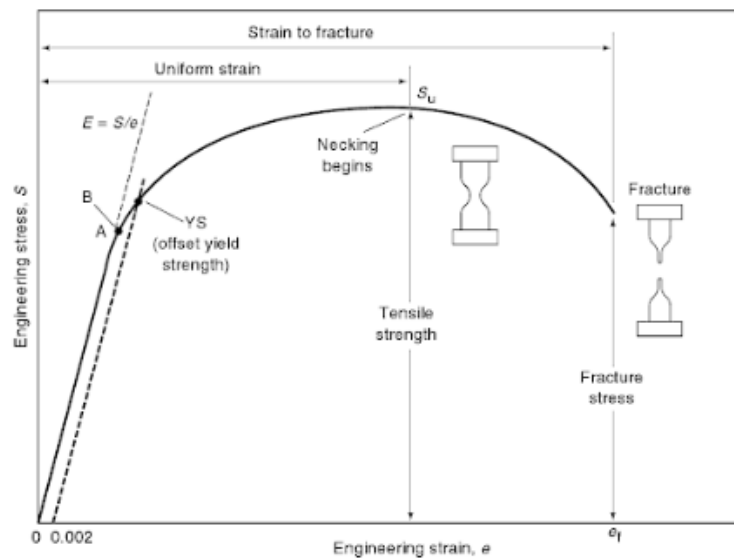


Figure 67 - Engineering Stress-Strain Curve⁴²

Analysing the early portion of the stress-strain curve, most materials typically obey Hooke's Law which is that the stress is proportional to the strain, with the constant of proportionality being the Young's Modulus (E) (Roylance, 2001). However, as the strain increases after the limit of proportionality, many materials deviate from the linear proportionality which is associated with stress induced 'plastic flow' in the specimen. This is the re-arrangement of its microscopic structure where atoms are being moved to new equilibrium positions. The type of material is typically defined due to this as materials that lack this mobility are usually brittle materials (Roylance, 2001).

⁴² ASM International. (2002). Atlas of Stress-Strain Curves (2nd ed.). United States of America: ASM International.

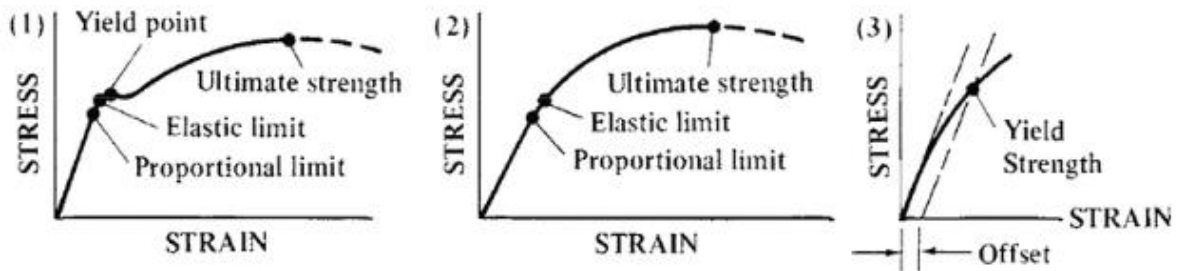


Figure 68 - Stress-strain curves⁴³

In the early stage of a tensile test, the plot rises steeply in a straight line – this is the linear elastic range which shows that the stress is directly proportional to strain and that the extension is reversible as the energy from the testing machine is stored in the specimen (Seward, 2014). Figure 69 shows the idealised stress strain relationship for a ductile material.

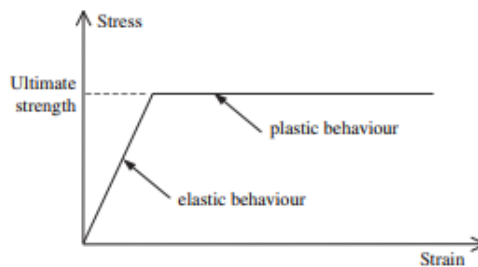


Figure 69 - Idealised stress strain relationship for a ductile material⁴⁴

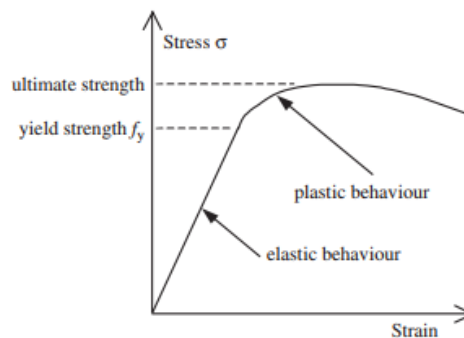


Figure 70 - Actual stress strain relationship⁴⁴

The stress-strain curves show that the ductile material is behaving elastically up to its yield strength (f_y) and then deforms plastically to reach an ultimate strength which is higher than the yield strength. Davis (2004) explains that there are several factors that influence the shape of the stress-strain curve which include the strain rate, temperature and anisotropy.

⁴³ Erik, O. (2012). Machinery's Handbook 29th Edition. Industrial Press.

⁴⁴ Davis, J. R. (2004). Tensile Testing (2nd ed.).

Plastic deformation occurs at higher stresses when planes of atoms slide over one another. The deformation is not recovered when the stress is removed and is given the term plastic deformation (Davis, 2004).

Analysis into the plastic section properties was briefly researched to understand where the material changes from elastic to plastic. This is essential to understanding the material behaviour as the aim is to prevent the material from going into the plastic stage – therefore elastic analysis will only be investigated.

The proportional limit referred to on a stress-strain curve is the point where the line deviates the straight-line relationship between stress and strain (Erik, 2012). To identify the tangent of the slope of the initial straight portion of the plot, the following equation needs to be used. This is also referred to as the Modulus of Elasticity/ Young's Modulus which is the measurement of the stiffness.

$$\tan \theta = \frac{\text{stress}}{\text{strain}}$$

Equation 4 - Slope of curve

YOUNG'S MODULUS

The Young's modulus represents the proportionality between stress and strain and is commonly referred to by the letter 'E'. It can easily be compared to different materials by this property. The stiffness (K) is usually proportional to the Young's modulus and is derived from the force and displacement. Davis (2004) explains that the Young's modulus is a common characteristic of a material under elastic loads - typically specified on a material datasheet. It is said that a stiff material has a high Young's modulus and a small increase in deformation under elastic loads. This is assuming that section properties of the sample are constant.

Materials which have a high Young's modulus value will be well placed and utilised where a product needs to resist impact and bending forces exerted during an LPCB test.

A material evaluation stage can be implemented where the Young's modulus of materials can be compared when evaluating materials by looking at that data from their datasheets. It can be noted that by choosing materials with a higher Young's modulus, it would be harder to attack as more force is needed to deform it when being subjected to loading. It is possible that

further work into the Young's modulus of materials can be manipulated to identify the stiffness of products made up from more than one material type.

Zhong (2015) states that the mechanically-measured Young's modulus of metals is consistently lower than the physically measured one, particularly after plastic straining. He goes on to explain that there are many reports of the modulus effects but the consistency of the behaviour among grades of steel or a single grade produced by alternate methods and suppliers is unknown. This makes the laboratory testing crucial to find the true Young's modulus values for the materials being used.

The investigation into the Young's modulus will identify the Young's modulus values for the materials tested in the laboratory, and to then compare the value to the one listed on the data sheet, identifying any variances. This will be completed by undergoing tensile tests to obtain the Young's modulus of a material, by obtaining the stress and strain values. The Young's modulus is calculated in the elastic range of the stress-strain curve, till the yield point.

The limit of proportionality is the point at the end of the linear portion of the plot. At this point the material will return to its original position as the material is perfectly elastic and follows Hooke's Law. Note that for Mild steel this point coincides with the yield point but isn't the case for all materials (Seward, 2014).

YIELD POINT

The yield point is sometimes referred to as the 'kink' in the curve between the elastic and plastic region (Seward, 2014). Some materials have an indistinct elastic-plastic transition zone – this depends on the type of material. The yield point is a point on the stress-strain curve where there is a sudden increase in strain without a corresponding increase in stress but however, not all materials have a yield point (Erik, 2012). See Figure 68 for a graphical representation of the yield point.

Seward (2014) described that for materials that don't have a distinct yield point such as aluminium alloys, a proof stress is needed to be defined to use in strength calculations. This property is the stress which occurs at a given permanent strain e.g. 0.2%. This is obtained by drawing a line parallel to the linear elastic portion of the curve.

ULTIMATE TENSILE STRESS

This is the stress at the maximum load in a test and the area on which the load act is taken to be the original area of section of the specimen (Hannah & Hillier, 1962).

Seward (2014) explains this point as the point just before failure (when necking is observed). The ultimate tensile stress and ultimate load (maximum load) is observed at this point but Seward (2014) explains that this point is less prevalent than the yield stress as at the ultimate tensile strength, the structure has suffered unacceptable permanent deformation.

$$\textit{Ultimate tensile stress} = \frac{\textit{Maximum load}}{\textit{Original Area}}$$

Equation 5 - Ultimate Tensile Stress

5.2.4 HARDNESS

This is the ability of a material to resist plastic deformation by penetration of a hard material or object (Raj & Ramasamy, 1983). This can be referred to as the stiffness or resistance to bending, cutting etc. This is an important property for engineers as the materials resistance to wear increases with hardness; dependant on the strength of the material. The hardness is expressed quantitatively by a hardness number which can be converted by use of a table for other hardness numbers. Analysis into this material property to see if it can be linked to any of the attacks by LPCB will take place.

Oberg, Jones, Ryffel, & McCauley (2012) explain that hardness testing is important in the industry even though what is being measured isn't a unique quality. Testing is empirical and are based on experimentation and observation rather than purely on the theory. It is said that if a material's hardness value is different, the materials aren't alike (Oberg, Jones, Ryffel, & McCauley, 2012).

A convenient conversion for quenched and tempered steel (provided the strength is not over 200,000 psi) is

$$\textit{Tensile Strength (psi)} \approx 500 \times \textit{Brinell Hardness}$$

Equation 6 - Tensile Strength vs Brinell Hardness⁴⁵

⁴⁵ Oberg, E., Jones, F. D., Ryffel, H. H., & McCauley, C. J. (2012). Machinery's Handbook (29th ed.). U.S: Industrial Press Inc.

The hardness testing is a representation of the strength of the material and the strength needed to penetrate the material - this is important as it can be linked to the LPCB drill attack tests. LPCB assess the material strength/hardness by how long it takes for them to penetrate the material by use of various drills and drill bits. If it is possible to link the hardness values to the LPCB drill attacks, a comparison of historic attack test data and hardness values can help when comparing potential new materials. This will reduce the amount of indicative material testing necessary to be completed as the hardness value of any potential new material can be compared to previous drill test data.

5.2.5 SUMMARY

Two main types of materials were investigated; ductile materials and brittle materials. These act very differently but can be used strategically when their material properties are considered. Analysis into these materials and their properties were completed to know their typical behaviours. By understanding typical behaviours of materials, a designer can be more efficient in searching for new materials, knowing what behaviour is expected.

This author was able to practically use the material knowledge to explain how to efficiently use materials and composites in the most effective positioning and appreciate their material properties. By identifying the attack methods that make the materials vulnerable, the materials can be moved to resist or to negate the attacks.

It was beneficial to create a material database which collated all the Company's current materials in an inventory detailing material property such as hardness value and tensile strength. This would also be tested in a laboratory to identify the laboratory values of the materials, giving the Company another means of obtaining material properties, if the data isn't present on the material datasheets created by the manufacturer. This second test in the laboratory also validates the data provided on any datasheet provided.

This research completed highlighted the importance of stress and strain characteristics when evaluating the suitability of a material and how to use material properties such as tensile and hardness values to compare materials in the initial design stage rather than going to LPCB to test the effectiveness of the materials.

Typically, at least two days of indicative material testing is undertaken by LPCB for the Company per test regime to assess materials and composites. Two days of LPCB testing costs £5000 – without the cost of resources for designing the product, the materials and

manufacture of the product. This can be eliminated with the added material research and tools available.

5.3 MATERIAL INVENTORY LIST

Analysis into the Company's current materials took place to understand the types of materials currently used by the Company, how they are specified and how they are positioned in products. This identified whether the materials are being used successfully in relation to their main properties. By creating a material inventory list, a quick evaluation can be completed on types of materials used at the Company. It can then be expanded and improved to include material properties taken from the datasheets and laboratory data completed by the author.

The material list created specified the type of material, description of the sheet sizes, unit price and laboratory testing information. This could then be used to categorise the materials into material types and further investigations into the product use and testing of the materials can take place.

Inventory List							
Material Classification	Material	Name	Description	Unit Price	Tested at University	Material Type	
Metal	Mild Steel	S275	2500x1250x2mm	£ 23.95	Y	Ductile	
Metal	Mild Steel	S275	2500x1250x3mm	£ 36.03	Y	Ductile	
Metal	Mild Steel	S275	2500x1250x4mm	£ 48.08	Y	Ductile	
Metal	Mild Steel	S275	2500x1250x6mm	£ 72.12	Y	Ductile	
Metal	Mild Steel	S275	2500x1250x8mm	£ 96.16	Y	Ductile	
Metal	Mild Steel	S275	2500x1250x10mm	£ 130.01	Y	Ductile	
Metal	Mild Steel	S275	2500x1250x12mm	£ 156.03	Y	Ductile	
Metal	D2	D2 (K110) Steel plates	2000x1000x4.5mm	£ 454.40	Y	Brittle	
Metal	Chequer	HRMS Chequer plate	2500x1250x4.5mm O/P	£ 68.51	N	Ductile	
Metal	Chequer	HRMS Chequer plate	2500x1250x6mm O/P	£ 94.72	N	Ductile	
Metal	Pre galv steel	Pre galvanised mild steel sheets	2500x1250x0.9mm	£ 15.98	Y	Ductile	
Metal	Pre galv steel	Pre galvanised mild steel sheets	2500x1250x2mm	£ 32.90	Y	Ductile	
Metal	Mesh	2073F Mesh	2440x1220 Flat	£ 33.84	N	Ductile	
Metal	Mesh	1576 Mesh	2440x1220 Raised	£ 41.99	N	Ductile	
Metal	Mesh	Weldmesh 50x50x3mm	2440x1220	£ 8.44	N	Ductile	
Metal	Grids	Open Steel Flooring LB 41/100 ctrs	25x3mm	£ 77.00	N	Ductile	
Metal	Grids	Open Steel Flooring LB 41/100 ctrs	30x5mm	£ 151.00	N	Ductile	
Metal	Stainless steel	Stainless Steel 316	3000x1500x2.5mm	£ 295.00	Y	Ductile	
Metal	Stainless steel	Stainless Steel 316	2500x1250x4mm	£ 295.00	Y	Ductile	
Metal	Stainless steel	Stainless Steel 316	2500x1250x6mm	£ 440.00	Y	Ductile	
Metal	Stainless steel	Stainless Steel 316	2500x1250x8mm	£ 572.00	Y	Ductile	
Polymeric	LDPE	LDPE	2440x1220x12mm	£ 45.00	N	Ductile	
Composite	Insulation	Insulation (Celotex)	2400x1200x25mm	£ 12.14	N	Brittle	
Composite	Insulation	Insulation (Celotex)	2400x1200x40mm	£ 15.93	N	Brittle	
Wood	Marine Ply	Marine Ply BS1088	2440x1220x12mm	£ 46.99	N	Brittle	
Wood	Marine Ply	Marine Ply BS1088	2440x1220x18mm	£ 31.79	N	Brittle	

Figure 71 - Material Inventory

The inventory breaks down the materials and into the following categories:

- Type of Material
- Name
- Unit price
- Product Use

Breaking down the different material types allows a quick filter of material type, to investigate the materials currently used by the Company. It was shown that currently there are four types of materials; metals, wood, polymers and foams.

The name of the material refers to the (manufacturing) name of the product, given to it by the manufacturer. For many steels this will be typically the same, but for more advanced/specialised materials this will be more of an individual name. An example of this

would be the Bohler D2 plate. When referring to metals such as carbon steel (275) / S275, the number refers to the tensile stress of the metal. In this case, it would be 275 N/mm².

The unit price is the current value for the product when purchased by the Company. This value fluctuates due to the price of the material at the time and will need to be updated throughout the year to reflect this. This is a factor that contributes to new material selection, as it is common that companies look for the cheapest materials to lower the manufacturing costs of products made in some cases. The price can also be compared for using two layers of a material to stop an LPCB attack rather than a singular section of specialist material.

The product use column details where certain materials are used in products - this will be an easier way to plan material stock and compare potential materials to new ones. This can be developed to include what LPCB tests certain products are effective at stopping.

The data from the material datasheets were inputted into the material inventory but when analysing the datasheets, it was noticed how they varied as this is something that was produced by the supplier. To investigate the material properties of the materials and compare them to the datasheet values it was thought to study material testing techniques and undergo material tests to have a clear comparison between the data and the datasheets. This would also allow a material database of tested materials to be compiled.

5.4 INVESTIGATING MATERIAL FAILURE

An investigation into material failure was completed to understand what kinds of failure the author would be expected to be seeing at the laboratory testing.

5.4.1 FAILURE MODES

The typical failure modes of materials were investigated to understand the typical behaviours of materials to know how they commonly fail. This would allow the author to see how a material is failing to understand and improve it to protect against a potential failure.

Research into common failure modes was completed to identify the different failure mechanisms and then compared to when materials are failed in a LPCB test. The most common failure modes are stated and described. Finite Element Analysis (FEA) can be used to simulate all of the failure modes but not all software packages offer this capability through various licenses.

- Yielding

This is when a body experiences stresses more than the yield stress. A way to replicate this kind of failure mechanism is by using linear static analysis or Finite Element Analysis (FEA).

- Deflection

This failure mode is caused by the insufficient stiffness of a material.

- Buckling

This is exhibited when there is a loss of stability in a specimen which in turn, creates catastrophic failure. If a structure loses stability, this is quickly followed by material yield and either local or global failure of the structure. Generally, theoretical buckling loads can usually be obtained through an eigenvalue solution which is present in many Finite Element (FE) packages. However, for 'real' buckling behaviour which involves large deformations and material yield, non-linear material and geometry must be employed in the solution process which tends to be reserved for high end commercial FE packages.

- Fatigue

Fatigue failures in metallic structures are a typical technical problem with this problem ranging back to the 19th century (Schijve, 2008). The fatigue of structures is now recognised as a significant problem. After so many cycles of loading, parts start to lose strength and become weaker and this causes a loss of strength.

- Creep

Some solid materials move slowly or deform permanently under stress – this is increased when materials are heated. Creep is present when a body deforms over time. This can be linked to the heat tools such as the gas torch. It is noted that it is possible that several failure modes can happen at the same time, so it is important to identify the differences in failure modes and how they affect the samples or material behaviours, to identify the failure modes present.

FAILURE CRITERIONS

Historically, the goal had been to find a general failure criterion that covered the full range from ductile to brittle types of materials (Christensen, 2013).

Christensen (2013) describes what they think is the most misunderstood but prominent failure concepts; Coulomb-Mohr type. This evolves from the original conception of Coulomb that on a failure surface, the shear stress at failure is related to the normal stress acting across the failure surface.

$$T \leq C - \mu\sigma$$

Equation 7 - Coulomb Equation

CUTTING

The study of fracture and tearing of thin sheets is challenging due to it coupling the geometry of large out of plane deformations to the failure of the material (Tallinen & Mahadevan, 2011). An important class of fracture and failure in thin sheets is due to the forcing of a solid object or tool through it, either the plane of the sheet or transverse to it.

Tallinen & Mahadevan (2011) investigates the role of ductility in thin sheet fracture by analysing the numerical simulations that combine finite elastic-plastic deformation with a simple fracture criterion to synthesise the variety of observed fracture morphologies in brittle and ductile sheets. They assume an ideal elastic-plastic stress-strain relationship with the Young's modulus and the yield stress. It is said that the elements are forced to break when the tensile or shear strain exceeds (Tallinen & Mahadevan, 2011).

For ductile materials, the material deforms plastically before failure

$$\frac{\sigma_y}{E} < \gamma_s$$

$$\frac{\sigma_y}{E} \ll \gamma_s$$

The fracture is seen to occur by in-plane stretching when the crack tip is at either extreme laterally and by out-of-plane shear when the tip is close to the centre line (Tallinen & Mahadevan, 2011).

The tearing is driven by a rectangular tool of width (15h) that leans in to the direction of motion at an angle of 45 degrees (Tallinen & Mahadevan, 2011).

MALLEABILITY

This is the property of a material where it can be uniformly lengthened or widened by hammering or rolling without rupture (Raj & Ramasamy, 1983). Some examples of these types of materials are wrought iron, copper and mild steel.

5.5 IMPROVEMENTS

It was identified that the Company didn't investigate the material properties when researching potential materials to be encompassed when designing new products. By creating documents to allow the comparison of material properties, a new insight into the behaviours of materials can be created to reduce the reliance of the testing of materials to be only considered if it is able to pass the indicative material stage of the LPCB tests.

By looking at properties such as tensile strength, Young's modulus and hardness, you can understand how the product would cope when being subjected to the various attack methods used by LPCB. A material with a high tensile strength will be good when being impacted with a sledgehammer, whereas a material with a high hardness value will potentially be well placed to stop a drill attack.

5.6 MATERIAL TESTING INVESTIGATION

An analysis into material testing techniques was undertaken to identify the easiest and most effective ways to test the materials used at Technocover. The most common methods were investigated to understand the pros and cons of material testing and the limitations. The aim of the material testing is to find out the 'actual' properties of a material and to see how accurate the data sheets are compared to the real-life testing data.

There are two main types of material testing; destructive testing and non-destructive testing. Non-destructive testing refers to tests that take place on the material but preserve the material sample. Destructive testing is when material samples undergo testing and are sometimes tested till failure (like tensile testing) or by indentation (like hardness testing). This was seen as the most similar to the LPCB attack testing as their aim is also to test till failure and because of this researched in more detail.

5.6.1 DESTRUCTIVE TESTING

A breakdown of destructive tests that can be carried out on materials are detailed :

- Bend test
- Break test
- Tensile test
- Hardness test
- Impact test
- Macro examination
- Micro examination

These are carried out for the following reasons and involve the following stages

- Used for finding out properties of materials
- Load is applied on material
- Material gets damaged due to the load application
- Specialist equipment needed
- Expensive
- Skillset required

Examples of this method of testing are tensile tests, compression tests, hardness testing. Two of these tests were carried out on the materials at the Company (tensile and hardness) as they can be linked to negating the effects of the LPCB attack methodology.

The main disadvantage is that the sample will be destroyed. This was acceptable though as it was thought finding materials with suitable properties to pass LPCB tests was much more cost effective than sending a whole sample to be destroyed made from an unsuitable material.

TENSILE TESTING

A tensile test is where a specimen is subjected to an increasing load when it is extended. The length of the specimen extends linearly with the load at a slow rate (Beer, Johnston, Jr, & DeWolf, 2004). This is displayed on the initial part of the strain-stress diagram where a linear line with a steep slope is exhibited. After the specimen reaches the critical value of stress, the specimen is shown to undergo a large deformation once the load has been increased by a small amount. Typically, deformation is caused due to the slippage that occurs along the

oblique surfaces due to the shear stresses. When the maximum load has been reached, the diameter of the sample decreases because of the local instability (necking). There are also lower loads present when necking occurs as the specimen is still elongating until rupture.

Beer, Johnston, Jr, & DeWolf (2004) states that tensile tests on the same material can have a variance due to conditions such as the temperature of the specimen or the speed of the loading.

3 POINT BENDING TESTING

This is a bending test whereby a simply supported beam is subject to a central point load. This creates a piecewise linear bending moment which is a maximum at the centre of the beam. Longitudinal compressive stress (at the top surface) and tensile stress (at the bottom surface) can be calculated to provide a measure of the materials capacity to withstand both tensile and compressive stresses in a bending sense. The stiffness of the beam sample and modulus of the material can also be determined by noting the deformation of the beam. All of the aforementioned parameters can be calculated through use of simple bending formula:

$$\frac{\sigma}{y} = \frac{M}{I} = \frac{E}{R}$$

Equation 8 - Simple bending equation

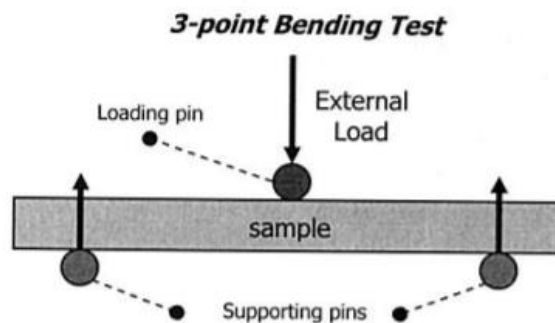


Figure 72 - Schematic of flexure tests⁴⁶

These two types of destructive material testing (Tensile testing and 3-point bending testing) were completed in the laboratory.

⁴⁶ Biomomentum. (2016). 3 point or 4 point bending test. Biomomentum.

5.6.2 NON-DESTRUCTIVE TESTING

The aim of Non-destructive Test and Evaluation (NDE) is to extract information on the physical, chemical, mechanical or metallurgical state of materials or structures (Prasad & Nair, 2009). The process of interaction does not damage or impair the sample's utility value and the process is influenced by the physical, chemical and mechanical properties as well as the fabrication procedure of the sample.

Non-destructive testing and evaluation methods have significantly advanced in recent years due to the development of new methods and sophisticated mathematic models (Reis, 1989). The driving force behind this is due to the need to evaluate and characterise newly engineered materials and accurately predict the fitness for service.

Historically, non-destructive testing was used almost exclusively for the detection of macroscopic defects which was mostly cracks in structures after they have been in service. It is evident that due to the practicality and the cost effectiveness, non-destructive testing evaluation is said to be expanded to include all aspects of manufacturing and construction (Reis, 1989).

Reis (1989) lists the non-destructive testing techniques for structural materials

- Acoustic emission
- Acoustical birefringence
- Acousto-ultrasonics
- Barkhausen noise
- Eddy current
- Dielectric measurements
- Penetrant inspection
- Radar
- Thermal wave imaging
- Thermography, vibrothermography
- Ultra-sonics
- X-ray diffraction, radiography, tomography

Figure 73 shows an evaluation of the NDT methods used for materials; metallics and composites.

<i>Sl. No.</i>	<i>NDT Method</i>	<i>Defects/Material Properties Normally Evaluated</i>
1	Visual (with or without aid)	Surface defects/damages, changes observed in transmitted or reflected light
2	Radiography	Internal and surface discontinuity, radiographic density variation and geometrical dimension of defects and discontinuities
3	Ultrasonic	Elastic moduli, variation in material homogeneity, geometric dimension of defects and discontinuities, residual stress
4	Magnetic particle methods	Surface and subsurface defects in magnetic materials
5	Eddy current	Surface and subsurface defects and damages in electrically conducting materials
6	Liquid penetrant	Defects open to the surface in all except highly porous materials
7	Acoustic emission	Accumulation of damage during services, initiation of cracks, failure of structural component/assemblies, leak in closed/sealed components/containers
8	Infrared thermography	Porosity, moisture, delamination, density variation

Figure 73 - Summary of properties evaluated by NDT⁴⁷

The examination of how NDE fits into the wider spectrum of design, manufacture and life cycle management activities of engineering systems. It shows that it plays a significant role at various stages of the engineering structures (Prasad & Nair, 2009).

<i>Activity</i>	<i>NDT Support</i>
Design and product development	<ol style="list-style-type: none"> 1. Statistical evaluation of strength, stiffness and dimensional features 2. Detection, location, sizing and volume dispersion of defects 3. Assessment of variation in material homogeneity, isotropy, residual stresses
Manufacturing stage	<ol style="list-style-type: none"> 1. Assessment of repeatability of manufacturing processes for different batches of production 2. Detection, location, sizing and volume distribution of defects and material in-homogeneity 3. Providing acceptance criteria for defects and material in-homogeneity
Life cycle management	<ol style="list-style-type: none"> 1. Estimation of variation in material homogeneity, dimensions due to corrosion, erosion, irradiation, damage due to fatigue, creep, impact and lightning strike 2. Generating defect-property correlation data and specific information related to life extension of components. Determination of adequacy of repair or replacement of materials and structures 3. Preparation of specifications/documents/test techniques for periodic NDT inspection for health monitoring and to determine the stage of damage in a structure till it reaches the critical stage of rejection and replacement

Figure 74 - NDT support⁴⁸

⁴⁷ Prasad, J., & Nair, C. K. (2009). Non-Destructive Test and Evaluation of Materials. Tata McGraw-Hill Education.

⁴⁸ Prasad, J., & Nair, C. K. (2009). Non-Destructive Test and Evaluation of Materials. Tata McGraw-Hill Education.

Non-destructive testing was not undertaken for this project as it was felt the cost associated would not be worth the results gained. All data needed on materials to replicate the LPCB testing could be gained from the less advanced destructive testing. This may be an option for future work to gain further info on other properties of the materials.

HARDNESS TESTING

Hardness testing is completed by pressing a hard indenter in to a surface of a material and creating an impression (Creyke, Sainsbury, & Morrell, 1982). The size of the impression relates to how resistant the material is. Typically, ceramics and cemented carbides are very hard and show very small hardness impressions.

Bishop, Hill, & Mott (1945) states that currently it is not possible to develop a mathematical theory of plasticity to the point where it will be capable of calculating the load required to force a cylindrical punch deep into a semi-infinite block of ductile material (Bishop, Hill, & Mott, 1945).

The hardness test will be a critical test in finding suitable materials for LPCB products as materials with a high hardness value will be harder to cut and drill.

Shabel (1987) explains the analysis showing that Rockwell hardness can be used to analyse the elastic recovery effects, strain hardening behaviour and represent the point of intersection of an alloy's plastic stress-strain curve (Shabel, 1987).

The surface roughness has little influence on the size of the indent, if the indent is large in comparison to the asperities of the surface (Tabor, 2007).

5.6.3 TESTING SUMMARY

Destructive testing is the preferred method of testing and has been the largely the only way to gain accurate results (Verichek Tech Services, 2017). However, they go on to say that due to the technological advances in non-destructive testing methods, they are proving to be more accurate and efficient, including the current common metal identification methods.

Because of this destructive testing may no longer be the most effective and accurate way to find out material properties. However, they were chosen for this work as the non-destructive testing does not involve a load being applied to the material, in turn not fully mimicking a controlled version of an LPCB test, which was crucial for this project.

Three main material testing techniques were chosen to be analysed. Hardness testing is a non-destructive testing chosen as it was seen to be a cost effective and quick process to complete, Rockwell hardness being the most popular test to complete.

The tensile test is a destructive test and was chosen due to its ability to obtain the yield strength, tensile strength and other properties of the materials all from one test. Typically, tensile values are shown on material datasheets. This would be investigated to identify the variances of the laboratory testing vs. material datasheets and test the accuracy. The test also identifies the material properties and the point at which the material stops behaving elastically – this data can be used as benchmark to make products stronger by aiming to keep all materials used in the elastic range.

The last material testing technique chosen was a flexural bending test which is a destructive testing technique. This was chosen to evaluate the materials ability to withstand bending and flexural forces as a flexural modulus is obtained by the test. This can judge a materials ability to bend and return to its original position, identifying materials well equipped to cope with levering forces in LPCB attacks.

5.7 LABORATORY TESTING

To understand the materials used at the Company, an analysis into the material behaviours was completed. This is to look at material properties and recognise what specific parameters affect the strength and bending of the material. This is crucial as a few of the LPCB attack tests can relate to this.

Following research, more companies use material testing methods in the earlier stages of the design procedure to increase the effectiveness of the techniques. This was implemented in the design procedure with the aim to reduce the indicative material testing taken place at LPCB and reduce the reliance of the LPCB testing to quantify the effectiveness of the material.

To be able to compare all the materials used in the Company, an analysis was undertaken into how the data should be captured. A material database would be completed detailing the theoretical data from material data sheets and the laboratory data from the materials tested. Graphs would be created to physically show the difference in material properties.

The first task was to base test the materials used in the current products to characterise the materials using a variety of techniques to have a better understanding of the current materials.

A standardised list of materials was created which listed their material properties, focusing on their properties beyond their elastic limits as in the LPCB tests, the materials will be forced to work beyond their normal documented material stress levels. This data is needed within the analysis and product selection processes, particularly at the preliminary design stage. It will also allow for the physical testing to be compared against the digital modelling – using material curves from practically tested data and be inputted into a software.

5.8 HARDNESS

Hardness is one of the most characteristic properties of materials and plays a key role in the progression of civilisation due to the progression of technology such as machinery and more sophisticated devices (Zhang, Li, & Zhang, 2011). Shabel (1987) explain that Rockwell Hardness is one of the most popular techniques of assessing a material's condition; thermal and mechanical processing. However, questions the relationship between the hardness number obtained using a particular scale to engineering properties (yield strength, tensile strength etc.) which isn't linear over a wide strength range.

Hardness is a characteristic of a material and is defined as the resistance to indentation. This can be obtained by measuring the depth of the indentation, in a material sample, when 2 successive loads are applied to it. The chosen hardness testing was the Rockwell hardness as it is typically used to characterise the hardness of metals as defined by the standard ASTM E-18.

The sample geometry and surface condition can affect the accuracy of the tests completed but the cost and convenience of hardness testing are advantages (Spiegel & West, 1996). Rockwell is a fast hardness test method developed for production control, with a direct readout, mainly used for metallic materials.

There are 3 main types of Rockwell hardness, HRA, HRC, HRD. A conversion chart was created from testing data showing the 'real life' scales that convert from one hardness to another. The conversion chart will allow the understanding of the material hardness in different scales and will allow the user to compare new potential materials with the different Rockwell hardness values.

5.8.1 FORMATION OF SAMPLES

It is important to keep the surface clean and decarburisation from heat treatment should be removed. The size of samples was 100mm x 100mm.

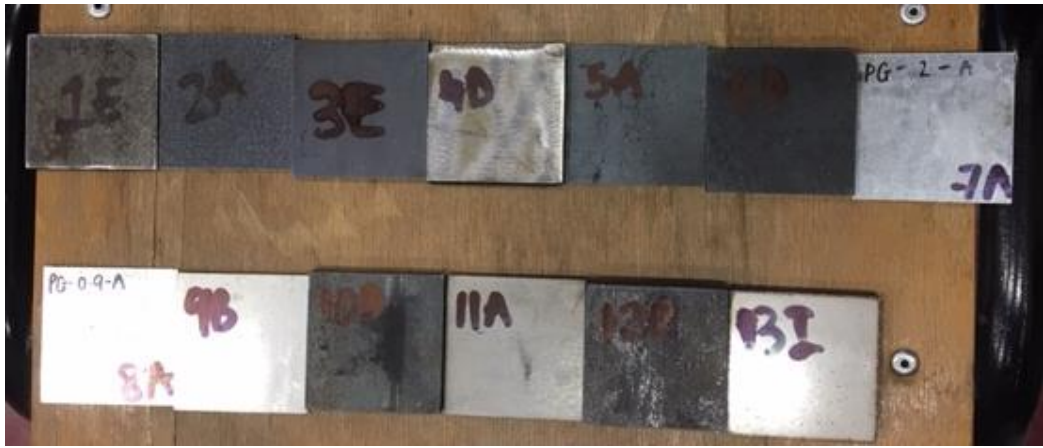


Figure 75 - Samples for Hardness Testing

5.8.2 TEST APPARATUS

The testing will be undertaken using the ZHR Rockwell hardness tester within the laboratory as per the standard ASTM E-18.



Figure 76 - Hardness test machine

1. Apply the pre-load/minor load (10kg) to the sample using a diamond indenter. This provides a reference position. This is completed by turning the handwheel clockwise.
2. Measurement of the indenter is displayed by a bar graph and the correct pre-load position is indicated when the horizontal bar touches the end of the fixed bar.

3. Ensure that when looking through the measuring microscope, the edge of the line has to be adjusted so it touches the corner of the impression
4. An audible beep will be heard by the machine and then vertical movement of the indicator should stop.
5. Apply the major load to reach the total test force and hold it in position till it overcomes elasticity
6. Release an additional force and measure the resulting indentation against the preliminary position
7. At the end of the load cycle, the hardness number will be displayed to 0.1 units
8. Convert the measurement achieved into the relevant hardness number using the appropriate Rockwell scale

5.8.2.1 REDUCING ERRORS

- A standard was used in this test which was provided with the machinery. This standard allows the testing and calibration of the machinery as it states the hardness value on the sample. The machine should produce the same hardness value stated on the sample.
- It is noted that due to material dependence of hardness tests, all conversions are approximate for comparative purposes.
- Both surfaces of the samples must be flat
- Rotation of the handwheel must be completed gently otherwise the indenter may be destroyed due to the abruptness of the strike

5.8.3 HARDNESS TESTING RESULTS

There was a calibration block that was used to calibrate the machinery, Sample 1, which stated a hardness value of 60.77 HRC.

Table 10 - Calibrated Sample - Hardness Testing

CALIBRATED HARDNESS (HRC)	MEASURED HARDNESS (HRC)
60.77	60.76
60.77	60.75
60.77	60.77
60.77	60.78
60.77	60.77
AVERAGE	60.77

The test was completed five times and an average value was obtained; this is to eliminate anomalies in the tests. The average value for the sample was the same value as it is said to be. This shows that the machine is calibrated correctly and allows the author to be assured that the results gained are accurate and reliable.

5.8.4 COMPARISON

HRD Hardness values were able to be taken for all the materials tested in this experiment. However, when testing the HRC values, the following material couldn't obtain values for - 4mm Mild Steel, 0.9mm Pre-galvanised Steel and 10mm Mild Steel. This can be due to the limitations of that specific scale.

Table 11 - Hardness results

MATERIAL	HRA RANGE
MILD STEEL	53-58
STAINLESS	59-61
D2	84
PRE GALV	46-56

MATERIAL	HRC RANGE
MILD STEEL	4-8
STAINLESS	7-13
D2	58
PRE GALV	2

MATERIAL	HRD RANGE
MILD STEEL	19-31
STAINLESS	30-35
D2	72
PRE GALV	14-26

A comparison between all the materials was undertaken to compare the values of hardness. D2 had the highest hardness rating and the 0.9mm pre-galvanised steel had the lowest hardness rating.

Table 12 - Hardness Table

SAMPLE	THICKNESS (mm)	MATERIAL	AVERAGE HRD
1	4.5	D2	71.98
2	4	MILD STEEL	24.08
3	6	MILD STEEL	30.24
5	3	MILD STEEL	31.02
6	8	MILD STEEL	31.32
11	10	MILD STEEL	18.99
7	2	PRE-GALVANISED	26.15
8	0.9	PRE-GALVANISED	14.44
4	8	STAINLESS	35.29
9	2.5	STAINLESS	31.62
10	4	STAINLESS	30.50
12	6	STAINLESS	33.8

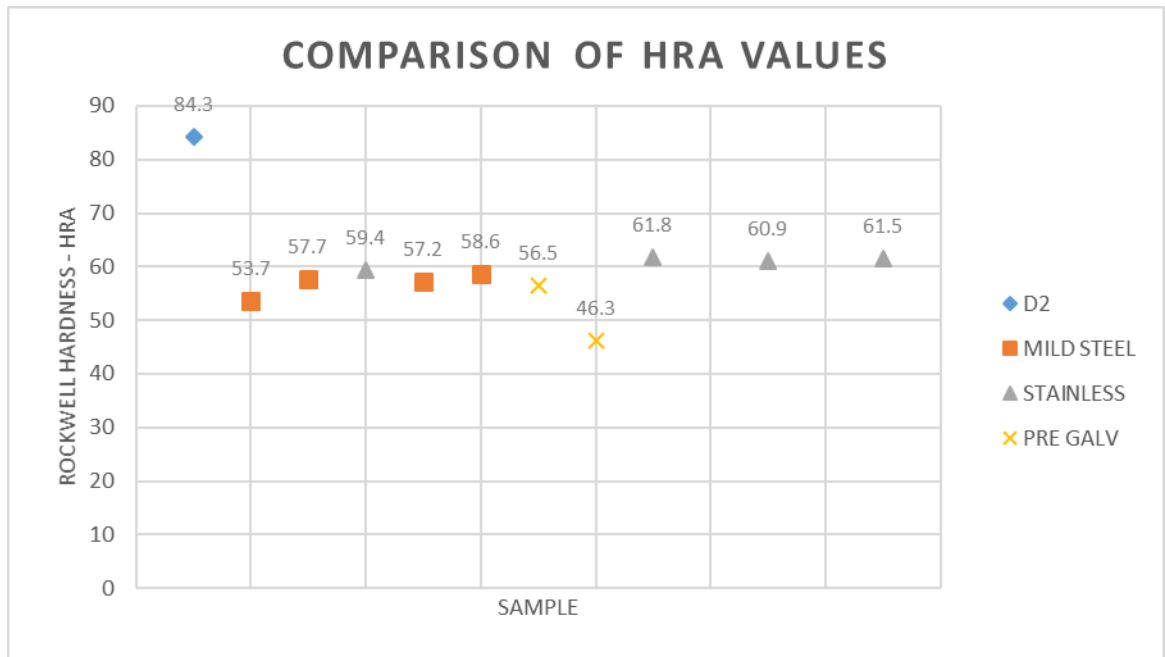


Figure 77 – HRA Hardness comparison graph

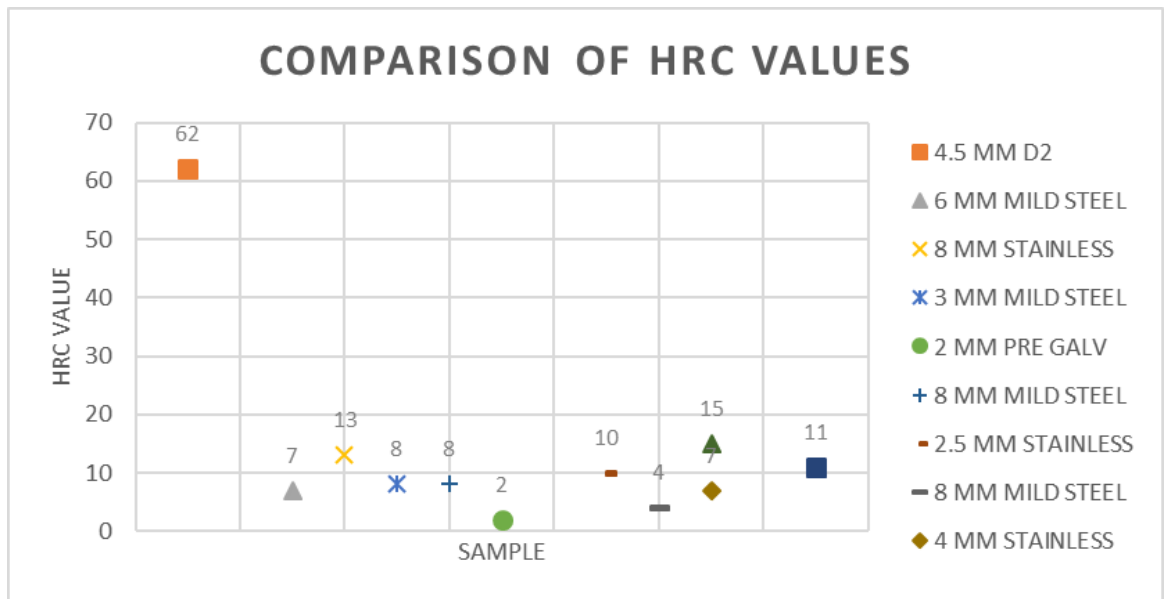


Figure 78 - HRC Hardness comparison graph

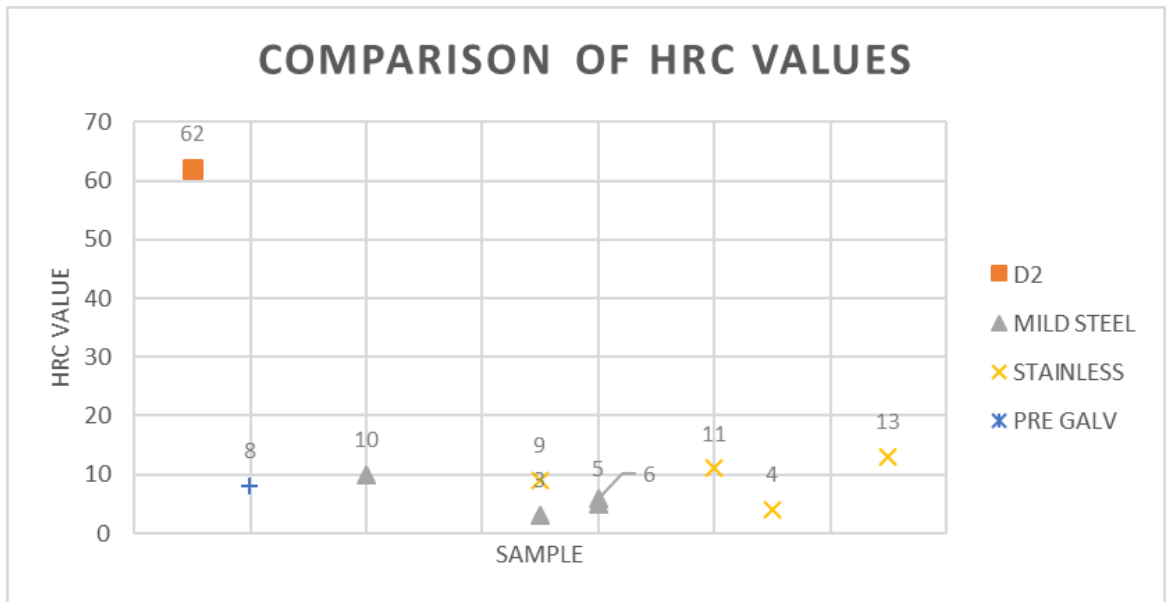


Figure 79 - HRC Hardness comparison graph

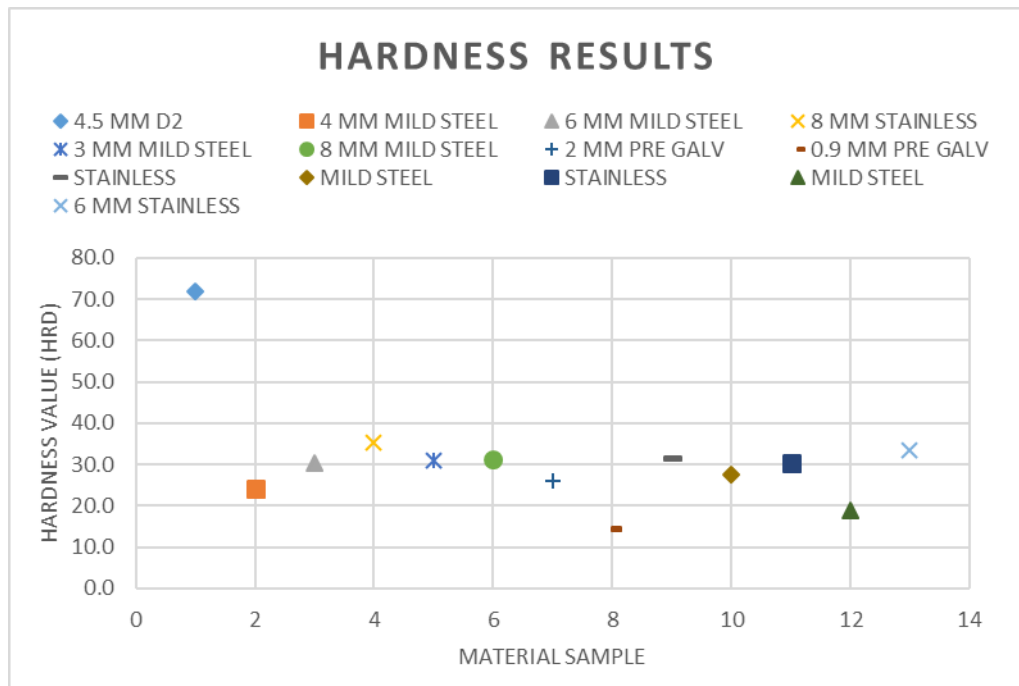


Figure 80 - Average Hardness Results

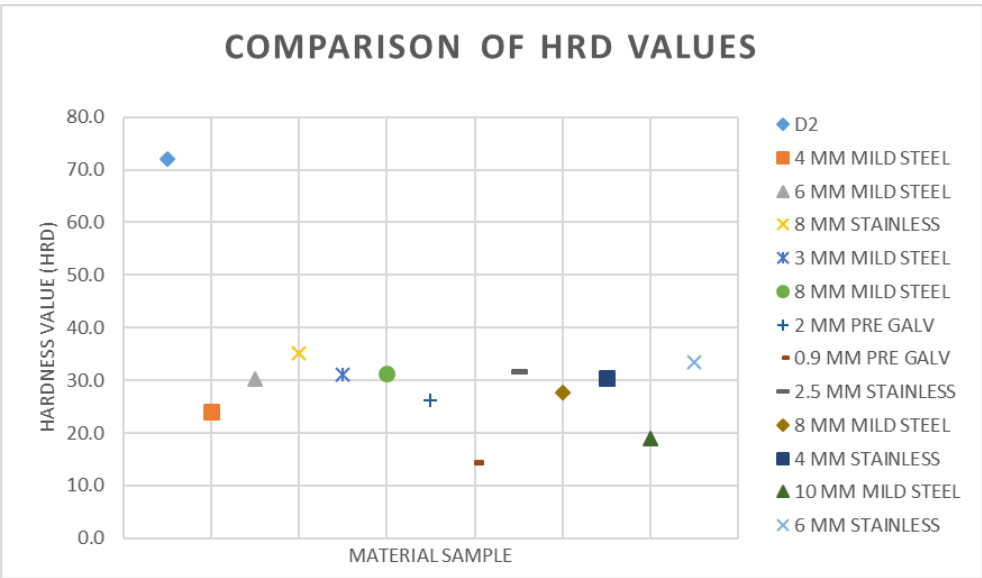


Figure 81 - HRD Hardness comparison graph

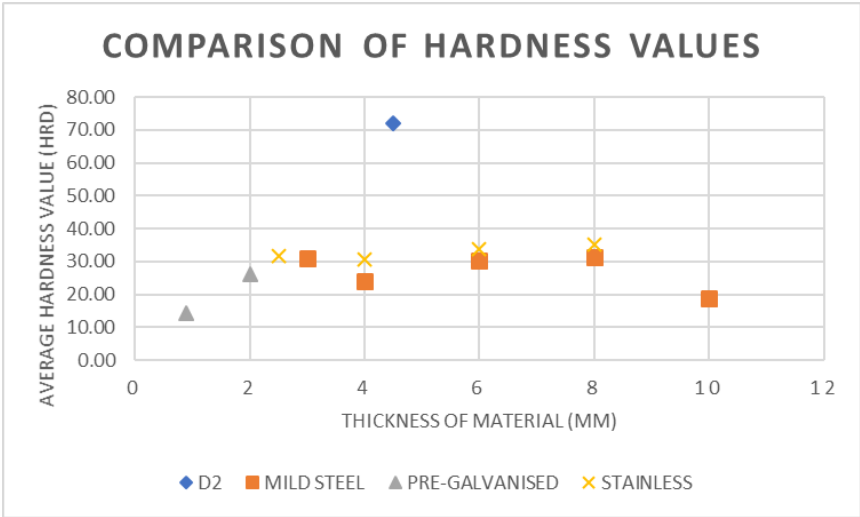


Figure 82 - Hardness Comparison

Table 13 - Material Comparison - Hardness

MATERIAL	AVERAGE HRD
D2	71.98
MILD STEEL	27.13
PRE-GALVANISED	20.30
STAINLESS	29.26

5.8.5 HARDNESS TESTING SUMMARY

Research was completed to evaluate the hardness testing methodologies present in the material testing industry. A method was chosen and research into the different testing scales was undertaken to choose the best testing scale for the materials. By undergoing the hardness tests, it was possible to create a database of hardness results. This is beneficial as potential materials can be compared to the materials tested in the database as the first evaluation stage.

The results showed that hardness is a simple and inexpensive means of gaining material properties and due to the test being non-destructive, the sample can be used afterwards. It is understood that great care needs to be taken when converting from different hardness scales due to their being a variety of indenters.

5.9 TENSILE TESTS

A tensile test is where a load is applied on a test specimen, resulting in an elongation of the member. The loads and deformations observed in the testing is converted to stresses and strains to give an insight into the material behaviour.

Davis (2004) explain the nature of tensile testing, which is to select materials for engineering applications. Tensile properties are generally included in material specifications to ensure quality and are often measured during the development of new materials and processes to compare materials. The tensile tests can predict the behaviour of a material under forms of loading other than uniaxial tension. Davis (2004) goes on to explain that the strength of a material is the primary concern when selecting a material.

For stress determination, the geometry and positioning of the sample are crucial. Some non-parallel alignment of the load can occur due to poorly controlled geometry of the sample in uniaxial compression. For the sample to bond well to the grips of the machine, an adhesive glue can be used in the tension test, at the cost of increasing the relaxation effects (Rees, Jacobsen, & Hickman, 1994). It is added that the Finite element analysis can negate the influence of those effects. Pearce (1977) explains that tensile tests are the most important and reliable tests for determining elastic and plastic properties of material up to the fracture.

Biaxial tensile experiments are becoming an increasing alternative to characterise the material behaviour of thin walled specimens. This is driven by digital image correlation systems to obtain information about the surface deformation. However, this varies when compared to tensile tests as only the deformation can be measured in a region on the specimen and not the

stress state (Hartmann, Gilbert, & Sguazzo, 2018). The typical tensile sample shape is shown below.

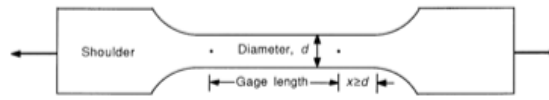


Figure 83 - Typical Tensile Specimen⁴⁹

The sample has enlarged ends and the most important part of this specimen is the gauge section. The cross-sectional area of the gauge section is reduced relative to the remainder of the specimen so that the deformation and the failure will be localisation in this region (Davis, 2004).

It is noted that the distances between the edges of the gauge section and the shoulders should be great enough that the larger ends do not constrain deformation within the gauge section as well as the gauge length being relative to its diameter. If this isn't taken account of, the stress state will be more complex than simple tension (Davis, 2004). With sheet tensile specimens, a portion of the elongation occurs during diffuse necking which can be standardised by maintaining the same ratio of width to gauge length. The localised necking is where a small portion of the elongation occurs, which depends on the thickness of the sheet (Davis, 2004).

Davis (2004) explains that as the aim of the material testing is to determine the suitability for its intended use, the sample must be from the same source and have undergone the same processing steps.

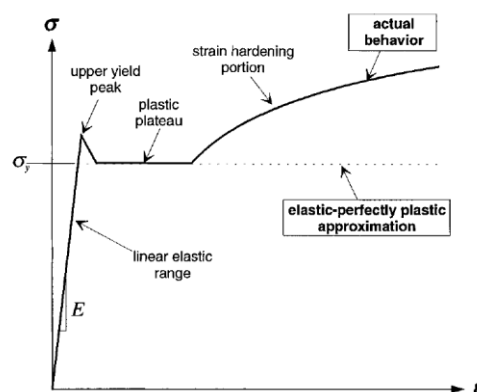


Figure 84 - Stress-strain curve of steel and elastic-perfectly plastic approximation⁵⁰

⁴⁹ Davis, J. R. (2004). Tensile Testing (2nd ed.).

⁵⁰ K.W. Poh. (2001). Stress-Strain-Temperature Relationship for Structural Steel. Journal of Materials in Civil Engineering.

The objective of this test is to apply controlled tension to a material sample until failure. The behaviours of the material through the linear and non-linear regions are documented. This test was chosen as the tensile strength of each material is needed.

The test was carried out to gather tensile strength data which can be inserted into the material database. It is an important consideration when designing security products as during the attack procedure, the tensile strength is needed to predict when the product may fail during a stage of the testing procedure.

Material curves were generated (stress-strain curves) within and beyond the elastic limits to the point of failure – this will allow for the data to be inputting into Solidworks to create the material curves.

5.9.1.1 FORMATION OF SAMPLES

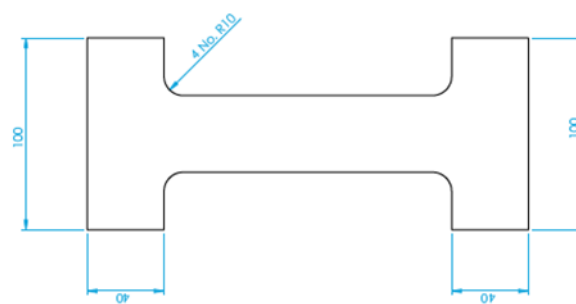


Figure 85 - Typical Sample Shape

Research into the most tensile tests identified the typical specimen shape which is called a dog bone shape. This is shaped so the sample will fail in the centre portion (Seward, 2014).

The sample is cut in the chosen shape to cause the tensile failure in the middle of the sample. The sample is wider at the edges to grip to the jaws so the displacement on the jaws doesn't interfere with the experiment. The thickness of the material needs to have been taken account of due to the sample slipping in the jaws if it's too thin.

5.9.1.2 PROVISIONAL CALCULATIONS

$$\sigma = \frac{F}{A}$$

Equation 9 - Stress Equation

Where:

σ = Stress (N/mm²)

F = Force Applied (N)

A = Cross Sectional Area (mm²)

$$\varepsilon = \frac{\delta}{L}$$

Equation 10 - Strain Equation

ε = Strain

δ = Change in specimen length (mm)

L = original length of specimen (mm)

$$E = \frac{\text{stress}}{\text{strain}} = \frac{\frac{F}{A}}{\frac{\delta}{L}}$$

Equation 11 - Young's Modulus Equation

5.9.1.3 TEST APPARATUS

The testing will be undertaken using the Zwick tensile testing machine within the laboratory and the samples will be sized to enable full tensile failure to occur before the machines limit of 70 kN with a factor of safety of 1.5.

5.9.1.4 REDUCING ERRORS

To ensure that the errors were reduced, a few precautions took place.

- Every measurement was taken 5 times and averaged (length, width and thickness)

- A set square was used to draw straight lines – this enabled that the micro meter was straight when measuring the sample
- A scribe and set square were used to draw two reference lines on the material to accurately obtain the extension of the sample
- Ensure that the sample is flush with the machine jaws
- Make sure that the extensometer is closed and secure on the sample

5.9.1.5 TENSILE TEST PROCEDURE

The test procedure that was followed is outlined:

1. Mark two parallel lines on the sample using a scribe and set square and measure the distance between them (original length)
2. Measure the thickness of the sample 5 times in different locations using a micrometre and obtain an average value
3. Measure the width of the sample 5 times in different locations using a micrometre and obtain an average value
4. Set the required separation distance value of the jaws
5. Insert the sample and move the top jaw to hold the sample in place
6. Reset the force to 0 and move the bottom jaw to hold the sample in place
7. Input the values for thickness and width
8. Attach the extensometer to the middle of the sample
9. Start the test
10. Take the extensometer off when the machine prompts
11. After the sample has failed, take out of machine and measure the distance between the lines drawn.

5.9.1.6 PROVISIONAL TENSILE TESTING

PERSPEX (4MM)

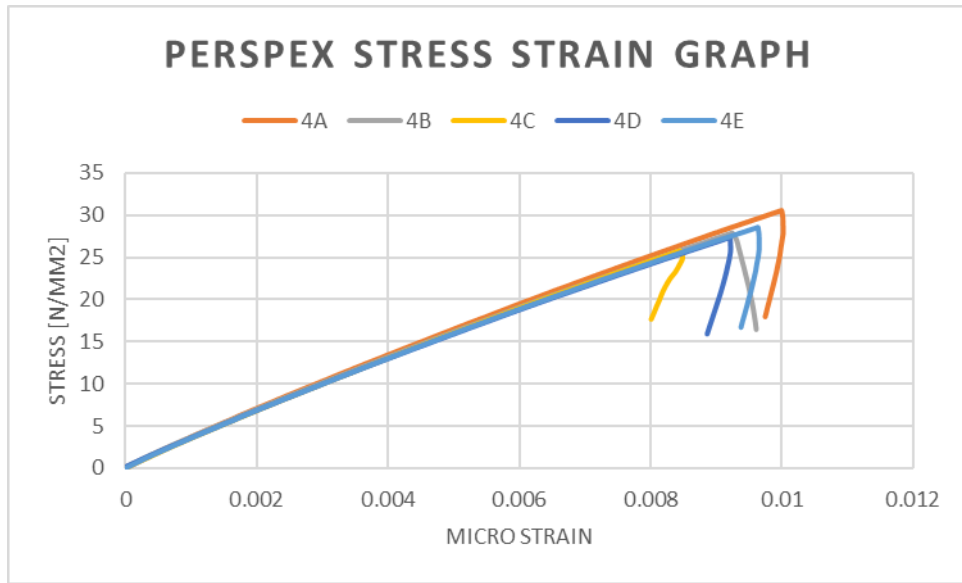


Figure 86 - Perspex Tensile Test Comparison

Table 14 - Perspex Tensile Results

Sample	E (N/mm2)	Stress x1	Force x1	Yield strength
4A	3010	30	3822	28
4B	2917	27	3591	25
4C	2945	25	3333	22
4D	2864	27	3523	24
4E	2887	28	3660	26

Table 15 - Average Perspex Tensile Results

	E (N/mm ²)	Stress x1	Force x1	Yield strength
Average of Samples	2925	27	3586	25
Theoretical	2500	-	-	17
% Difference	15.67	-	-	38

MILD STEEL (3MM)

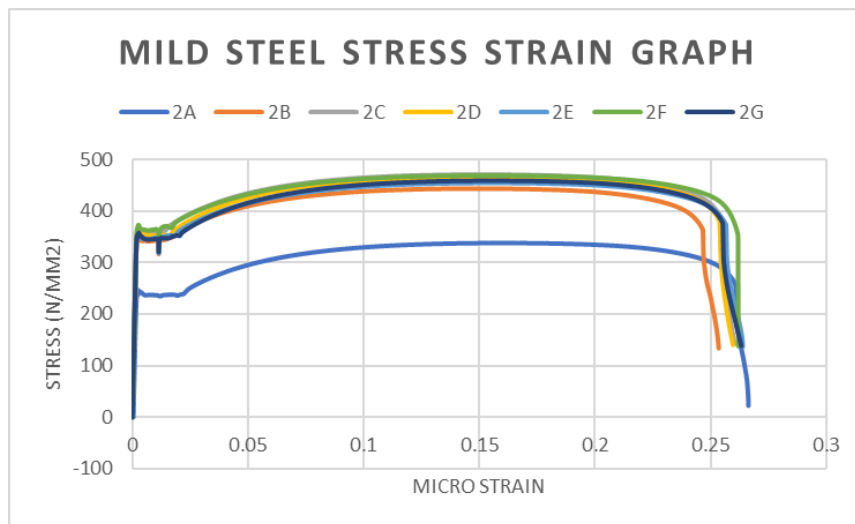


Figure 87 - Mild Steel Tensile Test Comparison

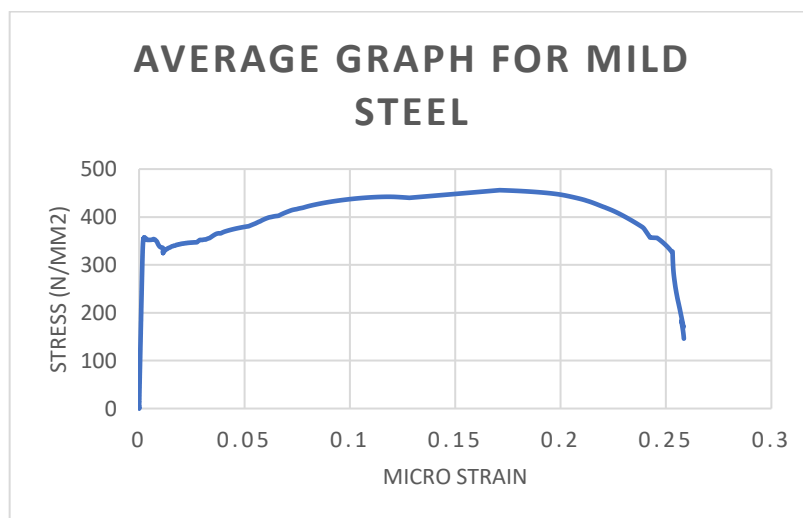


Figure 88 - Average stress strain graph for Mild Steel

OBSERVATIONS



Figure 89 - Necking in a tensile specimen⁵¹

5.9.1.7 FURTHER WORK

After analysing the data from the tensile test, it was noticed that a lot of slippage occurred at the start of the test due to the samples slipping when in the jaws of the machine. Analysis into this should be undertaken to identify if the slippage can be reduced. Computer modelling of this control test was created to validate the computer analysis approach needed to speed up the new product development. It will also be used in conjunction with the material property curves to identify safe working limits during extreme events.

5.9.1.8 SLIPPAGE INVESTIGATION

After going through the first stage of the testing at university, the results showed that there was slippage present between the sample pieces and the machine jig clamps. This caused anomalies at the start of the graph created by the machine, showing that there was strain present when no stress had been applied. Due to this, an investigation into the prevention of the slippage was undertaken. It was determined that to prevent the slippage from occurring, more friction would have to be present between the sample and the clamps.

In order to achieve this, the following methods can be used:

- Etching the top and bottom of the samples

If the samples were moved up so that they were flush with the machine clamps, then the possibility for updating would be expanded further to include the following:

- Welding a round bar to the top
- Welding an RSA angle to the top
- Welding 2No. RSA angles to the top

⁵¹ Seward, D. (2014). *Understanding Structures; Analysis, Material, Design*. Hampshire: Palgrave Macmillan.

A sample was created and a round bar was welded onto the top face of the sample.



Figure 90 - Slippage investigation (Round bar)

After further research, the Zwick manual stated that the sample should ideally be at least $\frac{2}{3}$ the size of the clamps (Zwick/Roell, 2016). Due to this reason, the above was eliminated.

Investigations into the method of etching the sample took place. Firstly, the sample was created on Solidworks as a 3D model. Then a sketch was created on the top faces of the relevant cross sections to represent the etching. A DXF version of the model was saved and sent to the laser office to process. The sample was created so the laser machine will be programmed to etch the sample. The results are shown in Figure 91.



Figure 91 - Laser etched sample

The samples that are lasered have produced precise lines but wouldn't provide much friction as they aren't extruded deep enough into the sample. Also, the pattern couldn't easily be recreated on the bottom faces of the sample without stopping the laser machine and resetting the program. For this reason, an investigation into the results of hand etching was undertaken.

When etched by hand with a hand engraver, the lines were extruded deeper into the sample which would create a better bond due to the increase in friction. It was easy to replicate on

both sides of the sample. Due to all of these reasons, this etching methodology was chosen to be applied on all of the samples being tested.



Figure 92 - Hand etched sample

5.9.1.9 TENSILE TESTING

The tensile tests were critical in finding out how the different materials used at the Company performed under load. This provided values for the following properties of the materials:

- Ultimate Tensile Strength
- Yield strength
- Modulus of elasticity

For each of the materials, five different sample sections were tested and the results for each material are shown in Figure 93.

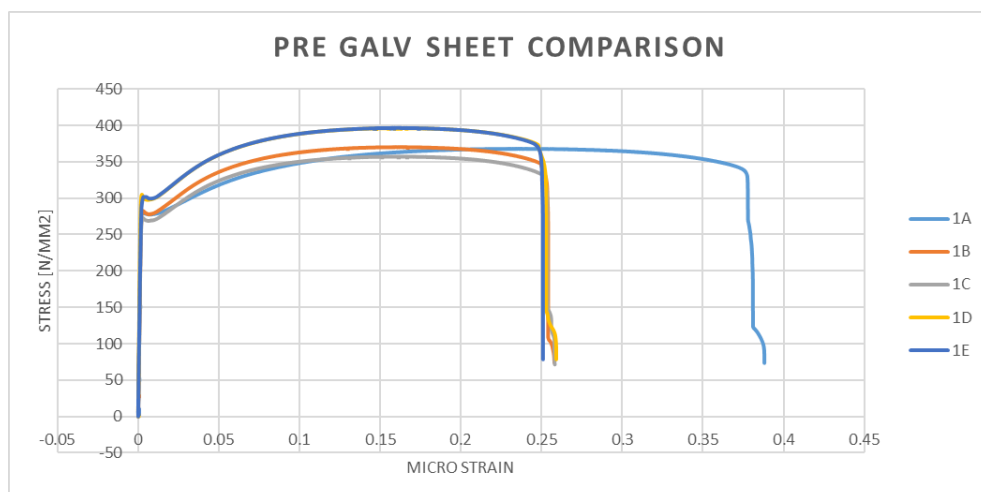


Figure 93 - Pre galvanised tensile comparison

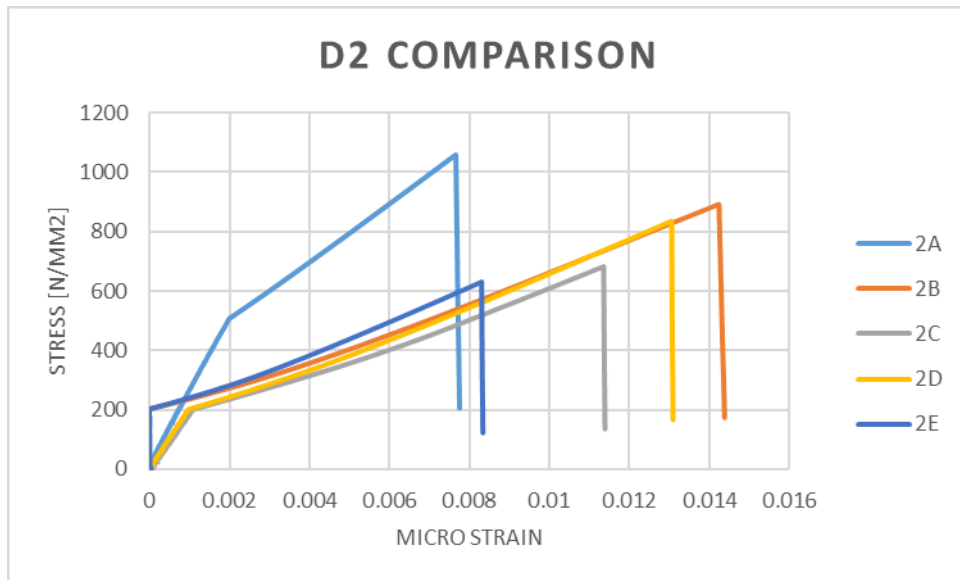


Figure 94 - D2 tensile comparison

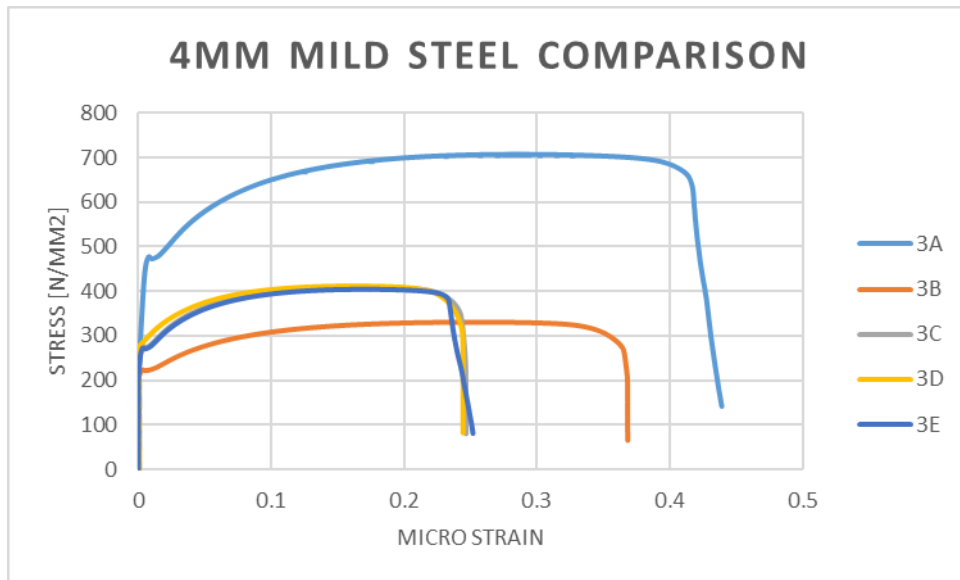


Figure 95 - 4mm mild steel tensile comparison

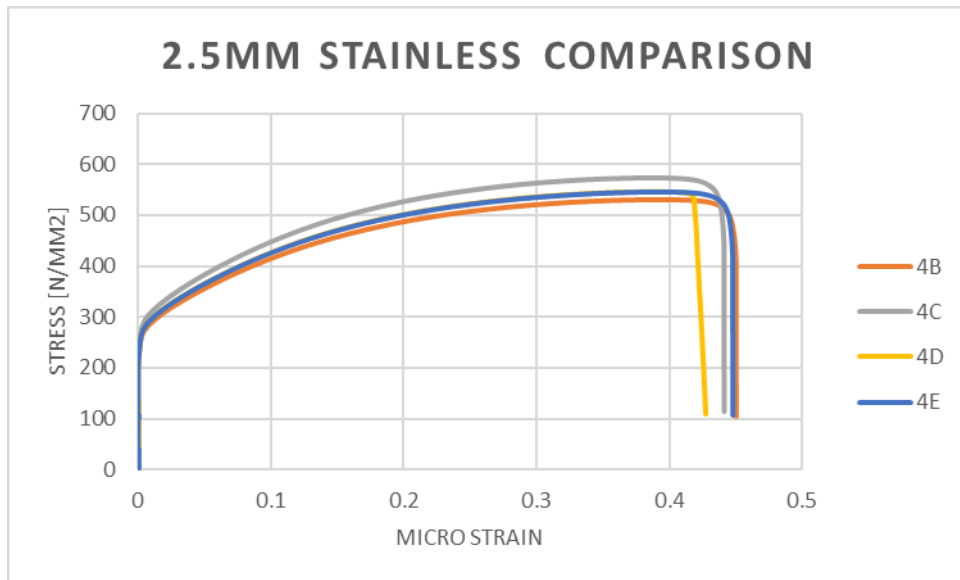


Figure 96 - 2.5mm stainless tensile comparison

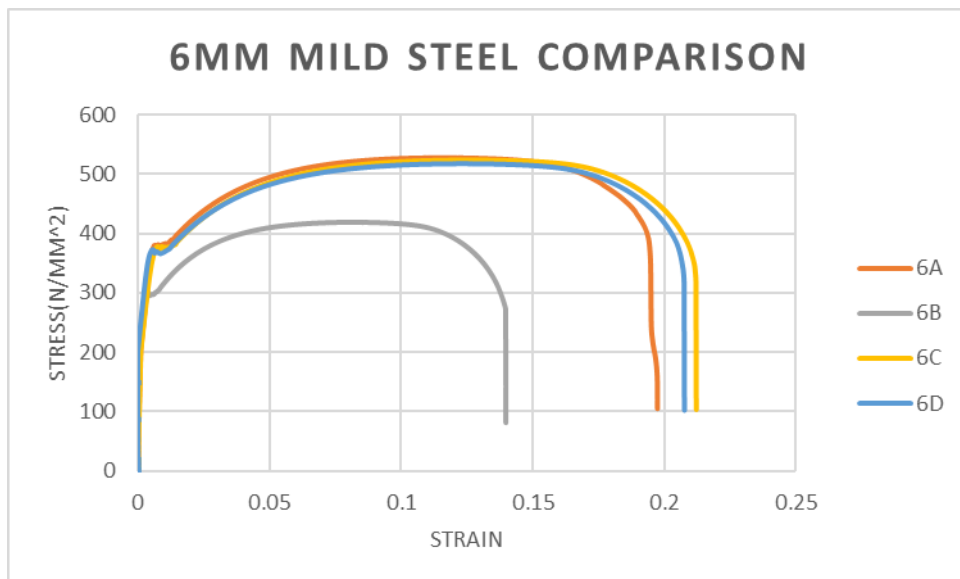


Figure 97 - 6mm mild steel tensile comparison

MEASUREMENTS OF SAMPLES

Before each test was completed the samples were fully measured and averages were taken for the sample sizes. This allowed for more accurate results when the strength values were calculated from the test results.

MATERIAL PROPERTIES	2A	2B	2C	2D	2E	2F	2G
L1(mm)	150.00	150.09	150.17	150.07	150.08	150.06	150.17
L2(mm)	150.12	150.21	150.08	150.12	150.32	150.07	150.14
L3(mm)	150.41	150.31	150.04	150.10	150.01	150.09	150.13
L4(mm)	150.30	150.04	150.15	150.08	150.17	150.14	150.12
L5(mm)	150.18	150.06	150.11	150.09	150.09	150.06	150.10
W1(mm)	39.75	39.91	39.84	39.80	39.72	39.73	39.77
W2(mm)	39.81	39.89	39.83	39.83	39.75	39.75	39.76
W3(mm)	39.79	39.84	39.77	39.84	39.80	39.77	39.78
W4(mm)	39.74	39.82	39.82	39.84	39.82	39.78	39.77
W5(mm)	39.82	39.81	39.85	39.82	39.84	39.80	39.76
T1(mm)	3.04	2.83	2.95	2.94	2.89	2.94	2.99
T2(mm)	3.02	2.85	2.92	3.05	2.90	2.95	2.91
T3(mm)	2.90	2.89	2.88	2.88	3.01	2.96	2.89
T4(mm)	2.99	2.88	2.99	3.02	2.96	2.91	2.90
T5(mm)	3.23	2.86	2.90	2.89	2.93	2.94	2.90
AVERAGE THICKNESS (mm)	3.04	2.86	2.93	2.96	2.94	2.94	2.92
AVERAGE WIDTH (mm)	39.78	39.85	39.82	39.83	39.79	39.77	39.77
AVERAGE LENGTH (mm)	150.20	150.14	150.11	150.09	150.13	150.08	150.13

Figure 98 - Measurements of Samples for Tensile Test

PREDICTED VALUES

The predicted values chart allowed for each material result to be predicted based on the load which would be applied to them. This allowed for unexpected results to be spotted with greater ease as they would give a false impression of the strength of the materials.

MATERIAL PROPERTIES	SAMPLE						
	2A	2B	2C	2D	2E	2F	2G
FORCE (kN)	33.21	31.37	32.06	32.37	32.15	32.15	31.91
FORCE (N)	33210	31370	32060	32370	32150	32150	31910
LOAD AMPLIFIER	2	2	2	2	2	2	2
AREA (mm ²)	120.78	114.06	116.6	117.73	116.89	116.91	116.04
FAIL STRESS (N/mm ²)	550	550	550	550	550	550	550
FAIL FORCE (N)	66420	62733	64130	64752	64290	64301	63822
FAIL FORCE (kN)	66.43	62.73	64.13	64.75	64.29	64.3	63.82
EXTENSION (mm)	0.39	0.39	0.39	0.39	0.37	0.39	0.39
PREDICTED STRAIN	0.26190	0.26190	0.26190	0.26190	0.26190	0.26190	0.26190
PREDICTED YOUNG'S MODULUS	2099.75	2100.04	2100.04	2100.04	2100.04	2100.04	2100.04
INITIAL DISTANCE BETWEEN LINES	122.06	126.97	124.49	127.88	122.82	119.34	123.1
INITIAL DISTANCE BETWEEN LINES	155.55	160.39	157.38	160.45	156.34	152.45	157.3
EXTENSION (MM)	33.49	33.42	32.89	32.57	33.52	33.11	34.2
STRAIN %	27.44	26.32	26.42	25.47	27.29	27.74	27.78

Figure 99 - Predicted values for Tensile Test

	2a	2b	2c	2d	2e	2f	2g
Initial distance between lines	122.06	126.97	124.49	127.88	122.82	119.34	123.1
New distance between lines	155.55	160.39	157.38	160.45	156.34	152.45	157.3
Extension (mm)	33.49	33.42	32.89	32.57	33.52	33.11	34.20
Strain %	27.44	26.32	26.42	25.47	27.29	27.74	27.78

Figure 100 - Actual values for Tensile Test

5.9.1.10 TENSILE TEST SUMMARY

A straight line is observed on a stress strain curve when the stress is proportional to strain which shows that Hooke's Law is obeyed. At this point in the graph, if the load is released, the material will go back to its original shape. The limit of proportionality was observed on

the graphs which showed the point where the strain isn't proportional to stress, but the material still retains its original shape after the removal of the load. The elastic limit of each material is observed, and it was identified and visually validated that beyond the elastic limit, deformation is not recoverable as the material experiences permanent set and exhibits the beginning of the yielding stage where the strain is large with a small increase of stress.

Point C and C' represent upper and lower yield points. Stress corresponding to C is the yield stress. CD represents the plastic yielding – the strain which occurs after the yield point with no increase in stress. The stressing in the material beyond D causes large strain for a very small increase in stress. E corresponds to the max stress. From D to E, cross section decreases in proportion with an increase in length. Beyond point E, extension continues without any increase in stress and material breaks at the stress corresponding to point F – breaking stress which is less than the ultimate stress.

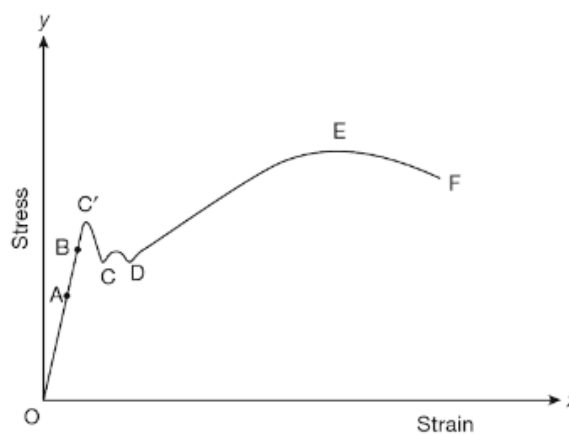


Figure 101 - Typical Stress-Strain Curve⁵²

The testing completed was valuable as accurate figures for the materials were gained including their ultimate tensile strength. The results also allow for the easy comparison of materials to identify which material is best suited for applications where a high tensile strength is required.

5.10 BENDING

There are numerous types of bending tests where the loads can be applied statically or dynamically. Static loads are loads which don't move whereas dynamic loads are those which fluctuate with time.

⁵² Raj, P. P., & Ramasamy, V. (1983). Strength of Materials. India: Pearson Education.

Static tests are completed to determine if the beams behave as expected within the elastic region. Using the elastic yield point from the tensile tests will allow for the allowable load to be predicted for this test.

When analysing the bending stresses in beams regarding the elastic behaviour, Draycott & Bullman (2009) explain that the stresses will vary from zero on the neutral axis (NA) to maximum at the top and the bottom.

Wang, et al. (2015) explain that the use of the Bernoulli-Euler Beam Equation is used to obtain the flexural strength and the elastic modulus. Due to the Bernoulli-Euler Beam theory being based on the hypothesis of a large, slenderness ratio, it can lead to an inaccurate assessment of stresses when the slenderness ratio is inadequate – which would also lead to an error in the evaluation of the modulus.

Beam flexure represents one of three most common loading categories for mechanical systems (Szaroletta & Denton, 2002). They go on to say that four-point bending has traditionally developed the theory from free body diagrams through beam deflection. There is excellent correlation between the theoretical and experimental results, but hardware requirements have limited the accuracy and amount of data collected.

This governing equation for elastic bending is:

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

Equation 12 - Elastic Bending Theory

Where:

M = Bending moment (Nmm)

I = Second moment of area (mm⁴)

σ = Bending Stress (N/mm²)

y = Distance from neutral axis (mm)

E = Young's modulus of elasticity (N/mm²)

R = Radius of curvature (mm)

It is noted that the term $\frac{E}{R}$ relates to the deformation of the beam and is used in calculating the deflections but not the strength calculations. The equation can then be re-arranged if the bending moment is needed.

$$M = \frac{\sigma \times I}{y}$$

Equation 13 – Bending Moment

The maximum stresses occur when y is at its maximum (top and bottom of a beam) and because I and y both are properties of the shape of the section, a new property can be defined, the elastic section modulus.

$$W_{el} = \frac{I}{y_{max}}$$

Equation 14 - Elastic Section Modulus

This can be rewritten to be integrated into the following equations.

$$M = \sigma \times W_{el}$$

Equation 15 - Maximum bending moment

$$\sigma = \frac{M}{W_{el}}$$

Equation 16 - Maximum Stress

$$W_{el} = \frac{M}{\sigma}$$

Equation 17 - Elastic section modulus

5.10.1.1 THREE POINT BENDING TESTS

This test is used commonly to measure the Young's modulus of a material in the shape of a beam. The beam is supported by two rollers with a load being applied at the centre of the beam.

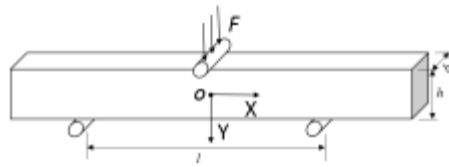


Figure 102 - Three-point bending tests⁵³

The deflection at the centre of the beam is calculated with the following formula

$$\omega_0 = \frac{PL^3}{48EI}$$

Equation 18 - Deflection at centre of beam

Where I is defined from Equation 19.

$$I = \frac{bd^3}{12}$$

Equation 19 - Second moment of area

By manipulation of the formula's above, E, the Young's Modulus can be calculated.

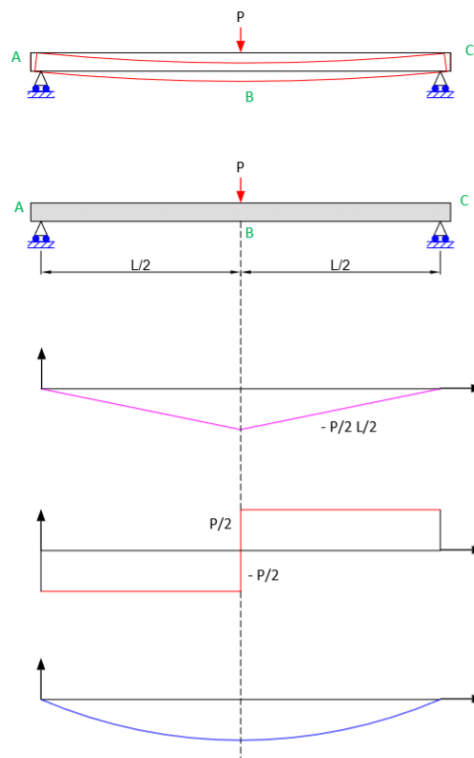


Figure 103 - Typical bending moment, shear force and deflection diagram (drawn by the author)

⁵³ Rees, J., Jacobsen, P., & Hickman, J. (1994). The Elastic modulus of dentine determined by static and dynamic methods. 11-15.

By plotting the force applied against the displacement at the centre of the beam, a straight line will be exhibited if the material remains in its elastic limit. To obtain the gradient of the line, the following equation needs to be used, which can be manipulated to find out the Young's modulus.

Equation 20 - Gradient from Force - displacement graph

$$\frac{dP}{d\omega_0} = \frac{48EI}{L^3}$$

This equation is more reliable when trying to obtain a value of E for the material as several measurements for the force and displacements can be taken, therefore, reducing the errors potential to this experiment. There will also be less calibration as only the change in length is needed to be known, rather than calculation of the new length.

It is known that in a three-point test, the peak stress is produced and the mid-point of the material and reduced everywhere else.

5.10.1.2 TEST APPARATUS

- Machine – Zwick Roell Z050
- Speed start position – 200 mm/min
- Span of the supports – 400 mm

5.10.1.3 REDUCING ERRORS

- Measure and mark the reference points where the supports will be placed to ensure the same position is used in each test
- Draw a line at the centre of the supports to show where the load will be applied on the sample
- Measure the thickness, length and width 5 times and obtain an average value for each
- Input the values of thickness and width into the software to gain accurate testing results
- Zero the force applies to ensure no force is present for every test
- Ensure that the loading pin and the sample are in contact – make sure a low approach speed is used to minimise the risk of overloading or damaging the load cell

5.10.1.4 BENDING TESTING

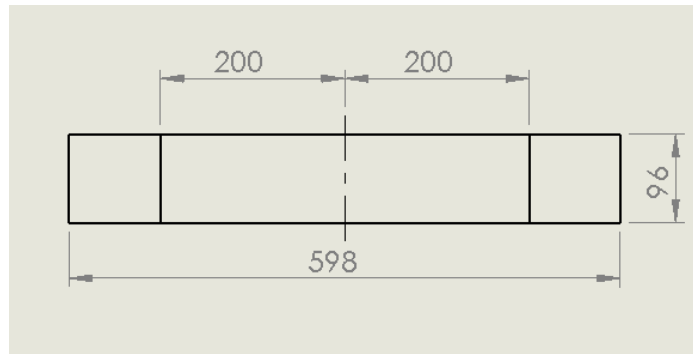


Figure 104 - Sample example

1. Mark the centre line of the sample
2. Mark a line 200mm either side of the centre line where the supports will be
3. Measure the thickness of the sample 5 times and obtain an average value
4. Input the thickness and the width of the sample
5. Adjust the head of the machine so it is touching the sample and set the tool separation value
6. Zero the force on the machinery
7. Start the machine and turn the test on
8. Stop when the force reaches a value of 600 N
9. To start a new test, reset the tool separation and start the test

5.10.1.5 MEASUREMENT VALUES

MATERIAL PROPERTIES	A	B	C	D	E	F	G	H	I	J	AVERAGE
L1(mm)	598.00	598.02	598.04	598.00	598.08	598.06	598.01	598.00	598.02	598.03	
L2(mm)	598.05	598.07	598.08	598.02	598.04	598.07	598.04	598.03	598.02	598.06	
L3(mm)	598.01	598.03	598.03	598.00	598.05	598.06	598.00	598.02	598.01	598.01	
L4(mm)	598.02	598.00	598.04	598.01	598.04	598.07	598.01	598.04	598.00	598.03	
L5(mm)	598.06	598.08	598.09	598.03	598.00	598.04	598.07	598.06	598.03	598.02	
W1(mm)	96.00	96.02	96.05	95.99	96.00	96.02	71.05	71.01	71.02	71.09	
W2(mm)	96.10	96.05	96.04	96.02	96.03	96.01	71.03	71.04	71.05	71.00	
W3(mm)	96.01	96.03	96.02	96.05	96.05	96.04	71.00	71.05	71.06	71.05	
W4(mm)	95.98	96.01	96.04	96.01	96.02	96.03	71.01	71.10	71.00	71.01	
W5(mm)	96.07	96.00	96.02	96.08	96.01	95.99	71.03	71.01	71.02	71.04	
T1(mm)	2.87	3.01	2.96	2.84	3.09	2.93	2.88	2.81	3.05	2.86	
T2(mm)	2.96	2.89	2.98	3.11	2.99	2.83	3.01	2.94	2.92	2.96	
T3(mm)	3.02	2.95	3.01	2.97	3.01	3.02	2.95	2.90	3.05	3.03	
T4(mm)	2.99	2.84	2.90	3.10	2.92	3.04	3.01	2.92	2.95	3.11	
T5(mm)	3.05	3.11	2.95	2.90	2.99	3.11	3.06	3.11	2.98	2.98	
AVERAGE THICKNESS (mm)	2.98	2.96	2.96	2.98	3.00	2.99	2.98	2.94	2.99	2.99	2.98
AVERAGE WIDTH (mm)	96.03	96.02	96.03	96.03	96.02	96.02	71.02	71.04	71.03	71.04	86.03
AVERAGE LENGTH (mm)	598.03	598.04	598.06	598.01	598.04	598.06	598.03	598.03	598.02	598.03	598.03

Figure 105 - Measurements from Bending Tests

5.10.1.6 RESULTS

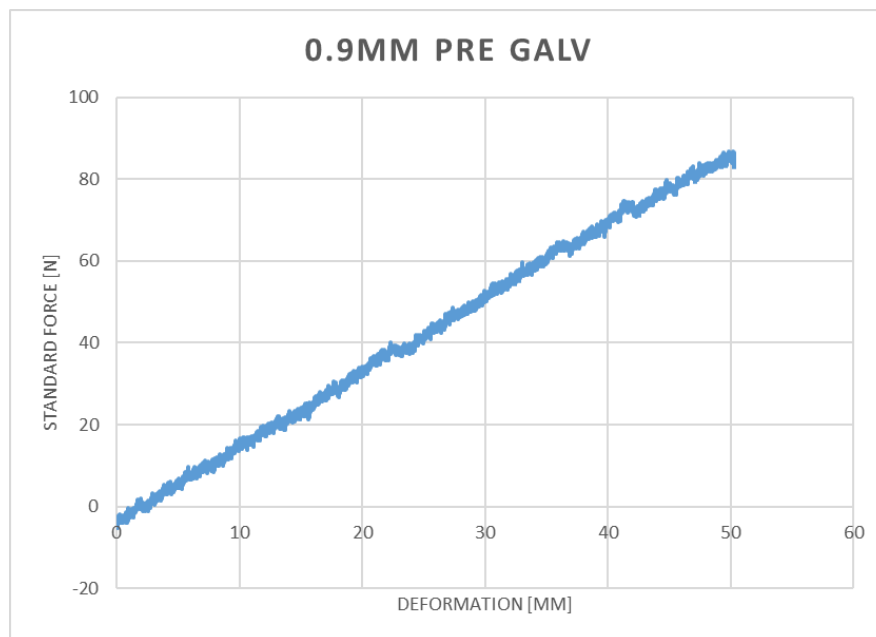


Figure 106 - 0.9 mm Pre-galvanised sheet results

It was clear that the material was not stable throughout this test, as the result don't portray a straight line – the results show lots of slippage through the sample. This could be due to the thickness of the material as it was only 0.9 mm. Next time the material supports can be moved closer to ensure that the material doesn't slip and effect the results.

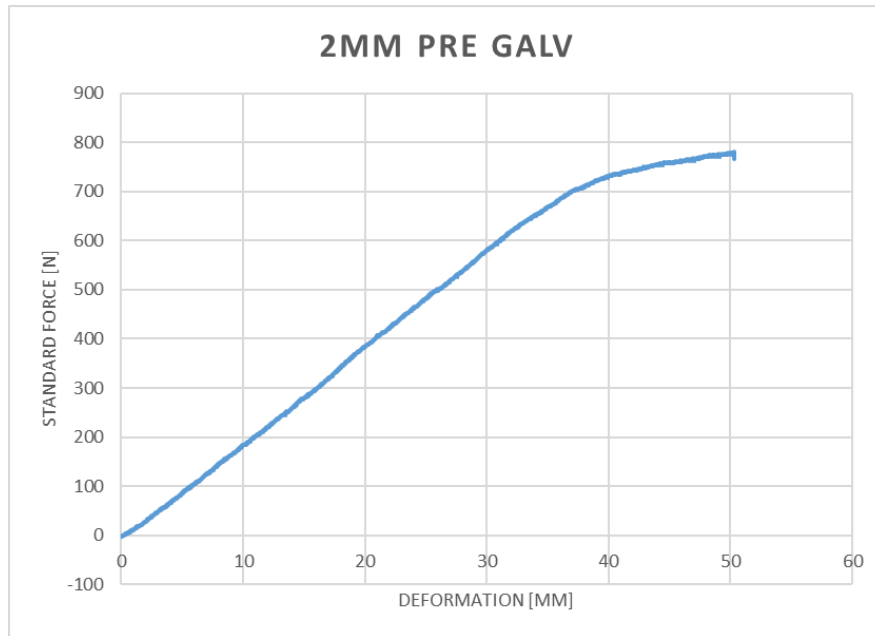


Figure 107 - 2 mm Pre-galvanised sheet results

This material plot shows the typical curve that is expected from a bending test and enhances the assumption that the previous material (0.9mm pre-galvanised steel) was too thin to undergo this test without modification of the span of the supports.

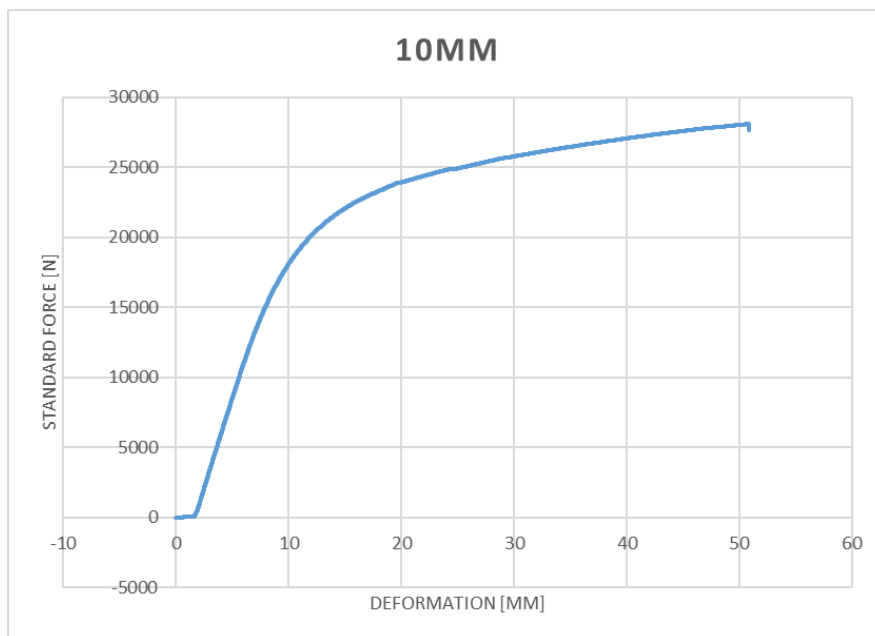


Figure 108 - 10 mm Mild Steel

5.10.1.7 COMPARISON

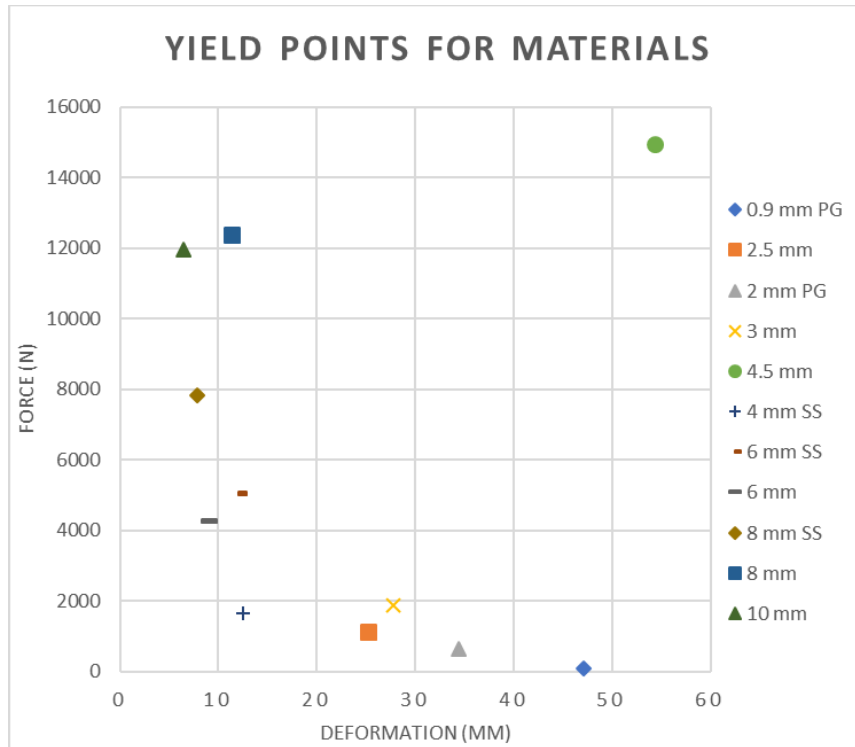


Figure 109 - Comparison of Yield Points for Materials Tested

Table 16 - Comparison of Young's Modulus

SAMPLE	MATERIAL	YOUNGS MODULUS (N/MM2)
0.9 mm	PRE-GALVANISED STEEL	123,512.93
2.5 mm	STAINLESS STEEL	152,590.70
2 mm	PRE-GALVANISED STEEL	127,193.77
3 mm	MILD STEEL	133,933.19
4.5 mm	D2 PLATE	141,472.21
4.5 mm	D2 PLATE	160,844.52
4 mm SS	STAINLESS STEEL	110,246.32
4 mm	MILD STEEL	126,329.16
6 mm SS	STAINLESS STEEL	103,495.44
6 mm	MILD STEEL	117,731.21
8 mm SS	STAINLESS STEEL	104,134.83
8 mm	MILD STEEL	114,252.38
10 mm	MILD STEEL	99,589.58

5.10.1.8 BENDING TEST SUMMARY

The advantages of the three-point bending tests is that it is easy to prepare the samples and test. The disadvantages are that the testing method is sensitive to the specimen, loading geometry and strain rate. It was seen that the flexural test produced compression stresses on

the concave side of the sample and tensile stresses on the convex side of the sample. It was noted that it was possible for shear stresses to occur rather than tensile or compressive stresses – this occurs if the span to depth ratio on the sample is too small, otherwise the material will fail from shear stresses. It is advised that a span to depth ratio of approximately 16 is generally acceptable for most materials. The sample must be flat to avoid torque generating when the load is applied on the sample.

5.11 MATERIAL DATABASE

It was understood and agreed that the data collected from the testing should be collated into a document which can be referenced and updated easily. This document will contain all the materials that the Company currently use to manufacture their products. The first page of the document contains a list with every material which is bought in. This includes the varying sizes in which the material is bought, the material specification, the unit price and the material composition.

The inventory also includes a tab to state whether the material has been tested at the university, these tests carried out the university included the following:

- Hardness Testing
- Tensile Testing
- Bending Testing

The result of these tests for each material are included within another section of the database. Each material has its own tab at the base of the document to allow them to be easily navigated through. On these tabs each material is broken down in greater detail including different thicknesses, different overall sizes, yield strength, hardness and tensile strength. All this data is taken from the product data sheets supplied with the material. Inputting it into this document makes it easier for somebody to search through the materials and find one which has the yield strength they think is required. To validate this process, and ensure the figures provided are correct, testing was conducted at the university.

From the testing that was carried out at university, the data gained was manually inputted into a document and used to calculate the following characteristics for each of the materials tested.

The bar chart in Figure 110 was created to show a comparison between all the characteristics for each of the materials. From the 4 samples tested for each material type an average was calculated, and this is what will be included within the material database.

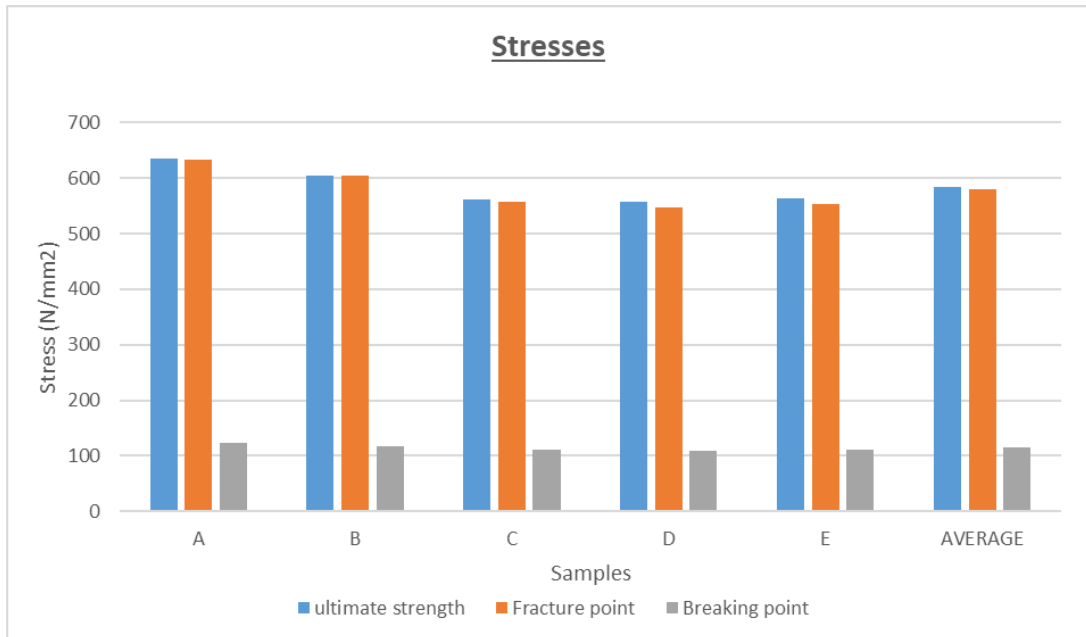


Figure 110 - Stress comparison

Whilst inputting and observing the data, it was noticed that there was some slippage which occurred at the start of the test. This slippage is at the very start of the test whilst the material is starting to be gripped by the test equipment.

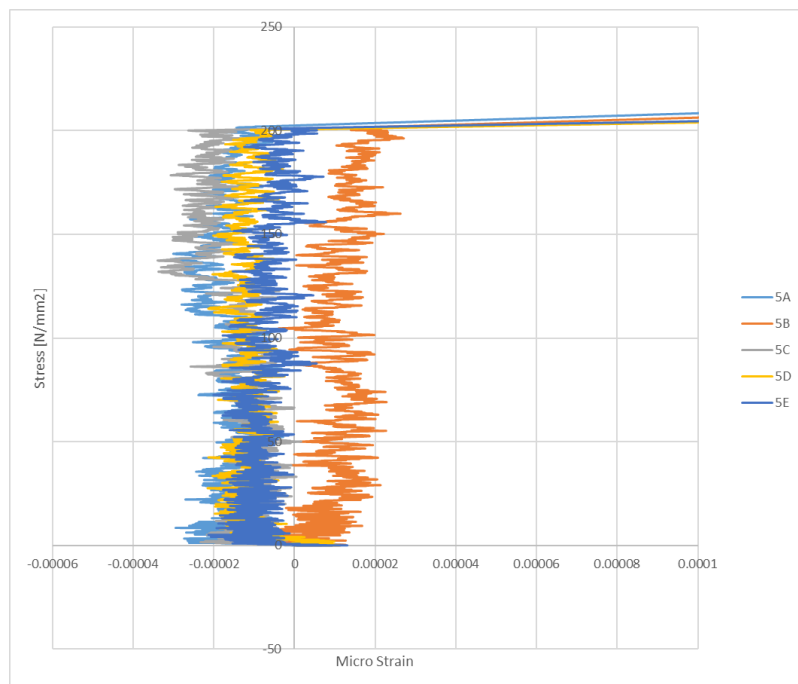


Figure 111 - Slippage graph

To compare how accurate the data that is provided which each material, the Young's modulus was calculated. Young's modulus was chosen as this is called up on the majority of data sheets that were provided.

To calculate this the value for the material stress at the yield point was found for each of the samples tested for every material. This was found on the graphs created from the test results, and then the relevant strain value taken at this point. These figures were then taken and put in the following formula to calculate the Young's modulus using Equation 11.

$$E = \frac{\text{stress}}{\text{strain}} = \frac{F/A}{\Delta l/l_o}$$

This calculation was carried out for every test sample on every material and the average found was then listed within the material database as a reference.

5.12 HARDNESS TESTING VS LPCB DATABASE

DRILL VS LPCB TESTING

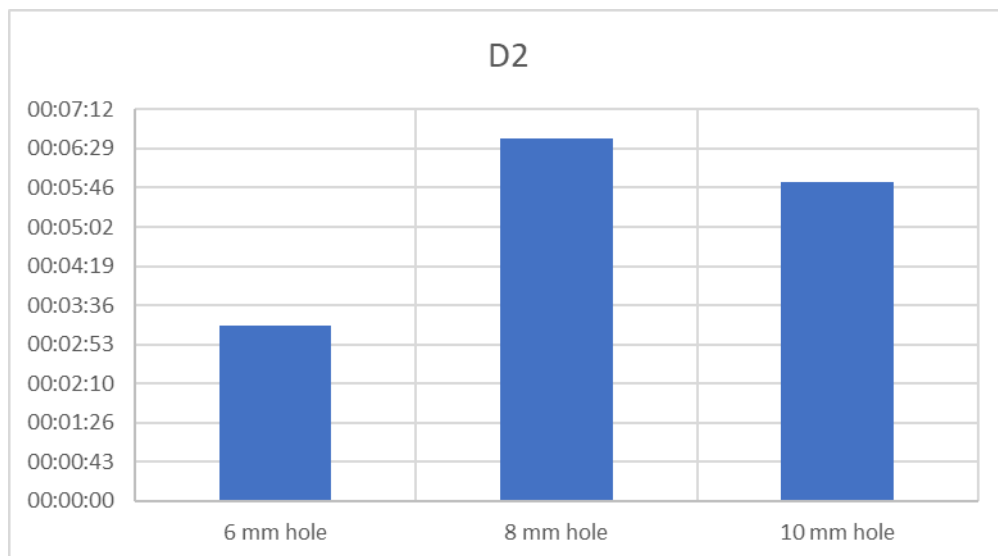


Figure 112- Drill time comparison

Figure 112 shows the comparison of drill times.

5.13 SUMMARY

After analysis of the current material process and research into ways to improve the process, an accurate method into obtaining the material properties of materials was created to be able

to rely less on the indicative material testing that takes place at LPCB and to create a link between material properties and the LPCB testing. This has numerous benefits to the Company, with the cost saving being the prime benefit.

FURTHER WORK

Further work would be simulating the material analysis on Solidworks. This can be validated using engineering calculations to understand the accuracy of the results produced. This would improve the efficiency of the material side of the testing, as it won't be necessary to complete all the material tests in the laboratory.

CHAPTER 6

6 UNDERSTANDING STRUCTURAL BEHAVIOUR

6.1 INVESTIGATING STRUCTURAL BEHAVIOUR

The common objective when designing structures is to ensure that the all stresses are within the elastic linear region, below the yield stress for the structure to safely carry its loads over any period. This is the same for the security products designed at the Company, with the aim to keep all materials within the product in their elastic region, which will increase the strength of the product with the aim to increase the certainty of passing the physical attack testing. By analysing the material properties shown in the previous section of this chapter, an investigation into the structural behaviour of structures will be completed to identify how a structure will behave under different conditions which will replicate the conditions the product has to endure during the physical testing process.

6.2 UNDERSTANDING BOUNDARY CONDITIONS AND RESTRAINTS

To understand the boundary conditions of the product, the author researched the different types of supports typically in structures. This will allow the recognition of how the products manufactured by the Company are supported and restrained.

A boundary condition is where a structure interacts with an environment either through a force or a displacement. They are typically expressed in terms of degrees of freedom; one horizontal, one vertical and one rotational, in 3D there are six degrees of freedom due to there being three rotational and three translation degrees of freedom.

Boundary conditions are the restrictions held on a beam by its supports and it is required for the conditions to be prescribed at each support before analysis of solving of beams. They can be a deflection and slope or a force and moment or a combination of both (Ugural, 2007). The typical supports are:

- Fixed support
- Simple support
- Free End

- Guided support

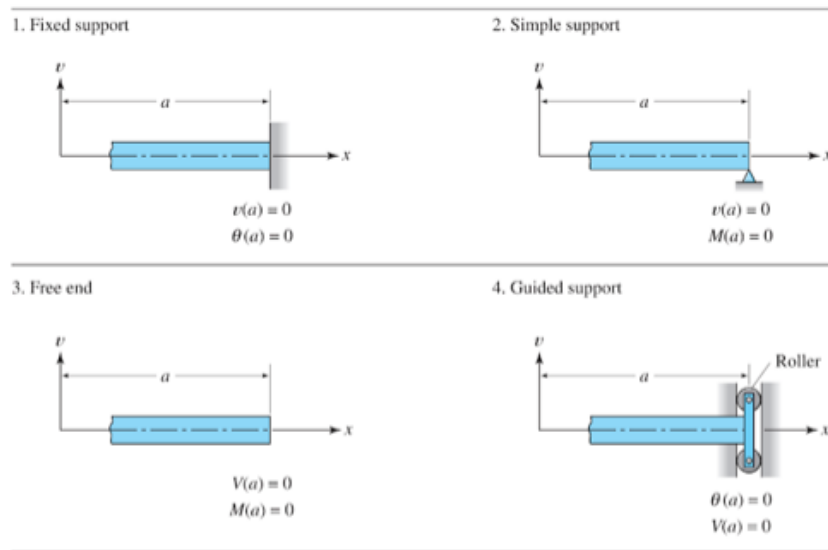


Figure 113 - Guided support diagram⁵⁴

Roller – can only restrain the structure in one degree of freedom (perpendicular to the roller) which allows translation parallel to the roller support plane and allows rotation at that point.

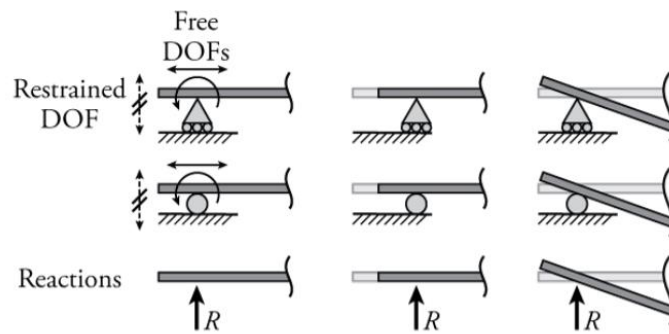


Figure 114 - Roller support diagram⁵⁴

Pinned – allows the structure to rotate about that point but is restrained translationally. An example of this from the products manufactured would be the locking latch to the door frame.

⁵⁴ Seward, D. (2014). Understanding Structures; Analysis, Material, Design. Hampshire: Palgrave Macmillan.

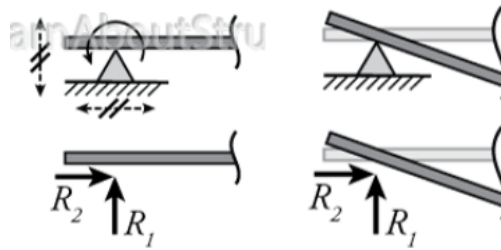


Figure 115 - Pinned support diagram⁵⁵

Fixed end – restrains in all three degrees of freedom; two are forces and one is a moment reaction. This will be the case for all of the products being fixed to the structure they are securing.

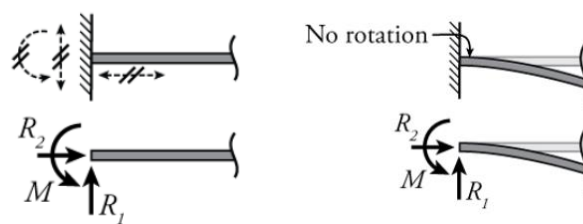


Figure 116 - Fixed support diagram⁵⁵

Seward (1994) explains the difference in supports. Pinned supports are translationally fixed but rotationally free, meaning that a single pinned support will not make a structure stable and another support must be included to prevent rotation. Fixed supports are fixed translationally and rotationally which means that this support can be the only support in a structure due to the three equilibrium equations being satisfied. With this being the case, the product as a whole may have fixed supports to the structure, but elements of the product will only have pinned supports keeping them structurally stable. The attacker's aim is to break this support and gain access through the unstable structure.

In practice, many structural connections are assumed to be pinned supports for the purpose of design such as bolted connections in a steel frame – assuming small moments present are negligible. (Seward, 1994)

⁵⁵ Seward, D. (2014). *Understanding Structures; Analysis, Material, Design*. Hampshire: Palgrave Macmillan.

FORCES

Forces are loads which are applied to structures in any direction. These forces can be classified as either external forces such as wind or gravity, or internal forces. The four internal forces are:

- Shear
- Tension
- Compression
- Torsion

It is important to consider the strength and stability of the structure and its individual components – structural analysis is used to calculate the effects of the forces acting on any component and the structure overall. The three main properties of forces are the magnitude, direction and position of the forces. It is noted that for a structure to remain static, the three basic equations should be true

- Sum of all vertical forces equals zero
- Sum of all horizontal forces equal zero
- Sum of all bending forces or moments equal zero

A shear force is a force applied perpendicular to a surface, which is in opposition of an offset force acting in the opposite direction, resulting in a shear strain. When a structural member experiences failure by shear, two parts of it are pushed in different directions. When designing high rise buildings, they must be designed with shear walls to resist shear forces otherwise racking will occur where parallel structural elements of the building will be pushed over.

DISPLACEMENTS

Displacements can occur within a structure when it is subjected to forces, either internal or external. Displacement is described as the distance of movement a structure has moved from its original location or position.

To help with the analysis of the products sent for testing at LPCB, the displacements that occur during the testing are to be measured so that they can be replicated with in house testing and 3D simulation software. These displacements can then be linked to the force required to reach that point, to ensure all new products are designed do not reach that point.

6.2.1 BEAM ANALYSIS

The aim is to analyse buckling and bending phenomenon in columns and beams respectively. Draycott & Bullman (2009) state that if a beam section is to not fail under load, an internal moment of resistance (MR) is available within the beam at least equal to the maximum bending moment (BM) produced by the loads – internal MR is at least as great as external.

This is followed under both or either of the conditions

- Under serviceability loads – when the material behaviour in the beam is elastic
- Under ultimate loads – when the material behaviour may be plastic

When under serviceability loads, the behaviour of the material will generally be elastic and consequently follow Hooke's Law.

6.2.2 LOADING

Buildings consist of numerous members connected to perform a specific function or withstand externally applied loads (Raj & Ramasamy, 1983). These can affect the four basic types of loading of a member and are frequently encountered in both structural and machine design

- Axial tension
- Axial compression
- Bending
- Torsion

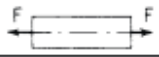

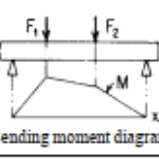
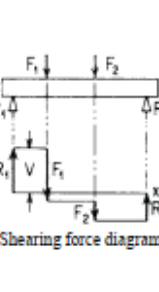
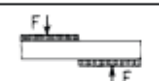
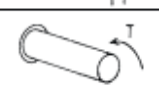
Case	Type of Loading	Illustration	Stress Distribution	Stress Equations
1	Direct tension		Uniform	$\sigma = \frac{F}{A}$ (9)
2	Direct compression		Uniform	$\sigma = -\frac{F}{A}$ (10)
3	Bending		Neutral plane	$\sigma = \pm \frac{M}{Z} = \pm \frac{My}{I}$ (11)
4	Shear		Neutral plane	For beams of rectangular cross-section: $\tau = \frac{3V}{2A}$ (12) For beams of solid circular cross-section: $\tau = \frac{4V}{3A}$ (13) For wide flange and I beams (approximately): $\tau = \frac{V}{a}$ (14)
5	Direct shear		Uniform	$\tau = \frac{F}{A}$ (15)
6	Torsion			$\tau = \frac{T}{Z_p} = \frac{Tc}{J}$ (16)

Figure 117 – Simple Stresses⁵⁶

These loadings can be linked to the attack tests explained below:

- By creating a doorset and applying direct compression, the lock capacity can be found.
- Levering can be mimicked by applying direct tension, but it is more suitable to evaluate the displacement instead of the forces applied.
- Bending is evaluated when the attack testers bend the materials to create a coupon – this is cutting the material, making flaps and bending the flaps.



Figure 118 - Coupon taken from LPCB Test Report

⁵⁶ Erik, O. (2012). Machinery's Handbook 29th Edition. Industrial Press.

6.3 LPCB PROCESS

The current LPCB procedure is detailed in Figure 119.

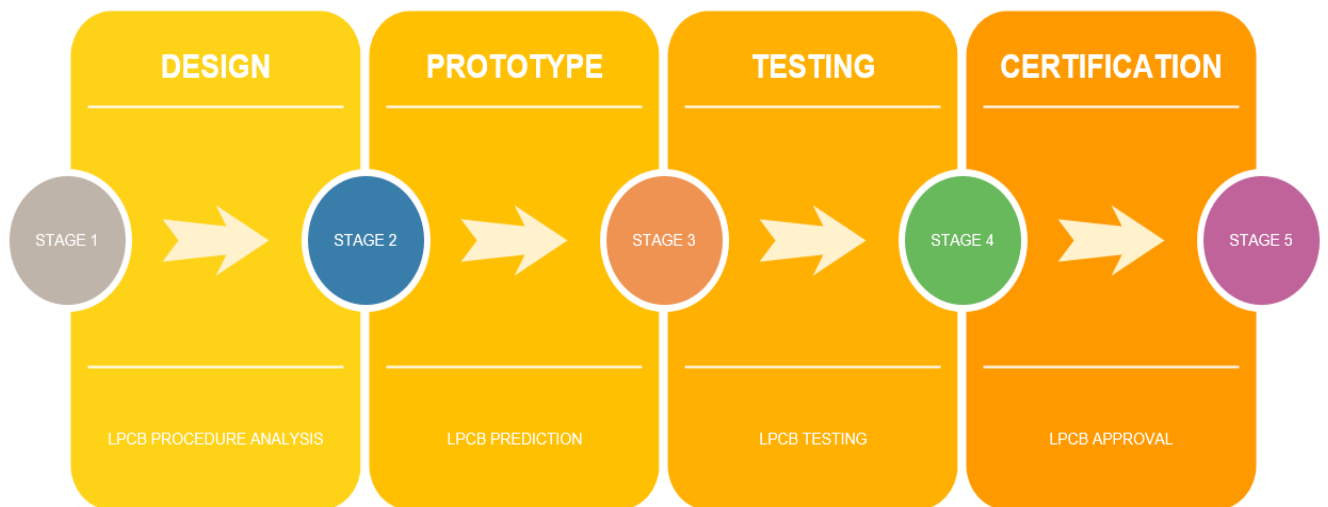


Figure 119 - LPCB Workflow

Examining the current LPCB workflow, it was noticed by the student that a prototype would be taken to LPCB to be tested and if it failed, it would be redesigned, remade in the factory and then tested again by LPCB. This process would be repeated until the product passed all of the testing required. The LPCB testing cost is £2500 per day of testing per product, which is costly when 95% of the products tested first time fail the LPCB testing (BRE Global, 2018).

The current process for new product design and development is detailed.

Table 17 - Current Design Process

OWNER	PROCESS	No. OF DAYS	COST
TECHNOCOVER	DESIGN & CONCEPTS	28	£ 3,360.00
TECHNOCOVER	MAKE TEST SAMPLES	14	£ 1,508.00
LPCB	INDICATIVE TEST DAYS	2	£ 5,000.00
TECHNOCOVER	RE-DESIGN AFTER TEST	14	£ 1,680.00
TECHNOCOVER	RE-MAKE TEST SAMPLES	14	£ 1,508.00
LPCB	LPCB TEST DAYS	5	£ 12,500.00
TECHNOCOVER	CREATE DRAWING PACK	28	£ 3,360.00
LPCB	LPCB ASSESSMENT	84	£ 5,000.00
		TOTAL COST	£33,916.00
		TOTAL DAYS	189
		TOTAL WEEKS	27

The typical process takes 189 days from initial concept idea to finished LPCB certified product. The cost of this process is £33,916, with 66% of this figure being spent with LPCB on test days and assessment work.

The aim when re-designing the design process is to reduce the overall cost of bringing a product to market which involves the design, testing, evaluation and certificate of security of the product from LPCB.

The main way to reduce this cost would be to reduce the number of test days undertaken by LPCB. This would be completed by undergoing several tests in house to examine the structural integrity of the prototype. By applying a greater ‘engineering knowledge’ to the prototypes such as analysing previous LPCB attack tests, investigating the properties of the materials used and using software to simulate certain LPCB tests, the overall certainty of the product passing an LPCB test will be greater than in the current design process.

Table 18 - New Design Process

OWNER	PROCESS	No. OF DAYS	COST
TECHNOCOVER	DESIGN & CONCEPTS 1: DATABASE ANALYSIS	1	£ 120.00
TECHNOCOVER	DESIGN & CONCEPTS 2: MATERIAL ANALYSIS	2	£ 240.00
TECHNOCOVER	DESIGN & CONCEPTS 3: SOLIDWORKS MODELLING & ANALYSIS	7	£ 840.00
TECHNOCOVER	MAKE FACTORY TEST SAMPLES	14	£ 1,508.00
TECHNOCOVER	DESIGN & CONCEPTS 4: FACTORY TESTING ANALYSIS	2	£ 240.00
TECHNOCOVER	DESIGN & CONCEPTS 3: SOLIDWORKS MODELLING & ANALYSIS	14	£ 1,680.00
TECHNOCOVER	MAKE LPCB TEST SAMPLES	14	£ 1,508.00
LPCB	LPCB TEST DAYS	3	£ 7,500.00
TECHNOCOVER	CREATE DRAWING PACK	28	£ 3,360.00
LPCB	LPCB ASSESSMENT	84	£ 5,000.00
TOTAL COST			£21,996.00
TOTAL DAYS			169
TOTAL WEEKS			24

Table 18 details the new design process from the same initial concept stage to finished product. The total cost of the process is reduced to £24,496, a saving of 28% compared to the current process. The amount spent on LPCB testing is reduced to £12,500 making up 57% of the total spend compared to 66% on the current method.

6.4 LPCB TESTING ANALYSIS

From the analysis of historic LPCB testing data, it was apparent that further testing needs to take place on prototypes manufactured by the Company, before taking them to LPCB for testing. As the LPCB testing was vast and different for every product, test methods for the product prototypes would be broken down and created specifically for each product type the Company manufactures.

After studying material and structural behaviour, a test method was created with the inclusion of this and linking to LPCB testing.

Before undergoing any testing, as there are a numerous amount of security products and products that LPCB test, a doorset was chosen as the product to be evaluated because this product is used within over 54% of the products manufactured at the Company. Analysis into the doorset was completed to understand the boundary conditions of the doorset which typically varies depending on the type of locking system. Tests were created using the same sample and boundary conditions, but the variable was testing at different positions on the sample.

6.4.1 WEDGES

The Company undertook an LPCB test regime in January 2017 for the inclusion of their frequent use ‘Sentinel’ doors within their range of walk in modular buildings and cabinets.

This test regime was chosen as the one to analyse, and specifically to investigate the ‘levering’ test method used by LPCB. The analysis was to find out whether the method of attack can be imitated and researched by the Company before carrying out actual LPCB testing.



Figure 120 - LPCB lever attack

The levering test method is a vital attack method used by the LPCB attackers. One of their main weapons during this test is the steel wedge. These come in different shapes and sizes and are used to displace the doorset by increasing the gap between the door frame and door leaf, by them being hammered into the gap. This allows easier access for the levering tools that are used with the wedges. This increased gap also reduces the force needed by the attackers to prise the door leaf and in-turn locking system away from its frame latch.

The wedges used during the test programme were analysed, looking at all the sizes typically carried by the testers.

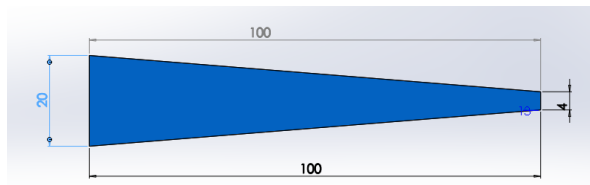


Figure 121 - Biggest wedge in LPCB tool kit

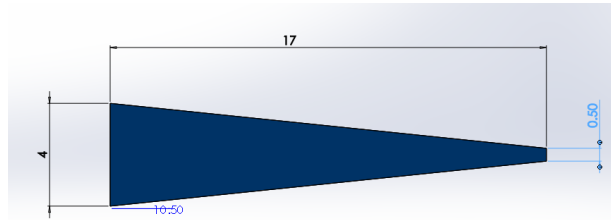


Figure 122 - Smallest wedge in LPCB tool kit

By measuring the displacement of the door leaf during the LPCB testing, the Company would have data on how their product was reacting during the attack test – in terms of displacements at various points on the doorset. This data can be stored, to be used when prototype testing at the Company and a force can be determined which can link to original deflection values. The doorset testing included other actions such as impact tests, which can be examined in further detail.

It was apparent that a method needed to be created to identify the strength of the doorset in terms of overcoming the lever testing, by measuring the force required to displace the leaf to the dimension of the biggest wedge size. To allow this test to be created, data will need to be captured during the LPCB testing regime, which then be used to replicate and predict the testing by the form of prototype testing and analysis.

A way to measure the change in displacement is to create reference points on the doorset where the attackers are attempting to break through the doorset. To make the test accurate as more than one reference point shall be analysed along the edge of the door leaf.

Due to the physical nature of the attack tests, the times decided to pause the testing to measure the displacement must be sensible as it can't be a detriment to the attackers from getting into the product. It was decided that the times would mirror the time restrictions for the physical attack testing in terms of the tool category ratings to create a validation of the LPCB testing. Stopping at any other point during the test could also give the Company advantages as they

could potentially be stopping the attack testers at critical points where they may be gaining access into the product.

6.4.2 NEW METHODOLOGY – LPCB

By understanding the lever attack undertaken by LPCB, it was noted that the aim of the attack would be to displace the angle, insert wedges to increase the gap between the leaf and frame and consequently disengage the lock. To observe the behaviour of the angle, three reference points were created along it. At each of these points the displacement was documented throughout the test. Particularly stopping at the test intervals for each security rating e.g. 1, 3 and 5 mins etc.

By obtaining data on the deformation of the doorset, cross calculation can be completed to understand the forces required by the LPCB attackers to gain access into the doorset. This analysis can also give an idea of how the product behaves under loadings and will allow you to identify the point where the doorset begins to fail. The aim of improving the testing is to identify these points and to try and improve the products to make it harder for them to reach these points.

6.5 NEED FOR FACTORY TESTING

Currently the Company does not carry out any preliminary testing within their factory, to test the structural integrity of the product before submission for LPCB testing. Because of this there is no indication as to how structurally sound the product is and how likely it is to react when submitted to a physical attack test until LPCB attack testing is completed.

By identifying the strength of the prototype before LPCB test the product, using material analysis and engineering knowledge could potentially increase the certainty of the prototype passing an LPCB test. This is due to undergoing further testing in-house to focus on prototype testing and identifying the strength of a prototype, rather than reliance of LPCB testing.

Certain physical attack tests completed by LPCB were linked to tests in-house by understanding the boundary conditions of the product when a force or a displacement is applied and how it will react. If the forces and displacements applied can be reduced by increasing the strength of the prototype – through analysis of historic data and material properties, then a stronger product will be created. This will increase the certainty of passing an LPCB test but will also reduce the testing required by LPCB, reducing the costs of LPCB.

This in turn will increase the Company's knowledge base on the forces and displacements the products can resist as well as the behaviour of the products, leading to reduced LPCB test programmes, reducing the cost of the new product development process by up to 28%.

Analysis into the feasibility of creating methodologies includes the evaluation of the equipment available at the factory, equipment needed to test products and the health and safety assessment of all the testing. The progression in the future would be the purchasing of extra equipment and test rigs dedicated to prototype analysis.

6.6 SIMPLIFICATION OF PRODUCTS

The doorset was analysed in its simplest form to understand the boundary conditions of the doorset in its locked condition. The supports in the door structure are between

- Hinges and lock
- Hinges and door frame
- Lock and door frame

By analysing the doorset an evaluation of the supports was completed. When the lock is engaged into the door frame, it represents a pinned support as the lock is fixed translationally but is free for the lock to move rotationally if a load was to be applied to the corners of the door leaf.

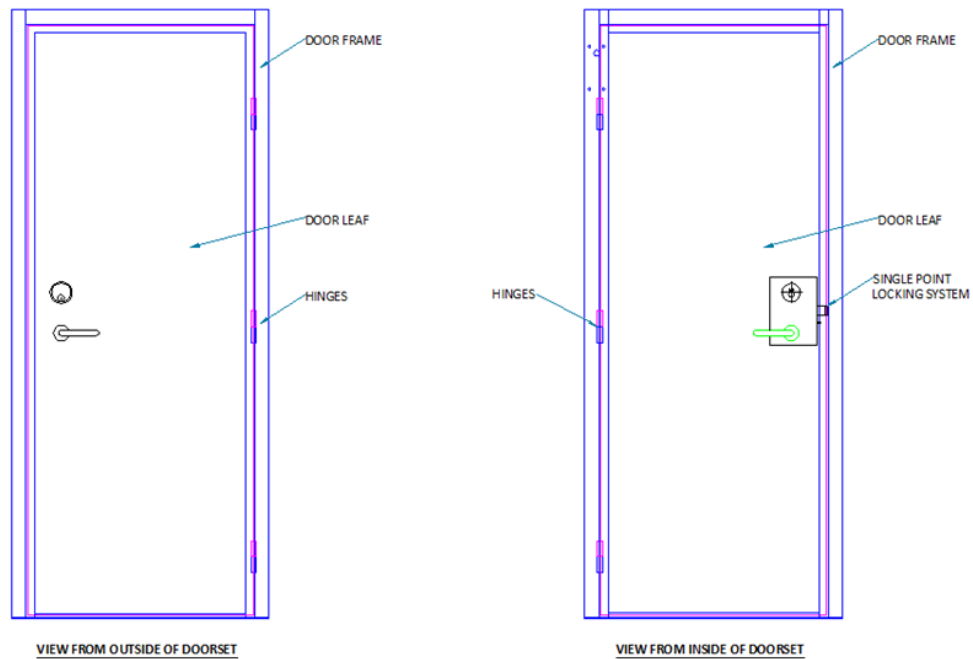


Figure 123 - Views of doorset

The hinges and the lock are the pinned supports which are connected to the door frame. This means to gain entry into the doorset, either the hinges or the lock support needs to fail.

The hinges need to be sheared to fail. For the lock support to fail either a force needs to be applied on the lock itself or displacements can be applied on the leaf of the door with the aim to create a lever big enough to overcome the lock and disengage with the frame.

Factory testing can be completed on these scenarios to understand the behaviour structurally. If the weakest point of this particular doorset is identified, modification can be completed to improve the strength of the doorset, for the Company to have a stronger doorset and a methodology to test the doorset.

6.6.1 TEST CONDITIONS

The doorset submitted to LPCB for testing was an SR4 security sentinel door. Up the leading edge of the door is an anti-jemmy angle used to increase the difficulty of levering the door open. This angle was welded to the door leaf and is fixed rotationally and translationally to the door leaf.

To ensure the repeatability of the testing, 3 reference points were created – one reference point which was 100 mm from the bottom of the door frame, one adjacent to the middle of the lock latch and one between the two points just explained.

The reference point at the same height of the lock was to analyse the displacement in the lock region. The reference point chosen at the bottom of the door leaf was chosen as the typical starting position when LPCB test the Company's doorsets via a lever attack.

The third reference point was half way between the top and bottom reference points and was chosen carefully to analyse the behaviour between the integral points.

These reference points were chosen carefully to investigate the behaviour at the points where

- The lock was engaged into the frame
- LPCB start attacking
- To see the behaviour between the two points explained above

The test was timed with a stopwatch and the displacement was measured using a Vernier calliper and a tape measure.

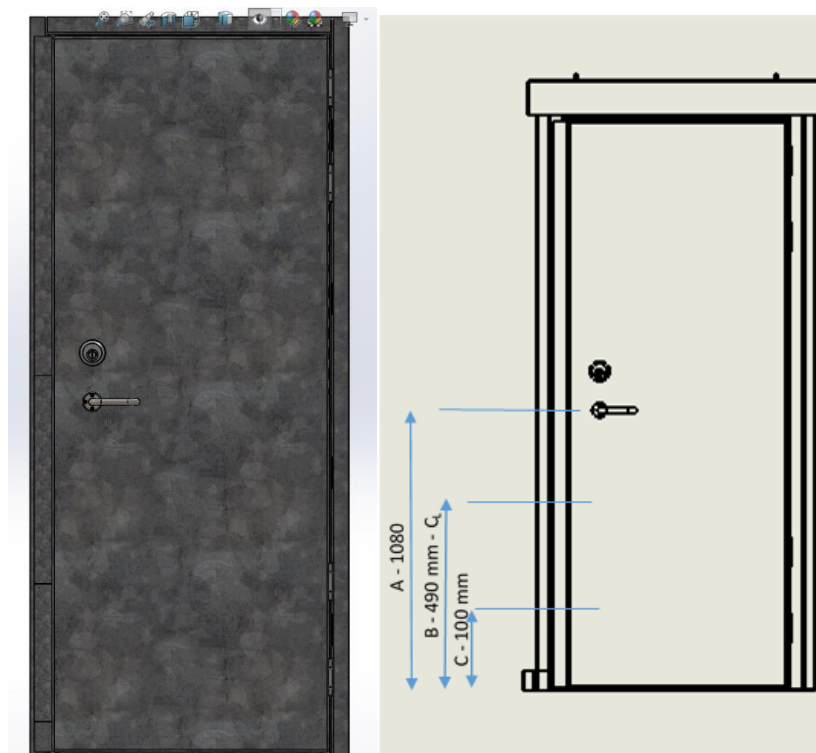


Figure 124 - Reference points on door

The doorset was simplified to understand its structural behaviour, to be mimicked in validation tests. By applying an unknown force on the edge of the door leaf, a displacement of the door leaf from the frame is measured to ascertain the behaviour of the product.

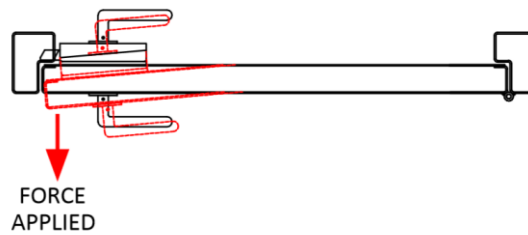


Figure 125 - Deflected shape

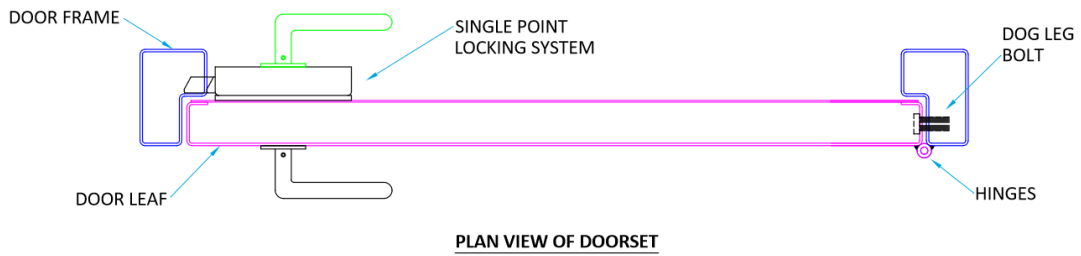


Figure 126 - Plan view of door

6.6.2 TEST RESULTS

The results of the displacement analysis of the doorset, tested by LPCB, is produced below detailing the displacements undergone at the three reference points at the times specified that correspond to the security levels of the product.

Table 19- LPCB Attack Test displacement results

ATTACKING POINTS	1 MINUTE	3 MINUTES	5 MINUTES
A	8.01 mm	9.87 mm	10.23 mm
B	12.2 mm	21.83 mm	37.05 mm
C	16.43 mm	37.54 mm	24.33 mm

From the analysis of the results, it was identified that reference point A was the least susceptible to deformation. This was expected as this is the point at which the leaf is primarily pinned to the frame by the lock latch. The further away you get from this point the lower the force required to increase the gap between leaf and frame as when analysing the side of the

door leaf that is pinned to the door frame via the lock is the only point of contact between the door leaf and the frame. Therefore, this means that the top and bottom of that side of the door leaf is free to translate and rotate.

Reference point A increases very slowly by only 10 mm. Reference point B increases by 37 mm overall and Reference point C increases by a maximum of 37 mm.

VIDEO ANALYSIS

The LPCB testing was recorded with a video camera for analysis in the future – which would enable anyone to watch the video to physically see the behaviour of the product under the physical attack tests. It would also allow the time capture of those tests which could possibly be broken down into greater detail than what the test report shows. Sometimes the test report will give a time to go through a composite to the inner skin, however, with the video analysis, it might be possible to break down that total time into further stages (when it penetrates every attack layer).

6.7 FACTORY TESTING

To allow this testing to be replicated within the factory, the doors needed to be simplified and understood to see where forces would need to be applied.

The hinges are pinned supports when the doorset is in its locked condition as they restrict translational movement but allow rotation of the leaf if the lock was to become free from its housing in the frame.

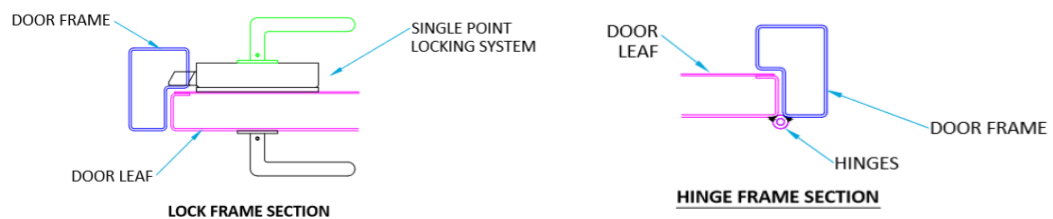


Figure 127 - Hinge and lock section of door

By identifying the supports, a prediction of the structural behaviour can be completed to understand the failure of the doorset in different conditions. The conditions that were analysed were

- Force applied on the lock – Force applied to the lock in its fully locked condition up until failure. This provided the capacity of the lock.
- Force applied on the hinges - Force applied to the hinged edge of the door in its fully locked condition.
- Force applied on the corner of the door leaf - Force applied to the corner of the door in its fully locked condition. Force applied until the displacements measured during the LPCB testing were achieved. Forces can then be matched to the displacements.
- Displacement measured on the lock – To measure the force required to displace the door leaf from the frame, as measured during the LPCB test programme. Force was applied continuously after measurements taken until failure.
- Displacement measured on the hinges – To identify if this is a weak point of the door.
- Displacement measured on the corner of the door leaf – This was to mimic the testing undertaken at LPCB to understand if it was possible to gain forces which linked to the applied displacement by LPCB

Tests were created using the same sample and boundary conditions, but the variable was testing at different positions on the sample. A real-life example of this was sought out, and the sentinel doorset manufactured by the Company was selected. This product is made up from a door frame and leaf which is hinged within it. The door frame is fixed to the structure in which it is to be used, on all 4 sides of the frame and acts as the fixed support, and the door leaf which is hinged within the frame is the pinned support. The door leaf is fixed within the frame by the locking system. This is either a single point lock, locked into just one side of the frame or a multi-point lock fixed into the side frame and the top and bottom of the frame.

6.8 APPLICATION OF FORCE

6.8.1 LOCK CAPACITY WITH CURRENT LOCK PLATE

It was highlighted that during the LPCB testing whilst the door was the subject of an attack, if the lock can be disengaged then it would allow easy access into the product. Due to this knowledge, analysis into the lock capacity of the door was undertaken. If the capacity of the lock can be obtained, the author will know when the lock will fail.

By applying a force onto the lock, a reaction force is present to keep the lock in equilibrium and therefore, keep the lock fixed translationally into the door frame. Once the load has past the linear elastic region, the lock fails, and the door opens.

It is necessary to identify this point so that the designer knows at what force they need to test loads up to, unless modifications of the doorset is completed. In this case, another lock capacity test will have to be completed to assess the lock capacity due to the modifications.

The objectives of the lock capacity testing are shown below.

- Understand the behaviour of the doorset under a controlled load
- To gain data regarding the displacement of the doorset under a controlled load
- To be able to create a repeatable methodology for testing the lock capacity of the doorset

6.8.1.1 SIMPLIFICATION OF PRODUCTS

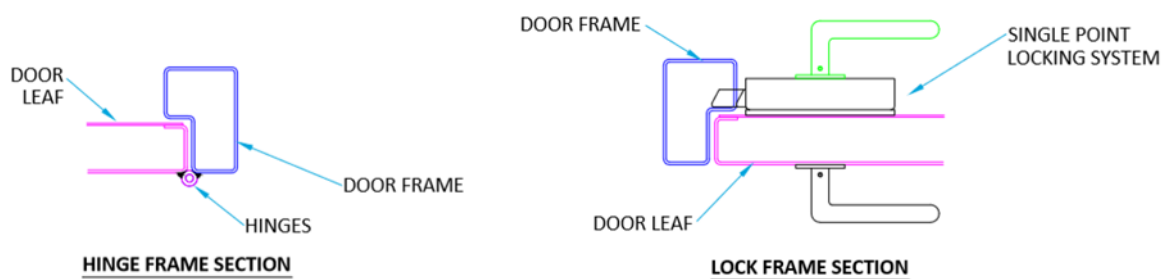


Figure 128 - Hinge and lock section of door

The lock plate shown in Figure 129 is placed in the door frame and the lock latch is engaged in the plate when the door is locked. For the LPCB attackers to gain access into the doorset, the latch will need to be disengaged out of the lock plate.

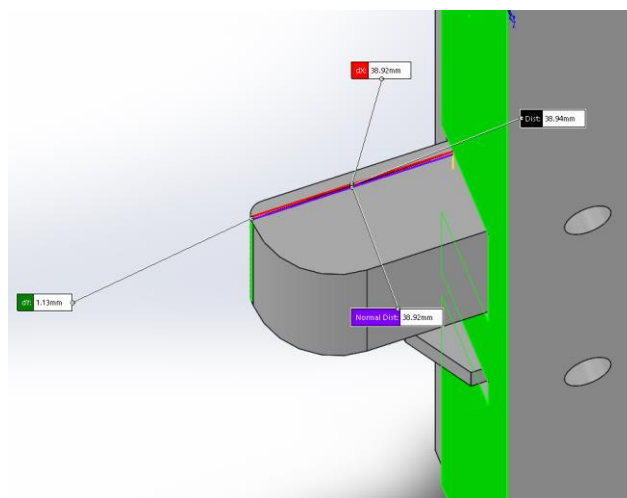


Figure 129- Lock latch

The measurement of the latch is 38.94 mm. The part of the lock plate that the latch is housed in is highlighted in pink in Figure 130.

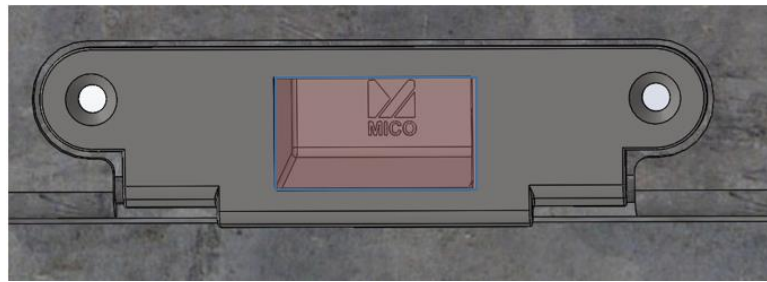


Figure 130 - Lock latch plate

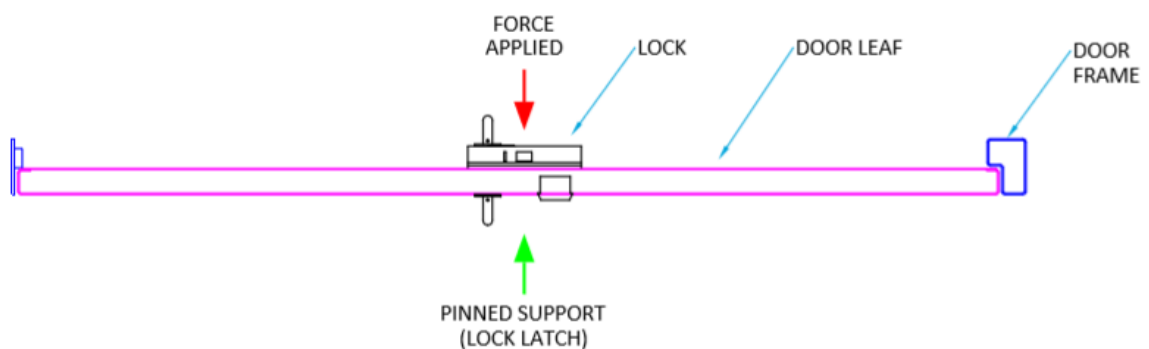


Figure 131 - Section through door

6.8.1.2 BOUNDARY CONDITIONS



Figure 132 - Simplified diagram

To be able to test the capacity of the lock, it must be fitted in a doorset and engaged – this is the same condition as it would be at LPCB prior to the testing commencing. The aim of this test would be to gain data on how the lock behaves under a constant load. Relative displacements mean that the lock becomes the weak part of the structure and is the most likely part of the doorset to fail. By knowing the load that the lock fails at, allowing the door to open

is important as it would be at this point the attack testers would gain entry in to the doorset. This also shows the author that the strength of the door leaf can be increased but ultimately, the lock will always fail at the capacity of itself.

Further work would be to create a database of data detailing each locking system used by the Company, and the maximum load applied before lock failure can be logged within the database.

Firstly, analysis into the lock itself was completed. A datasheet was analysed to see what properties were supplied by the manufacturer. Then a test procedure was composed to test the lock capacity. The door was to be set up in the test rig, with the lock positioned directly underneath the hydraulic ram. The doorset would be locked shut as this will mimic the locked condition when being attacked at LPCB. A force was then applied to the centre of the lock body by the hydraulic ram, increasing in increments of 10 kN until the locking system disengaged/ broke away from the door frame. After each increment of 10 kN the displacement was measured and recorded. The assumptions of this test were that the reading given from the equipment is accurate and the doorset was level on the test rig.

A reference point was needed to measure the displacement from. The back side of the frame was chosen, and the measurement was taken from the distance between the back side of the frame and the back of the door leaf.

6.8.1.3 EQUIPMENT NEEDED

- 1 Sample Door
- 1 Test Rig
- 4 'D' Clamps
- 2 I Beam Supports (welded to the doorset frame)
- Hydraulic Force Gauge - measured in kN, with a range between 0-2000 kN
- Vernier Callipers
- Tape Measure
- Ruler
- Marker Pen

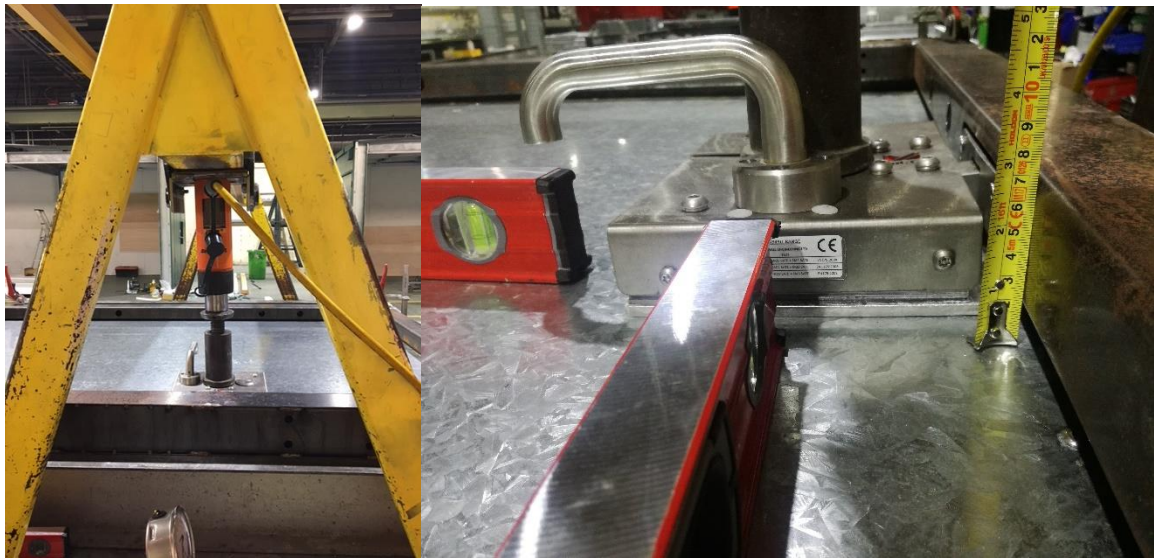


Figure 133 - Lock testing

- The door frame is clamped firmly to ensure that there is no movement of the door to guarantee valid test results and to simulate the structural behaviour of the doorset because the door leaf is fixed to the frame via the lock latch and the hinges are pinned to the door frame. A pinned support and a fixed support both resist vertical and horizontal forces and therefore there should be no movement of the door on the test rig, to be in equilibrium. An additional step for this to be maintained was welding the I beam to the bottom of the frame and clamping them to the test rig.
- Forces applied to the sample to be accurate; the hydraulic gauge is calibrated by an external body to ensure $\pm 1\%$ accuracy, which is stated in the datasheet and a certificate was given when the equipment was calibrated by a 3rd party member.

6.8.1.4 TEST PROCEDURE

1. Ensure that the two I Beams are welded to the outside/attack face of the doorset
This is part of the risk assessment to ensure the doorset sample doesn't incur resultant forces when a force is applied to it and affect the results.
2. Clamp the I beams to the test rig on each corner of the door frame to hold it into position and to stop translational and rotational movement of the door frame, to ensure that it behaves as a fixed support to mimic the behaviour in real life.
3. Measure the distance from the top face of the door frame channel to the top face of the door leaf. The reference point for this test will be the top face on the channel on the door frame as this doesn't move during the tests. Note, the measurements will be taken from the same position which will be marked on the door frame.

4. Position the hydraulic force gauge in the centre of the locking system, in-line with the latch.



Figure 134 - Lock testing

5. Measure the displacement at the reference position at every 10 kN
6. Continue until the lock is disengaged from the frame

6.8.1.5 RESULTS

Table 20 - Lock Capacity Testing Results

Force applied (kN)	Deflection value (mm)
0	0
10	3.2
20	5.1
30	10.5
40	20.4
45	30.9
48	48.4

The results were compiled into a graph to aid analysis and identify the linear regions of the experiment. This data can then be used to model the behaviour in FEA as it is demonstrated in the linear region.

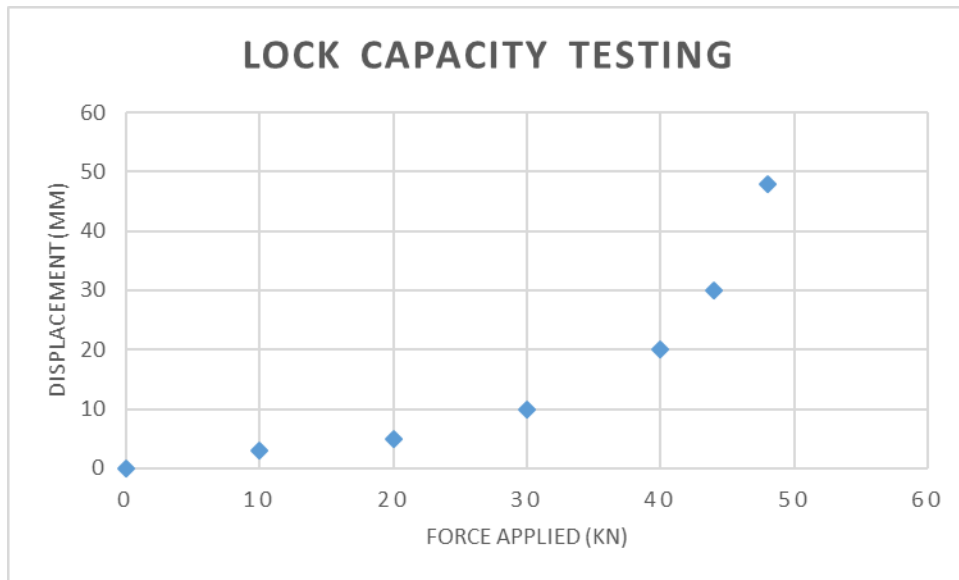


Figure 135 - Lock Capacity Testing Graph



Figure 136 - Lock testing

6.8.1.6 SUMMARY

Figure 136 depicts the displacement measured during the test procedure. The blue dots are plotted at every 10kN increment and show the displacement at this point. The graph has a linear force-displacement line up till 20 kN. After this point, the prototype has failed. After 20 kN it can be visually seen in the experiment that the lock starts to bend and deform, and the locking plate starts bending and translating out of the frame. At 30 kN the frame started to distort until it reached a point of 42 kN where the lock failed and disengaged from the doorset.

By undergoing this test, two types of crucial data were gained

1. The capacity of the lock, under a controlled compressive force, was 42 kN
2. The applied load on the lock and the stresses caused by the bending moment due to the doorset being bent, are all in the elastic region up to 20 kN

By displacing by 48 mm at the lock when the door leaf was translationally restrained to the door frame at the three hinges and the lock, would allow the locking latch to disengage and the doorset would open. Therefore, the aim would be to create a doorset that can withstand less than 15mm of displacement.

6.8.2 LOCK CAPACITY WITH NEW LOCK PLATE

The previous test was replicated with the new lock plate instead. This was to identify if the modifications changed the weak point of the doorset and if the capacity of the lock had changed. It was thought that due to the gussets being added and the system being welded together, the bending of the plate would reduce.

6.8.2.1 SIMPLIFICATION OF PRODUCTS

To visualise the simplification of the test, refer to Figure 131.

6.8.2.2 BOUNDARY CONDITIONS

To visualise the simplification of the test, refer to Figure 131Figure 132.

6.8.2.3 EQUIPMENT NEEDED

- 1 Sample Door
- 1 Test Rig
- 4 'D' Clamps
- 2 I Beam Supports (welded to the doorset and test rig)
- Hydraulic Force Gauge - measured in kN, with a range between 0-2000 kN
- Vernier Callipers
- Tape Measure
- Ruler
- Marker Pen

The door frame is clamped firmly to ensure that there is no movement of the door to guarantee valid test results and to simulate the structural behaviour of the doorset as the door leaf is fixed to the frame via the lock latch and the hinges are pinned to the door frame. A

pinned support and a fixed support both resist vertical and horizontal forces and therefore there should be no movement of the door on the test rig, and to remain in equilibrium. An additional step for this to be maintained was welding the I beam to the bottom of the frame and clamping them to the test rig.

Forces applied to the sample to be accurate; the hydraulic gauge is calibrated by an external body to ensure $\pm 1\%$ accuracy, which is stated in the datasheet and a certificate was given when the equipment was calibrated by a 3rd party member.

6.8.2.4 TEST PROCEDURE

1. Ensure that the two I Beams are welded to the outside/attack face of the doorset
This is part of the risk assessment to ensure the doorset sample doesn't incur resultant forces when a force is applied to it and affect the results.
2. Clamp the I beam's to the test rig on each corner of the door frame to hold it into position and to stop translational and rotational movement of the door frame, to ensure that it behaves as a fixed support to mimic the behaviour in real life.
3. Measure the distance from the top face of the door frame channel to the top face of the door leaf. The reference point for this test will be the top face on the channel on the door frame as this doesn't move during the tests. Note, the measurements will be taken from the same position which will be marked on the door frame.
4. Position the hydraulic force ram on the bottom corner of the door leaf, to the same side as the locking system.
5. Measure the displacement at the reference position at every 10 kN
6. Continue until the lock is disengaged from the frame

6.8.2.5 RESULTS

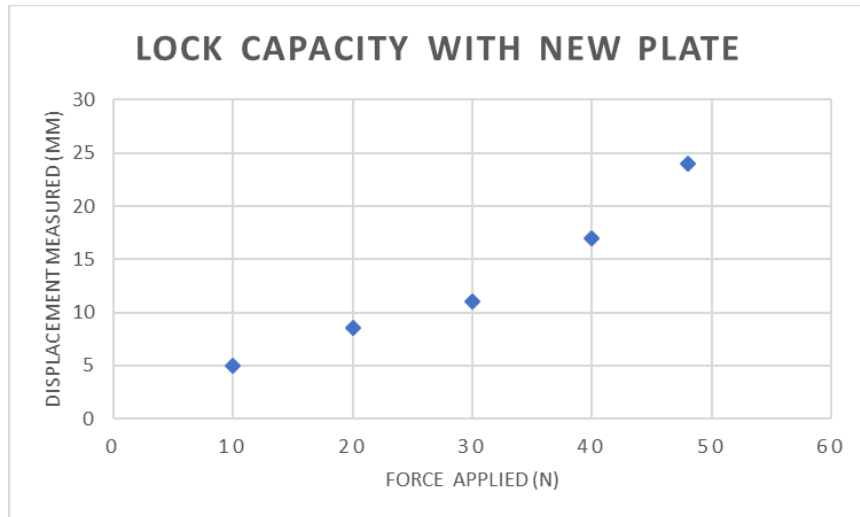


Figure 137 - New Lock Capacity Results

6.8.2.6 SUMMARY

By testing of the new lock arrangement inside the door frame, a greater force of 48 kN is now the capacity of the lock. This shows that the modifications increased the strength of the door arrangement, allowing an increase in strength of 13%.

6.8.3 BOTTOM CORNER OF DOORSET

This testing was chosen to replicate a lever test by LPCB but by using a standard controlled force and applying it in one fixed position. The aim of this test was to identify if the test would make the lock latch disengage, opening the door. The corner of the doorset was chosen, as this is where the LPCB attack testers typically start their attack lever testing.

6.8.3.1 SIMPLIFICATION OF PRODUCTS

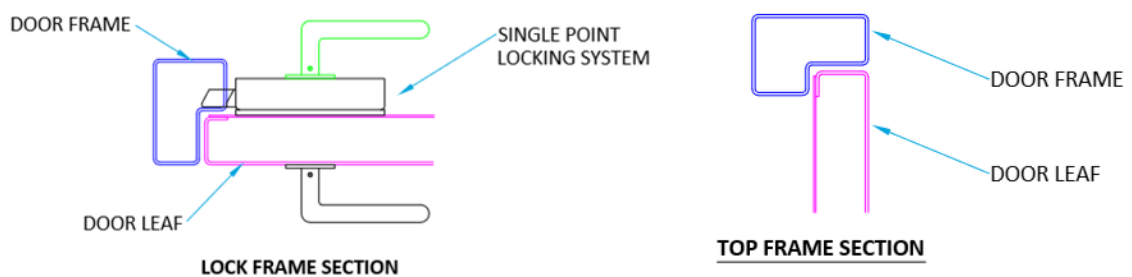


Figure 138 - Simplification of doorset

6.8.3.2 BOUNDARY CONDITIONS

Applying a force at the leading edge of the frame, will result in a deflected shape as shown in Figure 139.

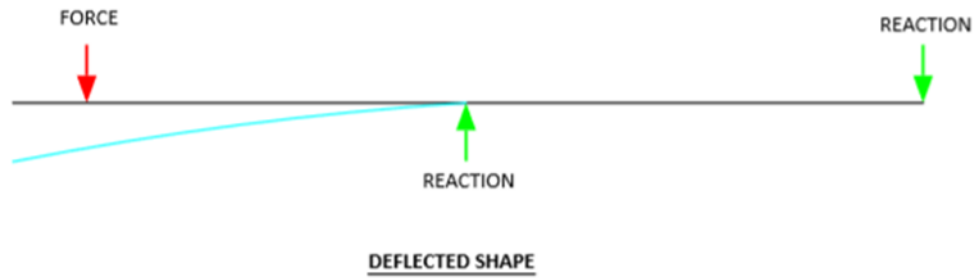


Figure 139 - Predicted deflected shape when force applied on corner

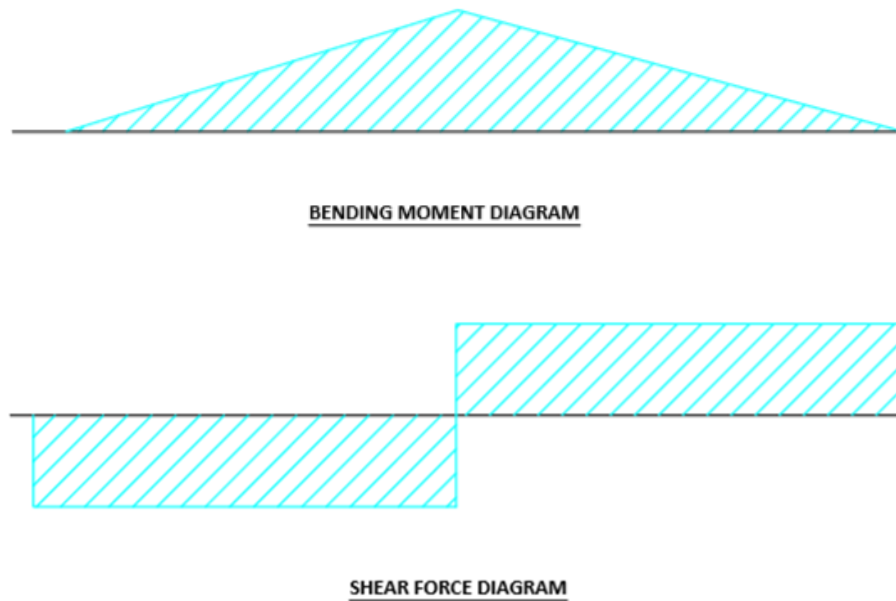


Figure 140 - Expected shear force and bending moment diagram

6.8.3.3 EQUIPMENT NEEDED

- 1 Sample Door
- 1 Test Rig
- 4 'D' Clamps
- 2 I Beam Supports (welded to the doorset and test rig)
- Hydraulic Force Gauge - measured in kN, with a range between 0-2000 kN
- Vernier Callipers
- Tape Measure
- Ruler
- Marker Pen

6.8.3.4 TEST PROCEDURE

7. Ensure that 2 I Beams are welded to the outside/attack face of the doorset
This is part of the risk assessment to ensure the doorset sample doesn't incur resultant forces when a force is applied to it and affect the results.
8. Clamp the I beams to the test rig on either corner of the doorset.
9. Measure the distance from the top face of the door frame channel to the top face of the door leaf. The reference point for this test will be the top face on the channel on the

door frame as this doesn't move in the tests. Note, the measurements will be taken from the same position which will be marked on the door frame.

10. Position the hydraulic force gauge on the right-hand corner of the door leaf.
11. Measure the displacement at the reference position at every 10kN.
12. Continue until the lock is disengaged.

6.8.3.5 RESULTS

Table 21 - Corner of Door leaf testing

Force applied (kN)	Deflection value (mm)
0	0
5	1.5
10	3.1
15	4.6
20	6.2
25	9.4
30	11.1
35	17.4
40	36.3

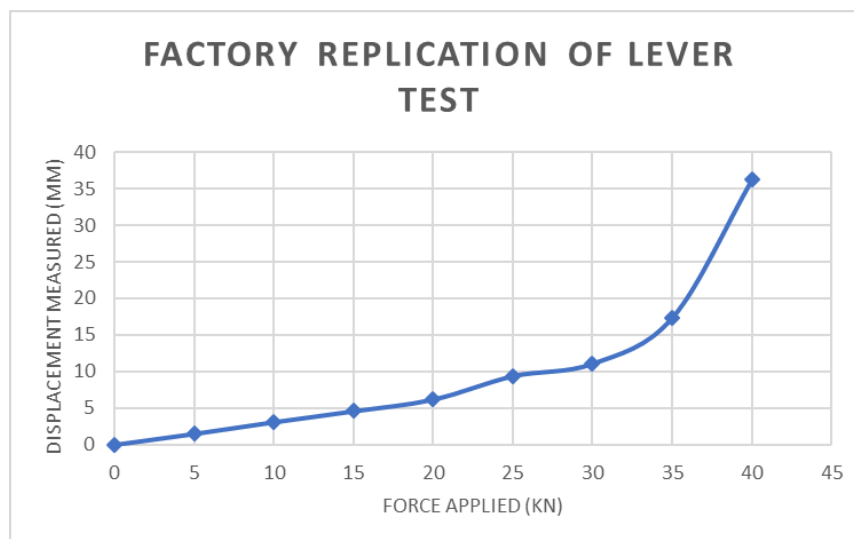


Figure 141 - Further analysis of replication of lever test in factory

After 20 kN of force is applied to the corner of the doorset, the graph represents a linear line showing that it is behaving in the elastically. As the product can be simplified to be a cantilever fixed translationally at one end, the bending moment was expected to be the highest

at the mid-point of the beam. An enlarged copy of the results was included in Figure 142 to show the linear line up till 20 kN.

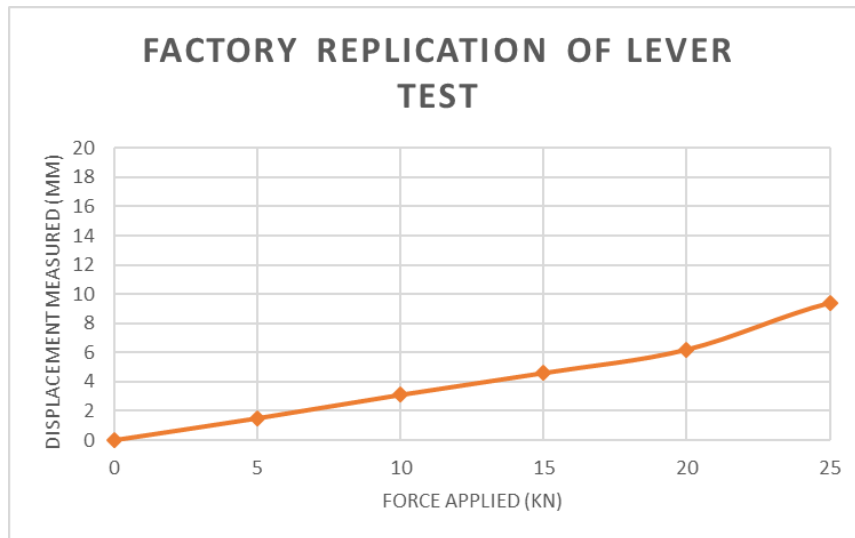


Figure 142 - Enlarged results - lever

6.8.3.6 LINEAR

This test was also completed again, to exhibit the behaviour of the doorset when the force of 20 kN is applied to the corner of the door leaf and then released. As expected, the door leaf corner returned to its original position – this reinforces that the doorset is behaving in an elastic behaviour.

Table 22 - Linear examination results

FORCE (kN)	DISPLACEMENT (mm)
0	0
10	35
15	57
20	78

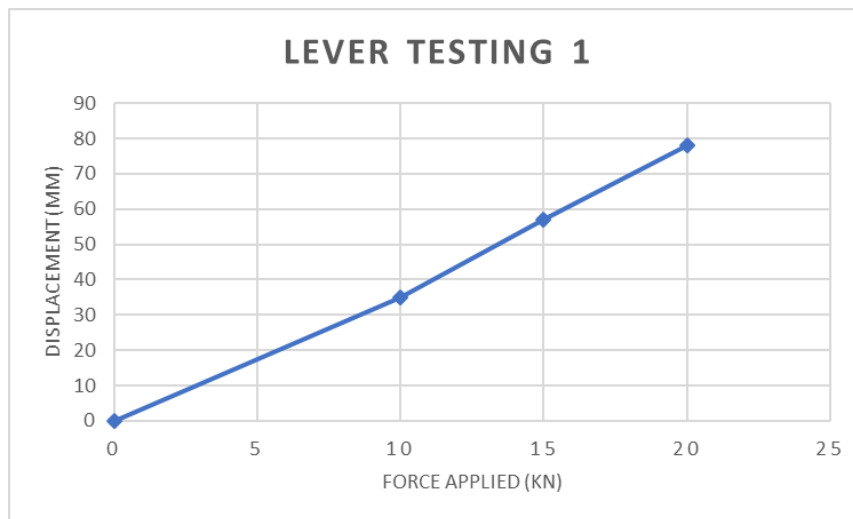


Figure 143 - Linear Examination Results

6.8.3.7 SUMMARY

Methods were found to identify the elastic behaviour observed in a doorset and by plotting the force-displacement graph, the linear regions can be seen visually. This is a great advantage as these results in the linear range can be used to complete a validation using finite element analysis.

6.8.4 HINGES

The hinges are not a common attack point but if a capacity can be developed, like with the lock, for the hinges, it can be based on the levering of the doorset to establish the structural behaviour of the system.

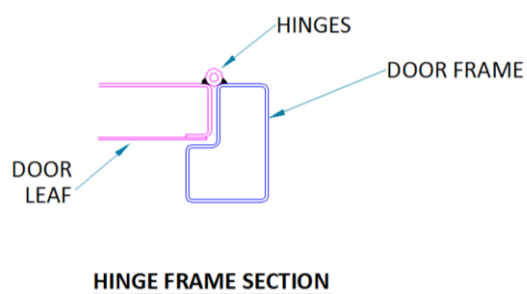


Figure 144 - Hinge system

This test was chosen to evaluate the strength of the hinge system under a controlled load and the hinges are pinned supports connecting the door leaf to the door frame. Overcoming at least 2 hinges would allow for access into the doorset.

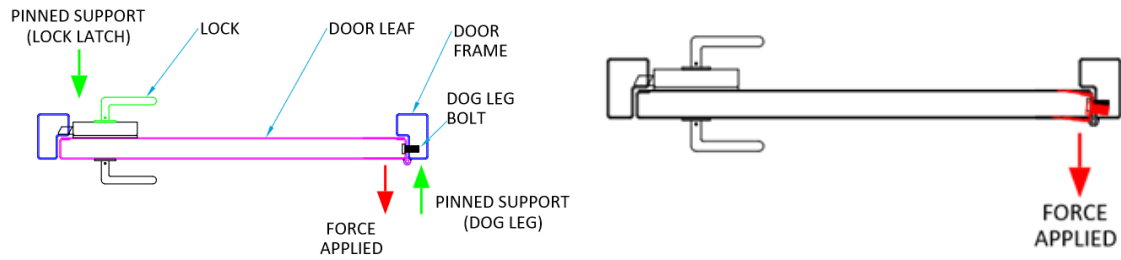


Figure 145 - Simplification of hinge system

The hinges are pinned into place along the edge of the doorset. Typically, LPCB do not choose this method when attacking a doorset but the aim was to analyse and determine if the hinges are or are not the weakest part of the doorset, to identify the strength of the main components of the doorset.

The hinges are an integral part of any doorset. The number of hinges depend on the size of the product. Three hinges are used as standard, to take the weight of the door leaf but if the door leaf increases above 1200(w) on a single or 2300(w) on a twin, a 4th hinge is added.

6.8.4.1 SIMPLIFICATION OF PRODUCTS

The objective of this test is to investigate the strength of the hinges when a compressive force is constantly applied to them, as there is a reaction force to stay in equilibrium, keeping the hinges intact. The difference in the system being tested, is that integrated within the frame in line with the hinges are a dog leg system. The dog leg system is to keep the door leaf tied into the frame in case of the hinges being cut/removed. This stops the door simply being hinged out from the lock side allowing access through the hinge side. The dog bolts extend from the hinge side of the door leaf and protrude into the frame. These would also have to be removed along with the hinges to allow access. They provide a pinned support when the door is attempted to be levered away from the frame, meaning a load great enough to shear these bolts is needed to open the door.

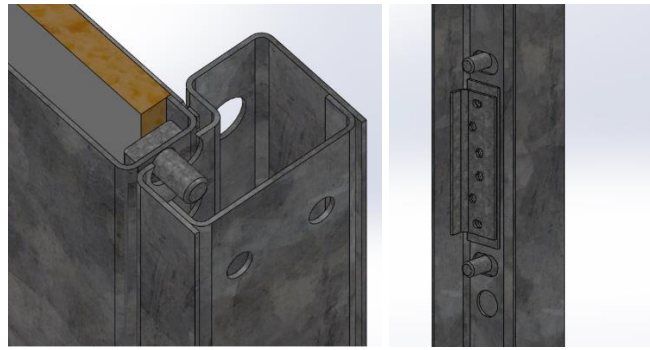


Figure 146 - Analysis of hinge system

6.8.4.2 BOUNDARY CONDITIONS

By assuming the doorset is a beam, the reaction forces and the applied force is shown. This easily shows that the test is a compressive test as the force is being applied onto the lock where there will be a reaction force present to keep the doorset in equilibrium for sensible values of force.



Figure 147- Beam representation of hinge system

6.8.4.3 EQUIPMENT NEEDED

- 1 Sample Door
- 1 Test Rig
- 4 'D' Clamps
- 2 I Beam Supports (welded to the doorset and test rig)
- Hydraulic Force Gauge - measured in kN, with a range between 0-2000 kN
- Vernier Callipers
- Tape Measure
- Ruler
- Marker Pen

The door frame is clamped firmly to ensure that there is no movement of the door to guarantee valid test results and to simulate the structural behaviour of the doorset because the door leaf is fixed to the frame via the lock latch and the hinges are pinned to the door frame.

A pinned support and a fixed support both resist vertical and horizontal forces and therefore there should be no movement of the door on the test rig, to be in equilibrium. An additional step for this to be maintained was welding the I beam to the bottom of the frame and clamping them to the test rig.

Forces applied to the sample to be accurate; the hydraulic gauge is calibrated by an external body to ensure $\pm 1\%$ accuracy, which is stated in the datasheet and a certificate was given when the equipment was calibrated by a 3rd party member.

6.8.4.4 TEST PROCEDURE

1. Ensure that the two I Beams are welded to the outside/attack face of the doorset
This is part of the risk assessment to ensure the doorset sample doesn't incur resultant forces when a force is applied to it and affect the results.
2. Clamp the I beams to the test rig on each corner of the door frame to hold it into position and to stop translational and rotational movement of the door frame, to ensure that it behaves as a fixed support to mimic the behaviour in real life.
3. Measure the distance from the top face of the door frame channel to the top face of the door leaf. The reference point for this test will be the top face on the channel on the door frame as this doesn't move during the tests. Note, the measurements will be taken from the same position which will be marked on the door frame.
4. Position the hydraulic force ram in the centre of the hinge system that has been chosen to be tested
5. Observe the behaviour of the hinge and the doorset together and measure the displacement of the doorset at the reference position at every 10kN
6. Continue until the hinge system fails

6.8.4.5 RESULTS

The results are shown in Table 23.

Table 23 - Corner of Door leaf testing

Force applied (kN)	Deflection value (mm)
0	0
5	10
10	16
15	23
20	35
25	46
30	57
35	68
40	75

6.8.4.6 SUMMARY

It was established that after assessment of the hinge system, the lock system is the weakest part of the doorset. This is useful data to know for the Company and an assessment into how to improve the strength of the doorset can take place. The structural failure and the mechanisms are easier to establish with the simplification of the products as beams.

6.9 APPLICATION OF DISPLACEMENT

6.9.1 BOTTOM CORNER OF DOORSET

Typically, in the LPCB testing, forces are applied by the attackers on the corner of the doorset by levering. To be able to understand the behaviour of the doorset analysis into replicating the values found in the LPCB testing took place.

The objective of this test would be to replicate the deformation caused by the LPCB testing to translate the relevant force applied to it. In this instance, the variable would be the force applied to the doorset.

6.9.1.1 SIMPLIFICATION OF PRODUCTS

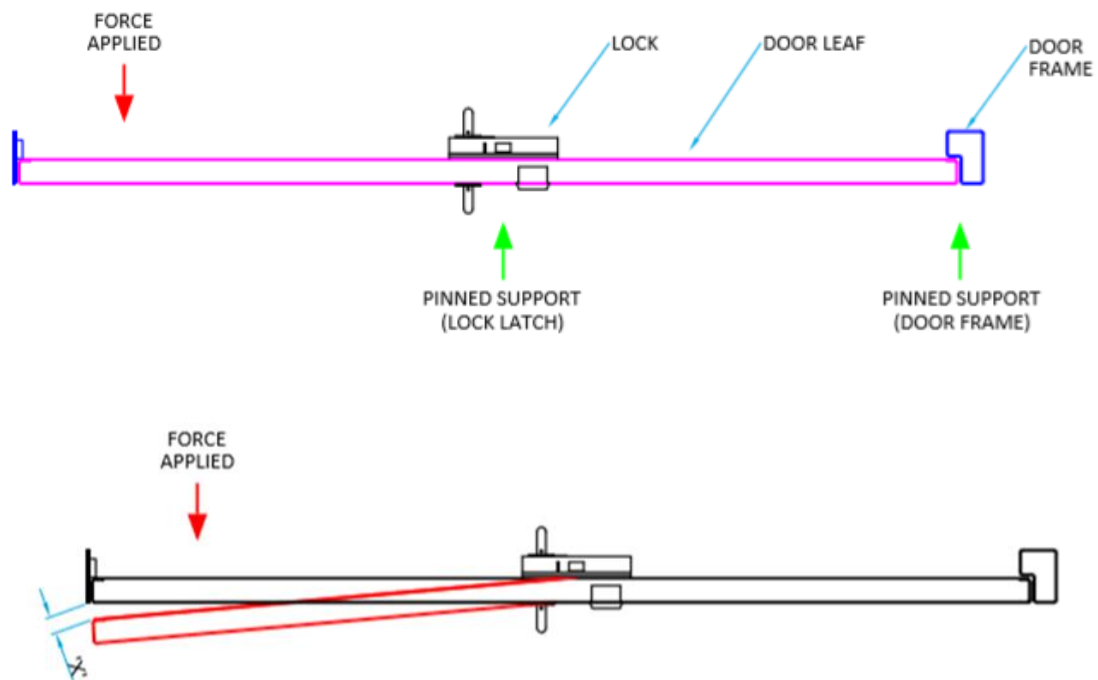


Figure 148 - Analysis of doorset

6.9.1.2 BOUNDARY CONDITIONS

The boundary conditions of the LPCB attack tests were the same as present in this test – the lock and hinges are all pinned supports that connect the door leaf and the door frame, which is shown in Figure 148.

The application of forces at the leading edge of the frame will cause a deflected shape as shown in Figure 139. The displacement shown will be measured until the figures reached during LPCB testing are met, they can then be matched to the force applied at that time. The expected shear force and bending moment diagram are visualised in Figure 140.

6.9.1.3 EQUIPMENT NEEDED

- 1 Sample Door
- 1 Test Rig
- 4 'D' Clamps
- 2 I Beam Supports (welded to the doorset and test rig)
- Hydraulic Force Gauge - measured in kN, with a range between 0-2000 kN

- Vernier Callipers
- Tape Measure
- Ruler
- Marker Pen

The door frame is clamped firmly to ensure that there is no movement of the door to guarantee valid test results and to simulate the structural behaviour of the doorset because the door leaf is fixed to the frame via the lock latch and the hinges are pinned to the door frame. A pinned support and a fixed support both resist vertical and horizontal forces and therefore there should be no movement of the door on the test rig, to be in equilibrium. An additional step for this to be maintained was welding the I beam to the bottom of the frame and clamping them to the test rig.

Forces applied to the sample to be accurate; the hydraulic gauge is calibrated by an external body to ensure $\pm 1\%$ accuracy, which is stated in the datasheet and a certificate was given when the equipment was calibrated by a 3rd party member.

6.9.1.4 TEST PROCEDURE

1. Ensure that the two I Beams are welded to the outside/attack face of the doorset
This is part of the risk assessment to ensure the doorset sample doesn't incur resultant forces when a force is applied to it and affect the results.
2. Clamp the I beam's to the test rig on each corner of the door frame to hold it into position and to stop translational and rotational movement of the door frame, to ensure that it behaves as a fixed support to mimic the behaviour in real life.
3. Measure the distance from the top face of the door frame channel to the top face of the door leaf. The reference point for this test will be the top face on the channel on the door frame as this doesn't move during the tests. Note, the measurements will be taken from the same position which will be marked on the door frame.
4. Position the hydraulic force ram in line with each of the dimensions noted during the LPCB test regime.
5. Measure the displacement of the doorset at the reference position until the displacement matches the corresponding figure in the stages below.
6. Detail the force applied to reach the displacement above
7. Continue until locking system fails.

6.9.1.5 RESULTS

To view the displacement results taken from the LPCB testing, refer to Table 19. The results were used to replicate the displacements in the factory testing and to define the loads needed to replicate the displacements defined in the LPCB testing.

Table 24 - Equivalent force results for displacements measured at LPCB

ATTACKING POINTS	FORCE REQUIRED AT 1 MINUTE (kN)	FORCE REQUIRED AT 3 MINUTES (kN)	FORCE REQUIRED AT 5 MINUTES (kN)
A	4	4.5	4.6
B	8	10	14.2
C	34	42	40

6.9.1.6 SUMMARY

The displacement testing in the factory was a valuable exercise as it allowed values for the force applied to be matched to the displacement measured during the LPCB testing that was witnessed. This provides the company with values of force they can use to test future products within the factory, with the aim of improving the stiffness of the doorset and reducing the displacement to prevent the levering of the door.

6.10 SUMMARY OF UNDERSTANDING STRUCTURAL BEHAVIOUR

Analysis of the products were completed to understand the structural behaviour of the product - this is by understanding whether a force or a displacement is applied and how the typical behaviour will be under the load. The bending moment diagram is an analytical tool to perform structural design by which to determine the shear force and the bending moment at a given point on the beam, as well as the maximum bending moment and where it occurs. It also shows if the beam is in tension or compression. This was all validated by evaluation of the doorset, applying the same boundary conditions in the factory on a doorset.

Finite element analysis was used with the aim to reduce the bending that occurred in the lock plate. This was by modification of gussets which were placed behind the lock plate in the frame. Further analysis of this is completed in Chapter 8. Analysis shows that the bending moment is reduced in the lock plate due to the addition of the gussets. This methodology of

using a simplification of a product can be used to fully understand the boundary conditions of the product and analysing the performance of the structural design. This can also be used to be validated by means of finite element analysis and the testing completed in the factory to replicate the real-life conditions. By prototype testing in the factory, the prototyping cost is significantly lower than testing at LPCB. The analysing of the performance of structural design is a very quick method used to assess the boundary conditions of the test being completed and gives the designer an idea of the typical behaviours that will be exhibited either in the testing completed in the factory or via finite element analysis. The main benefit of this tool is the efficiency of analysing the prototypes structural design as it takes a matter of minutes to complete, with no costs associated with completing this tool.

By analysing the LPCB attack testing methodology, a controlled recreation was devised to identify the lock capacity when the doorset was in its fully locked state. A risk assessment was completed, and preliminary testing conducted. These tests produced valuable data regarding the force and displacements registered during sections of the testing process. This was new data that hadn't been previously captured. LPCB do not measure the force being applied during the testing process, only the time taken to get to the breaking point.

The testing visually mapped out the design recommendations and highlighted the points of weakness and bending, in turn identifying components within the assembly that needed to be reinforced. By value engineering the products, they can be re-designed to be lighter, stronger and easier to manufacture. By using less material, the wastage and CO2 consumption to manufacture the product will be significantly reduced. The overall product testing cost has been significantly reduced as the cost to produce prototypes for testing is £3016 compared to the £7500 needed for LPCB tests as part of the testing regime. By implementing the in-house testing regime, a reduction in LPCB testing time has been achieved, with an associated reduction in overall product development cost.

Potentially, a way to validate the testing that had taken place at the factory and possibly the testing at LPCB was to use a 3D modelling package that includes a simulation software. The software needed will be able to recreate linear static analysis to validate the material and factory testing.

DOOR MAP

To able to understand the locking systems further, a map was created for the general locking systems used at the Company and the points at which the test loads were applied in the factory. These points can be linked to the analysis of the performance of the structural design of the product.

- Single point locking
- Multi point locking



Figure 149- Single point locking

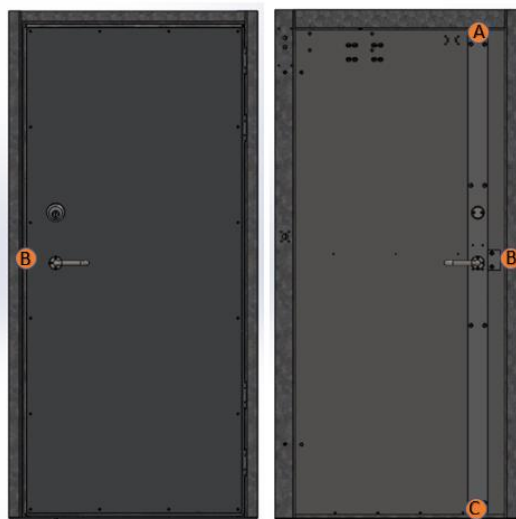


Figure 150 - Multi point locking

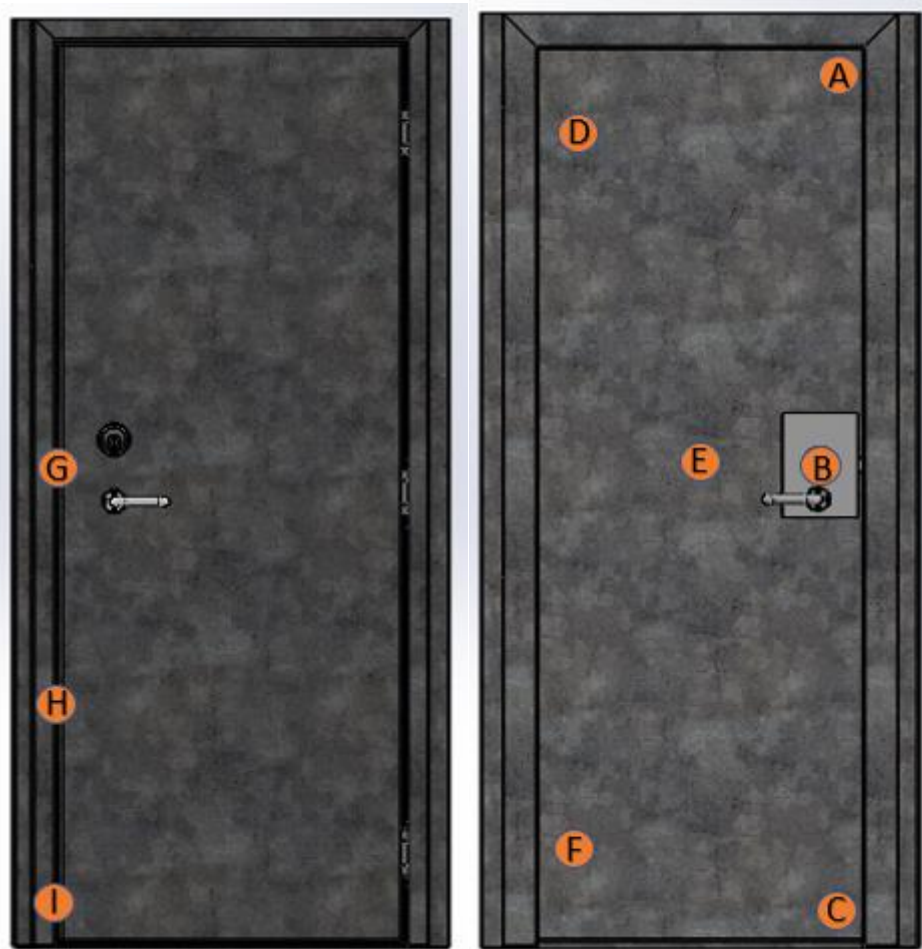


Figure 151 - Door Map

The door map details the points on the door at which the load is to be applied during the simulation stage, to replicate the attack tests carried out on the door.

The first image details the outside 'attack' face of the doorset. The main points shown here are the points at which the attack testers try to lever open the doorset, and where measurements were taken during the test. This allows for the simulation to be verified and compared to the actual testing.

The second image details the inner face of the security doorset. The points marked on this doorset are as follows:

A – Top corner, locking side of door

B – Centre of the single point locking system

C – Bottom corner, locking side of door

D – Top corner, hinge side of door

E – Centre of the leaf in-line with the locking system

F – Bottom corner, hinge side of door

SINGLE POINT LOCKING

For the lower security doorsets, they are typically secured by a single point system. This secures the leaf with a single bolt from the centre of the lock, into a latch within the upright of the frame. How far the lock bolt penetrates the frame is dependent on the lock manufacturer and model. The lock map details the point at which this is on the outside and inside of the doorset.

For the higher security doorsets, they are typically secured by a multi-point system. This higher security system secures the door leaf to the frame with the central bolt as per the single point but with the addition of two extra points to the top and bottom of the leaf. One into the top section of frame and one through the base of the frame. Again, with the single point system, the depth of penetration into the frame depends on the manufacturer and model. Another factor which also must be considered is how far away from the end of the leaf the extra two bolts lock into the door frame.

CHAPTER 7

7 SOFTWARE AND VALIDATION

7.1 INTRODUCTION

After creating tools and tests that can be used to test the structural integrity of products/parts/prototypes, it was understood that to reduce the number of prototypes that are made in the factory, finite element analysis can be used as part of the design process.

The Finite Element Method (FEM) is a mathematical technique that simulates physical behaviour by means of a numerical process (Jolley, Grandin Jr. , & Rencis, 2007).

This method has been used for the past 30 years in industry and is typical standard engineering tool for both analysis and design. Analysis of engineering has faced challenged of modelling complex real problems by replacing real problems with designed and simpler problems which obey same fundamental principles (Jolley, Grandin Jr. , & Rencis, 2007).

Currently, FEM is widely used formulating simplified or idealised problems in the fields of solid, fluid mechanics and heat transfer. By experiencing the method, real complex systems can be modelled with reasonable reliability if the fundamentals of the technique is understood but it is important to highlight that the method is reliant on the skill of the engineer in the application of the method (Jolley, Grandin Jr. , & Rencis, 2007). Modern FEM has become sophisticated by introducing graphical pre and post processes which has become easy to use and therefore, it is even more important to ensure that the best method of modelling is used with the correct tools.

Finite Element Analysis (FEA) is said by (Kurowski, 2017) to have been widely implemented by the automotive industry as a tool for design engineers to improve their productivity to and reduce their development time and development cost. Jolley, Grandin Jr. , & Rencis (2007) says that to be more competitive, companies have also moved FEA from the later stages of the design cycle into the early design stage.

7.2 MIMIC ON SOFTWARE

Finite element analysis is a mathematical approximation technique for solving complex real-world problems. The accuracy of the results depends on the size of the small sub divisions which are referred to as elements. These elements are not infinitely small – hence why this is called finite element analysis.

Solidworks simulation is a design analysis tool based on a numerical technique called Finite Element Analysis (Dassault Systems, 2016). They go on to say that FEA isn't the only tool available for numerical analysis – others include the Finite Difference Method, Boundary Element Method and Finite Volumes Method. However, due to its high numerical efficiency and versatility, it has come to dominate the software market for engineering analysis.

Solidworks – in stress, FEA software solves for displacement based on applied external forces by calculating the stiffness of all the elements taken together.

Jolley, Grandin Jr. , & Rencis (2007) explain that there are two objectives when addressing the technology. The researcher needs a thorough understanding of FEM theory in order to develop new or extending methodologies to integrate finite element software. The user needs to understand the proper use of FEM for the solution of complex problems – which will require fundamental understanding of theory.

FEA is used to solve problems ranging from very simple to complex. Design engineers use FEA during the product development process to analyse the design-in-progress and due to time restraints and limited availability of product data call for numerous simplifications of the model being analysed (Dassault Systems, 2016).

We need instead to change workflows to build on these design and modeling skills and deploy them in the analysis preparation and development stage. All too often, the FEA process is appended at the end of the design task. This just emulates the traditional role of the analysts—to check the design after completion.

Jolley, Grandin Jr. , & Rencis (2007) proposed eight objectives for the FEM course

1. Understand the fundamental of strength of materials theory
2. Understand the basis of finite element theory
3. Recognise the physical behaviour and usage of each type of element commonly used in practise

4. To select a suitable finite element model for a given engineering problem
5. Interpret and evaluate finite element solutions, highlighting the importance of verification
6. Be aware of the assumptions and limitations of FEM
7. Understand how FEM is used and applied in a design process
8. Solve finite element problems by hand and be able to compare the solutions obtained through traditional engineering theory of the strength of materials

7.3 SOLIDWORKS CAPABILITIES

To reduce errors, a simplification of the model was undertaken. This would aid the simulation solver and aim to speed up the simulation. The most effective way to do this was by using the feature 'Delete face/ body'. This was completed on holes or bodies that had no structural effects/aids to the model/part.

DEFEATURING

This feature suppresses or removes geometry which is deemed insignificant for analysis such as external fillets, round or logos etc (Dassault Systems, 2016).

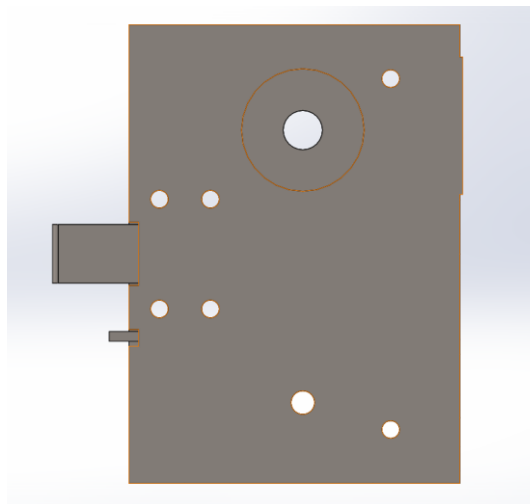


Figure 152 - Solidworks Model of Lock

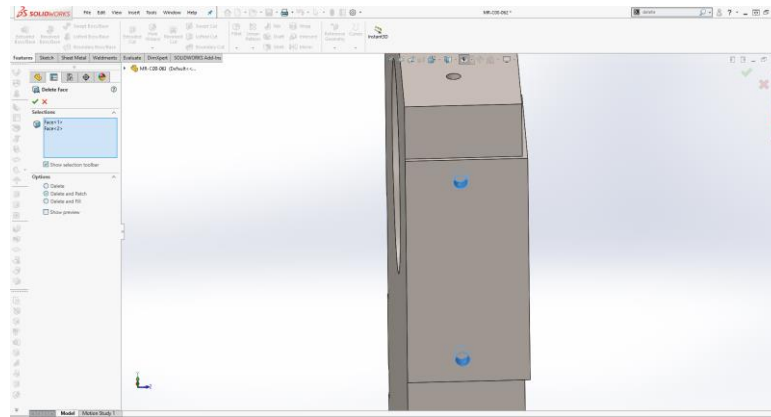


Figure 153 - Simplification of model

The method of FEA relies on a set of discrete finite elements to represent the structure and this representation has two fundamental weaknesses – it cannot be a continuous representation and it is reliant on the accuracy of the element (Abbey, *The Art of Idealization in Finite Element Analysis*, 2013).

MIXED PARTS

Thick structures are ideally considered to be solid elements and thin structures are preferred to be shell elements. When putting solid and shell elements adjacent to each other, due to shell elements having six degrees of freedom and solid elements having three degrees of freedom at each node. Connecting the element types for common nodes means that a piano hinge is created – as this connecting solid cannot transmit bending or torsion (Abbey, *The Art of Idealization in Finite Element Analysis*, 2013).

7.4 UNDERSTANDING THE SOFTWARE

Regardless of the complexity of the project or the field of the application, the fundamental steps in any FEA project are always the same (Dassault Systems, 2016).

- Geometric model
- Assign material properties
- Define loads
- Apply restraints
- Discretisation process
- Pre-processing
- Solution

- Post processing

It is noted that this can be broken down and simplified further into 4 main steps (Dassault Systems, 2016).

1. Building the mathematical model
2. Building the finite element model
3. Solving the finite element model
4. Analysing the results

The author followed the methodology set out by Dassault Systems (2016).

7.4.1 ELASTIC ANALYSIS

As it was chosen to investigate the structural integrity of models in the elastic analysis, data was used from previous tests to validate the factory and laboratory testing. The aim was to understand if it was possible to undertake testing in the software.

IDEALISATION

The aim of this step is to create a mathematical model.

1. Create geometric model
2. Clean up and simplify model in readiness for discretisation
3. Type of analysis, material properties, fixtures and loads

DISCRETISATION (PRE-PROCESSING)


The aim of this step is to create the finite element model

1. Apply mesh controls (optional)
2. Split the mathematical model into a mesh of a finite number of elements
3. Loads and fixtures are discretised to the nodes of each element

7.4.2 APPLYING RESTRAINTS

To apply a restraint in the study, follow the procedure below:

1. Right click fixtures
2. Click on restraints
3. Click simulation → loads/fixtures → fixtures

4. Set type to one of the following
 - a. Fixed geometry
 - b. Immovable (no translation)
 - c. Roller/slider
 - d. Fixed hinge
 - e. Advanced
 - i. Symmetry
 - ii. Cyclic symmetry
 - iii. Use reference geometry
 - iv. On flat faces
 - v. On cylindrical faces
 - vi. On spherical faces
5. Select the model entities to which the restraint is applied
6. If advanced geometry is selected, select a valid entity for direction
7. In the property manager click 

7.4.3 BUILDING THE MATHEMATICAL MODEL

This focuses on the geometry of the model as it must be able to be meshed into a correct and reasonable small (referring to the number of elements in the mesh) finite element mesh. Sometimes, to obtain a correct mesh, modifications in the form of defeaturing, idealisation or clean up can be used (Dassault Systems, 2016).

7.4.3.1 CREATION OF MATERIAL CURVE

The main objective was to create a library of material properties in Solidworks which represent the physical 'real life' test results undergone in the laboratory. This would then increase the accuracy of the simulation results as the material properties mirror the same values as seen in the laboratory testing.

- If the material type is plastic, check that the first point in the table is (0.0, 0.0)
- Check that the second point in the table corresponds to the initial yield point
- Check that the slope of the line joining the origin to the yield point equals the Young's modulus (E) specified on the MATi Bulk Data Entry (If the material type is NLELAST (nonlinear elastic))
- If the table is defined in the first quadrant only, check that the first point is (0.0, 0.0)

- If the table is defined in the first and third quadrants, check that one of the points is (0.0, 0.0)

MATERIAL CURVE LIBRARY

A library was created in a custom Solidworks library which was created by using the average data from the laboratory testing.

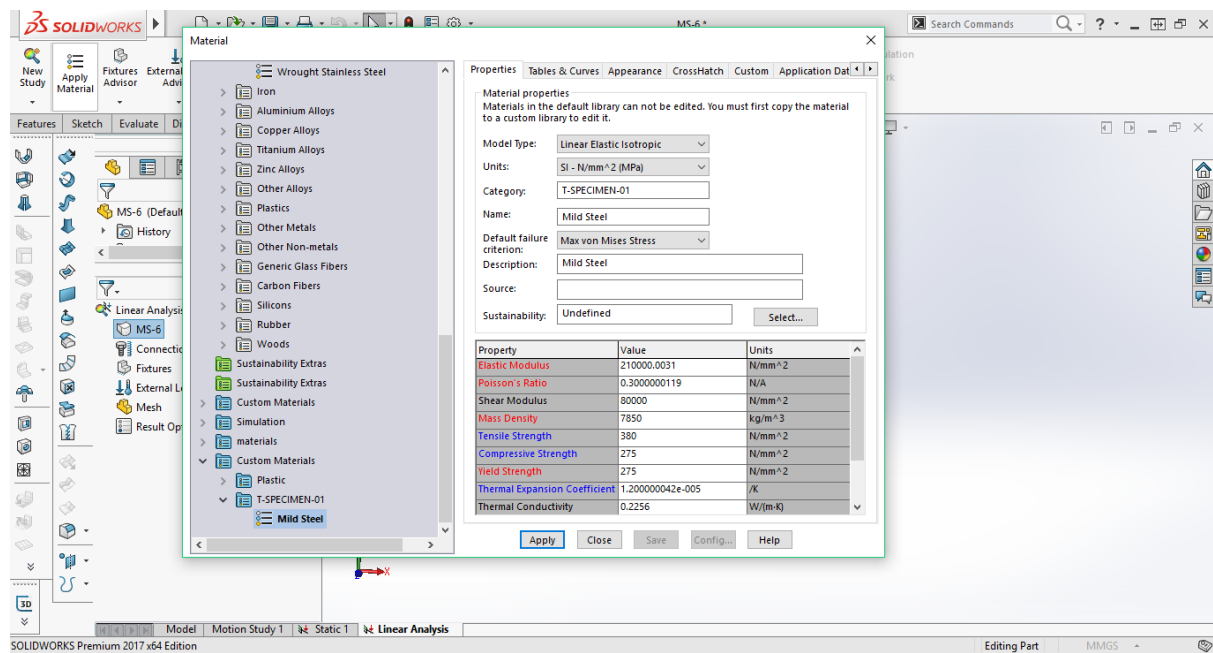


Figure 154 - Material Curve

IDEALISATION

Idealisation in FEA is the reduction of a structure down to an assembly of finite elements (Abbey, The Art of Idealization in Finite Element Analysis, 2013). The operation would consist of a single geometric model and be fully meshed in one operation, giving a consistent mesh throughout which in turn will adequately represent the response of the real structure.

This is questioning how the structure will respond and the geometry will support elements that simulate the response the best.

7.4.4 BUILDING THE FINITE ELEMENT MODEL

RESTRAINTS

- Roller/slider – a planar face can move freely into its plane but can't move in the direction normal to its plane; the face can shrink or expand under loading.

- Fixed hinge – this specifies that a cylindrical face can only rotate about its own axis. The radius and the length of the cylindrical face remain constant under loading
- Pinned support – can rotate freely but is fixed translationally

7.4.5 SOLVING THE FINITE ELEMENT MODEL

1. Make sure the simulation add on is selected on Solidworks
2. Go to new study and click static
3. Assign the material properties
4. Apply the fixed geometry

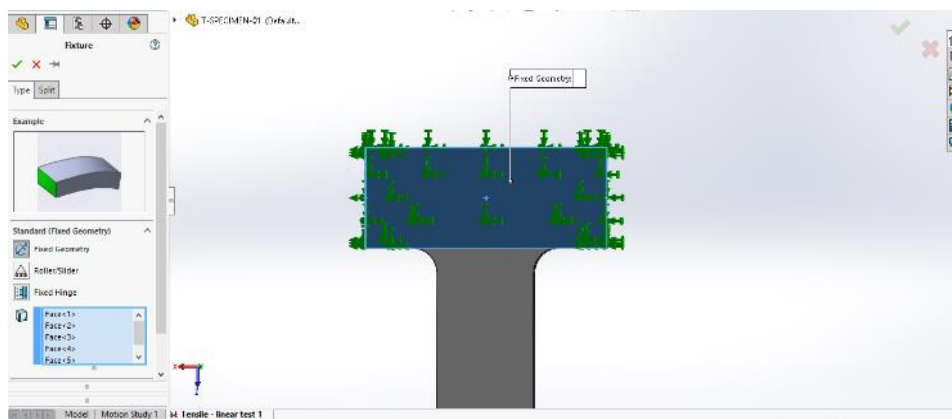


Figure 155 - Applying fixture

5. Apply the force on the bottom face of the sample with a reversed direction
6. Identify the global contact set needed
7. Mesh – curvature based, default settings

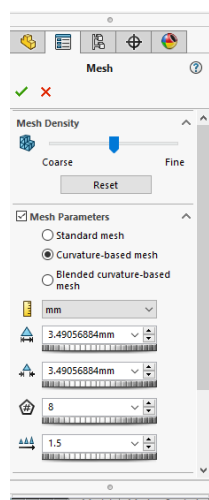


Figure 156 - Mesh analysis

8. Check mesh – at least 2 elements through every thickness of the part

9. Re-mesh if needed (apply mesh control)

10. Run

Continuous emphasis is placed on the fact that the answer will converge only to the computer's representation of the problem, even if the model is not valid (Jolley, Grandin Jr. , & Rencis, 2007). It is said that the stress will never converge due to the theory of elasticity stating that an infinite stress arises at the re-entrant of a corner. This is a point to consider for the author.

7.4.6 RESULTS SUMMARY

By obtaining a plot of the stress, strain and the displacements measured in the analysis, there was a focus on relating the properties of material to the results shown. The yield stress was used as a value to identify if a part is failing etc. The aim would be to create a product that is below the yield stress, so it is in the elastic range of its material behaviour and will behave elastically. A factor of safety plot was useful as if there were any parts where the plot was >1 , then a redesign is required as the loading and geometry chosen will cause the part to fail.

7.5 SOLIDWORKS VALIDATION

It was decided that a validation was needed on the factory testing, LPCB testing and the laboratory testing. This was to check if the software can identify the point of elastic limit for the test specimens. If this is the case, products can be prototyped on the software initially and reiterated before factory testing is completed on the final prototype. The objective of the analysis of the software is to determine if the software can predict the behaviour of materials as linear characteristics. A validation of the laboratory material testing was needed to be tested on Solidworks first as the samples are the simplest and easiest to replicate using the software.

7.5.1.1 TENSILE TESTS

This test involves a sample being pulled until breakage. The machinery used during the laboratory testing created a graph with the data collected to show a graphical visualisation of the tests. Each sample was mimicked in Solidworks and a comparison table was created showing the stress, strain, displacement and Young's modulus of each sample.

The test procedure for this test on Solidworks is explained in detail.

TEST PROCEDURE

1. Create a 3D sample in Solidworks, with the same dimensional size and shape
2. Create 2 split faces on the cross-sectional area of the sample that is being tested
3. Open the simulation software package
4. Create a new static study
5. Navigate to the simulation properties and tick the automatic solver option
6. Check that all parts in the model are assigned a material – the Part icon should be ticked once this is completed
7. Identify the types of parts that will be used in the model (Beam, shell or solid)
8. Click on connections and then contact sets. Ensure that every contact that is touching is individually has their own contact set – this is a requirement for mixed mesh parts
9. Identify the boundary conditions for the model and where the fixed supports or pinned supports are. For a tensile test, the bottom face of the sample is fixed to the machine. The top of the sample is pinned to the machine and this side of the sample is extended upwards.
10. Add a pinned support to the top of the sample – this is when the conditions highlighted are chosen; see below
11. Add a fixed support to the bottom of the sample – this is when the conditions highlighted are chosen; see below
12. Apply the external load to the sample, specifying the directions of the load
13. Click mesh and choose a curvature-based mesh. Ensure that the minimum thickness of one element is the same as the minimum thickness of your model – to ensure an accurate mesh
14. Click Run
15. Once the simulation has run, it will produce 3 plots as standard – stress plot, strain plot and displacement plot
16. Make sure that all the plots are in their true scale under the definition properties and under deformed shape. Also set the legend to floating under position/format under the chart option tab.

7.5.1.2 BENDING TESTS

This test involves a force being applied to the middle of a sample whilst the ends of the sample are supported on a roller on either side. The machinery in the laboratory testing produced a graph with the data collected to show a graphical visualisation of the tests. Each

sample was mimicked in Solidworks and a comparison table was created showing the stress, strain, displacement and Young's modulus of each sample.

The test procedure for this test on Solidworks is explained in detail below.

TEST PROCEDURE

1. Create a 3D sample in Solidworks, with the same dimensional size and shape.
2. Create two split faces on the cross-sectional area of the sample that is being tested.
This is the area between the two rollers and split in the middle of the sample.
3. Open the simulation software package
4. Create a new static study
5. Go the simulation properties and tick the automatic solver option
6. Check that all parts in the model are assigned a material – the Part icon should be ticked once this is completed
7. Identify the types of parts that will be used in the model (Beam, shell or solid)
8. Click on connections and then contact sets. Ensure that every contact that is touching is individually has their own contact set – this is a requirement for mixed mesh parts
9. Identify the boundary conditions for the model and where the fixed supports or pinned supports are. For a tensile test, the bottom face of the sample is fixed to the machine. The top of the sample is pinned to the machine and this side of the sample is extended upwards.
10. Add a pinned support to the top of the sample – this is when the conditions highlighted are chosen; see below
11. Add a pinned support to the bottom of the sample – this is when the conditions highlighted are chosen; see below
12. Apply the external load to the sample, specifying the directions of the load in the middle of the sample
13. Click mesh and choose a curvature-based mesh. Ensure that the minimum thickness of one element is the same as the minimum thickness of your model – to ensure an accurate mesh
14. Click Run
15. Once the simulation has run, it will produce 3 plots as standard – stress plot, strain plot and displacement plot

16. Make sure that all the plots are in their true scale under the definition properties and under deformed shape. Also set the legend to floating under position/format under the chart option tab.

7.5.2 FACTORY TESTING VALIDATION

A validation was required to ensure the testing method was accurate and repeatable. In the factory testing, it was understood that the limit of elastic behaviour was identified for the doorsets being tested. By knowing this limit, the Solidworks simulation can test below these conditions and aim to stop the displacement by strengthening key areas of the doorset.

SIMULATION – LOCK AND FRAME

The model was created and before any simulation testing was completed, a simplification of the model was undertaken to optimise the simulation study – as the more parts are included in the study, the more complicated and the more time it takes to complete. All components which were deemed not to add any additional relevance to the test were removed leaving only the primary components which make up the door. The FOS plot showed that in the region where the lock is, the model is failing as the FOS is less than one.

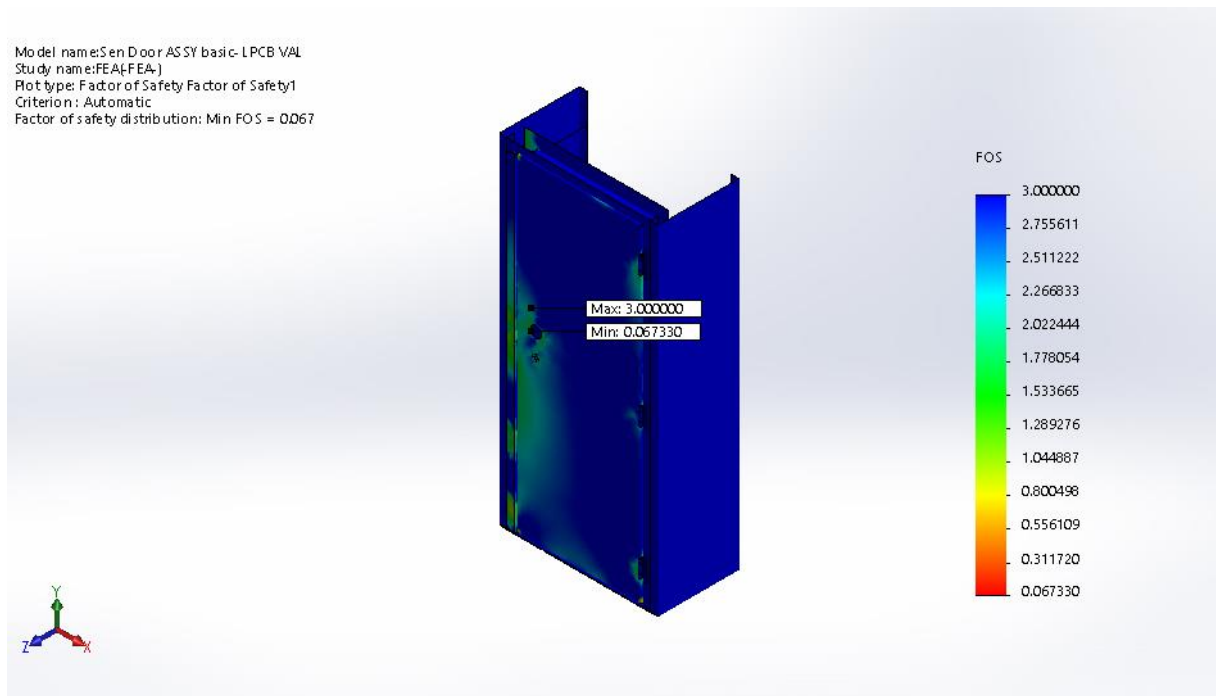


Figure 157 - FOS Plot

7.6 SUMMARY

Potentially, a way to validate the testing that had taken place at the factory and possibly at LPCB was to validate the test using a 3D package software. The software needed will be able to recreate linear static analysis to validate the material and factory testing. The linear analysis being undertaken on the software will eliminate weak materials or components at the earliest stages of the design process possible. This will save time and money on physical prototype testing at either LPCB or in the factory.

CHAPTER 8

8 TESTING METHODOLOGY ON SIMPLER COMPONENTS

8.1 INTRODUCTION

To validate the core methodologies created; database, material analysis, factory testing and Solidworks FEA, case studies were chosen to investigate the effectiveness of the methodologies created. By investigating real-life case studies, it will highlight the complexities that are encountered when designing products, how the methodologies can be implemented and how they will overcome the complex problems.

The aim of this chapter is to test the methodologies proposed to be in the new design procedure and evaluate the four main strands of the procedure proposed.

8.2 MATERIAL EVALUATION

The Bohler D2 steel plate is used by the Company to resist most drill attack tests by LPCB and is the companies most effective material at doing this. However, it has a minimum of a 4-week lead time so very effective planning needs to be taken on this material to make sure that the Company has the right amount purchased and in stock. It is approximately £400 per unit and the Company were looking at alternatives to be sought which were more readily available or cheaper, but with the same aim of being a drill resistant material.

A sample material was sourced and supplied to the Company to be used as a more readily available anti drill material, than the Bohler D2 steel currently used. This material was planned to be tested by LPCB, to find out its suitability in being a replacement.

The material sourced was called K700 and manufacturer Bohler, it is an Austenitic Manganese Steel. It is a cold working tool steel and Bohler states that this material has a high toughness. If it is strain hardened the material can achieve up to a surface hardness of 600 Vickers.

The current process was for the material to be tested at LPCB to evaluate the effectiveness of being a drill resistant material and to identify the security level the material can protect to and where it may be possible to use the material.

8.2.1 LPCB ANALYSIS

Following the current procedure at the Company, it was to be tested at LPCB and evaluated on the results of the attack tests. The testing was completed when LPCB were present at the Company undertaking a test regime. The results of the drill tests can be seen in Figure 158.

Attack test ref.:	P110886b-A	Date:	29/01/18	
Objective:	Drill holes through the 4 mm thick Bohler K700 steel plate using a 12 V drill.			
Test specimen:	P110886b/05	Locked condition:	N/A	
Tool category:	D	Target security rating:	4	
Name of tester:	P. Mason			

Attack action	Attack tools	Working time (min:sec)		Notes
		Increment	Running	
P110886b-A1 – 6 mm diameter hole				
Drill a 6 mm diameter hole through the 4 mm thick steel plate.	12 V drill with 6 mm carbide tip drill bit	00:46.41	00:46.41	Hole completed.
P110886b-A2 – 8 mm diameter hole				
Drill an 8 mm diameter hole through the 4 mm thick steel plate.	12 V drill with 8 mm carbide tip drill bit	01:06.53	01:06.53	Hole completed.
P110886b-A3 – 10 mm diameter hole				
Drill a 10 mm diameter hole through the 4 mm thick steel plate.	12 V drill with 10 mm carbide tip drill bit	01:35.06	01:35.06	Hole completed.
P110886b-A4 – 13 mm diameter hole				
Drill a 13 mm diameter hole through the 4 mm thick steel plate.	12 V drill with 13 mm carbide tip drill bit	01:40.50	01:40.50	Hole completed.

Figure 158 - LPCB Test Report for Material Testing 1

The first test was carried out with the 12v drill, with the aim to create a hole all the way through the section of material. Four different sized drill bits were used, 6mm 8mm 10mm and 13mm all manufactured from carbide. The results were collated into a graph to visually analyse.

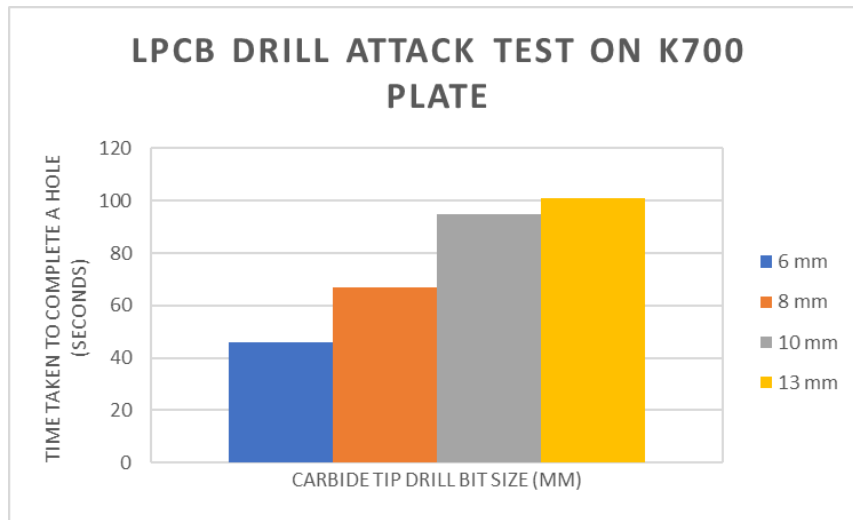


Figure 159 - LPCB Drill Attack Test on K700

As expected, as the 6mm drill bit is quickest and forming a hole in the sample. It didn't achieve a level of security as it didn't sustain a minute of the attack testing. The 8mm, 10mm and 13mm drill bit all achieved a Level 1 security rating as they were able to withstand a minute of attack testing. The trend in these results showed that the greater the drill bit, the longer it takes to create a hole in this sample, which is as expected as a greater size hole is needed to be achieved and more metal will need to be removed.

Attack test ref.:	P110886b-B	Date:	29/01/18
Objective:	Drill holes through the 4 mm thick Bohler K700 steel plate using a 10.8 V Li-ion drill.		
Test specimen:	P110886b/05	Locked condition:	N/A
Tool category:	D	Target security rating:	4
Name of tester:	P. Mason		

Attack action	Attack tools	Working time (min:sec)		Notes
		Increment	Running	
P110886b-A1 – 6 mm diameter hole				
Drill a 6 mm diameter hole through the 4 mm thick steel plate.	10.8 V drill with 6 mm carbide tip drill bit	01:15.44	01:15.44	Hole completed.
P110886b-A2 – 8 mm diameter hole				
Drill an 8 mm diameter hole through the 4 mm thick steel plate.	10.8 V drill with 8 mm carbide tip drill bit	02:11.59	02:11.59	Hole completed.
P110886b-A3 – 10 mm diameter hole				
Drill a 10 mm diameter hole through the 4 mm thick steel plate.	10.8 V drill with 10 mm carbide tip drill bit	02:17.50	02:17.50	Hole completed.

Figure 160 - LPCB Test Report for Material Testing 2

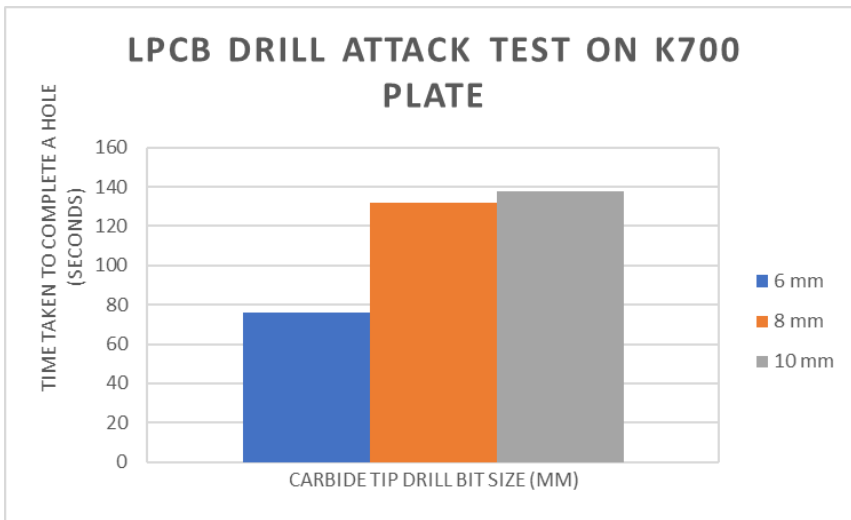


Figure 161 - LPCB Drill Attack Test 2 on K700

The second test was carried out using the 10.8v lithium iron drill which is a lower voltage drill than what was used on the first test. This test had the same aim of drilling a hole all the way through the material, but with only the 6mm, 8mm and 10mm drill bits. The same type of carbide drill bit was used. The larger 13mm drill bit is not included as this wouldn't be included within the tool category to match the drill being used. As with the first test the hole is created through the material using the 6mm drill bit the quickest but took almost double the time it took with the larger 12v drill.

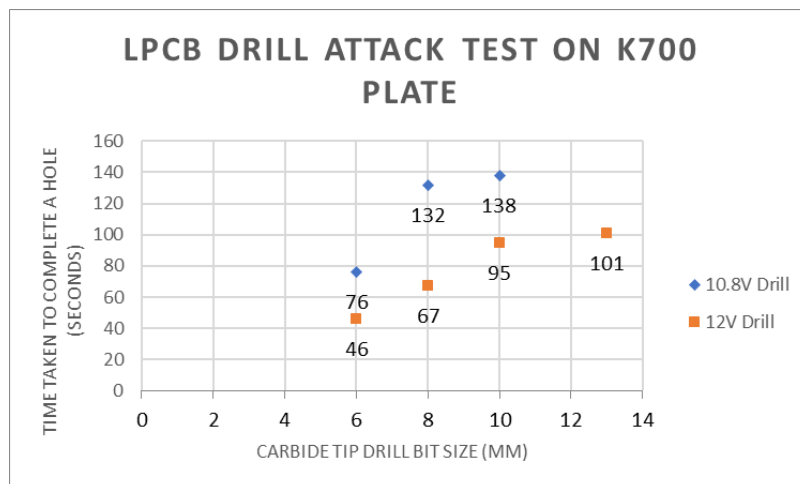


Figure 162 - Comparison of LPCB Drill Attack Test on K700

There was a minimum of a 31% time saving to create a hole through this material by using the 12V drill in the attack test. The attack tests carried out overall were a wasted exercise with an added cost to the Company, as the material was shown not to be useful at stopping any of the drill tests carried out and would only be suitable for a level 1 security product of which Technocover do not produce any products.

8.2.2 MATERIAL EVALUATION

To eliminate this time wasted it was possible to use the material analysis procedure stated in the previous chapters, to understand if a prediction could be made by investigating the material properties of the K700 specimen and comparing to the current materials, specifically, the D2 plate already tested by the Company.

As the material was being sourced to stop the LPCB attack test, drill resistance, by undergoing the material testing completed in the laboratory in Chapter 5 showed that a hardness value can be used to compare materials to identify the success of passing a drill resistance test completed by LPCB.

Table 25 - Material Properties extraction from Datasheet

Material Name	Tensile Strength (N/mm ²)	Hardness Value	0.2% proof stress (N/mm ²)	Minimum Elongation %	Minimum reduction of area %	Impact Strength (J)
K700	800-1000	200 HB	350	35	35	100

To do this, a hardness value of the K700 material was sourced from the datasheet and converted into the same scale that was used in the material database. The hardness property of the new sample material was stated as 200 HB in its datasheet.

Steel Hardness Conversion Calculator

Brinell Hardness HB

Calculate

Reset

Rockwell HRC

Rockwell HRB

Vickers HV

Figure 163 - Hardness Converter⁵⁷

⁵⁷ Universal Metals. (1997). Steel Hardness Conversion Calculator. Retrieved from Hardness:

<https://www.universalmetals.com/steel-hardness-conversion-calculator/>

By using a hardness scale to convert the hardness value from HB to HRC, which gave a value of 15 HRC. As the D2 has a value of 62 HRC, the new material is 24% less strong than the D2 and won't be capable of matching or surpassing the results obtained at LPCB.

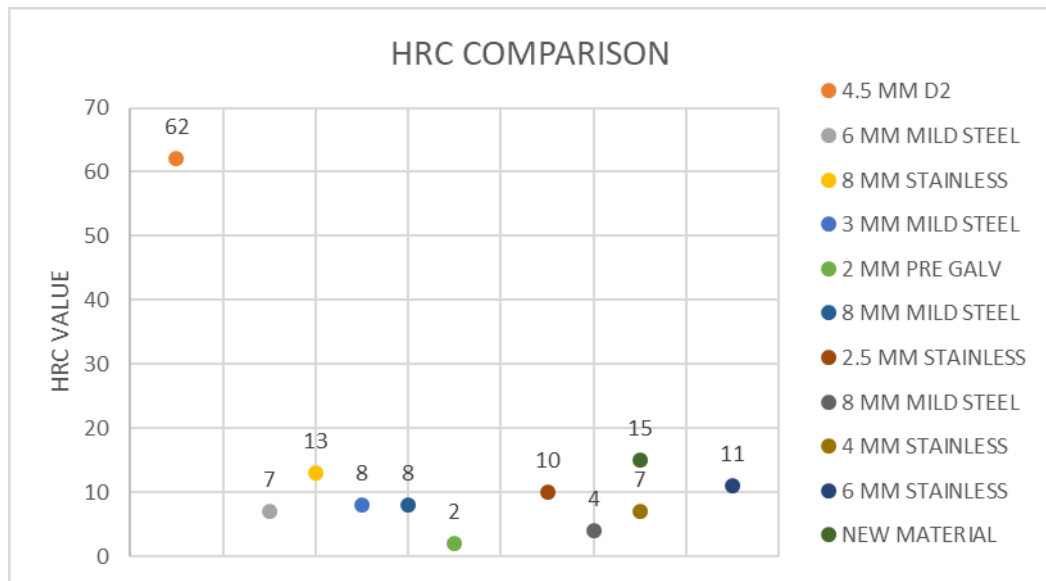


Figure 164 - HRC Comparison Material Database

By plotting the new material data on the HRC database, a visual comparison was obtained of the materials and their subsequent Rockwell Hardness Category C (HRC) values. This allowed a clear comparison of the K700 sample and the Company's material inventory – displaying that the hardness value of the potential material was much lower than for the D2 and is not suitable to be replacing the hardened D2 plate. The plate was only 2 figures higher on the HRC scale than the 8mm stainless used already by the Company.

8.2.3 PROPOSED MATERIAL EVALUATION WORKFLOW

By evaluation of the success of the success of the new material evaluation process, an update workflow was proposed for the evaluation of new materials and their suitability for passing certain LPCB attack tests. An overview of this new workflow can be seen in Figure 165.

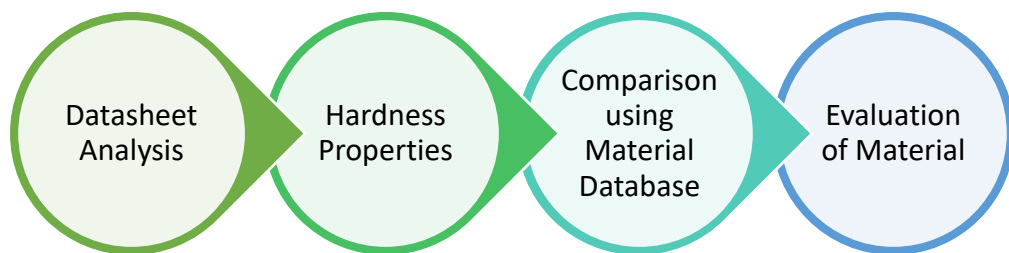


Figure 165 - Proposed Material Hardness Workflow

DATASHEET

The first step of the new workflow is to analyse the datasheet that is provided by the manufacturer of the material. These data sheets usually list typical properties for the material which can be inputted into the material database to see how the new material compares to existing materials. If this value is deemed to be potentially good for drill resistance, the material will have to be tested in the laboratory to obtain the true figure for its hardness value.

HARDNESS SCALE CONVERSION

By using the material database, a comparison of the hardness values can be completed to compare the material to material records currently held. With D2 being the benchmark for a drill resistant product its hardness value will give an indication as to how long a new material will resist each drill attack.

MATERIAL DATABASE COMPARISON

Again, the database can compare the new material for its potential to be used by the Company. Not only just the strength of the material but also its price and availability. There's the potential for new products to be found which may be twice as hard as D2 plate but also three times the cost. Factors like this can be considered when a decision is made as to test the material with LPCB.

8.2.4 SUMMARY

Material analysis can be costly and time consuming when trying to value engineer to obtain a cheaper material or a material that is in more demand. The current process of the evaluation of material analysis undertaken at LPCB is very effective, as a result is provided after the test has been completed (subject to assessments afterwards) but it is a very expensive process with it costing £2500 a day plus costs for resources. As the aim is to reduce the design and development costs; in terms of time and money, by reducing the indicative material testing by assessing the material properties in house, in turn less money will be spent designing the product.

The material analysis procedure has been validated with cost savings analysis being completed to show how effective this would have been for previous test regimes. Engineering knowledge has been implemented to compare material properties and reduce the reliance of indicative material testing at LPCB.

Using the material testing methodologies researched in the previous chapters, a validation test was created to analyse the effectiveness of the testing material methodology and how it would fit in with the LPCB testing. This could potentially be used in the Company as a material testing model before committing to LPCB tests, instead of the indicative testing that normally takes place on new materials/composites.

This exercise, to convert the hardness rating, was a quick process and took a matter of minutes to do compared to the current process of going to LPCB to complete this evaluation during a test day.

8.3 IMPLEMENTATION OF LPS 1175: ISSUE 8

At the start of 2019, LPCB published the new Issue 8 standard of LPS 1175. The new security classification table was shown which detailed the delay for a product. Using the database, it would be possible in the future to detail the delay of tools by using previous historic testing and creating a database of tools vs security levels achieved in the same format as Figure 166 which was published by LPCB. Figure 166 shows a comparison of the change in tool category from Issue 7 to Issue 8 where D+ is changed to E and the addition of the tool category H. However, with the tool matrix that has been created by the author, this can easily be visualised with a breakdown of all the tools in the current and previous revisions of LPS 1175.

		Security Rating Classification							
Delay	20 Minutes	A20	B20	C20	D20	E20	F20	G20	H20 (SR8)
	15 Minutes	A15	B15	C15	D15	E15	F15	G15	H15
	10 Minutes	A10	B10	C10	D10 (SR4)	E10 (SR5)	F10 (SR6)	G10 (SR7)	H10
	5 Minutes	A5	B5	C5 (SR3)	D5	E5	F5	G5	H5
	3 Minutes	A3	B3 (SR2)	C3	D3	E3	F3	G3	H3
	1 Minute	A1 (SR1)	B1	C1	D1	E1	F1	G1	H1
Tool Kit	LPS 1175: Issue 8	A	B	C	D	E	F	G	H
	LPS 1175: Issue 7	A	B	C	D	D+	E	F	G

Figure 166 - Comparison of security rating classifications used in LPS 1175 Issue 7 and Issue 8⁵⁸

Security Rating (#t _w)	Maximum Working Time - t _w (minutes)	Maximum Test Duration - t _t (minutes)
#1	1	10
#3	3	15
#5	5	20
#10	10	30
#15	15	45
#20	20	60

Note: '#' indicates the tool category (A to H).

Figure 167 - Maximum Test Duration permitted for individual attack tests⁵⁸

		Security Rating Classification							
Maximum Working Time - t _w (minutes)	20	A20	B20	C20	D20	E20	F20	G20	H20 (SR8)
	15	A15	B15	C15	D15	E15	F15	G15	H15
	10	A10	B10	C10	D10 (SR4)	E10 (SR5)	F10 (SR6)	G10 (SR7)	H10
	5	A5	B5	C5 (SR3)	D5	E5	F5	G5	H5
	3	A3	B3 (SR2)	C3	D3	E3	F3	G3	H3
	1	A1 (SR1)	B1	C1	D1	E1	F1	G1	H1
Tool Category		A	B	C	D	E	F	G	H
Maximum Number of Test Operatives (Clause 4.4.2.1)		1	1	1	1	1	2	2	2
Maximum Total Mass of Tools Per Test Operative (kg)		2.5	5	10	20	25	25	25	25

Figure 168 - Security rating requirements for each manual intervention attack test⁵⁸

8.3.1 PROPOSED WORKFLOW

There are two tasks that need to be completed when LPCB publish a new revision of the LPS 1175 standard – add the breakdown of the tool category into the tool matrix and the LPCB database. The tool category breakdown was typed out into a list and compiled into the matrix.

⁵⁸ BRE Global. (2019). LPS 1175: Issue 8. LPCB.

8.3.2 TOOL MATRIX

The new tool category was inputted into the time tool graph/ tool matrix to visually see the changes in Issue 8. The key is shown in Figure 169.

A	B	C	D	E	F	G	H

Figure 169 - Key of the tool matrix

Table 26 - Issue 8 Matrix Part 1

TOOL	ISSUE 8							
	A	B	C	D	E	F	G	H
>50 mm diameter Hole Saw						Yellow	Grey	
240 V Arcair								Blue
6 mm drill saw						Yellow	Grey	
10 mm Carbide jobber drill bit				Orange				
10 mm HSCO jobber drill bit			Blue	Grey	Grey			
10 mm HSS jobber drill bit			Blue	Grey	Grey			
10 mm masonry jobber drill bit			Blue	Grey	Grey			
10 mm Drill bits (tile/glass)						Yellow		
54 V Circular Saw with 3 cutting blades							Red	
54 V Disc Grinder with 3 Cutting discs							Red	
54 V Drill							Red	
54 V reciprocating saw							Red	
12 V battery			Blue	Grey	Grey			
12 V d.c. Jigsaw with 3 (HSCO/Carbide/HSS) blades				Orange	Grey			
12 V Disc grinder plus 3 cutting discs				Orange	Grey			
12 V drill			Blue	Grey	Grey			
14 mm screwdriver		Green	Grey	Grey				
18 V battery					Blue			
18 V d.c. Circular saw (cordless) with 3 blades					Blue			
18 V d.c. Jigsaw with 3 Carbide blades					Blue			
18 V d.c. Jigsaw with 3 HSCO blades					Blue			
18 V d.c. Jigsaw with 3 HSS blades					Blue			
18 V d.c. Reciprocating saw with 3 Carbide blades					Blue			
18 V d.c. Reciprocating saw with 3 HSCO blades					Blue			
18 V d.c. Reciprocating saw with 3 HSS blades					Blue			
18 V Disc grinder plus 3 cutting discs					Blue			
18 V drill					Blue			
1900 W breaker								
36 V Drill						Yellow	Grey	
36 V jigsaw						Yellow	Grey	
36 V Reciprocating Saw						Yellow	Grey	
Drill bit (Step drill / cone cutter)						Yellow	Grey	
36 V Disc Grinder with 3 Cutting discs						Yellow	Grey	
3.6 V battery		Green	Grey	Grey	Grey			
36 V battery						Yellow		
36 V circular saw with 3 Cutting discs						Yellow	Grey	
3.6 V drill / driver		Green	Grey	Grey	Grey			
38 mm Tube								
50 mm diameter Hole saw				Orange				
400 mm ring saw blades								Blue
50 mm diameter tube, 300mm long		Green	Grey	Grey	Grey			
5kW Cut-off Stihl Saw with 3 blades								
5No. 13 mm Carbide jobber drill bit					Blue	Grey	Grey	
5No. 13 mm Carbide long series drill bit					Blue	Grey	Grey	
5No. 13 mm HSCO jobber drill bit					Blue	Grey	Grey	
5No. 13 mm HSCO long series drill bit					Blue	Grey	Grey	

Table 27 - Issue 8 Matrix Part 2

TOOL	ISSUE 8							
	A	B	C	D	E	F	G	H
5No. 13 mm HSS jobber drill bit					Blue			
5No. 13 mm HSS long series drill bit					Blue			
5No. 13 mm SDS drill bit						Yellow		
5No. 20 mm Carbide jobber drill bit							Red	
5No. 20 mm Masonry jobber drill bit							Red	
5No. 20 mm SDS plus jobber drill bit							Red	
5No. 20 mm HSCO jobber drill bit							Red	
5No. 20 mm HSS jobber drill bit							Red	
54 V battery							Red	
6 mm Carbide jobber drill bit								
6 mm HSCO jobber drill bit		Green						
6 mm HSS jobber drill bit		Green						
6.5 mm Screwdriver	Orange							
7 mm screwdriver		Green						
7.2 V drill								
75 mm Tube - 1500 mm long							Red	
75 mm Tube - 1000 mm long						Yellow		
75 mm Tube - 500 mm long				Yellow				
Adhesive Tape	Orange							
Arcair rods								Blue
A-tool lock puller				Yellow				
Axe			Blue					
Bolt cutter - 350 mm long		Green						
Bolt cutter - 400 mm long			Blue					
Bolt cutter - 500 mm long				Yellow				
Brick Bolster			Blue					
Cable Cutter	Orange							
Cargo strap (selection)	Orange							
Electric cable (Single core)	Orange							
Engineers hooks (Selection)	Orange							
Firefighters key	Orange							
Chisel bits (SDS-Plus)						Yellow		
Claw hammer		Green						
Cold chisel			Blue					
Concrete chainsaw								Blue
Chainsaw 2 stroke							Red	
Crowbar			Blue					
Diamond core drill bit								Blue
Electric cable (Single core)		Green						
Enforcer - 450 mm long							Red	
Enforcer - 600 mm long								Blue
Felling / fire axe				Yellow				
Fishing line	Orange							
Fishing hooks	Orange							
Flexible plastic coupon	Orange							
Fluorocarbon based freeze spray			Blue					
Gas torch			Blue					
General purpose saw					Blue			
Glasmaster saw						Yellow		
Glass cutter	Orange							
Grinder (2 stroke)							Red	Blue

Table 28 - Issue 8 Matrix Part 3

TOOL	ISSUE 8							
	A	B	C	D	E	F	G	H
Hacksaw plus 2 HSS blades			Blue					
Hammer			Blue					
Hand drill								
Hexagon wrench	Orange							
Hooligan bar - 760 mm long				Yellow				
Hooligan bar - 910 mm long							Red	
Hydraulic head and toe jack								Blue
Junior hacksaw plus 2 HSS blades	Orange							
Knife	Orange							
K-tool lock remover				Yellow				
Lever	Orange							
Metal plate shears		Green						
Multiple slip joint pliers		Green						
Maul - wood splitting (8lb / 3.63kg nominal weight)						Yellow		
Oxyacetylene "Saffire Portapak" cutting kit - 250l								Blue
Pad saw plus 2 HSS blades			Blue					
Pick axe (5lb / 2.27kg nominal head weight)						Yellow		
Pinch bar						Yellow		
Pipe wrench	Orange							
Plastic wedges								
Plate shears				Yellow				
Pliers - 200 mm long	Orange							
Pliers - 250 mm long		Green						
Pneumatic impact tool								
Punches	Orange							
Ratchet strap		Green						
Rescue chainsaw (2-stroke)								Blue
Rope	Orange							
Ring saw (2-stroke)								Blue
Scissor jack			Blue					
Scriber (selection)	Orange							
Sledgehammer - 3kg				Yellow				
Sledgehammer - 4.5kg						Yellow		
Sledgehammer - 6kg								
Soft Body Impactor								
Socket / screwdriver set	Orange							
Spanner	Orange							
Steel wedges				Yellow				
Traction screws	Orange							
Trolley Jack - 4 tonne							Red	
Tweezers	Orange							
Universal Key	Orange							
WD40	Orange							
Wire	Orange							
Wood boring spade bits (selection)						Yellow		
Wood chisels			Blue					
Wood wedges	Orange							

8.3.3 TOOL CATEGORIES INTO LPCB DATABASE

To input the new tool category into the database, a record is needed to be created for every tool and every tool category it is included in. This can then be inputted into the database under the tool table and will be shown in the user interface when an Issue 8 test regime is completed, filtering all the Issue 8 tools.

TOOL	Revision	Tool Category
>50 mm diameter Hole Saw	8	F
>50 mm diameter Hole Saw	8	G
>50 mm diameter Hole Saw	8	H
240 V Arcair	8	H
6 mm drill saw	8	F
6 mm drill saw	8	G
6 mm drill saw	8	H
10 mm Carbide jobber drill bit	8	D
10 mm HSCO jobber drill bit	8	C
10 mm HSCO jobber drill bit	8	D
10 mm HSCO jobber drill bit	8	E
10 mm HSCO jobber drill bit	8	F
10 mm HSCO jobber drill bit	8	G
10 mm HSCO jobber drill bit	8	H
10 mm HSS jobber drill bit	8	C
10 mm HSS jobber drill bit	8	D
10 mm HSS jobber drill bit	8	E
10 mm HSS jobber drill bit	8	F
10 mm HSS jobber drill bit	8	G
10 mm HSS jobber drill bit	8	H
10 mm HSS jobber drill bit	8	D

Figure 170 - Issue 8 Tool List Created

A table needed to be updated linking the tool categories and the maximum working time of the relevant categories. This will therefore create a relationship that links the three properties together.

TOOL CATEGORY BREAKDOWN			
TC	Maximum Working Time (minutes)	Click to Add	
5D	00:10:00		
5E	00:10:00		
5F	00:10:00		
6A	00:01:00		
6B	00:03:00		
6C	00:05:00		
6D	00:10:00		
6D+	00:10:00		
6E	00:10:00		
6F	00:10:00		
6G	00:20:00		
7A	00:01:00		
7B	00:03:00		
7C	00:05:00		
7D	00:10:00		
7D+	00:10:00		
7E	00:10:00		
7F	00:10:00		
7G	00:20:00		
8A	00:01:00		
8B	00:03:00		
8C	00:05:00		
8D	00:10:00		
8E	00:10:00		
8F	00:10:00		
8G	00:10:00		
8H	00:20:00		

Figure 171 - Tool Category Breakdown

TOOLS				
TOOL ID	TOOL NAME	REVISION	TOOL CATEGORY	
6494	>50 mm diameter Hole Saw	8	F	
6495	>50 mm diameter Hole Saw	8	G	
6496	>50 mm diameter Hole Saw	8	H	
6497	240 V Arcair	8	H	
6498	6 mm drill saw	8	F	
6499	6 mm drill saw	8	G	
6500	6 mm drill saw	8	H	
6501	10 mm Carbide jobber drill bit	8	D	
6502	10 mm HSCO jobber drill bit	8	C	
6503	10 mm HSCO jobber drill bit	8	D	
6504	10 mm HSCO jobber drill bit	8	E	
6505	10 mm HSCO jobber drill bit	8	F	
6506	10 mm HSCO jobber drill bit	8	G	
6507	10 mm HSCO jobber drill bit	8	H	
6508	10 mm HSS jobber drill bit	8	C	
6509	10 mm HSS jobber drill bit	8	D	
6510	10 mm HSS jobber drill bit	8	E	
6511	10 mm HSS jobber drill bit	8	F	
6512	10 mm HSS jobber drill bit	8	G	
6513	10 mm HSS jobber drill bit	8	H	
6514	10 mm HSS jobber drill bit	8	D	
6515	10 mm masonry jobber drill bit	8	C	
6516	10 mm masonry jobber drill bit	8	D	
6517	10 mm masonry jobber drill bit	8	E	

Record: 1 of 1416 No Filter Search

Figure 172 - Issue 8 imported into Database

The implementation of the new tool categories from Issue 8 into the database was successful and when Issue 8 is specified through the user interface to add new test reports, the new Issue tool categories are shown.

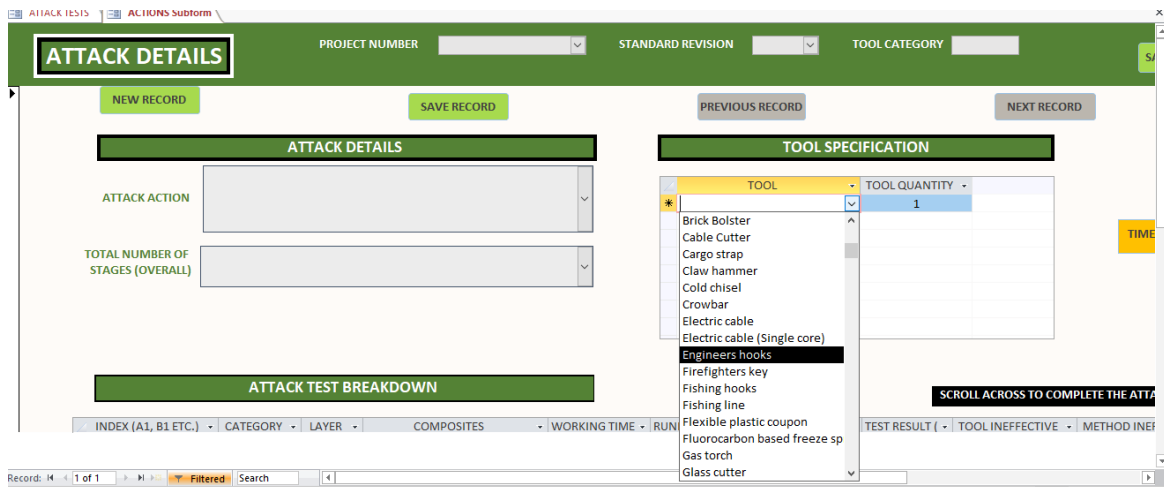


Figure 173 - Screenshot of Issue 8 tool list implemented in Database

8.3.3.1 ANALYSIS OF TOOL CHANGES AND MODIFICATIONS

In 2019 the LPS 1175 security standard will be upgrading from its current Issue (7) to Issue 8. This upgrade is said to address a greater and more diverse range of threat scenarios, by introducing a two-part performance classification system. This new system will involve a matrix where by each tool category can be chosen for any set time restriction, removing the time limits set to tool categories and security ratings in previous versions of the standard. This broadens the current database to find tests which may have been a fail when originally tested, into their own unique category saving the need for the company to carry out additional test days to re-align their certification with the new standard.

The Issue 8 standard will also provide a security rating to a product being tested even if it fails to meet the required time target initially set. This can help to eliminate future testing when the product is required to be in a lower category. There is also the possibility that existing data will be used to certify lower security products, having the database set up to enable searches for this existing data will save time when looking to get new products certified.

The main changes within the tool listings and categories can be seen below:

- Category A – Addition of electrical wire, fireman’s key, cargo strap and universal key
- Category B – Hand drill replaced by a 3.6V drill, ratchet strap and electrical wire added
- Category C – 7.2V drill replaced by a 12V drill
- Categories B & C – Carbide drill bits replaces with masonry type
- Category order updated from D+ to G, to E to H
- Categories E to G – Mains tools replaced with portable battery powered or petrol driven alternatives. Several additional tools added
- Categories F to H – A second attacker added
- Limit placed on the weight of tools each test operative may select for an attack test

8.3.1 SUMMARY

The upgrade to LPS 1175: Issue 8 has been successfully included in the LPCB database, allowing the Company to be set up and ready for the introduction of the new Issue of the standard. This will give them an edge when it comes to the selection of materials and composites of materials to deter the new tool kits for the varying range of times now available. Drawing from information gained over the years on certain tools and attack methods. Failed test programmes which may have been ignored in the past can now become useful as they could potentially be a certified product now.

It was simple for the addition of the new LPS 1175: Issue 8 standard into the database, which shows that the database is set up for any changes that needs to be taken place such as new tool categories. The way that the database has been set up allows for the data to be added without affecting the core structure of the database.

8.4 BRACKET

A grid support bracket was re-designed by the engineering team at the Company and an investigation into value engineering of the bracket was required. This was to be confident for the part to be made as efficiently as possible in terms of the type of material used, material thickness, strength and ease of manufacture.

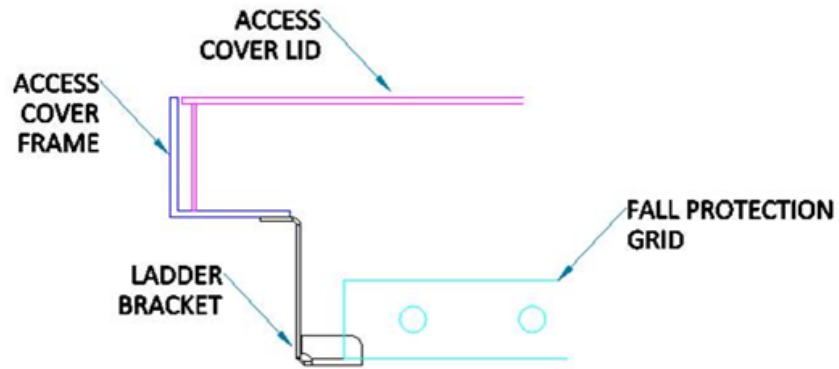


Figure 174 - Grid Simplification

The bracket was chosen as a case study to validate the new design process that has been put in place. The bracket was a suitable product to be tested, as it needs to pass a load test to ensure that it is strong enough for use with the fall protection fitted beneath access covers manufactured by the Company. There was also some scepticism within the Company whether a single section of folded steel would be strong enough to pass the relevant load tests required. It currently weights 1.5kg.

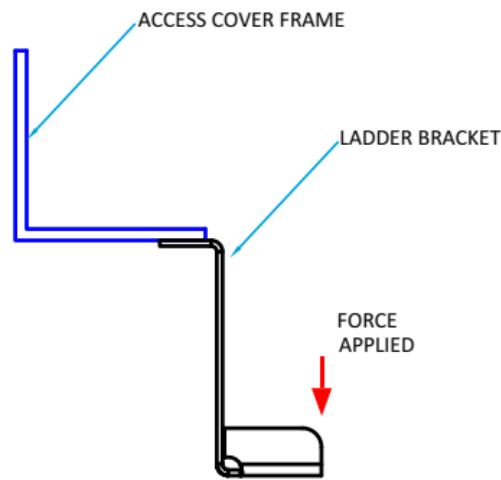


Figure 175 - Bracket

Figure 175 details how the bracket is fitted beneath the cover frame, to support the grid when in the closed position. The force is applied to the end of the bracket via the fall protection when closed.

8.4.1 CURRENT ANALYSIS

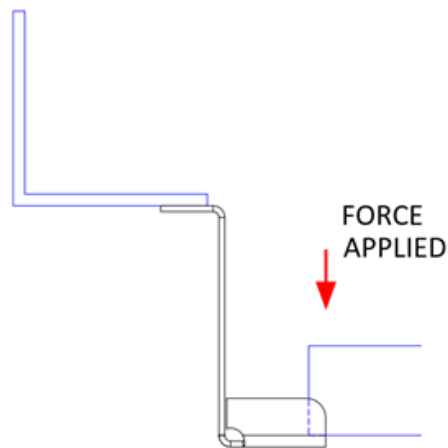


Figure 176 - Simplification of bracket

Figure 176 details the projected shape of the bracket when a load is applied to the end of it. The bracket will have to be tested by the Company before implementation to ensure it will not permanently deform as it is a part of an assembly which needs to resist the 250N applied to it. This load is specified from the test standard BS EN 124:2015 to comply with a class rating of C250. To do this the bracket will be fully analysed to understand the structural behaviour of it, drawn on 3D software and then simulated using the software to check its suitability.

The main aim of the assessment of the bracket was to design a cheaper and potentially easier to make product - the current bracket is made from sections of 6mm angle with welded connections. This is a time-consuming process as it would be easier and cheaper for the bracket to be made from a single bending sheet of steel.

Before the new bracket was manufactured and tested, the current bracket design was modelled using the 3D software and analysis took place on FEA.

This first required a breakdown of the structural behaviour of the bracket to understand the typical behaviour, boundary conditions etc. and then analysis on FEA of the current bracket to assess the structural integrity of it and to highlight any potential weak points or over engineering of the bracket. In turn this will also tell you how strong the bracket is, and the load required to cause failure.

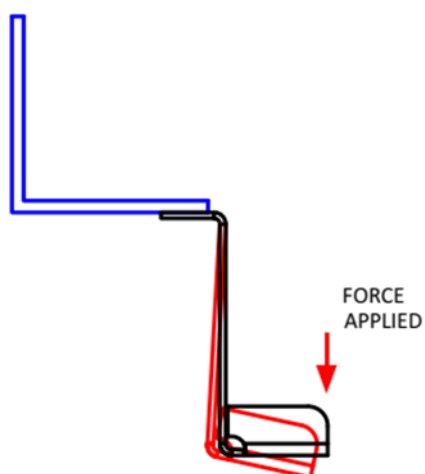


Figure 177 - Simplification of bracket when force is applied

It was calculated that the existing bracket costs £4.01 to manufacture. This includes the cost of the material and the labour time to cut, fold and weld the bracket together.

Product Code	Description	Material Reference	Cost	Total No from Sheet	Material Per Component
C09-001	RSA 125x75x8 -L=75	RMRSA01250075008	48.85000	78	0.63
C03-098	FLAT BAR	RMSSP12771250040	27.53000	217	0.13
					£ 0.75

Figure 178 - Material Costs

Labour		£23	per hour		
Product Code	Work Centre	Operation	Description	Time (m)	Total Cost
C09-001	Laser	PR1810	Cut 78 Items from angle (est 234 mins)	3	£1.15
C03-098	Laser	PR1410	Cut 217 Brackets from plate (est 434 mins)	2	£0.77
C03-098	Folding	PR1410	Fold Bracket Edges	1	£0.38
				6	2.3
Product Code	Work Centre	Operation	Description	Time (m)	Total Cost
A09-003	Welding	PR4110	Weld Together Stock Parts	2.5	£0.96

Figure 179 - Labour cost

Assembly	Description	Component	QTY	Component Description	Material Comp	Comp Labour	Total Cost	Routing Cost	Assembly Cost
A09-003	Grid Rest Bracket - Cup	C09-001	1	RSA 125X75X8	0.63	1.15	1.78		
A09-003	Grid Rest Bracket - Cup	C03-098	1	SHORT LADDER CUP	0.13	1.15	1.28		
A09-003	Grid Rest Bracket - Cup	A09-003	1	Routing				0.96	
									£ 4.01

Figure 180 - Total manufacturing cost for current bracket

The aim of this process was to reduce this cost and produce a bracket from a smaller gauge material with reduced manufacturing processes.

8.4.2 PROPOSE WORKFLOW

The proposed new workflow for designing new products of this type.

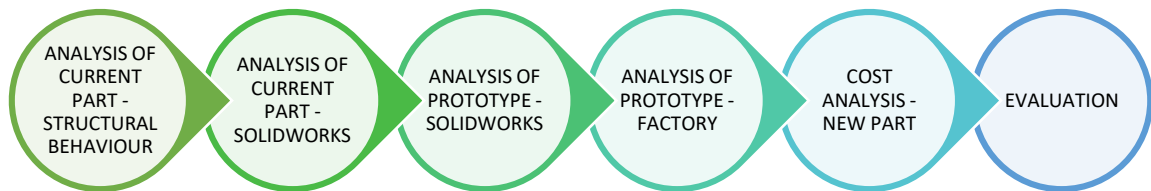


Figure 181 - Proposed Workflow of Bracket

The understanding of the structural behaviour of the bracket is crucial so that the author is aware of what the typical behaviour of the bracket should be - including deflected shape, bending moment diagram and shear force diagram. This gives an indication as to how the bracket should react when the FEA analysis is completed. The software is a great tool for simulating results but can be misleading if you don't have the engineering understanding of how the simulation results should look and the conditions that should be applied to assume the real-life conditions are the same as the ones modelled in the software.

When investigating different prototypes in FEA, different thicknesses of materials can be used paired with the knowledge of the test load being applied, to ensure the best cost saving and strength balance is achieved for the new design.

8.4.3 SIMPLIFICATION OF PART

Before the FEA analysis was carried out using the 3D software package, hand sketches and diagrams were created for the simplified bracket design. The expected deflected shape when

the load was applied to the bracket can be seen in Figure 182. When the load is applied to the end of the bracket, as the bracket is fully fixed to the underside of the frame on the left-hand side there will be an anti-clockwise reaction moment present there. This will stop the bracket from rotating and breaking loose from the frame.

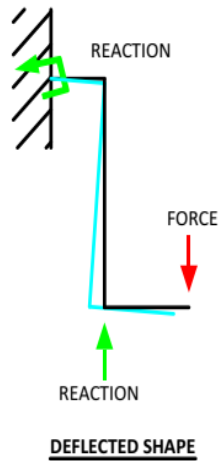


Figure 182 - Deflected Shape of bracket

The bending moment diagram and the shear force diagram of the bracket can be seen in Figure 183.

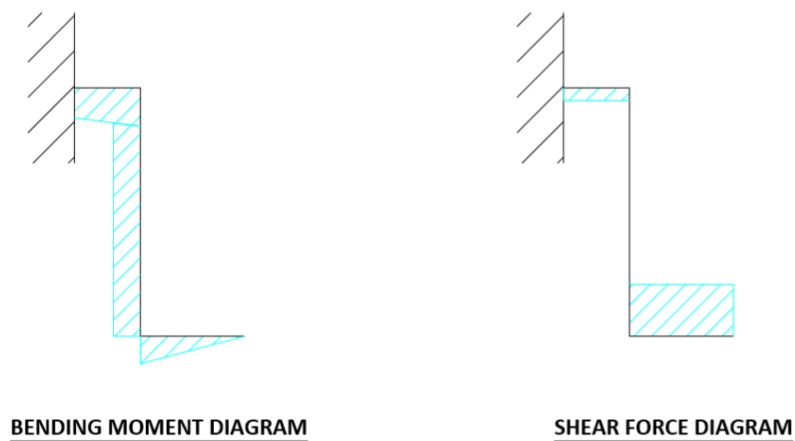


Figure 183 - Bending moment and shear force diagram of Bracket

8.4.4 FEA

After the 3D model was created using SolidWorks, it was analysed via the simulation section of Solidworks. It was fixed to replicate where it would be positioned within the main product. The test load of 250 kg specified in the standard for the fall protection system was then

applied to the face of the bracket which would take the force of the grid when a load was applied to the top of it.

Figure 184 is taken from the results of the FEA. This shows the maximum stress of 56.028N/mm^2 within the bracket whilst under a load of 250 N. The plot acknowledges that the bracket doesn't reach the yield strength value, with the highest stress being only a fifth of the yield strength.

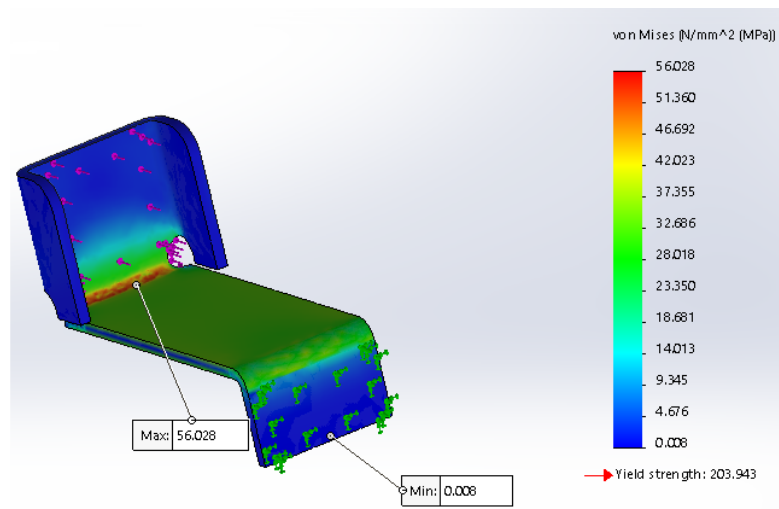


Figure 184 - Bracket Stress Analysis

MADE OUT OF 3MM MILD STEEL

The FOS plot was all over 1, so the design is acceptable and can withstand the loads produced.

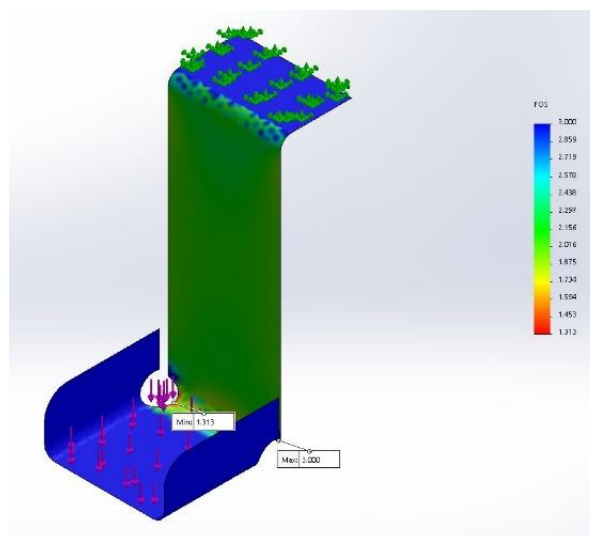


Figure 185 - Factor of Safety Plot

MADE OUT OF 2MM PRE-GALVANISED STEEL

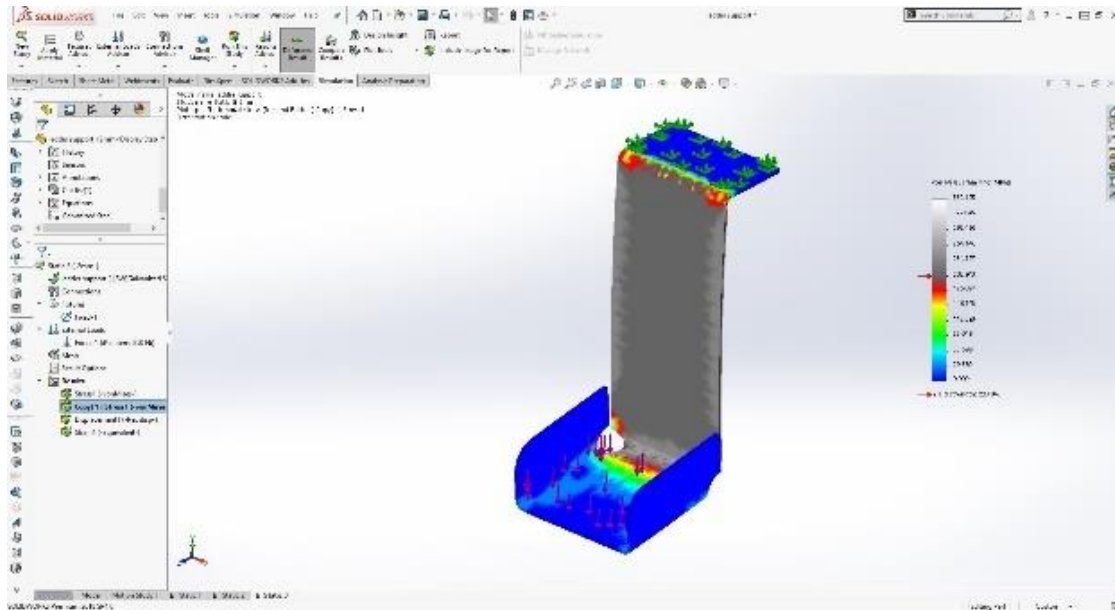


Figure 186 - 2 mm analysis

When designed out of 2 mm, the plate was failing in the section coloured in grey.

8.4.5 SUMMARY

This bracket case study relied on the Solidworks prototype testing to evaluate the optimum thicknesses of the bracket to obtain the required strength. The bracket created was cheaper, weighed less than the original prototype and eliminated the need for multiple prototype testing to be completed in the factory. This reiterated that this process is more efficient to use due to saving time on resources in terms of sample manufacturing and design time.



Figure 187 - New manufactured bracket

Figure 187 shows the finished bracket which was manufactured which weights 0.29kg. Cost analysis was completed to identify how much the new bracket would cost. It was broken down into material costs and labour costs which was combined to give an accurate cost of the manufacture of the bracket.

Product Code	Description	Material Reference	Cost	Total No from Sheet	Material Per Component
C03-098	FLAT BAR	RMSSP12771250040	27.53000	123	0.22
					£ 0.22

Figure 188 - Material component costs

Product Code	Work Centre	Operation	Description	Time (m)	Total Cost
Labour £23 per hour					
New Grid Cup Com 001	Laser	PR1410	Cut 123 Brackets from plate (est 434 mins)	2	£0.77
New Grid Cup Com 001	Folding	PR1410	Fold Bracket Edges	1	£0.38
New Grid Cup Com 002	Welding	PR4110	Weld edges of bracket	2.5	£0.96
				3	£2.11

Figure 189 - Labour costs

Assembly	Description	Component	QTY	Component Description	Material Comp	Comp Labour	Total Cost	Assembly Cost
New Bracket	Grid Rest Bracket - Cup	New Grid Cup Com 001	1	SHORT LADDER CUP	0.22	2.11	2.33	
								£ 2.33

Figure 190 - Cost of bracket

The bracket was made from a thinner material, which decreases the weight of the product overall, therefore, saving a weight saving of 87% and decreasing the cost by 42%.

8.5 LOCK PLATE

Chapter 6 identified that the brackets and lock positions can be limiting factors within the design of compatible doorsets and the associated leaf's, particularly when subjected to forced displacement attacks where the corner of the doors are wedged open. Whilst the leaf can be made stiffer and the frames can have more fixtures integrated to reduce the effective lengths, this chapter will look at establishing a method of reviewing and improving the load carrying capacity of the door locking brackets through the implementation of static linear analysis of the door bracket to investigate scenarios that could lead to an increased capacity of the locking system.

Investigating historical videos taken at the LPCB testing showed that the lock was the most vulnerable part of the doorset, hence, why it was LPCB's typical route to attack Technocover's Doorsets.

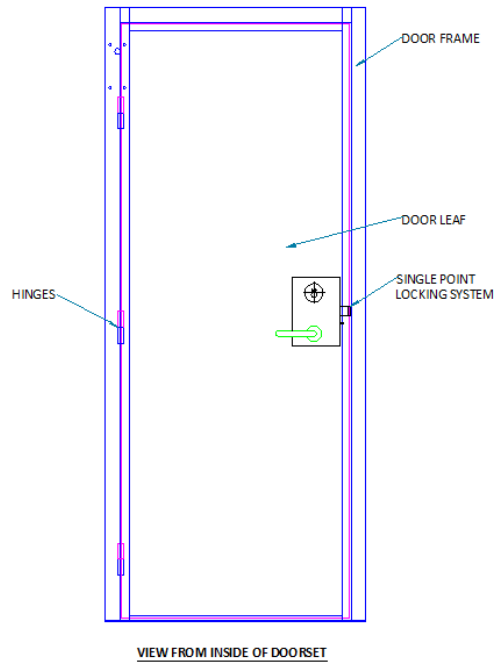


Figure 191 - Typical view from inside doorset

The lock and the hinges are the only pinned supports on the doorset, so to be able to open the door, either the hinges or the locking system needs to fail.

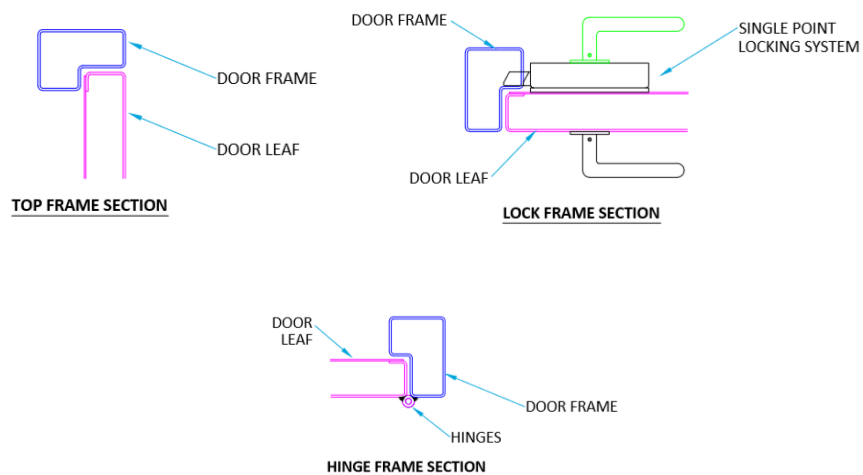


Figure 192 - Top, lock and hinge frame section of doorset

Strengthening the lock plate was investigated as this will make it harder for the lock to disengage and allow access through the door. The easiest way to strengthen the lock would be

to choose a different locking system, but this would involve sending the doorset for a complete LPCB testing programme for the inclusion of the lock within the doorset certificate. This would incur high testing costs and a potential increased cost for the new lock. Instead of this, additions to the locking system within the doorset were completed to strengthen it, resulting in a minor increase in cost of the product to be manufactured but with an increase in strength.

The lock plate was sourced from MICO and was manufactured from Cast Alloy steel. It wasn't possible to modify the plate from MICO but possibly in the future, recommendations can be given to the manufacturer of the locks that gives details of a stronger material which could be used or an increased number of fixing points to secure the plate in position. If more fixings were used, the overall bending moment would be reduced, reducing the bending observed within the locking system.

Situated behind the lock plate was a mount plate which is welded within the inside of the frame. This connects the MICO plate to the frame and is shown in more detail in Figure 193. As it was determined that the MICO plate can't be modified, the next solution would be to analyse the locking plate to investigate the current strength and the improvements needed to stop the failure due to bending.

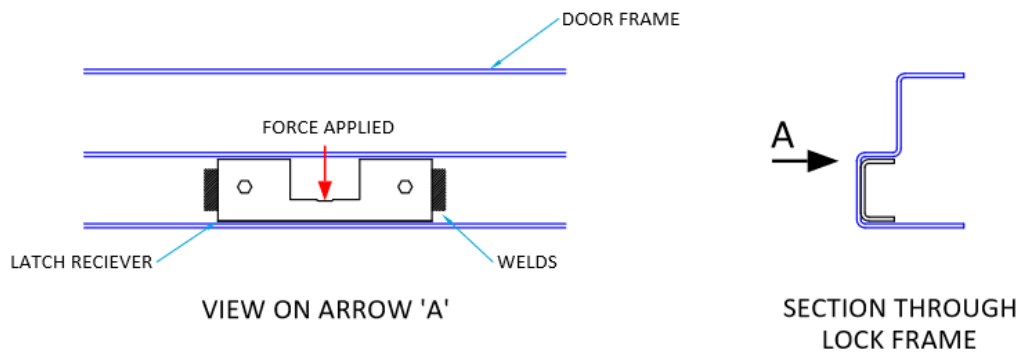


Figure 193 - Lock plate section through

8.5.1 SIMPLIFICATION OF PART

$$M = \frac{PL}{4}$$

Where

P = load applied

L = distance from the support the load is applied

And the reactions = $V = P/2$ (due to their being 2 reactions)

$$R = V = \frac{P}{2} = 650 \text{ N}$$

Maximum moment

$$M = \frac{PL}{4} = \frac{1300 \times 42}{4} = 13650 \text{ Nmm}$$

Maximum deflection is

$$\frac{PL^3}{48EI} = \frac{1300 \times 42^3}{48 \times 30 \times 10^6 \times 14.355} = 0.0466 \text{ mm}$$

$$I = \frac{BD^3}{12} = \frac{6.38 \times 3^3}{12} = 14.355 \text{ mm}^4$$

$$\sigma = \frac{M}{Z} = \frac{13650}{60} = 228 \text{ N/mm}^2$$

$$Z = \frac{bd^2}{6} = \frac{40 \times 3^2}{6} = 60 \text{ mm}^3$$

The expected deflected shape, bending moment and shear force diagram for the current mount plate are shown in Figure 194. To increase the strength of this plate, the distance of the span between the reaction forces would have to be reduced. This process was also carried out for the latch plate which bolts to the receiver bracket within the door frame.

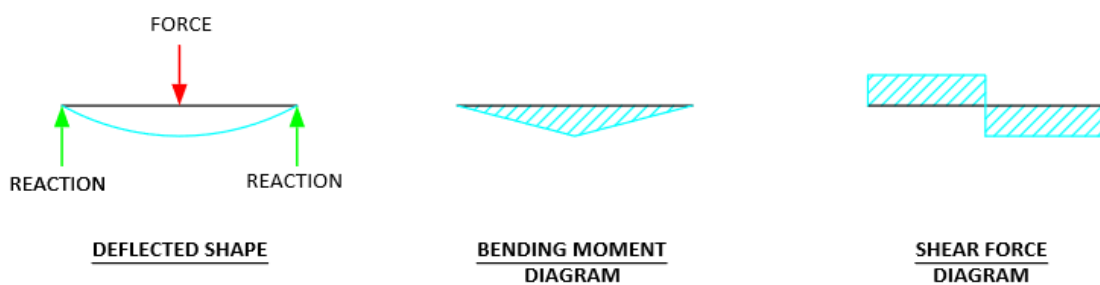


Figure 194 - Lock plate deflected shape, bending moment and shear force diagram

The doorset and lock plate was simplified to understand the structural behaviour of it and how strengthening the components made by the Company would reduce effects on the lock plate.

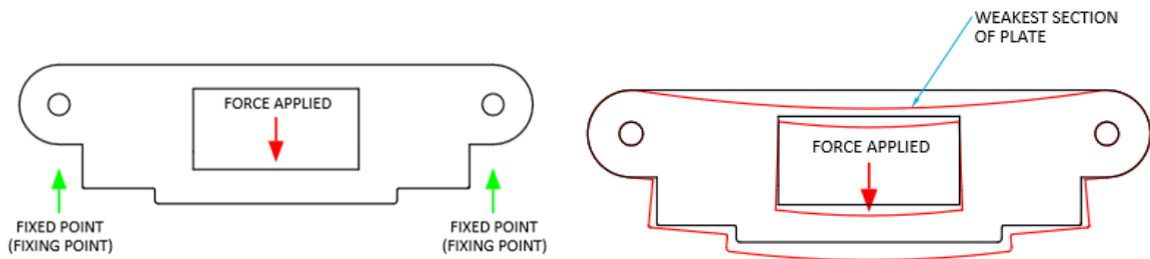


Figure 195 - Understanding failure of lock plate

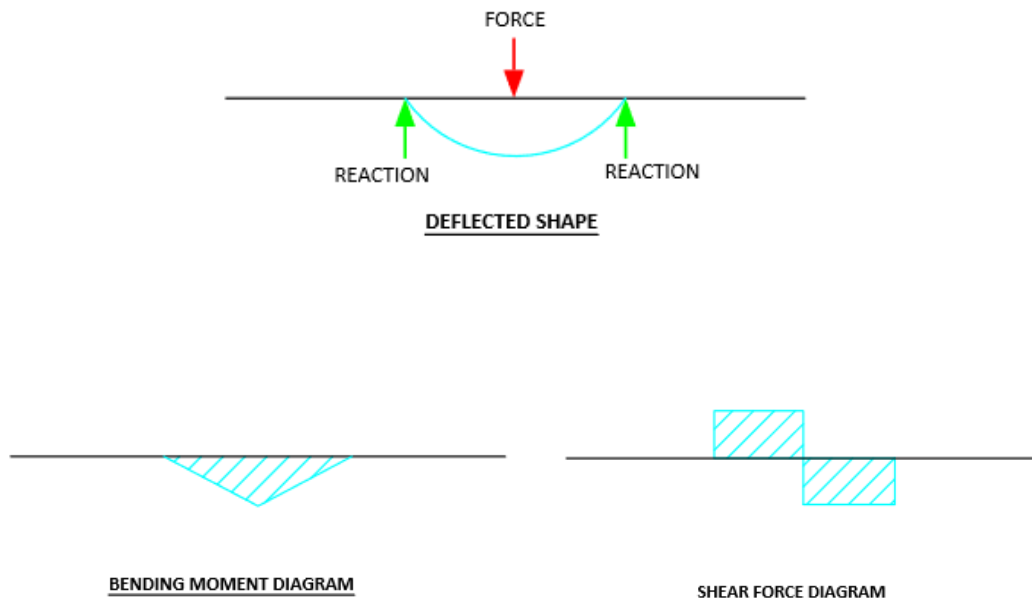


Figure 196 - Structural Behaviour of lock plate

The weakest part of this component is the small section of material, spanning above the cut out where the locking system latch engages. This is due to the decrease in the material depth compared to where the plate fixes to the mount plate and is the part of the latch likely to fail when the load is applied to the door.

The lock plate is situated inside the door frame with the MICO latch locking plate bolted to the inside face of the door frame. By undergoing factory testing to test the capacity of the lock, it was observed that the MICO lock plate failed by bending out of place. It was apparent that the locking system arrangement needed to be made stronger and aspects of the new design procedure was used to complete this.

8.5.2 FEA

The method of failure noted whilst undergoing testing was the latch plate deforming when the load applied increased. As discussed, the aim of this re-design was to improve the strength of the door and plate in this area to increase its resistance to the forces applied.



Figure 197 - Analysis of failure of lock plate

A 3D model of the MICO lock plate was created to mimic the plate as a 3D model. FEA was undertaken on the plate to analyse the stresses, strains and displacements undertaken after a force is applied onto the MICO plate.

The limitations of using the software to analyse this was that, it stayed within its elastic region and didn't show the past this point of analysis. The welds used to secure the bracket within the frame cannot be replicated but only represented as a fixed point instead. This may make the model stronger than real life situations. The simulation software also doesn't take into account the shear of the fixings when a load is applied. This may be the case with an improvement in the strength of the plate the weakest section may now be the fixings which would fail first.

The assumptions made using the software are that the part will return to its original length/size when the load is removed. For this not to happen the non-linear analysis would be required. The other assumption is that the loads are applied gradually until reaching their maximum value. This may not accurately represent the force being applied as one full hit much like it would during the testing.

Analysis of the current part was completed to identify the weakest points of the part. This was completed by using a feature in the simulation programme that highlighted the areas that were past the yield point – this is the weakest points of the part as it is past the elastic limit and therefore, failing by bending and then buckling out of the frame.

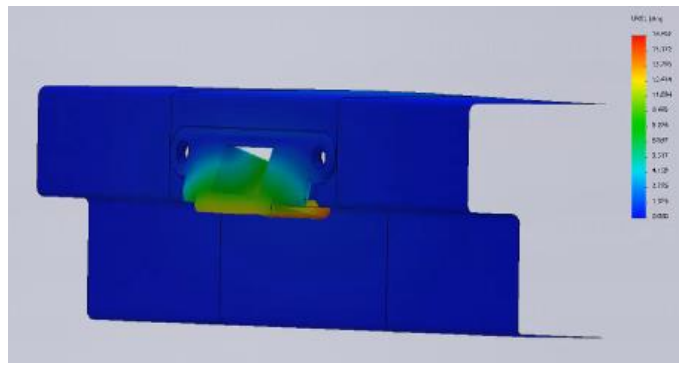


Figure 198 - Simulation of lock plate analysis – current plate

8.5.3 PROTOTYPES – SOLIDWORKS ANALYSIS

Analysing the FEA results from the current part were as expected, mimicking the behaviour described in the deflection plots bending moment diagrams from the simplification process at the start of this chapter. The locking plate displaces away from the frame when the load is applied and bends.

This can be reduced by enhancing the strength of the lock plate in the inside of the door frame, the bending moment would be reduced and in turn make the latch plate more secure.

The part is currently made from the thinnest material gauge possible (3mm), so it was not possible to increase the material thickness of the plate to increase the stiffness of the component. It was thought that by the addition of two gussets to the inside of the lock plate, would increase the stiffness of the mount plate by reducing the distance between the fixed supports.

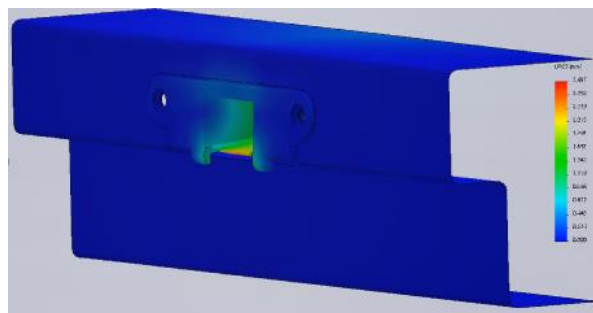


Figure 199 - Stress Plot of lock plate analysis – new plate

8.5.4 RESULTS

To increase the stiffness of the bracket additional plates were welded into the plate as either side of the cut out. This will in theory reduce the bending moment within the bracket due to the introduction of the additional reaction forces from the welded plate.

The bending moment diagram, shear force diagram and expected deflected shape can be seen in Figure 200.

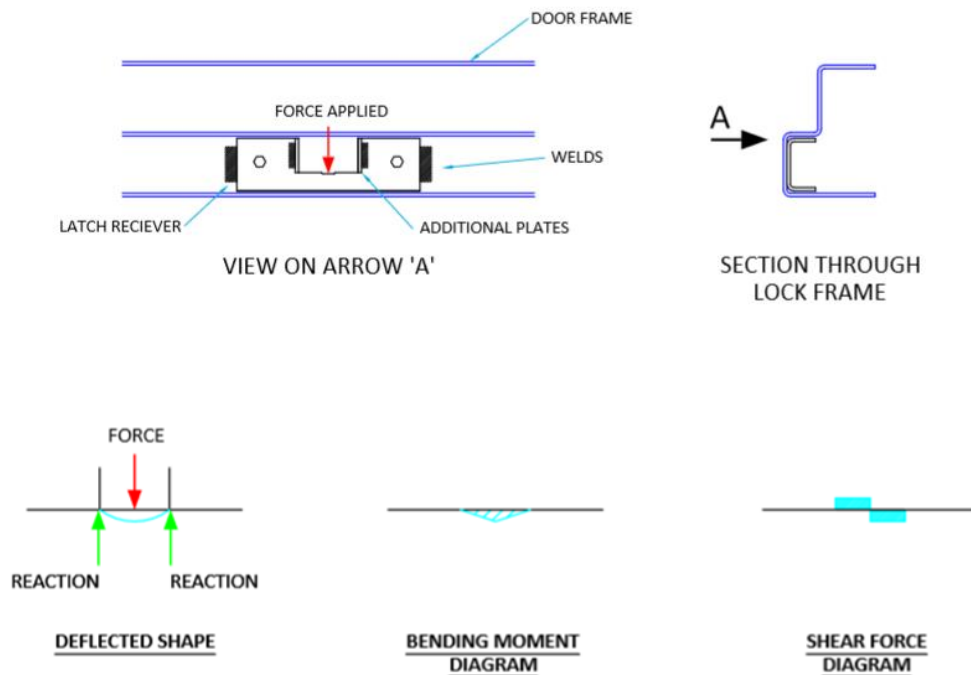


Figure 200 - Deflected shape, bending moment and shear force diagram

From the diagrams it was expected that these plates would half the bending affect that the latch has on the mount plate, in turn increasing the strength of the doorset.

The new design bracket was modelled using the 3D package and then subjected to the same forces as the current design. It was found that it was x8 stronger due to the displacement measured only being 2 mm as opposed to the 16 mm.

8.5.5 FACTORY TESTING

Factory testing on a doorset with the modified MICO lock plate was undertaken. The aim of this testing was to obtain the capacity of the lock to identify if the modified plate contributed to the strength of the locking arrangement. The lock capacity testing was completed with the same test methodology as stated in the previous chapters of this Thesis with the only difference being the presence of the MICO lock plate. The new prototype with the new lock plate assembly was manufactured in the factory and was then tested following the lock capacity testing to evaluate if the new lock plate contributed to the strength of the doorset when being subjected to controlled forces. The breakdown of this testing is laid out in Chapter

6. The results of the factory testing concluded that there was an increase in strength of 12% as well as the capacity of the lock increasing.

8.5.6 COST ANALYSIS

A cost analysis of the current part was completed to identify how much it costed the Company to make and to compare the updated part afterwards to assess if the updated part is commercially viable for the Company.

It costs £42.39 per sheet of 3mm Mild Steel and 182 of the current lock plates can be fitted on one sheet of the 3mm Mild Steel. Therefore, it costs £0.23 per part to make currently.

A cost analysis was undertaken on the new prototype to see if it was feasible to increase the cost of the product. It was known that from a 3mm mild sheet, the lock plate can fit 182 plates on the sheet. It is possible to cut 178 of the brackets with the wastage of the sheet which saves the cost of creating the part on a separate sheet. The cost of the two brackets which are needed per part is £0.48, increasing the part to £0.71, with an addition of £0.96 for labour, the new total cost of £1.67. With the overall price of a doorset being around £1100 including the locking arrangement, the overall increase in cost is only 0.13% of the product cost with an increase in the lock capacity of 12.5%.

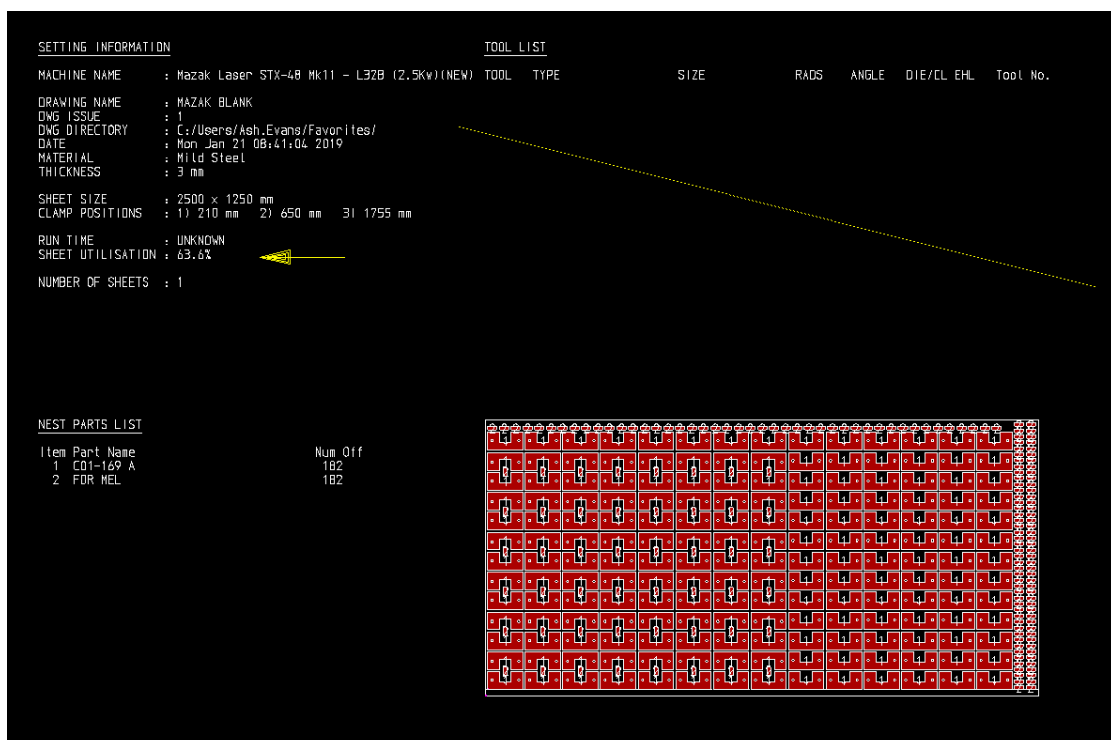


Figure 201 - RADAN Capture

8.5.7 PROPOSE WORKFLOW

The proposed design process is shown through a flow chart in Figure 202. This involves all of the steps documented in this chapter to improve the efficiency and effectiveness of the new design process.

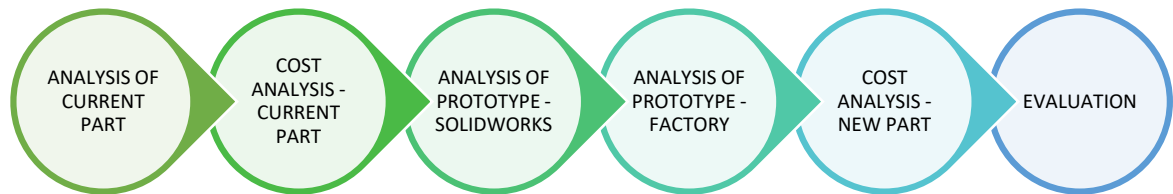


Figure 202 - Proposed workflow of lock plate

8.5.8 SUMMARY

When testing the lock capacity of the doorset with the old lock plate, a force of 42 kN was documented when the doorset was open. When testing the lock capacity of the doorset with the new lock plate designed, it reached a force of 48 kN and increase in strength of 6 kN or 14%. The lock plate has been analysed and strengthened effectively, increasing the cost of the product by only 0.13% but with an increase in the lock capacity by 12.5% showing the effectiveness of the new increased engineering logic used.

8.6 NEW DESIGN PROCEDURE

Following the research and investigations detailed in previous chapters, it was determined that a new design procedure could be created to link the four main methodologies set out in this thesis together making them most effective.

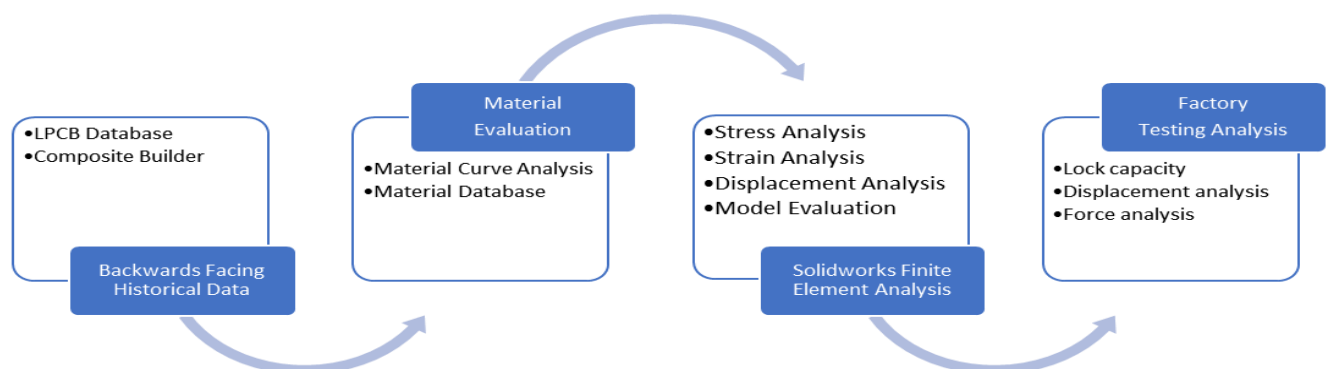


Figure 203 - Main Four Methodologies

The methodologies are compatible and effective when used together but have limitations when separated.

BACKWARD FACING HISTORICAL DATA

The historical data is limited to testing which has been completed by the Company and is a tool designed to make the best use of the historic data available important because of the large number of previous tests. This tool would not be effective or possible without the previous test data.

MATERIAL EVALUATION

The material database is limited in that it can only evaluate the material properties of materials used by the Company. It could be expanded and improved by the addition of further materials.

SOLIDWORKS FINITE ELEMENT ANALYSIS

As the Solidworks FEA package user interface is easy to manipulate, engineering knowledge isn't needed to complete a FEA test which can generate invalid results. A limitation is that the designer is solely reliant on the software and it is difficult to validate the results by other means. This limitation can be eliminated by employing theoretical hand calculations before using the FEA software to obtain values and diagrams of expected results.

FACTORY TESTING ANALYSIS

The limitation of factory testing is that it is costly to undertake pre-tests on prototypes without a complete evaluation of the prototype which would increase the development time of the product. The tool should be used in conjunction with the results of FEA which should be completed prior to factory testing to establish if the design is structurally sound and the cost of producing a prototype is viable.

The methodologies need to be linked together in a way which integrates into the company's workflow regardless of whether it is a security product or a non-security product. A workflow was created to show the typical procedure that needs to be followed, with consideration given to pathways if there was a failure in a main analysis step and detailing how documents would be stored in the system.

8.6.1 PRODUCT SPECIFICATION SHEET

A new product design specification sheet was designed which needs to be completed at the beginning of the design process, when designing a new product or making a modification to a new product. This was to include aspects of engineering that hadn't been previously included and to be able to mitigate risks that would hold up the design. It should also identify the standards that needs to be adhered to right from the start of the project.

REV 1.0	
NEW PRODUCT SPECIFICATION SHEET	
PRODUCT TITLE:	
TYPE OF PRODUCT:	
PRODUCT MODIFICATION OR NEW PRODUCT DESIGN:	
MARKET FOCUS:	
REQUIRED FOR TENDER/QUOTE:	
PROJECTED DATE REQUIRED:	
EXPECTED PRODUCT SIZE:	
EXPECTED PRODUCT WEIGHT:	
EXPECTED QUANTITY:	
EXPECTED PRODUCT AESTHETICS/FEATURES:	
TESTING REQUIRED:	

Figure 204 - New Product Specification Sheet (Part 1)

REV 1.0

SKETCH:
H&S, REGULATORY/ENVIRONMENTAL ISSUES:
PRODUCT SERVICE LIFE:
STANDARDS NEEDED TO ADHERE TO:
MARKET RESEARCH:
SIMILAR PRODUCTS AND COMPETITORS:
POTENTIAL CUSTOMERS:
TARGET PRICE:
OUTSOURCING REQUIRED:
MATERIAL REQUIREMENTS:

Figure 205 - New Product Specification Sheet (Part 2)

REV 1.0

MANUFACTURING PROCESS REQUIREMENTS AND LIMITATIONS:
FINISHES NEEDED:
PRODUCT CODES:
PROTOTYPE TESTING:

Figure 206 - New Product Specification Sheet (Part 3)

8.7 LPCB PRODUCT

This is the workflow for modifying or creating a new security product that has to undergo LPCB testing. This focuses on the integration of prototype testing on the product.

8.7.1 TOOL CATEGORY MATRIX

Due to the change in Issue 8, analysis needs to be carried out into whether the product will be evaluated by LPCB using the Issue 8 tool categories or whether only certain tools and times will be tested. A decision will be made based on whether the product is being modified or a new product is being created. By using the tool category matrix, an appreciation of the types of tools in the tool categories are shown and an immediate understanding of the types of tools that the product needs to combat can be determined.

8.7.2 LPCB TESTING DATABASE

The next part of the process is to use the LPCB database to understand whether there is any historic testing that can be used to predict the times taken to attack the product. This can be completed by searching for the materials used in the product, objectives, time restrictions etc. By being able to locate historic test data, there is a high chance that LPCB may accept that there is already test data for some of the attack actions on the product and not require these tests to be completed again. This would reduce the testing time by LPCB and more importantly, reduce the cost of the testing.

NO PREVIOUS DATA - ESTIMATE TIME FOR EVALUATION

If there was no previous data for the composite in question, the materials in the composite would be broken down and analysed in the database to determine if there is historic testing that can be included to predict the time taken for LPCB to attack the product through the use of the time builder.

PREVIOUS DATA - COMPOSITE EVALUATION

If there was previous data of the composite in the LPCB database, an investigation into how the product had behaved in previous testing could be established.

8.7.3 MATERIAL EVALUATION

The next step in the design process involves checking the material database to analyse the materials used in the product.

CURRENT MATERIAL USED

If a current material is used, no further evaluation is required as the material database will have all the relevant material properties and curves for that material.

NEW MATERIAL

If a new material is chosen for inclusion in the product, an evaluation of that material will be undertaken by using the material database and comparing the data on its material datasheet to similar materials tested at Technocover where possible. If this produces successful results, a material curve would be created in the Solidworks material library using the information from the datasheet.

The properties of the new material will be input into the material database to expand the data in the database. It has been determined that analysing the material using the material database and comparing its material properties is much more efficient than having the material tested at LPCB. If there is no previous data to compare the material to, for example if it is a fibre composite, then indicative testing will need to be completed at LPCB to identify the housing of the composite.

8.7.4 CREATE SOLIDWORKS MODEL

Once the material properties are evaluated, the next step of the procedure is to create a 3D model of the product on Solidworks. This is to visually illustrate how the product is going to look.

8.7.5 SOLIDWORKS ANALYSIS - FEA

The model may need to be simplified to test the main parts of the product which will in turn, assess the structural integrity of the product.

The relevant boundary conditions and loads will be used to investigate the product and the results will show its weakest points. If any modifications are required to the product, re-modelling will be completed on the product and then re-tested using FEA to evaluate the differences in results. This stage will be completed until the product designed is fit for purpose and that it is as economical as it can be, as well as complying with the relevant standards and requirements.

FEA allows value engineering to take place on products to identify the minimum thickness, lowest weight or the cheapest method of manufacturing a product due to its ability to test various prototypes using the software before making them in the factory. Advice may need to be sought from the manufacturing factory to understand the capabilities of the machinery used to make the products. This step in the procedure minimises the indicative prototype testing in the factory which takes time to complete and has associated costs. The aim would be to reduce the number of prototypes as a prototype would only be created to ensure the manufactured product was compliant.

A flowchart was created which highlighted the main steps required to effectively create a simulation model in Solidworks. This flow chart shows how complex the modelling process of the simulation is and provides tips to create an accurate model. This has been trialled by members of the design team and has been updated so that they are prompted when running a simulation.

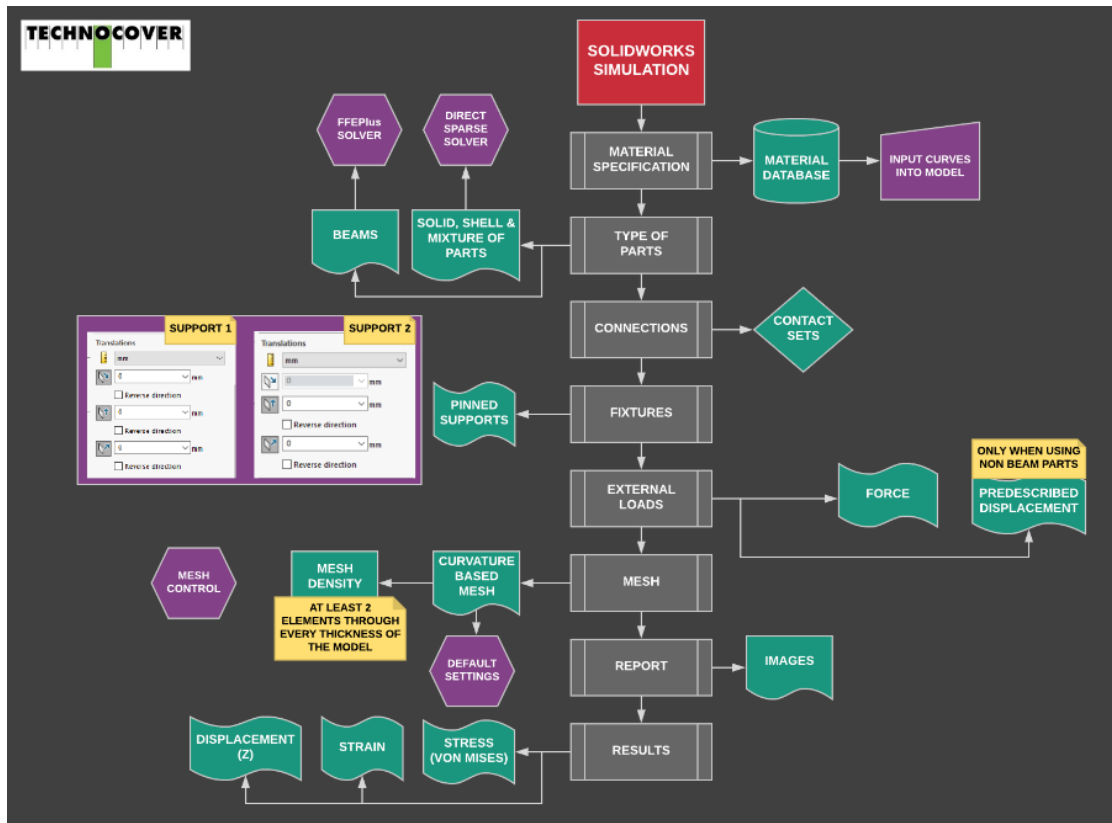


Figure 207 - Solidworks Simulation Process Flow Chart

8.7.6 CREATE PROTOTYPE IN FACTORY

A prototype is developed in the factory to allow an investigation into the manufacturing of the product. For a security product, further factory testing is needed to assess the integrity of the product in preparation for security attack testing.

8.7.7 FACTORY TESTING

The type of product and the aim of the testing needs to be known at this stage. There are various types of testing that can take place using the rig set up in this thesis. Evaluation of the equipment and the rig needs to take place to identify the limitations of the equipment such as the maximum load, and to ensure that the testing can take place without the purchase of more sophisticated equipment.

Once the aim of the product is known, an evaluation into the components requiring testing is undertaken. An overview into the fixed points of the product and the restrained points needs to be undertaken as this will allow for the boundary conditions to be understood. This is followed by an evaluation of the capacity of a lock, hinges, displacement analysis or load analysis. The lock variation table was created for the product doorsets and breaks down the boundary conditions of the doorset when analysing the locking arrangement of the doorset.

By breaking down the boundary conditions of the prototype being tested, analysing the forces applied, the supports which are fixed, pinned, roller or free, a test can be formed to mimic the real-life conditions of the prototype. A selection of factory testing methodologies has already been created detailing the steps required to undergo testing and indicating which data needs to be captured. It has also been determined that all testing should be recorded via video recorder to visually analyse the testing after the test has taken place.

8.7.8 ACTUAL LPCB TESTING

After completing the analysis of the historic LPCB testing, material evaluation, FEA and the factory testing, the next step would be to have the product tested at LPCB. If there was previous historic data present (as shown in the database), it would be included in a report and taken to LPCB for their approval of the test data present from historic data. The prototype testing allows for the product to be evaluated by analysing the engineering of the product rather than allowing LPCB to test prototypes. The LPCB testing should be recorded via video recorder to analyse this test data after the testing has taken place. It is noted that by advising LPCB to obtain individual times for penetration through every material (if possible, on certain attack tests), gaps within the database for material analysis can be filled which can be used when analysing the material in different composites.

8.7.9 CREATE LPCB DESIGN PACK

If the product passes the LPCB testing, the next stage of the process is to create a manufacturing drawing pack for the product which will instruct the factory how to make the product. If the product passes the assessment at LPCB, documentation relating to the testing, along with a certificate from LPCB will be provided to confirm the security level the product has obtained.

This procedure was created by the author and compiled into a flowchart and is set out in Figure 208.

8.8 NON-LPCB PRODUCT

If a new product needs to be designed which doesn't require LPCB certification, a similar methodology can be created encompassing some of the procedures in the LPCB procedure such as the material analysis and the FEA of the product. These procedures should be completed regardless of whether testing is required at LPCB or not due to the savings in effort, resources and time. The new methodology can be adopted for any type of product including non-security products designed by the Company.

The flow chart in Figure 209 highlights the steps that are required.

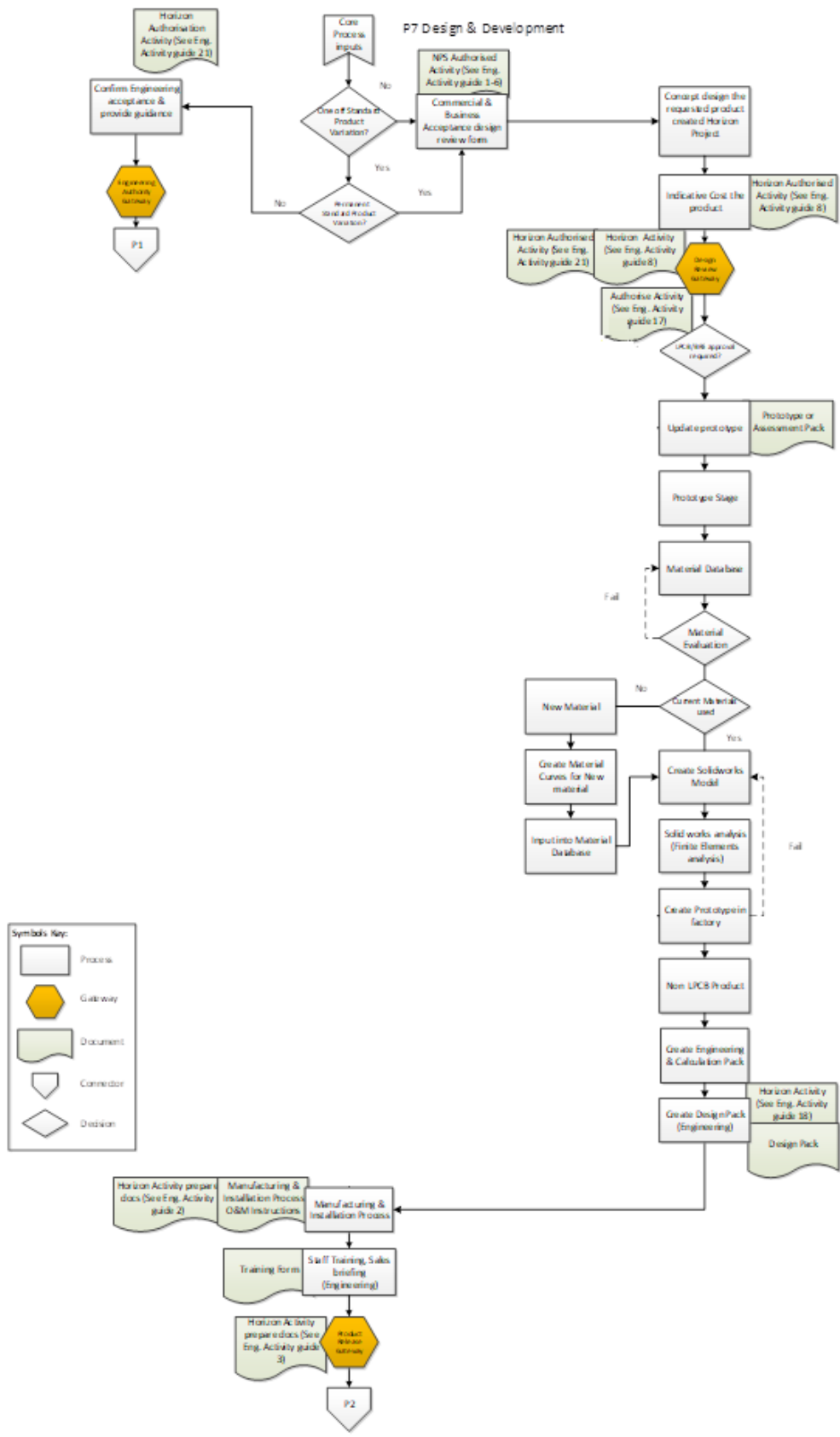


Figure 209 - New design procedure flowchart (NON LPCB route)

COMPARISON OF CURRENT AND NEW DESIGN PROCEDURE

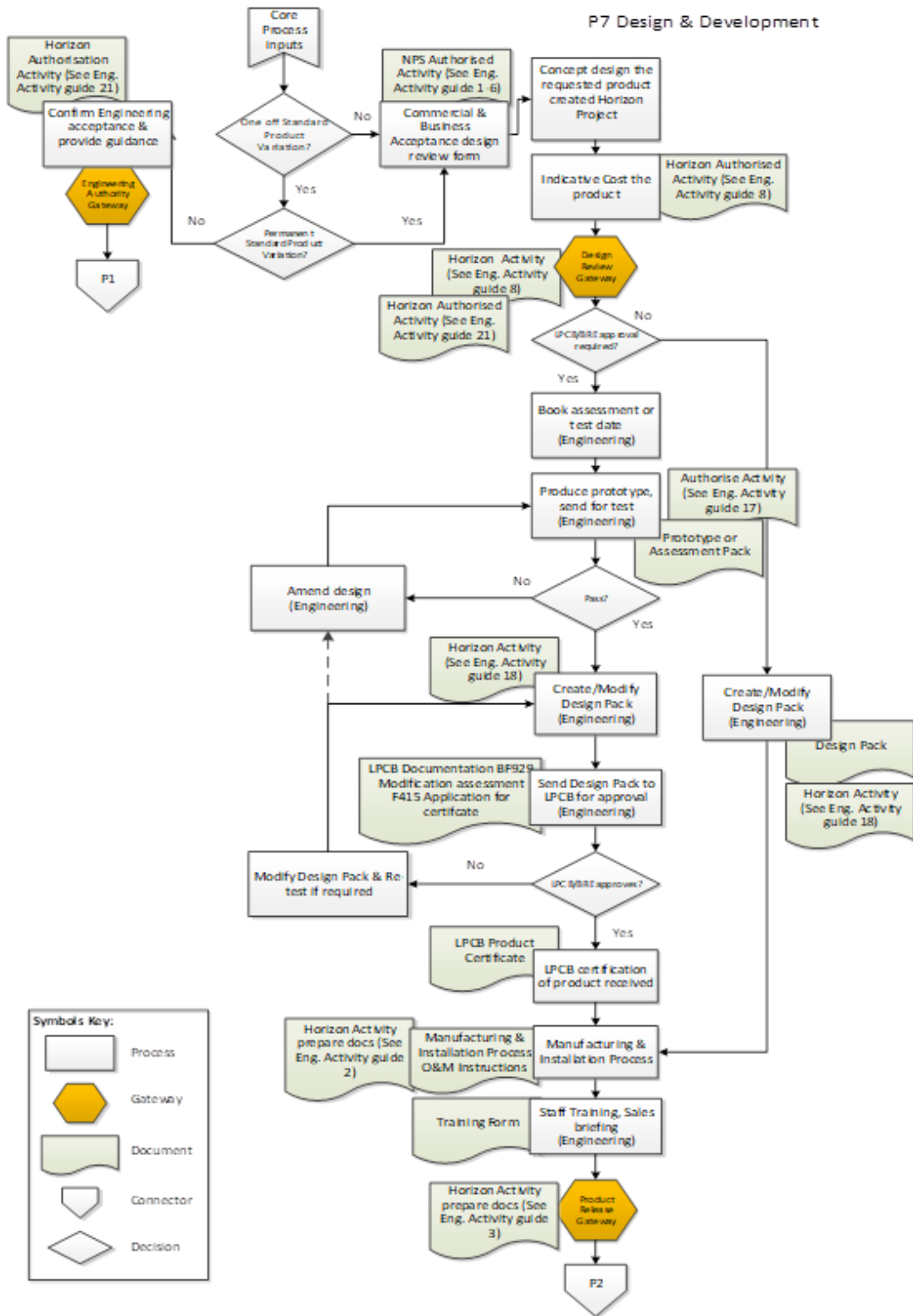


Figure 210 - Old Design Procedure

Figure 211 shows the process that Technocover had adopted of booking a test date at LPCB and then sending the prototype to LPCB to be tested once manufacturer. This emphasises the

author's point of the need of creating additional prototype testing in terms of the design procedure set out in this Thesis.

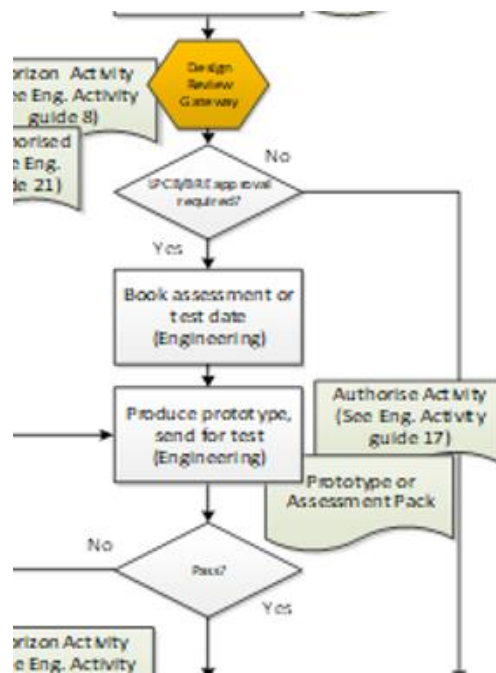


Figure 211 - Prototype Testing from Old Design Procedure

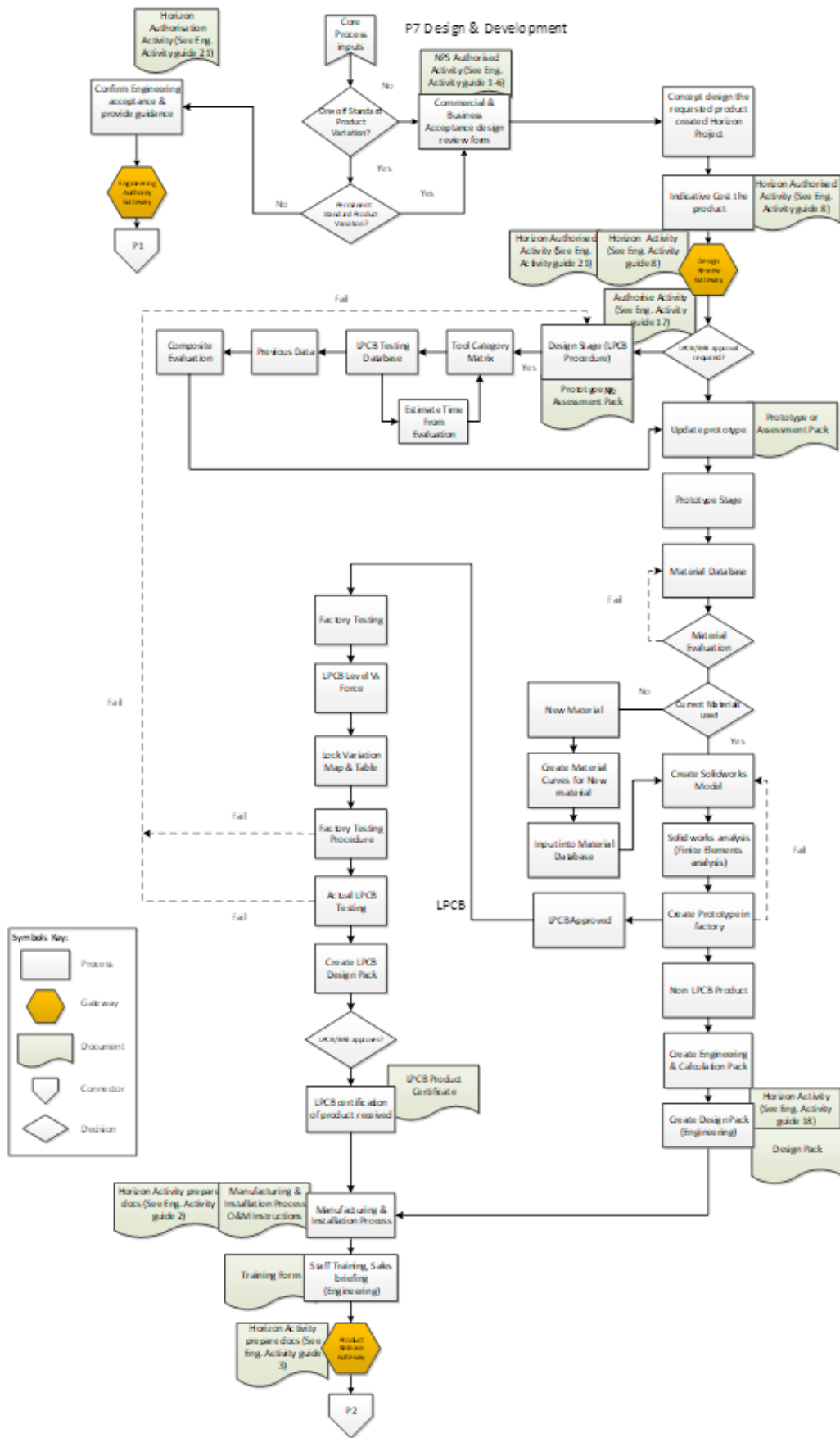


Figure 212 - New Design Procedure

8.9 SUMMARY

The new design procedure has 4 main core processes:

1. LPCB historic data
2. Material Evaluation
3. Solidworks FEA
4. Factory Testing

This procedure implements core processes with the overall aim to test the structural integrity of the prototype before testing at LPCB. By using the core processes, LPCB resources are reduced and in turn money is saved.

By developing the new procedure, it eliminates the dependence on tacit knowledge at the Company and increases the success rate of physical testing. This in turn can increase the Company's competitiveness in existing markets and has the potential to reduce a single test programme cost by up to 40%, delivering an overall minimum saving of 60% of the LPCB testing cost for a year.

The author concludes that the proposed methodology is a viable option for use by Technocover. Case studies were used to demonstrate the effectiveness of the new methodology and the results were validated against known test results. For each of the case studies the results from the new methodology concurred with the available results. In conclusion it is considered that the proposed new methodology would be effective in the design of a new product.

CHAPTER 9

9 CONCLUSIONS

The primary aim of this thesis is to create a design methodology that increases the likelihood of a new security product passing an LPCB attack test. LPCB state that they have a 95% first-time failure rate for security products being tested. This identified a requirement to introduce a new methodology to enable designers and manufacturers to complete more advanced prototype testing on new products prior to submitting them to LPCB for assessment.

There is an identified need for the physical security of assets which is critical to the national infrastructure of the country. Public and private organisations are seeking to incorporate higher levels of security to protect their assets and protect the country from terror attacks and prevent unauthorised access to critical assets.

Research was conducted into the different government standards which companies can utilise to undergo physical testing regimes. The author determined that each standard had their own advantages, and each adopted a variety of approaches and conditions to be followed. EN 1627 allows the manufacturer of a product to carry out in-house testing without the need for external bodies whereas LPCB's LPS 1175 standard requires the manufacturer to undergo physical attack tests on a product following set rules and standards all undertaken by external bodies. On completion of the attack testing a full manufacturing pack is submitted for assessment prior to certification being granted for the product.

LPS 1175 was chosen as the preferred standard due to the comprehensive nature of its test regime. The standard is constantly being evolved and updated to match emerging security threats stemming from the increased availability of tools to attackers and evolving attack methodologies. The standard has the added peace of mind and security that comes with third-party verification, requiring all products submitted to be tested against this standard to follow and pass the same goals regardless of the manufacturer. The high failure rate of 95% for first time testing shows its complexity and demonstrates the attention to detail required to achieve compliance with LPCB standards.

By choosing to follow this standard, it was recognised that the physical attack testing logic and reasoning needed to be completely understood. This involved examining the

terminologies used, the methods used to attack the products, the tools available and revisions to the LPS 1175 standard. This comprehensive analysis allowed the overall testing process to be inspected and understood, to establish how best to improve the design process to meet this standard.

Research has been undertaken to investigate the methodologies currently in use within engineering. Materials and software analysis can effectively be applied to evaluate the integrity of a product prior to the physical attack testing, making it more sophisticated. A literature review was conducted to evaluate the current research in the field.

The threats vs security level of the products was determined based on the tool kits and times available to the LPCB test attackers. It was shown that as the security rating is increased the greater the number of tools on offer to the attackers. This is a representation as to how critical the product being designed is to the overall security of a building, site or the country and who is likely to try and gain access through the asset.

The LPCB testing procedure was documented including an overview of all the limitations and guidelines to be followed whilst undergoing a test programme. This involved an overview of LPCB as a company, including where they started from and how they have evolved over the years. This helped to quantify all the attack methods in use and how these have evolved with the introduction of new tools. The tool categories were broken down and linked to the relevant security levels to determine what tools are at their disposal when attacking the new product being designed. Technocover had a vast amount of previous test data from its 25-year history which wasn't being used to its maximum potential. A database was created to record the data, which could be searched and manipulated to aid product design. The database can be used to demonstrate criteria for previous product failures, where materials have overcome certain attack tests and identify gaps within Technocover's testing knowledgebase.

An investigation into material properties was undertaken for all materials in use by the company, to determine if material properties can be used to combat certain LPCB attack methodologies. The main properties that were researched and tested for were:

- Hardness
- Tensile Strength
- Young's Modulus

It was found that the hardness correlates to the drill attack tests; the higher the hardness value registered the greater the time needed to complete a hole through the material, however increasing the hardness makes the material more brittle. Tensile strength and Young's modulus can be linked to attack testing involving levering and impact forces. A breakdown of the product was undertaken and is part of the procedure to identify the product's boundary conditions such as how it is connected, where external loads are applied, whether external displacements are applied etc. By sketching the forces out and creating bending moment and shear force diagrams, the typical behaviour of the product can be established. The deflected shape of the product is created to understand how the product will fail. This facilitates a comparison of factory testing against the Solidworks simulation and confirms the assumptions made when breaking down the product. The 3D modelling software can be used to keep all elements below their yield stress values and within the elastic range.

A materials database was created which compiles all the material data and facilitates the reduction of indicative testing days at LPCB in situations where the material has previously been tested by LPCB. In scenarios where there is no historic test data, a time builder can be used to predict the time taken to breach the materials used to compose the product. If this methodology had been implemented for the last test programme undertaken by the company, it would have reduced the testing cost by £10,000; the equivalent of 4 days of testing at LPCB.

If a material hasn't been tested by LPCB, the material database can be used to compare the material properties of the potential material to materials with similar material properties for which there is previous test data. This can save valuable resources in the form of material wastage, manpower and test costs by eliminating tests on materials with properties which are inadequate based on the test results of materials with similar material properties already held on record. This has been completed as a case study with positive results, eliminating the need for LPCB to test if there is historic testing present for the Company.

Material curves can be derived from the results of material analysis which can then be manipulated and input into the Solidworks material library further increasing the accuracy of the simulation results produced.

Following extensive research into material techniques, a methodology to determine the properties of materials was established which involved a series of tests devised using the most optimum techniques. After the material's behaviour was characterised, the results were used

to evaluate the positioning of the material to predict how it is likely to behave under certain physical security attack tests. This provides a basis for devising the optimum position in which to place materials when designing new products.

It was possible to identify the safe working regions of materials by analysing material behaviour and producing data and graphs to visually illustrate the behaviour when force is applied. This is a benefit to the procedure as these safe working regions are what the tests on the software are completed to

- To perform stress analysis via computer simulation
- To perform displacement analysis via computer simulation

By developing a solution-based database the initial product selections and pre-identified solutions have been expedited.

A method to assess the performance of structural design was implemented at the start of the design process to evaluate the boundary conditions and relate to the real-life testing that is being mimicked. To test for the lever attack test on the doorset, by analysing the displacement of the doorset using wedges at LPCB, steps can be taken to evaluate the product. The stiffness of the door leaf was completed, and the force displacement graphs were created using testing within the factory compiled with the data from the LPCB Testing. A bending moment diagram was created analysing the limits of the doorset. This was validated both in the factory and at LPCB.

The new procedure eliminates the dependence on tacit knowledge by developing and digitally simulating new product development, thus increasing the success rate of physical testing. This in turn can increase the company's competitiveness in existing markets and has the potential to reduce a single test programme cost by up to 40%, delivering an overall saving of up to 60% of the LPCB testing cost for a year.

An updated design procedure has been introduced to the company following the completion of the material testing and digital simulation of the design and testing process. The primary aim of this new procedure is to identify fundamental failures, including flaws in the strength of components and structural integrity of products prior to starting LPCB testing. This is achieved by introducing the following steps in the design of a new product:

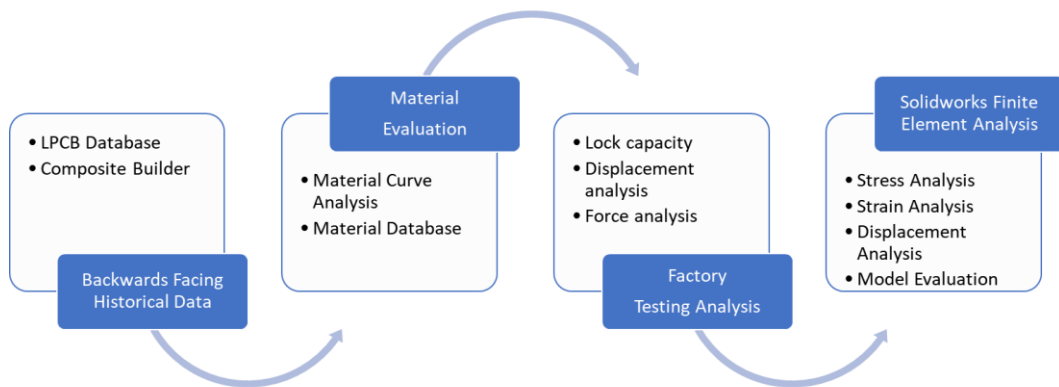


Figure 213 - New Design Procedure

The overall outcome of this new procedure is a significant saving in product development costs by reducing the number of LPCB tests required. LPCB testing currently forms more than three quarters of the product development cost at the company, this reduction in testing costs can be a strong driver for other companies to adopt the new design procedure.

The proposed methodology was tested on a selection of small case studies to review its effectiveness which was successful, increasing the strength of the capacity of products. If this methodology is implemented at the start of a new design process, a greater benefit can be shown.

To improve the success rate for attack testing of security products, the design procedure was designed and implemented. This procedure uses retrospective data analysis and Finite Element Analysis (FEA) to evaluate how the components of each product will behave under certain conditions. Independent testing was completed using FEA, LPCB testing and prototype testing to verify that the new design procedure produced valid results.

The new design procedure was created to devise the most optimum method of testing products to a high standard. The procedure originally focused on security rated products but has since been applied to non-security rated products with results which are just as effective. The non-security rated products focused on evaluating material behaviour and simulation of the prototypes on Solidworks, followed by prototype testing in the factory. The procedure encompasses all the relevant engineering knowledge to create a product that has been value-engineered.

By creating and implementing the new design procedure, the overall physical testing cost is shown to be reduced by 42%, by reducing the overall number of actual LPCB test days required, therefore reducing the cost to market. With the implementation of the new design procedure it is possible to research and develop products within a shorter timescale, bringing about a reduction in the overall test process by 3 weeks.

A detailed analysis of the procedure for creating an LPCB product and undertaking a physical security attack test was carried out to identify how to increase the likelihood of passing an LPCB attack test.

As part of the FEA the physical attack testing was halted after certain periods to record the displacement of the product. This was outside of LPCB's normal routine and was trialled to determine its effectiveness for the company. The data has been used in FEA tests to predict the outcome of future tests.

CHAPTER 10

10 FURTHER WORK

To further this work, processes can be produced, and tests created to improve the design process and reduce LPCB testing costs can be expanded and developed for further types of security products produced by the manufacturer. As a Company Technocover has the greatest array of security products on the market producing the following products:

- Upstand access covers
- Flush access covers
- Mesh cages
- Mesh Panels
- Cylinder clamps
- Walk in buildings
- Cabinets
- Window Bars
- Doorsets

Test data for each of the above products has already been gathered and input into the materials database created as part of this project. These tests can be analysed and broken down into simple form to determine the supports for each product and where loads are applied for each type of attack test.

To allow the work to expand to different products, factory testing will need to be developed to replicate the complete range of attack actions and objectives used by LPCB. Specialist test rigs and locations in the factory could be established to facilitate the development of prototypes and complete the appropriate test regimes.

Research into further properties of materials will be required within the laboratory to build a complete profile for the materials used by Technocover. This can be developed to enhance more than just the security aspect of products:

- Density
- Electrical conductivity
- Thermal conductivity
- Corrosion resistance
- Formability
- Machinability

To expand the database, data can be added which details all the other testing previously carried out on the products manufactured by the Company. This testing, including fire testing, blast testing, ballistic testing and acoustic testing also costs a considerable amount of money and is undertaken to gain accreditations similar to the LPCB certification. A breakdown of the costs for each test regime can be seen below:

- Fire testing: £7500 per test day
- Blast testing:
- Ballistic testing:
- Acoustic testing: £500 per test day

To allow acoustic testing to be added to the database, further testing will need to be carried out in the laboratory to obtain the acoustic properties of all the materials in use.

There is potential for databases to be created for all LPCB's standards.

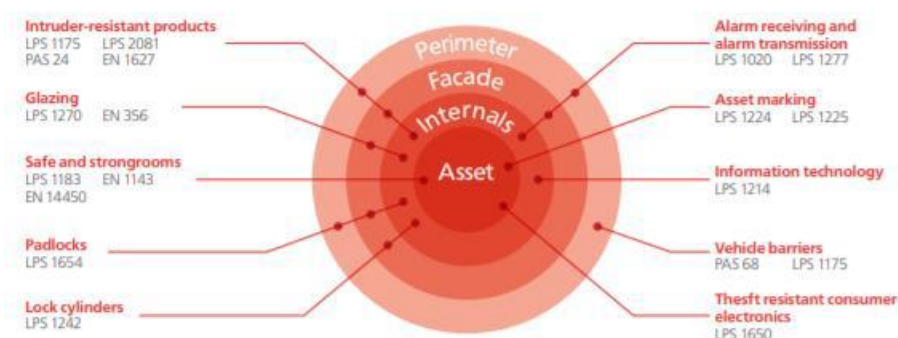


Figure 214 - LPCB Standards⁵⁹

⁵⁹ BRE Global. (2015). LPS 1175 – Requirements and testing procedures for the LPCB approval and listing of intruder resistant building components, strongpoints, security enclosures and free-standing barriers.

A further extension of this work could be the creation of a database containing data related to each locking system used by the Company, which can include the maximum loads applied before lock failure. The lock variation table could be completed and produced for every product manufactured by the Company. Many of these are secured via shoot-bolts and padlock arrangements, with hinges to open the products.

The lock variation tables detail the critical points on the products that secure multiple sections of each component or product together, allowing the breakdown of each product and its structural analysis.

The LPCB testing process can be further broken down detailing every tool in each category and the time limits set by LPCB. A calculation can then be done to predict which is the greatest risk to the product failing the LPCB test. As the latest Issue of the LPS 1175 standard allows for each tool category to be used for every time period, the biggest threat can be determined.

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12 APPENDIX

12.1 DATABASE

12.1.1 NEW REPORT GUIDE

This option is to be used when there is a new report which has been created for a new test from LPCB.

PROJECT NUMBER

The project number for the database will be the project number that has been given by LPCB – see highlighted section.

CHANGING THE PROJECT NUMBER

Note that the field size of the project number is restricted to 15 – if the project number is more than this, then follow the steps below to change the field size.

Go to Access Navigation Page → Tables → Attack Tests → Design view → Field name (Project number) → Click on Data Type (short text) → General → Field size → Increase the field size to the relevant amount of characters.



TYPE OF PRODUCT

This refers to the type of product that is classified in Technocover. There are 3 categories that categories that types of products;

- Above Ground
- Below Ground
- Building Hardening

However, the database compiles the products further into product types – this is so it is possible to search for all of one product e.g. access covers. The current categories are listed below.

- Access cover
- Barsets
- Building
- Cabinet
- Cage
- Doorset
- Flush cover
- Louvre
- Padlock

CHANGING THE PRODUCT TYPE

To change the product type, follow the instructions detailed:

Go to Access Navigation Page → Tables → Product Descriptions → Datasheet view → Add the next product ID number → Add the new product type (In capitals) → Save and close

PRODUCT NAME

The product name links to the name given on the LPCB report – see highlighted section.



CHANGING THE PRODUCT NAME

To change the product name, follow the instructions detailed:

Go to Access Navigation Page → Tables → Product Name → Datasheet view → The next product ID number will be automatically added → Add the new product name (In capitals) → Save and close

STANDARD REVISION

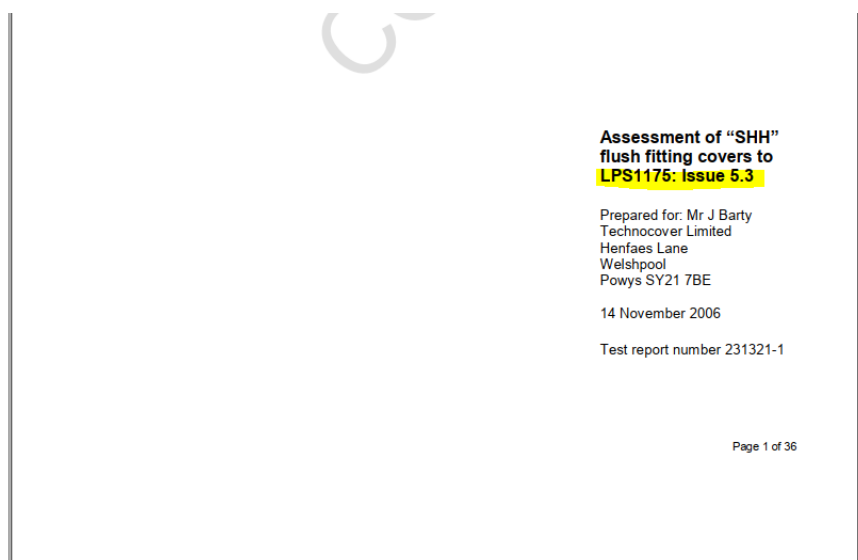
This refers to the revision of the standard LPS 1175. Currently there are 3 revisions; 5, 6 and 7. See the highlighted image below to identify the common places to find the standard revision. These standards vary with each other as they have different tool categories and tools in each standard. To see the change in variation, refer to the Tool matrix that was created (see details on how to get to the document).

Group → Research and Development → KTP Handover Documents → LPCB → Tool Category Matrix - Change in LPS 1175

CHANGING THE STANDARD REVISION

To change or add to the standard revision, follow the instructions:

Go to Access Navigation Page → Tables → Attack Tests → Design view → Field name (Standard Revision) → Click on Data Type (Number) → Look Up → Row source → Add new numbers to the row source – make sure to include a colon between each number.



ATTACK TEST REFERENCE

The attack test reference is given by LPCB to every test completed, linking the breakdown steps of that test together. It is either a letter or number normally – this isn't supposed to be unique but will link to the relevant BRE Project number and differ depending on the age of the report/standard revision. See images below with highlighted attack test references for examples.

The security rating of the product was determined by a series of manual intervention attack tests. The results of these tests are detailed below.

4.1 Exploratory data

Objective: Exploratory attack tests on the leaf to gain tool effect data

Test specimen: 231321/1

Tool category: C

	Method	Attack tools	Working time (min:sec)
E1	Drill 4 holes along a 40 mm span (Figure 11)	7.2V drill and 6 mm diameter HSCO drill bit	02:23.05
E2	Utilising lifting hole as a free cutting edge, create a 10 mm cut in leaf (Figure 12)	Cold chisel and club hammer	02:30.44

The permitted maximum test duration of 30 minutes was not exceeded during the tests.

Comments: An attempt to cut through the outer skin using the padsaw confirmed it was ineffective since the blade was easily bent during the attack.

Based on the above exploratory attack methods it was evident that there was insufficient time remaining to successfully complete the following test objectives:

1. Cut across entire leaf in order to isolate locking point and open leaf.

Attack test no.: **31** Date: 18 May 2010

Objective: Isolate tray hinges to open tray by driving a chisel into the gap between the tray and cabinet and cutting the hinge.

Test specimen: 259712/06 Locked condition: Optimum

Tool category: D Target security rating: 4

Attack action	Attack tools	Working time (min:sec)		Notes
		Increment	Running	
Insert tools into the gap at the bottom of the tray in increase access to the hinge.	Club hammer and steel wedge	00:23.44	00:23.44	-
Drill through the edge of one hinge plate.	12 V drill and 6 mm HSCO drill bit	01:04.34	01:27.78	Hole drilled through weld between the hinge plate and the hinge mounting plate as there was insufficient access to only drill the hinge plate. Hole drilled to maximum reach if drill bit.
Drill second hole through the hinge plate weld.	12 V drill and 6 mm HSCO drill bit	00:54.54	02:22.32	Hole drilled to maximum reach if drill bit.
Impact chisel into hinge plate weld.	Club hammer and cold chisel	01:48.15	04:10.47	Hinge plate weld cut to approximately 1/3 of its depth. Test halted.

Duration of attack test: < 30 mins Security rating achieved: 4

Comments: The test was halted after 4 minutes 11 seconds because it was evident that it would not

OBJECTIVE

This is the main objective of the individual test and is highlighted in the image. The objectives are typically repetitive but, in the case that the objective isn't present, follow the steps to add a new objective.

CHANGING THE OBJECTIVE

Go to Access Navigation Page → Tables → Objectives → Datasheet view → The next product ID number will be automatically added → Add the new objective → Save and close

The security rating of the product was determined by a series of manual intervention attack tests. The results of these tests are detailed below.

4.1 Exploratory data

Objective: Exploratory attack tests on the leaf to gain tool effect data

Test specimen: 231321/1

Tool category: C

	Method	Attack tools	Working time (min:sec)
E1	Drill 4 holes along a 40 mm span (Figure 11)	7.2V drill and 6 mm diameter HSCO drill bit	02:23.05
E2	Utilising lifting hole as a free cutting edge, create a 10 mm cut in leaf (Figure 12)	Cold chisel and club hammer	02:30.44

The permitted maximum test duration of 30 minutes was not exceeded during the tests.

Comments: An attempt to cut through the outer skin using the padsaw confirmed it was ineffective since the blade was easily bent during the attack.

Based on the above exploratory attack methods it was evident that there was insufficient time remaining to successfully complete the following test objectives:

1. Cut across entire leaf in order to isolate locking point and open leaf.

TARGET SECURITY RATING

Attack test no.: 31 Date: 18 May 2010

Objective: Isolate tray hinges to open tray by driving a chisel into the gap between the tray and cabinet and cutting the hinge.

Test specimen: 259712/06 Locked condition: Optimum

Tool category: D **Target security rating: 4**

Attack action	Attack tools	Working time (min:sec)		Notes
		Increment	Running	
Insert tools into the gap at the bottom of the tray in increase access to the hinge.	Club hammer and steel wedge	00:23.44	00:23.44	-
Drill through the edge of one hinge plate.	12 V drill and 6 mm HSCO drill bit	01:04.34	01:27.78	Hole drilled through weld between the hinge plate and the hinge mounting plate as there was insufficient access to only drill the hinge plate. Hole drilled to maximum reach if drill bit.
Drill second hole through the hinge plate weld.	12 V drill and 6 mm HSCO drill bit	00:54.54	02:22.32	Hole drilled to maximum reach if drill bit.
Impact chisel into hinge plate weld.	Club hammer and cold chisel	01:48.15	04:10.47	Hinge plate weld cut to approximately 1/3 of its depth. Test halted.

Duration of attack test: < 30 mins Security rating achieved: 4

Comments: The test was halted after 4 minutes 11 seconds because it was evident that it would not

Target security rating format – ‘SR_’

SPECIMEN

The security rating of the product was determined by a series of manual intervention attack tests. The results of these tests are detailed below.

4.1 Exploratory data

Objective: Exploratory attack tests on the leaf to gain tool effect data

Test specimen: 231321/1

Tool category: C

	Method	Attack tools	Working time (min:sec)
E1	Drill 4 holes along a 40 mm span (Figure 11)	7.2V drill and 6 mm diameter HSCO drill bit	02:23.05
E2	Utilising lifting hole as a free cutting edge, create a 10 mm cut in leaf (Figure 12).	Cold chisel and club hammer	02:30.44

The permitted maximum test duration of 30 minutes was not exceeded during the tests.

Comments: An attempt to cut through the outer skin using the padsaw confirmed it was ineffective since the blade was easily bent during the attack.

Based on the above exploratory attack methods it was evident that there was insufficient time remaining to successfully complete the following test objectives:

1. Cut across entire leaf in order to isolate locking point and open leaf.

TOOL CATEGORY

The security rating of the product was determined by a series of manual intervention attack tests. The results of these tests are detailed below.

4.1 Exploratory data

Objective: Exploratory attack tests on the leaf to gain tool effect data

Test specimen: 231321/1

Tool category: C

	Method	Attack tools	Working time (min:sec)
E1	Drill 4 holes along a 40 mm span (Figure 11)	7.2V drill and 6 mm diameter HSCO drill bit	02:23.05
E2	Utilising lifting hole as a free cutting edge, create a 10 mm cut in leaf (Figure 12).	Cold chisel and club hammer	02:30.44

The permitted maximum test duration of 30 minutes was not exceeded during the tests.

Comments: An attempt to cut through the outer skin using the padsaw confirmed it was ineffective since the blade was easily bent during the attack.

Based on the above exploratory attack methods it was evident that there was insufficient time remaining to successfully complete the following test objectives:

1. Cut across entire leaf in order to isolate locking point and open leaf.

TEST DATE

BRE Attack Test Results Sheets		BRE Project No: 258712A		
Attack test no.:	31	Date: 18 May 2010		
Objective:	Isolate tray hinges to open tray by driving a chisel into the gap between the tray and cabinet and cutting the hinge.			
Test specimen:	259712/06	Locked condition:	Optimum	
Tool category:	D	Target security rating:	4	
Attack action	Attack tools	Working time (min:sec)		Notes
		Increment	Running	
Insert tools into the gap at the bottom of the tray in increase access to the hinge.	Club hammer and steel wedge	00:23.44	00:23.44	-
Drill through the edge of one hinge plate.	12 V drill and 6 mm HSCO drill bit	01:04.34	01:27.78	Hole drilled through weld between the hinge plate and the hinge mounting plate as there was insufficient access to only drill the hinge plate. Hole drilled to maximum reach if drill bit.
Drill second hole through the hinge plate weld.	12 V drill and 6 mm HSCO drill bit	00:54.54	02:22.32	Hole drilled to maximum reach if drill bit.
Impact chisel into hinge plate weld.	Club hammer and cold chisel	01:48.15	04:10.47	Hinge plate weld cut to approximately 1/3 of its depth. Test halted.

LOCKED CONDITION

BRE Attack Test Results Sheets		BRE Project No: 258712A		
Attack test no.:	31	Date: 18 May 2010		
Objective:	Isolate tray hinges to open tray by driving a chisel into the gap between the tray and cabinet and cutting the hinge.			
Test specimen:	259712/06	Locked condition:	Optimum	
Tool category:	D	Target security rating:	4	
Attack action	Attack tools	Working time (min:sec)		Notes
		Increment	Running	
Insert tools into the gap at the bottom of the tray in increase access to the hinge.	Club hammer and steel wedge	00:23.44	00:23.44	-
Drill through the edge of one hinge plate.	12 V drill and 6 mm HSCO drill bit	01:04.34	01:27.78	Hole drilled through weld between the hinge plate and the hinge mounting plate as there was insufficient access to only drill the hinge plate. Hole drilled to maximum reach if drill bit.
Drill second hole through the hinge plate weld.	12 V drill and 6 mm HSCO drill bit	00:54.54	02:22.32	Hole drilled to maximum reach if drill bit.
Impact chisel into hinge plate weld.	Club hammer and cold chisel	01:48.15	04:10.47	Hinge plate weld cut to approximately 1/3 of its depth. Test halted.

SECURITY RATING ACHIEVED

Attack test no.: 31		Date: 18 May 2010		
Objective: Isolate tray hinges to open tray by driving a chisel into the gap between the tray and cabinet and cutting the hinge.				
Test specimen: 259712/06		Locked condition: Optimum		
Tool category: D		Target security rating: 4		
Attack action	Attack tools	Working time (min:sec)		Notes
		Increment	Running	
Insert tools into the gap at the bottom of the tray in increase access to the hinge.	Club hammer and steel wedge	00:23.44	00:23.44	-
Drill through the edge of one hinge plate.	12 V drill and 6 mm HSCO drill bit	01:04.34	01:27.78	Hole drilled through weld between the hinge plate and the hinge mounting plate as there was insufficient access to only drill the hinge plate. Hole drilled to maximum reach if drill bit.
Drill second hole through the hinge plate weld.	12 V drill and 6 mm HSCO drill bit	00:54.54	02:22.32	Hole drilled to maximum reach if drill bit.
Impact chisel into hinge plate weld.	Club hammer and cold chisel	01:48.15	04:10.47	Hinge plate weld cut to approximately 1/3 of its depth. Test halted.
Duration of attack test: < 30 mins		Security rating achieved: 4		
Comments: The test was halted after 4 minutes 11 seconds because it was evident that it would not				

Security rating achieved format – ‘SR_’

12.1.1.1 ATTACK DETAILS

This category details the Attack tests such as attack actions and total numbers of stages.

ATTACK TEST REFERENCE

4.6 Attack test 5: Leading edge

Objective: Lever leading edge corner

Test specimen: 231321/2 – Attack test was carried out on the passive leaf. The padlock on the active leaf was fitted adjacent to the hinge side of the passive leaf (Figure 15).

Target security rating: 3

Tool category: C

Method	Attack tools	Working time (min:sec)	
		Increment	Running
Force tools into leading edge corner, lever passive leaf until sufficient gap for scissor jack to be inserted.	Crow bar, club hammer, 14 mm square screw driver, tube, tyre lever and wooded wedges	00:38.35	00:38.35
Insert scissor jack and force leaf open (Figure 15).	Scissor jack	03:10.54	03:48.89

Duration of attack test: 10 minutes

Comments Full body entry was achieved using category C tools in 3 minutes 48 seconds (Figure 15). This result was largely due to the following:

OBJECTIVE

4.6 Attack test 5: Leading edge

Objective: Lever leading edge corner

Test specimen: 231321/2 – Attack test was carried out on the passive leaf. The padlock on the active leaf was fitted adjacent to the hinge side of the passive leaf (Figure 15).

Target security rating: 3

Tool category: C

Method	Attack tools	Working time (min:sec)	
		Increment	Running
Force tools into leading edge corner, lever passive leaf until sufficient gap for scissor jack to be inserted.	Crow bar, club hammer, 14 mm square screw driver, tube, tyre lever and wooded wedges	00:38.35	00:38.35
Insert scissor jack and force leaf open (Figure 15).	Scissor jack	03:10.54	03:48.89

Duration of attack test: 10 minutes

Comments Full body entry was achieved using category C tools in 3 minutes 48 seconds (Figure 15). This result was largely due to the following:

TEST SPECIMEN

4.6 Attack test 5: Leading edge

Objective: Lever leading edge corner

Test specimen: 231321/2 – Attack test was carried out on the passive leaf. The padlock on the active leaf was fitted adjacent to the hinge side of the passive leaf (Figure 15).

Target security rating: 3

Tool category: C

Method	Attack tools	Working time (min:sec)	
		Increment	Running
Force tools into leading edge corner, lever passive leaf until sufficient gap for scissor jack to be inserted.	Crow bar, club hammer, 14 mm square screw driver, tube, tyre lever and wooded wedges	00:38.35	00:38.35
Insert scissor jack and force leaf open (Figure 15).	Scissor jack	03:10.54	03:48.89

Duration of attack test: 10 minutes

Comments Full body entry was achieved using category C tools in 3 minutes 48 seconds (Figure 15). This result was largely due to the following:

TARGET SECURITY RATING

4.6 Attack test 5: Leading edge

Objective: Lever leading edge corner

Test specimen: 231321/2 – Attack test was carried out on the passive leaf. The padlock on the active leaf was fitted adjacent to the hinge side of the passive leaf (Figure 15).

Target security rating: 3

Tool category: C

Method	Attack tools	Working time (min:sec)	
		Increment	Running
Force tools into leading edge corner, lever passive leaf until sufficient gap for scissor jack to be inserted.	Crow bar, club hammer, 14 mm square screw driver, tube, tyre lever and wooded wedges	00:38.35	00:38.35
Insert scissor jack and force leaf open (Figure 15).	Scissor jack	03:10.54	03:48.89

Duration of attack test: 10 minutes

Comments Full body entry was achieved using category C tools in 3 minutes 48 seconds (Figure 15). This result was largely due to the following:

TOOL CATEGORY

4.6 Attack test 5: Leading edge

Objective: Lever leading edge corner

Test specimen: 231321/2 – Attack test was carried out on the passive leaf. The padlock on the active leaf was fitted adjacent to the hinge side of the passive leaf (Figure 15).

Target security rating: 3

Tool category: C

Method	Attack tools	Working time (min:sec)	
		Increment	Running
Force tools into leading edge corner, lever passive leaf until sufficient gap for scissor jack to be inserted.	Crow bar, club hammer, 14 mm square screw driver, tube, tyre lever and wooded wedges	00:38.35	00:38.35
Insert scissor jack and force leaf open (Figure 15).	Scissor jack	03:10.54	03:48.89

Duration of attack test: 10 minutes

Comments Full body entry was achieved using category C tools in 3 minutes 48 seconds (Figure 15). This result was largely due to the following:

ATTACK ACTION

This is the breakdown of the specific test and refers to the section of the report shown below.

4.6 Attack test 5: Leading edge

Objective: Lever leading edge corner

Test specimen: 231321/2 – Attack test was carried out on the passive leaf. The padlock on the active leaf was fitted adjacent to the hinge side of the passive leaf (Figure 15).

Target security rating: 3

Tool category: C

Method	Attack tools	Working time (min:sec)	
		Increment	Running
Force tools into leading edge corner, lever passive leaf until sufficient gap for scissor jack to be inserted.	Crow bar, club hammer, 14 mm square screw driver, tube, tyre lever and wooded wedges	00:38.35	00:38.35
Insert scissor jack and force leaf open (Figure 15).	Scissor jack	03:10.54	03:48.89

Duration of attack test: 10 minutes

Comments Full body entry was achieved using category C tools in 3 minutes 48 seconds (Figure 15). This result was largely due to the following:

The attack action refers to the LPCB table attack action. If the attack action isn't present in the dropdown list, close all the open forms in the database. Open the Attack action table and add the next available record number and paste in the attack action. Save and re-open and the attack action should show in the dropdown menu. This doesn't need to be inputted in ascending A-Z order as this automatically orders the list in the form.

1. Attack actions and total number of steps need to be completed first
2. Tool specification can then be completed
3. Attack test breakdown

TOTAL NUMBER OF STAGES

This refers to the number of rows on the LPCB report. In the report detailed, there are 3 stages involved. A number 3 needs to be put into the database for this.

Attack test no.: I Date: 16/7/09
 Objective: Cut bars and plates with cat B bolt croppers to create access aperture through which to pass elliptical test block.
 Test specimen: 254687/2 Locked condition: N/A
 Tool category: B Target security rating: 2

Attack action	Attack tools	Working time (min:sec)		Notes
		Increment	Running	
Cut through plates with bolt croppers. (Time taken from attack test B)	Bolt croppers	01:39.94	01:53.65	5 plates cut.
Cut through wires down vertical edges of coupon.	Bolt croppers	00:24.66	02:18.31	Cut through 18 wires.
Impact coupon inwards.	Feet	00:06.72	02:25.03	240 mm by 760 mm aperture created.

Duration of attack test (min:sec): <20 minutes Security rating achieved: 1

Comments: It was possible to create an aperture through which to pass the elliptical test block in the mesh within 2 minutes 26 seconds.

The specimen therefore did not offer resistance to this method of attack commensurate with Security Rating 2.

ATTACK TOOLS

Choose the relevant tools for each test. When a tool category is chosen in the Attack Test form, the tools available to the user to choose from are filtered to the specific tool category chosen.

Note the terminology of the tools:

Hammer = Club hammer

Bolt cutter = Bolt cropper

4.6 Attack test 5: Leading edge

Objective: Lever leading edge corner

Test specimen: 231321/2 – Attack test was carried out on the passive leaf. The padlock on the active leaf was fitted adjacent to the hinge side of the passive leaf (Figure 15).

Target security rating: 3

Tool category: C

Method	Attack tools	Working time (min:sec)	
		Increment	Running
Force tools into leading edge corner, lever passive leaf until sufficient gap for scissor jack to be inserted.	Crow bar, club hammer, 14 mm square screw driver, tube, tyre lever and wooded wedges	00:38.35	00:38.35
Insert scissor jack and force leaf open (Figure 15).	Scissor jack	03:10.54	03:48.89

Duration of attack test: 10 minutes

Comments Full body entry was achieved using category C tools in 3 minutes 48 seconds (Figure 15). This result was largely due to the following:

INDEX

The index refers to the number of stages in the report (see example below). As there are 3No. stages in this test, an index must be created for each stage. Stage 1 is A1, Stage 2 is B1 and stage 3 is C1.

Attack test no.:	I	Date:	16/7/09		
Objective:	Cut bars and plates with cat B bolt croppers to create access aperture through which to pass elliptical test block.				
Test specimen:	254687/2	Locked condition:	N/A		
Tool category:	B	Target security rating:	2		
	Attack action	Attack tools	Working time (min:sec)		Notes
			Increment	Running	
A1	Cut through plates with bolt croppers. (Time taken from attack test B)	Bolt croppers	01:39.94	01:53.65	5 plates cut.
B1	Cut through wires down vertical edges of coupon.	Bolt croppers	00:24.66	02:18.31	Cut through 18 wires.
C1	Impact coupon inwards.	Feet	00:06.72	02:25.03	240 mm by 760 mm aperture created.
Duration of attack test (min:sec):		<20 minutes		Security rating achieved: 1	
Comments:		It was possible to create an aperture through which to pass the elliptical test block in the mesh within 2 minutes 26 seconds.			
		The specimen therefore did not offer resistance to this method of attack commensurate with Security Rating 2.			

The letter refers to the number of steps/attack tests. The number refers to the breakdown of the single attack test if there are multiple steps to reach the overall objective.

These are different stages as they have different attack actions. However, if there is the same attack action and tools, the test can be broken down like this and a new record doesn't need to be created (it can be on the same form):

Attack action	Attack tools	Working time (min:sec)		Notes	
		Increment	Running		
Impact the knife to pierce the external skin of the wall panel then impact the lever to cut the external skin.	Claw hammer, knife and Stanley 55-117 lever	00:06.62	00:06.62	External skin pierced twice.	A1
		01:00.03	01:06.65	150 mm and 140 mm long cuts were made.	A2

CATEGORY

The test inputted will be categorised into one of the following:

- Fixings – tests that take place on fixings such as M10 bolts
- Composites – tests that take place on the composite as a whole
- Material – tests that take place on one material

LAYER

- OUTER
- 2ND
- 3RD
- 4TH
- 5TH
- 6TH
- 7TH
- 8TH
- 9TH
- INNER

WORKING TIME

In the LPCB reports, the time is formatted in MM:SS.00. This needs to be converted by the user into HH:MM:SS for example, a time of 00:06.62 stated in the LPCB report needs to be inputted into the database in the format 00:00:06.

Attack action	Attack tools	Working time (min.sec)		Notes
		Increment	Running	
Impact the knife to pierce the external skin of the wall panel then impact the lever to cut the external skin.	Claw hammer, knife and Stanley 55-117 lever	00:06.62	00:06.62	External skin pierced twice.
		01:00.03	01:06.65	150 mm and 140 mm long cuts were made.

To eliminate human error, a spreadsheet on Microsoft Excel was created to convert from the LPCB report time to the required database time format. This was integrated into the database using macros, through a button. When the button is clicked, the hyperlink in the background is opened and the spreadsheet opens. The LPCB test times have to be converted from LPCB's format MM:SS.00 to the database format HH:MM:SS.

ISSUE OF STANDARD & TOOL CATEGORY	MAXIMUM WORKING TIME (MINUTES)	MAXIMUM TEST DURATION (MINUTES)
5A	1	10
5B	3	15
5C	5	20
5D	10	30
5E	10	30
5F	10	30
6A	1	10
6B	3	15
6C	5	20
6D	10	30
6D+	10	30
6E	10	30
6F	10	30
6G	20	60
7A	1	10
7B	3	15
7C	5	20
7D	10	30
7D+	10	30
7E	10	30
7F	10	30
7G	20	60

LPS 1175 REVISION	TOOL CATEGORY	MAXIMUM WORKING TIME (HH:MM:SS)
5	A	00:01:00
5	B	00:03:00
5	C	00:05:00
5	D	00:10:00
5	E	00:10:00
5	F	00:10:00
6	A	00:01:00
6	B	00:03:00
6	C	00:05:00
6	D	00:10:00
6	D+	00:10:00
6	E	00:10:00
6	F	00:10:00
6	G	00:20:00
7	A	00:01:00
7	B	00:03:00
7	C	00:05:00
7	D	00:10:00
7	D+	00:10:00
7	E	00:10:00
7	F	00:10:00
7	G	00:20:00

The test results are

- Fail
- Pass
- Pass with lower security rating
- Pass with lower security rating – LPCB Recommendation (see the notes in the LPCB reports as it will flag up there)
- Pass with higher security rating

12.1.1.2 LOOK UP QUERIES

MATERIAL LOOK UP

1. Enter objective
2. Enter in tool category – in the format standard revision and then tool category
3. e.g '7C' if a certain standard is required.

12.1.1.3 MATERIAL TESTING

X

Health, Safety & Welfare Risk Assessment (to be submitted to the School Safety Officer).

Hazard	Persons at Risk	Raw Risk			Comments or Control Measures Specified by the Assessor	Residual Risk		
		Probability of Occurrence	Severity of Occurrence	Risk		Probability of Occurrence	Severity of Occurrence	Risk
Heavy loads Material with sharp rough edges		H	H	H	MINIMISE MANUAL HANDLING, USE LIFTING EQUIPMENT & PPE COVER SURFACES, WEAR PPE (GLOVES)	L	L	L
Demolition of sample rejected material		M	M	M	NET TO CATCH DEPOSITS, SAFETY GLASSES,	L	L	L
Material rolling off SUPPORTS.		M	M	M	PUT IN ROM AND ATTACH TO CHAINS	L	L	L

Table 29 - D2 Hardness Test Results

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
1A	4.33	77.00	70.80	71.10	74.70	75.10	73.74
1B	4.52	75.80	73.50	70.80	72.60	69.80	72.50
1C	4.35	68.80	75.00	72.80	72.60	72.20	72.28
1D	4.52	67.10	68.60	68.40	72.10	75.60	70.36
1E	4.34	67.80	68.90	74.40	72.80	71.20	71.02
AVERAGE	4.41	71.30	71.36	71.50	72.96	72.78	71.98

12.1.1.4 DUCTILE MATERIALS

3MM MILD STEEL

Table 30 - 3mm Mild Steel Hardness Test Results

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
5A	2.93	30.60	32.00	30.10	29.00	28.60	30.06
5B	2.83	31.90	30.60	28.80	31.90	31.90	31.02
5C	2.78	30.30	31.70	32.70	32.50	31.70	31.78
5D	2.80	28.80	32.00	32.30	32.80	32.50	31.68
5E	2.98	31.50	29.50	30.30	31.50	30.10	30.58
AVERAGE	2.86	30.62	31.16	30.84	31.54	30.96	31.02

4MM MILD STEEL

Table 31 - 4mm Mild Steel Hardness Test Results

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
2A	4.09	24.70	17.50	27.70	25.30	24.60	24.00
2B	4.01	23.60	22.40	27.40	26.00	26.80	25.20
2C	3.83	26.80	25.20	27.50	23.20	25.60	25.70
2D	3.81	23.10	23.90	26.20	11.20	22.50	21.40
AVERAGE	3.94	24.55	22.25	27.20	21.43	24.88	24.08

6MM MILD STEEL

Table 32 - 6mm Mild Steel Hardness Test Results

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
3A	5.94	6.70	31.40	31.60	31.30	32.10	26.62
3B	5.89	30.00	26.90	33.40	32.80	32.00	31.02
3C	5.92	13.60	31.40	32.70	31.00	33.50	28.44
3D	5.96	31.70	31.90	32.70	32.70	32.20	32.24
3E	5.90	33.80	32.00	32.40	33.40	32.80	32.88
AVERAGE	5.92	23.16	30.72	32.56	32.24	32.52	30.24

8MM MILD STEEL

Table 33 - 8mm Mild Steel Hardness Test Results

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
6A	7.75	24.40	29.70	31.80	27.10	28.30	28.26
6B	7.76	29.60	34.70	33.00	33.50	37.20	33.60
6C	7.77	31.00	32.80	31.00	32.80	33.00	32.12
6D	7.74	29.60	32.70	31.90	31.80	30.40	31.28
AVERAGE	7.76	28.65	32.48	31.93	31.30	32.23	31.32

10MM MILD STEEL

Table 34 - 10mm Mild Steel Hardness Test Results

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
12A	9.95	21.20	25.20	28.00	25.60	24.40	24.88
12B	9.98	16.60	11.60	19.20	14.80	19.90	16.42
12C	9.83	13.50	18.80	23.10	23.90	21.90	20.24
12D	10.05	10.20	20.90	20.40	17.80	15.10	16.88
AVERAGE	9.95	15.38	19.13	22.68	20.53	20.33	19.61

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
11A	9.95	21.20	25.20	28.00	25.60	24.40	24.88
11B	9.98	16.60	11.60	19.20	14.80	19.90	16.42
11C	9.83	13.50	18.80	23.10	23.90	21.90	20.24
11D	10.05	10.20	20.90	20.40	17.80	15.10	16.88
11E	10.01	18.00	14.90	10.80	21.70	17.20	16.52
AVERAGE	9.96	15.90	18.28	20.30	20.76	19.70	18.99

0.9MM PRE-GALVANISED STEEL SHEET

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
8A	0.93	14.40	11.80	10.90	15.10	24.20	15.28
8B	0.91	23.60	17.10	17.70	16.80	15.00	18.04
8C	0.77	11.10	15.10	7.80	6.70	13.10	10.76
8D	0.78	15.10	15.50	14.30	13.90	14.40	14.64
8E	0.80	17.30	11.70	11.90	12.30	14.20	13.48
AVERAGE	0.84	16.30	14.24	12.52	12.96	16.18	14.44

2MM PRE-GALVANISED STEEL SHEET

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
7A	1.97	28.80	28.80	9.60	28.60	26.70	24.50
7B	2.09	27.70	26.60	26.60	26.80	26.40	26.82
7C	1.92	19.40	26.30	28.20	26.70	24.70	25.06
7D	1.92	26.10	27.50	27.10	26.60	27.10	26.88
7E	1.95	26.40	27.00	27.70	26.70	29.70	27.50
AVERAGE	1.97	25.68	27.24	23.84	27.08	26.92	26.15

2.5MM STAINLESS STEEL SHEET

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
9A	2.55	32.60	33.80	34.20	33.80	31.40	33.16
9B	2.53	32.30	31.50	34.60	33.30	31.70	32.68
9C	2.66	31.20	33.70	33.20	34.00	30.60	32.54
9D	2.67	29.70	30.40	29.90	28.50	33.50	30.40
9E	2.61	26.50	29.10	29.60	30.70	30.80	29.34
AVERAGE	2.60	30.46	31.70	32.30	32.06	31.60	31.62

4MM STAINLESS STEEL SHEET

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
10A	4.13	32.00	32.80	31.80	30.60	32.80	32.00
10B	4.09	27.10	29.10	27.30	30.40	31.40	29.06
10C	4.14	31.20	31.00	32.80	32.10	30.60	31.54
10D	4.12	28.30	29.10	30.60	34.20	31.50	30.74
10E	4.15	25.40	30.50	28.80	32.10	29.10	29.18
AVERAGE	4.13	28.80	30.50	30.26	31.88	31.08	30.50

6MM STAINLESS STEEL SHEET

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
12A	6.10	35.80	35.80	35.00	35.00	34.90	35.30
12B	6.05	33.50	34.40	33.60	33.40	31.90	33.36
12C	6.03	32.70	30.90	33.90	30.90	32.80	32.24
12D	6.08	33.80	35.00	35.30	34.30	33.10	34.30
12E	6.02	30.30	33.20	33.10	34.00	36.40	33.40
AVERAGE	6.07	33.95	34.03	34.45	33.40	33.18	33.80

8MM STAINLESS STEEL SHEET

SAMPLE	MEASURED THICKNESS (mm)	HRD VALUES					AVERAGE
		1	2	3	4	5	
4A	7.92	35.30	33.40	36.50	36.80	36.70	35.74
4B	7.91	35.80	38.10	34.70	34.40	34.80	35.56
4C	7.91	34.80	32.90	32.20	33.70	34.10	33.54
4D	7.87	35.50	35.40	37.20	38.10	37.10	36.66
4E	7.93	33.20	33.60	36.30	36.00	35.70	34.96
AVERAGE	7.91	34.92	34.68	35.38	35.80	35.68	35.29

12.2 MATERIAL GRAPH CURVES

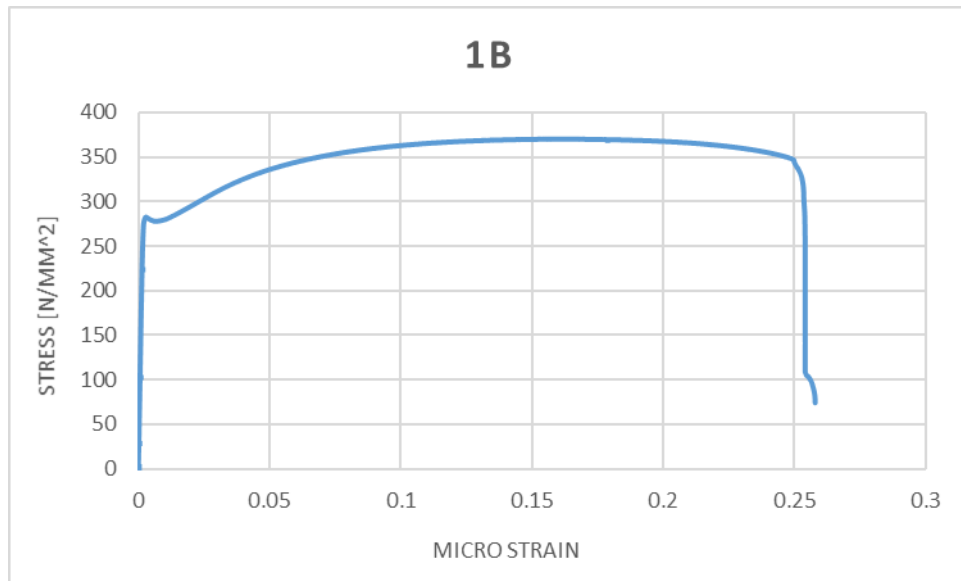


Figure 215 - Tensile Test 1B

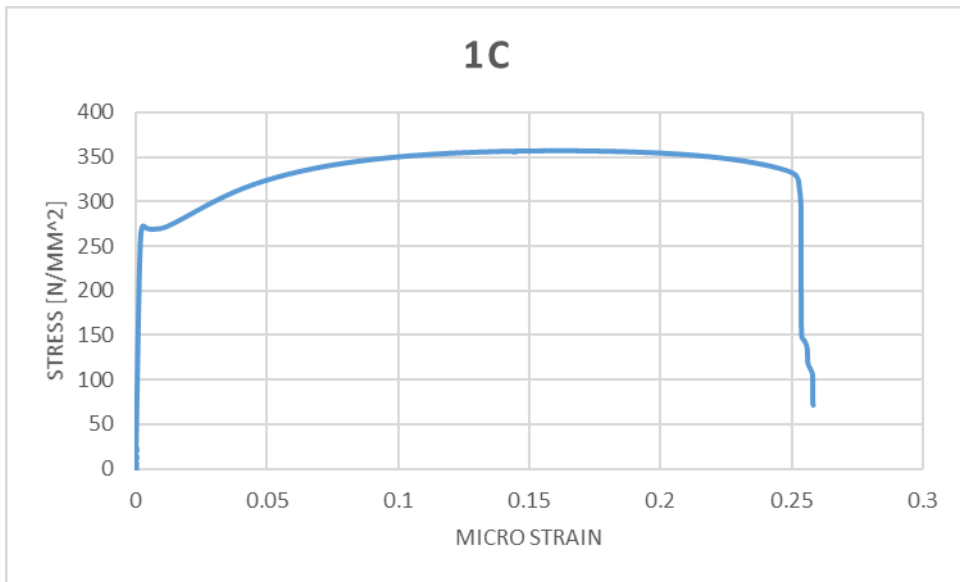


Figure 216 - Tensile Test 1B

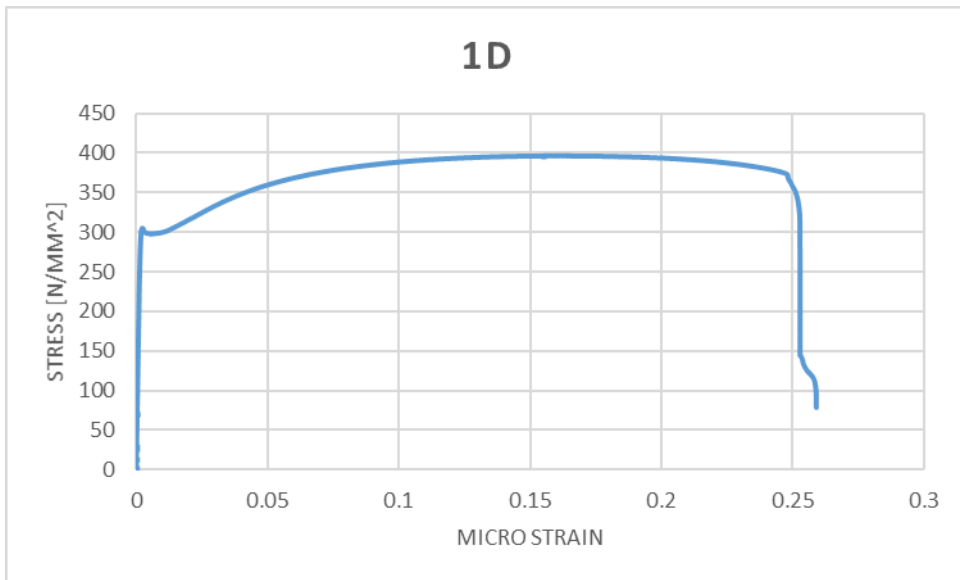


Figure 217 - Tensile Test 1B

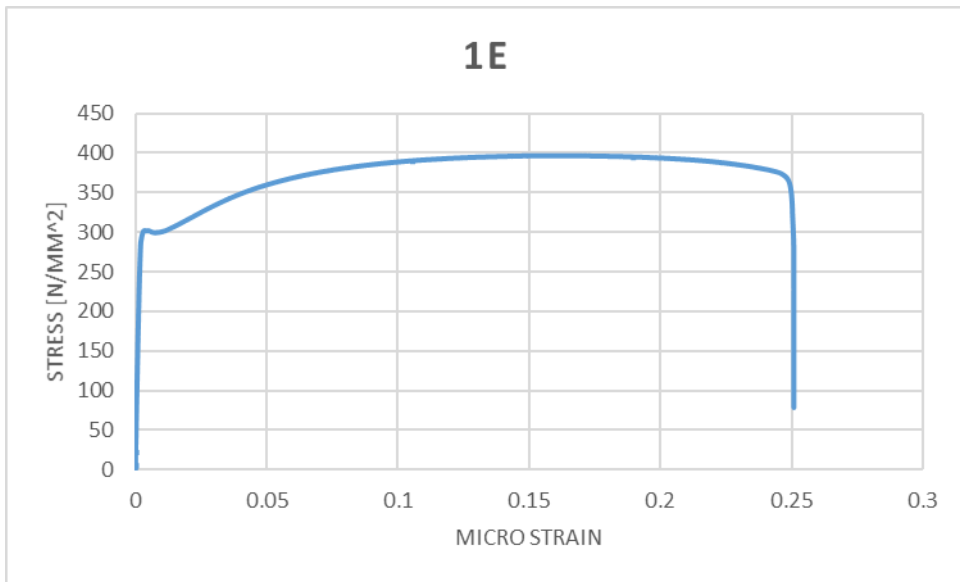


Figure 218 - Tensile Test 1B

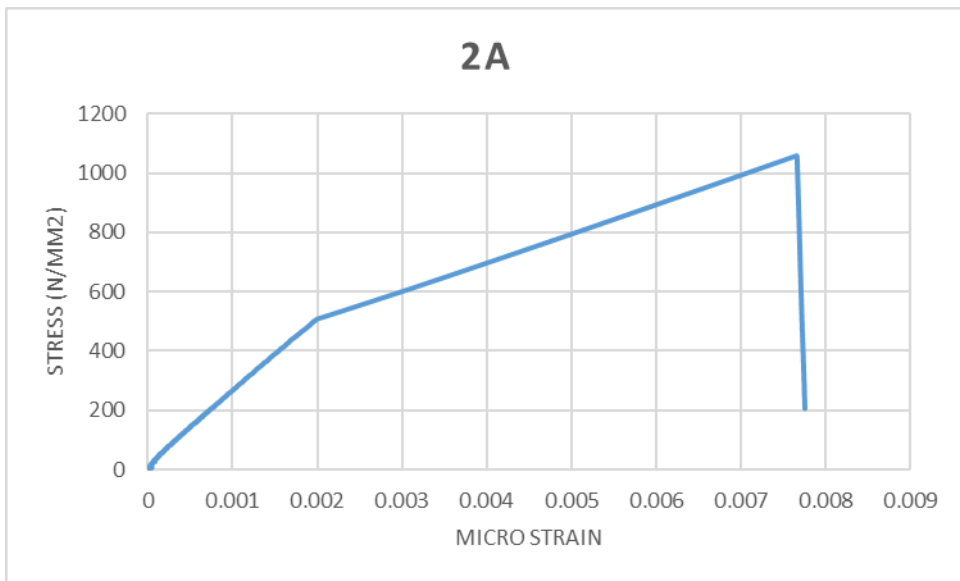


Figure 219 - Tensile Test 1B

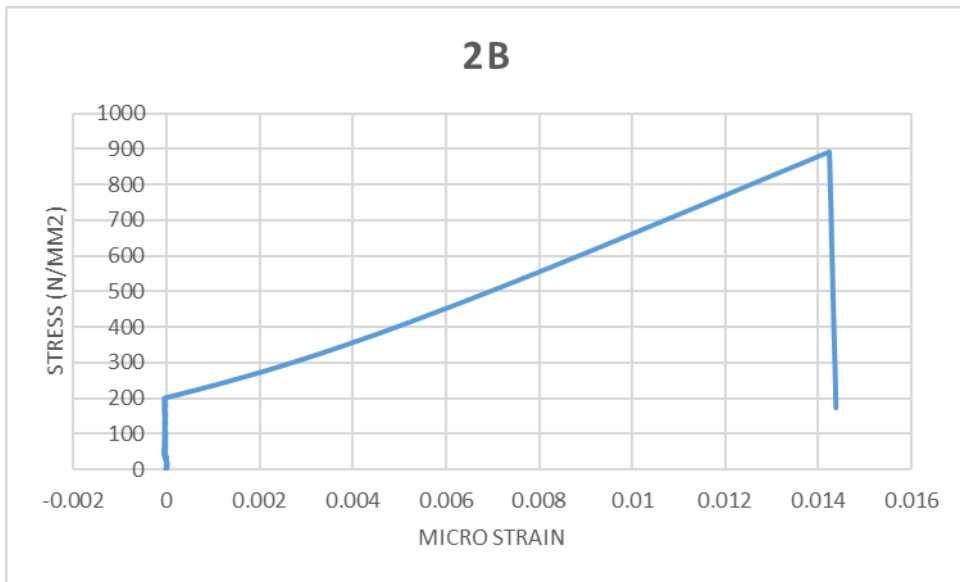


Figure 220 - Tensile Test 1B

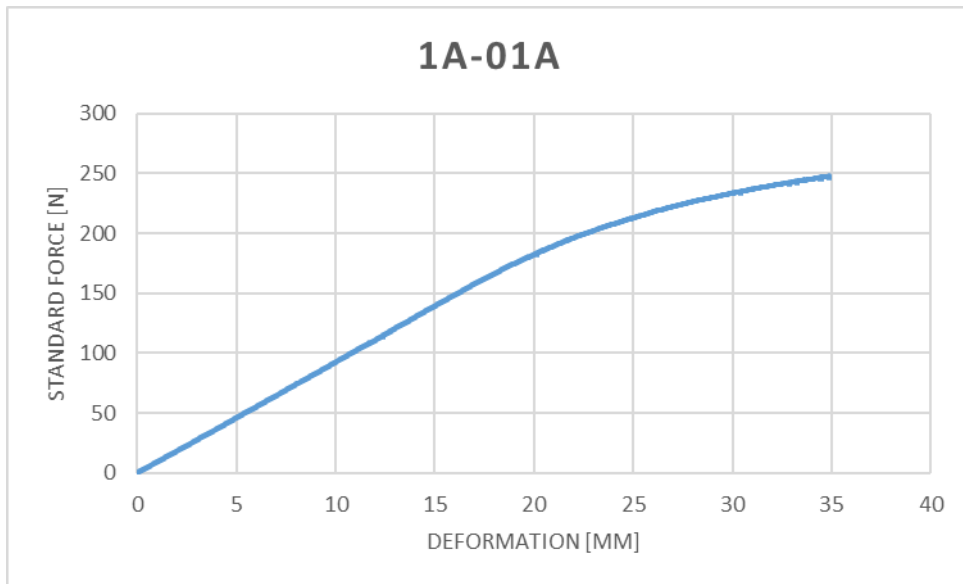


Figure 221 - 1A Bending Results

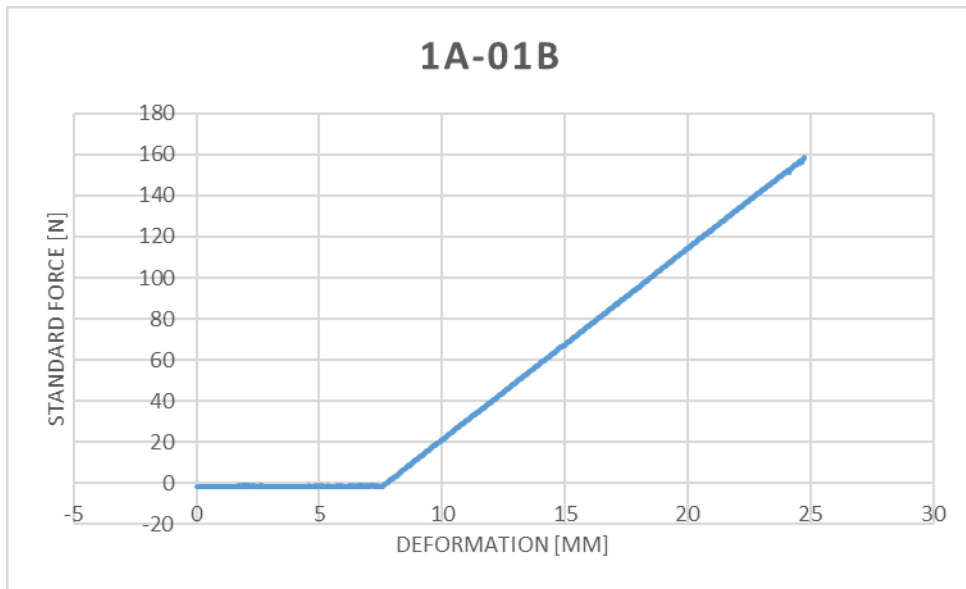


Figure 222 - 1A-1 Deformation Results

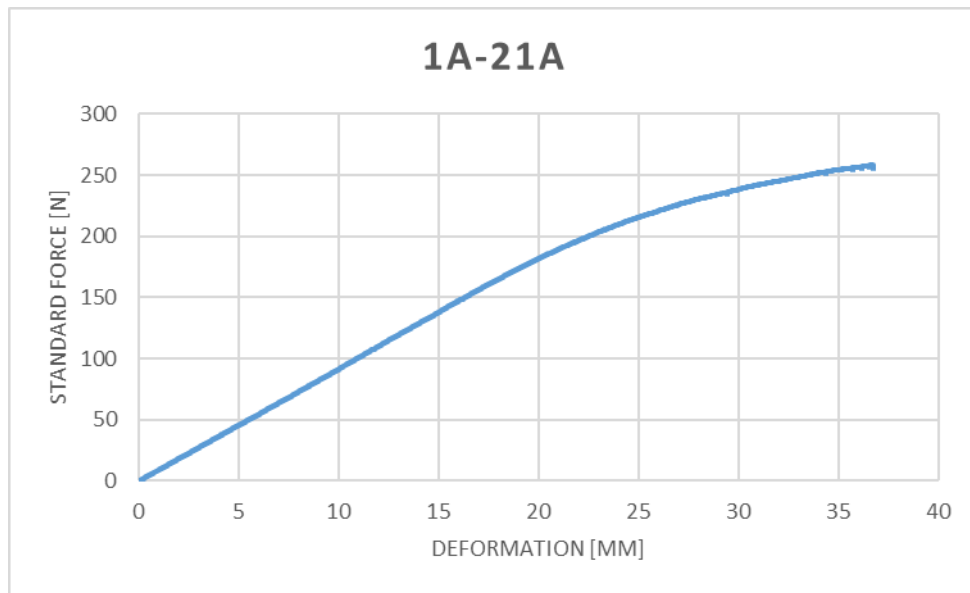


Figure 223 - 1A-2 Bending Results

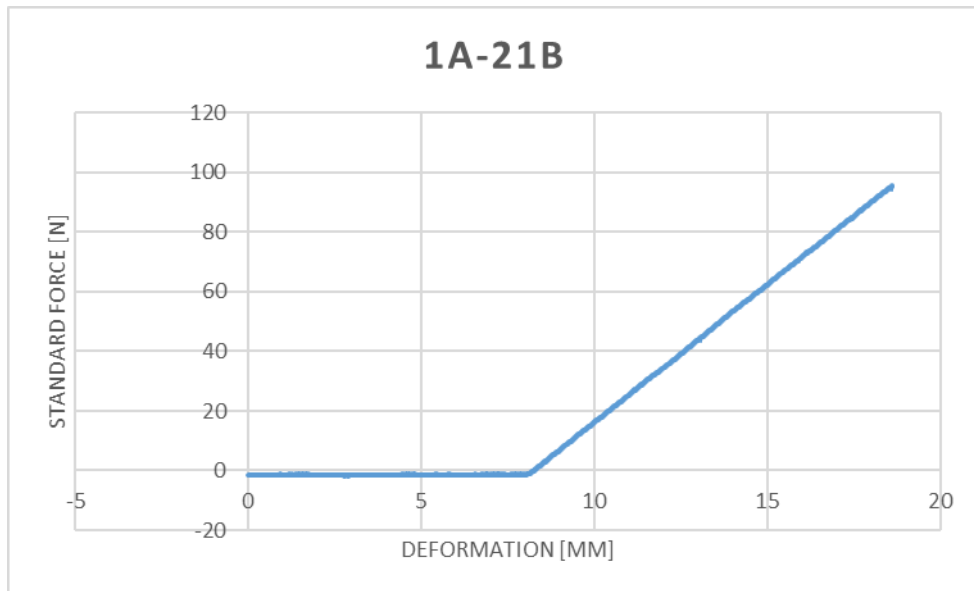


Figure 224 - 1A-2 Deformation Results

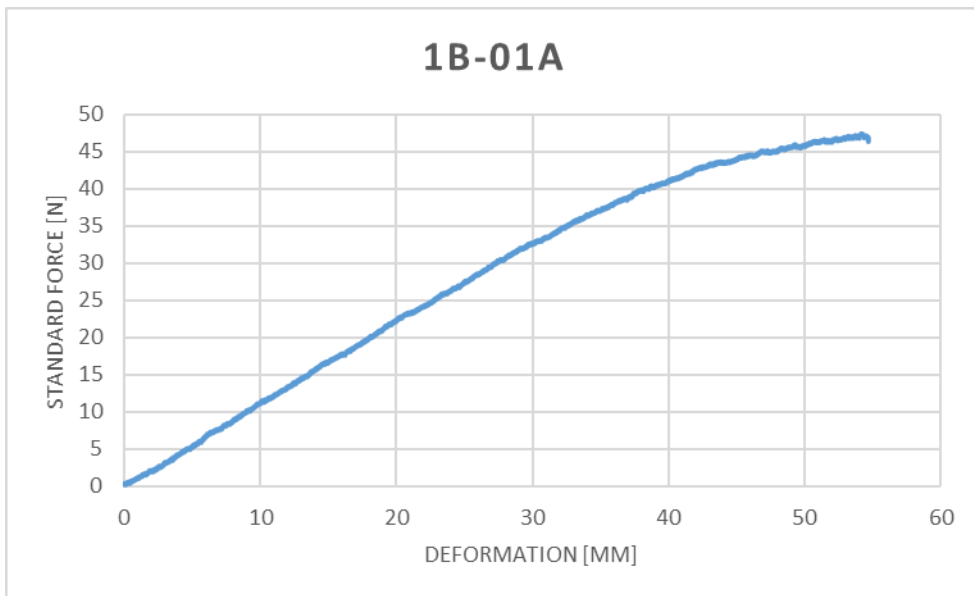


Figure 225 - 1B Bending Results

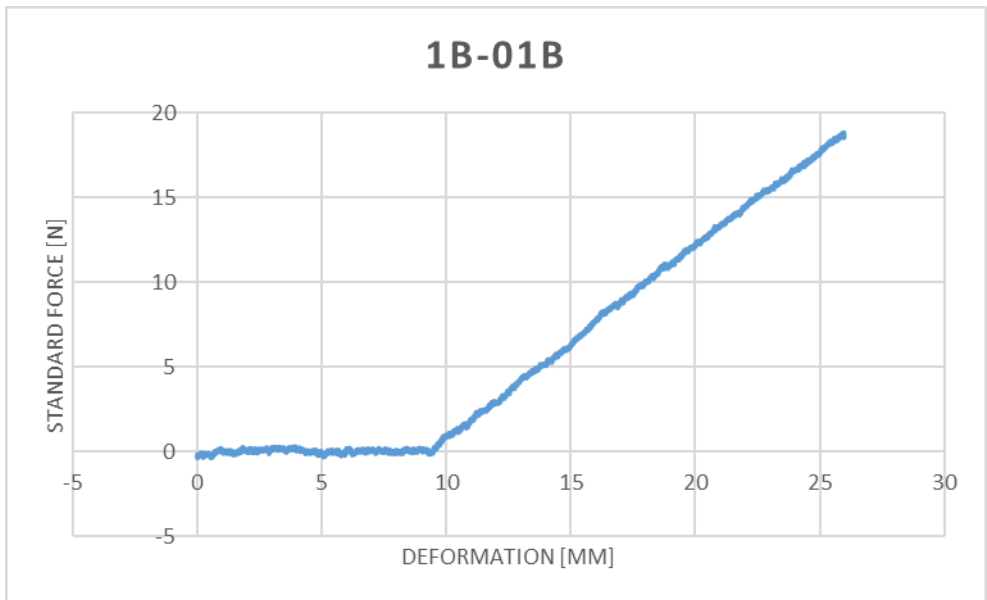


Figure 226 - 1B-1 Deformation Results

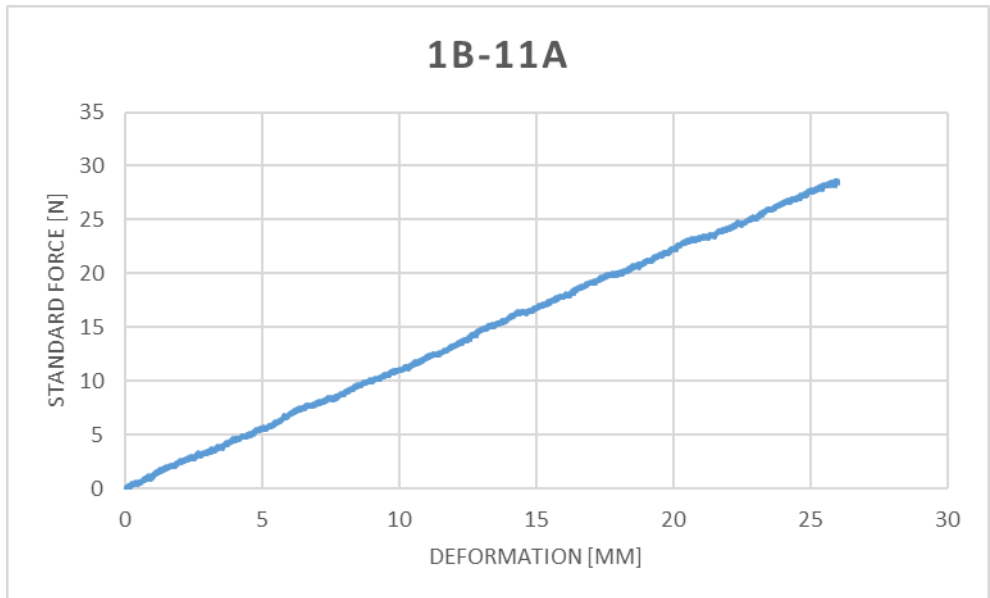


Figure 227 - 1A-1 Deformation Results

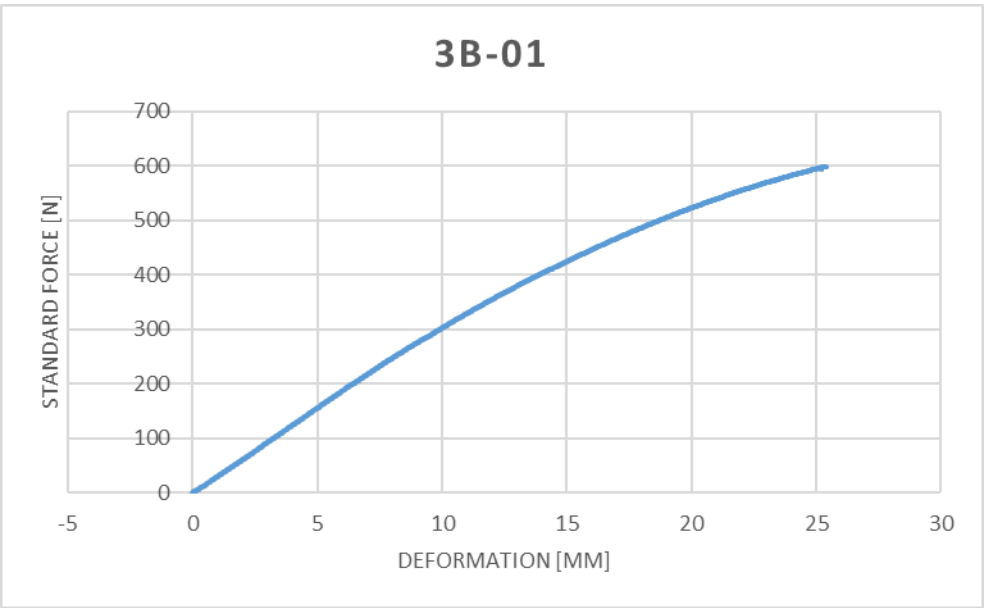


Figure 228 - 3B Bending Results

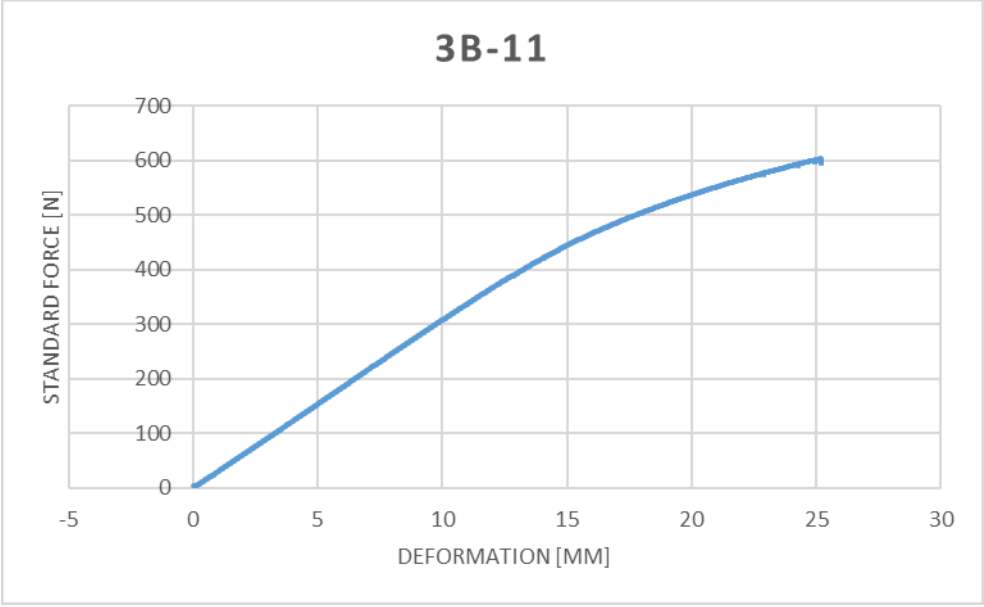


Figure 229 - 3B-1 Deformation Results

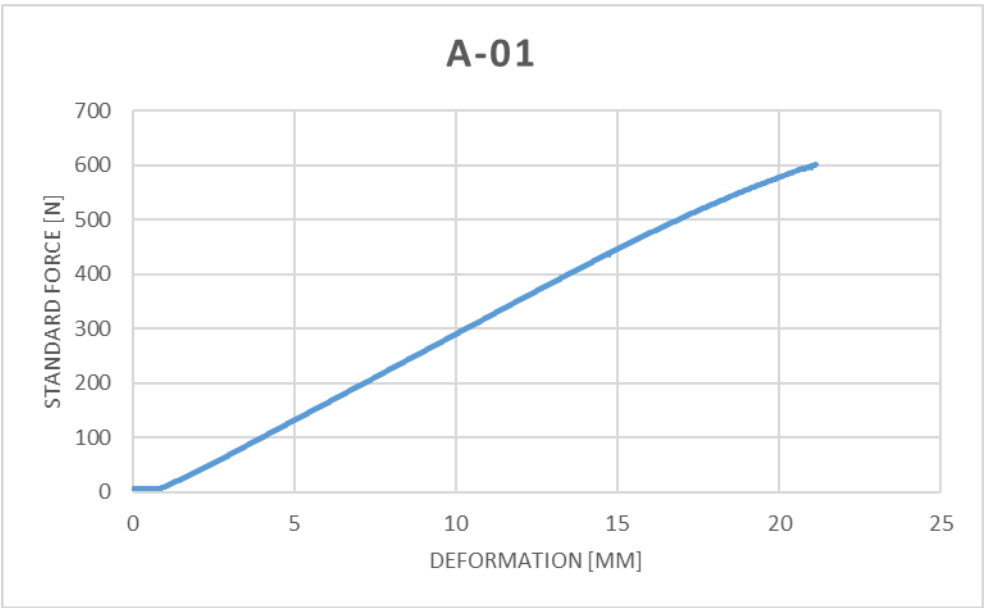


Figure 230 - A Bending Results

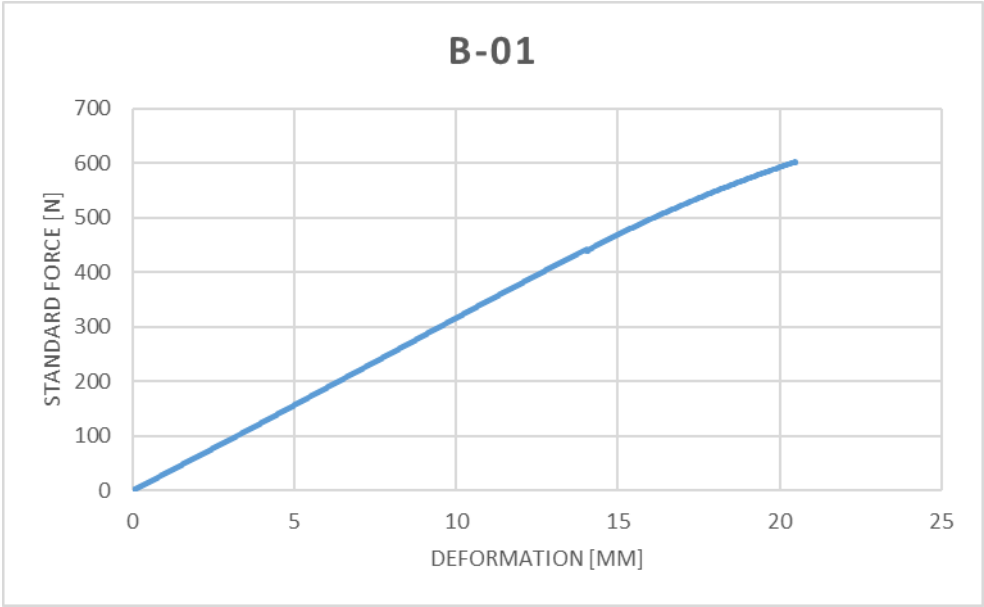


Figure 231 - B Bending Results

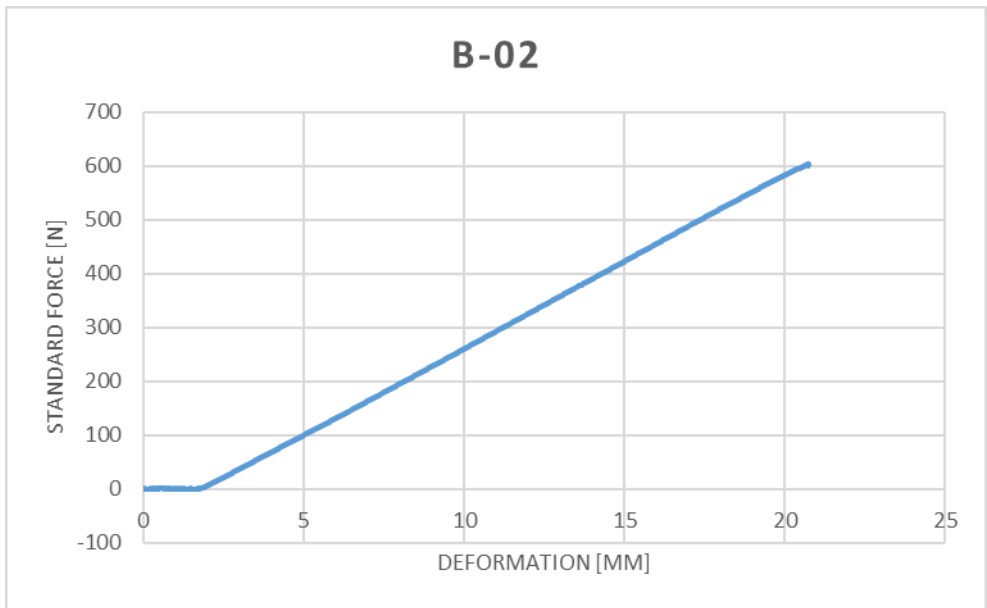


Figure 232 - B Deformation Results

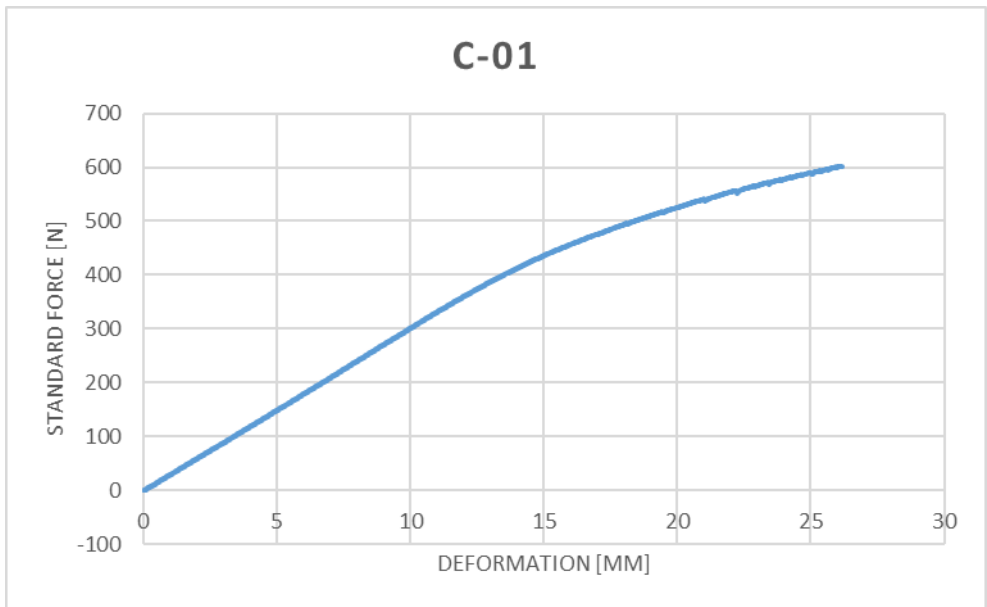


Figure 233 - C Bending Results

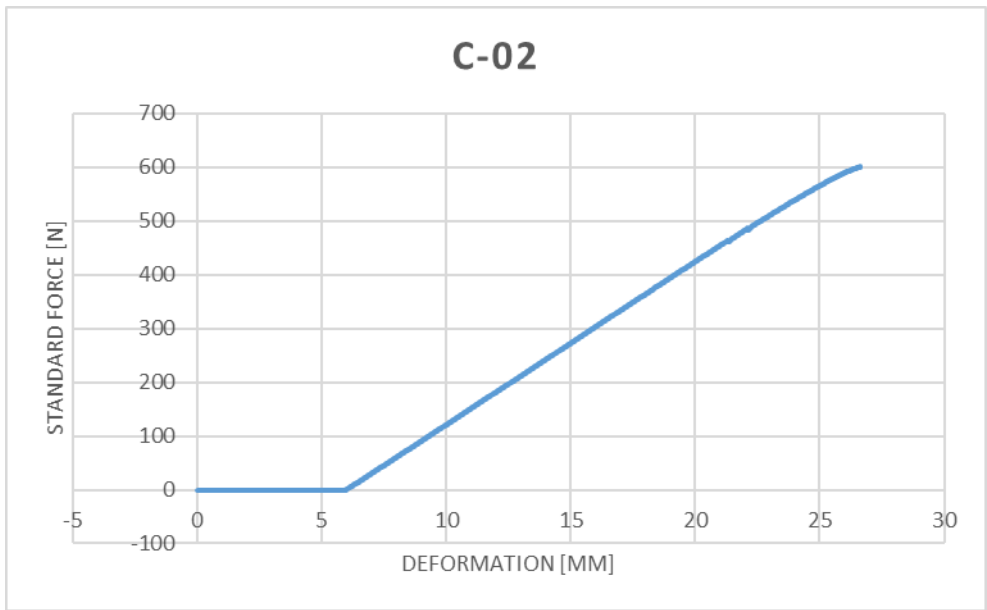


Figure 234 - C Deformation Results

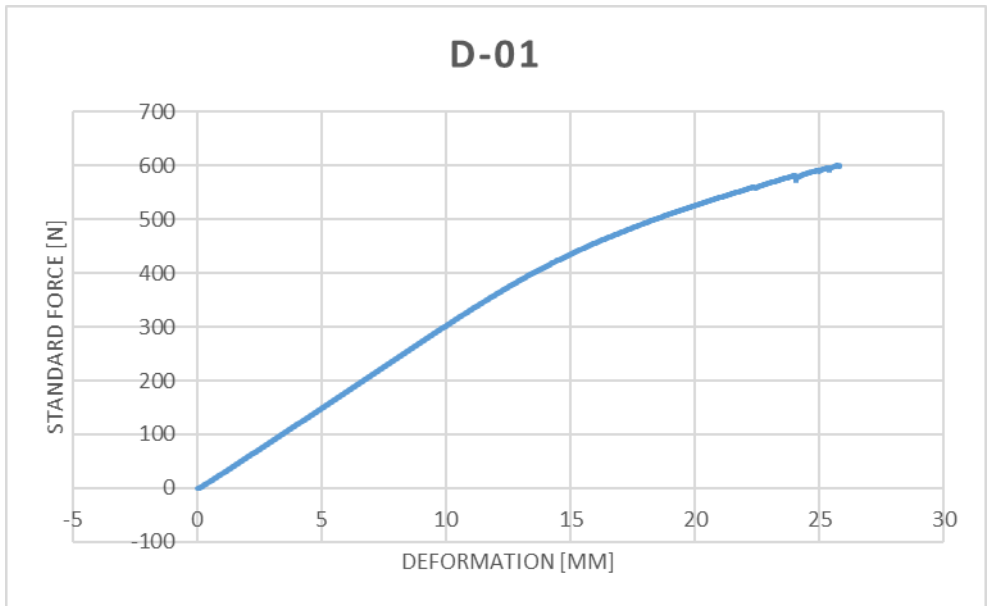


Figure 235 - D Bending Results

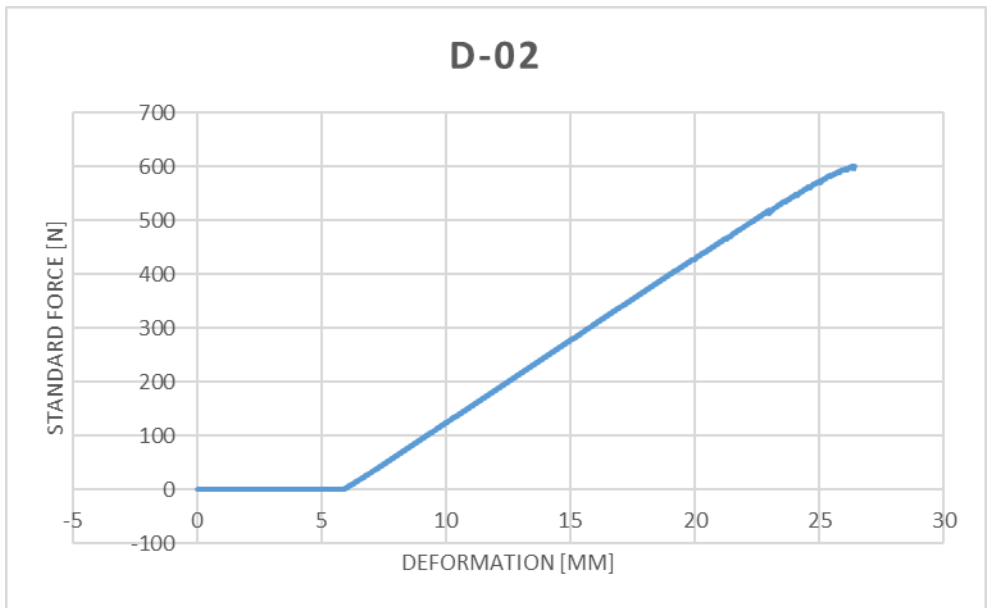


Figure 236 - D Deformation Results

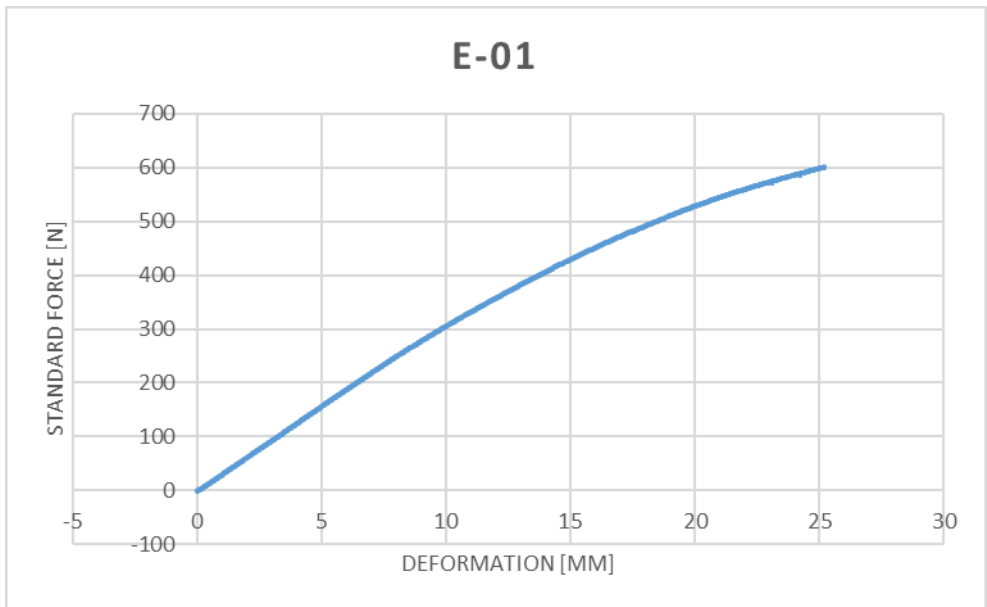


Figure 237 - E Bending Results

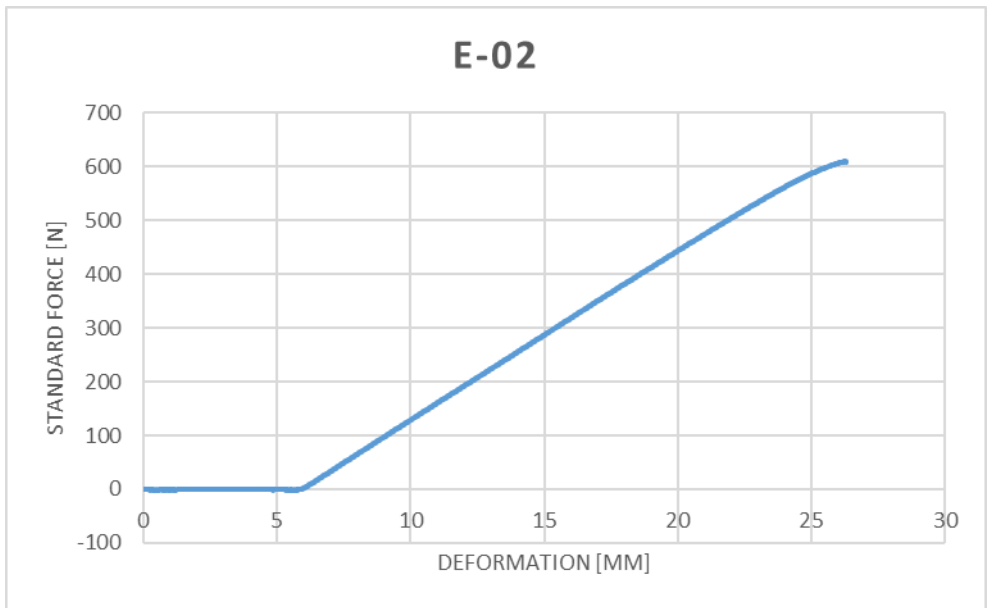


Figure 238 - E Deformation Results

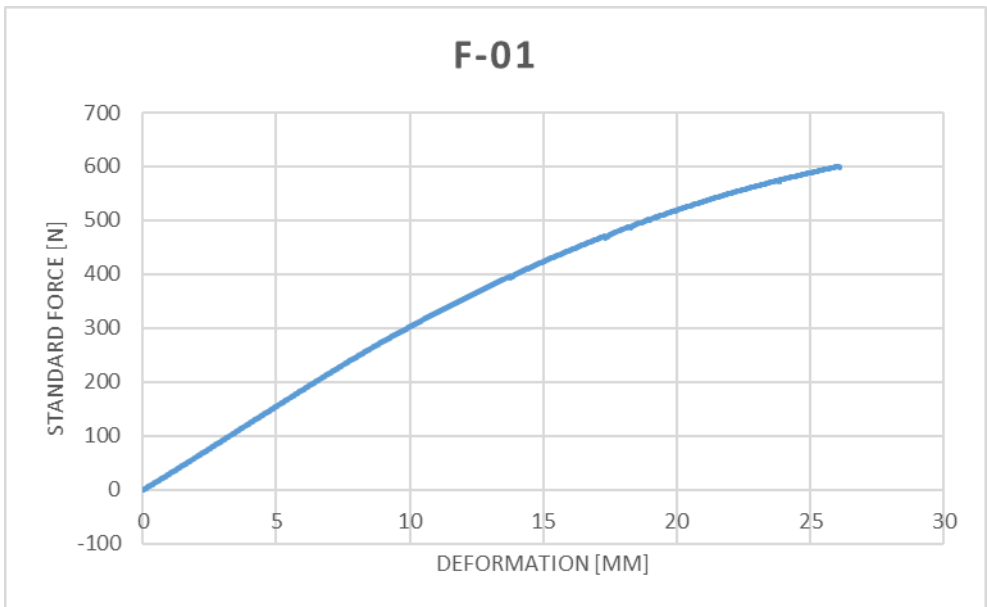


Figure 239 - F Bending Results

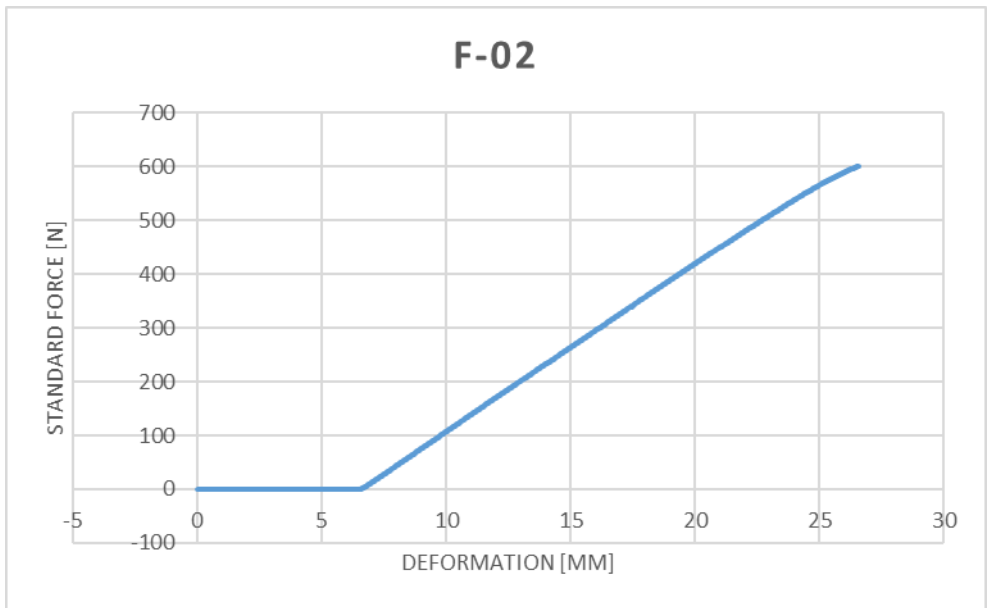


Figure 240 - F Deformation Results

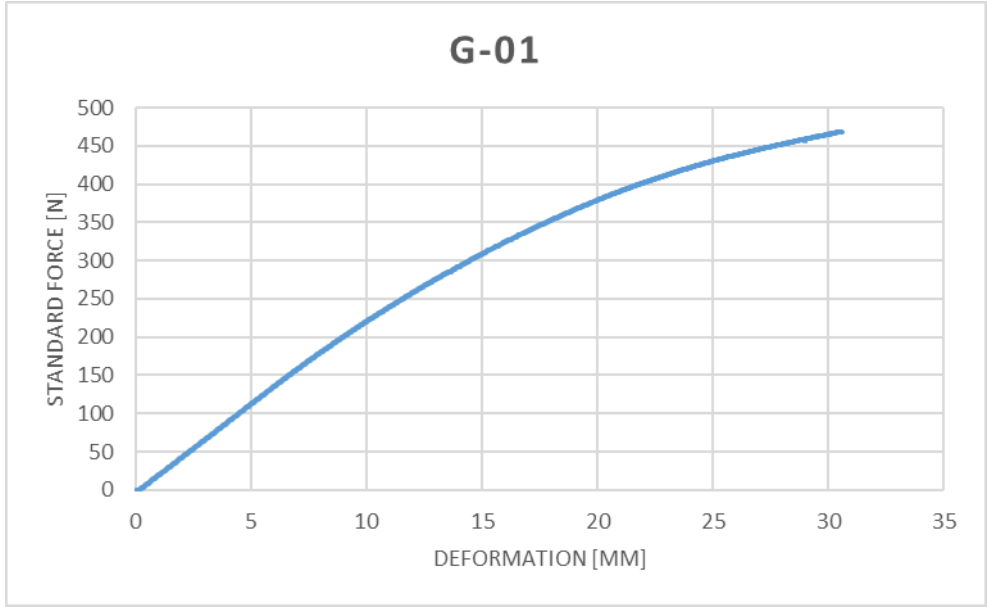


Figure 241 - G Bending Results

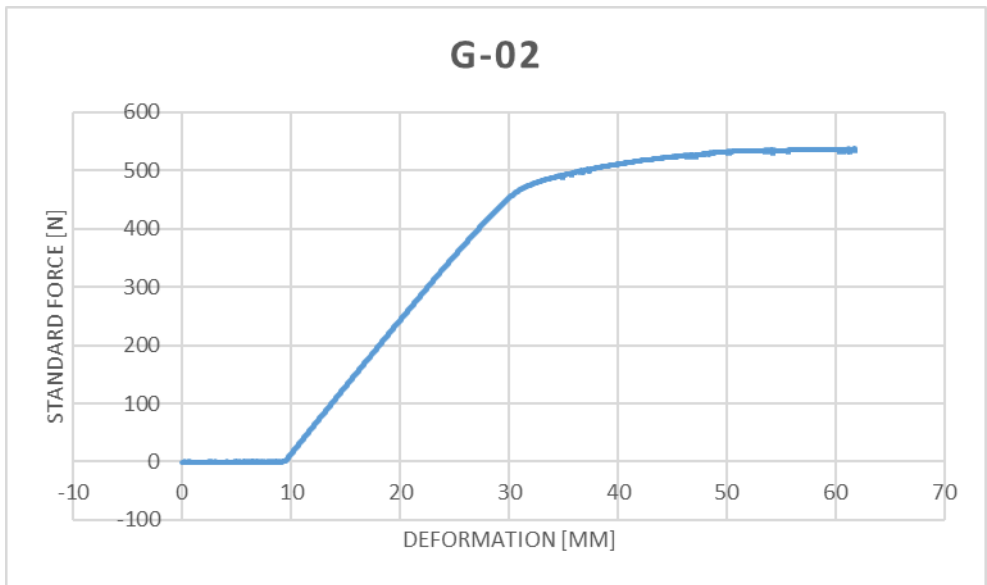


Figure 242 - G Deformation Results

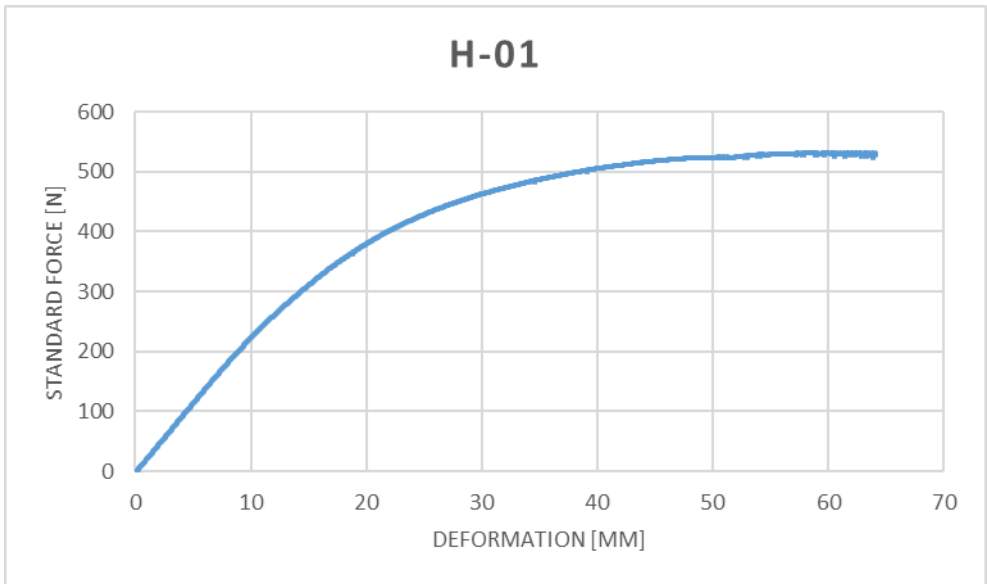


Figure 243 - H Bending Results

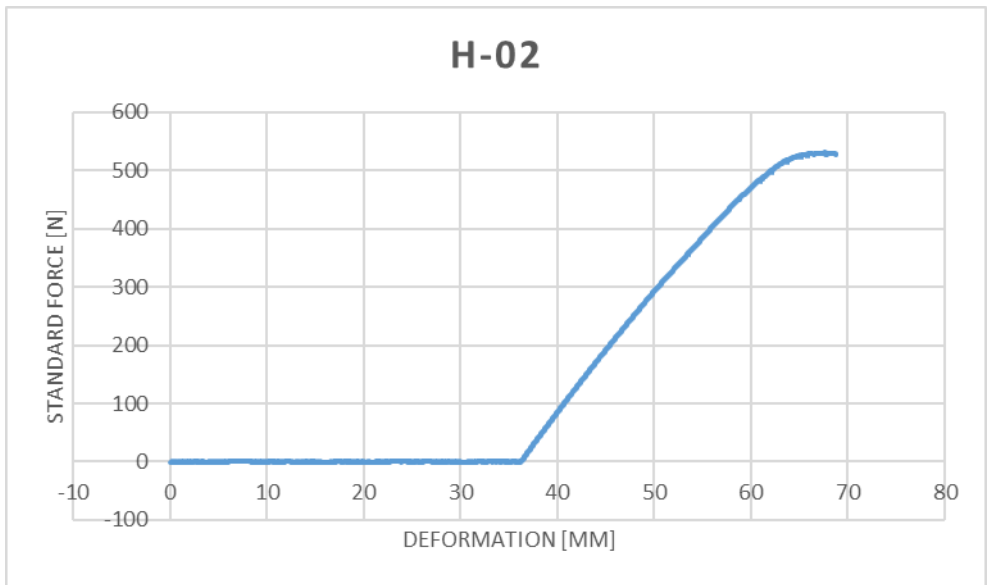


Figure 244 - H Deformation Results

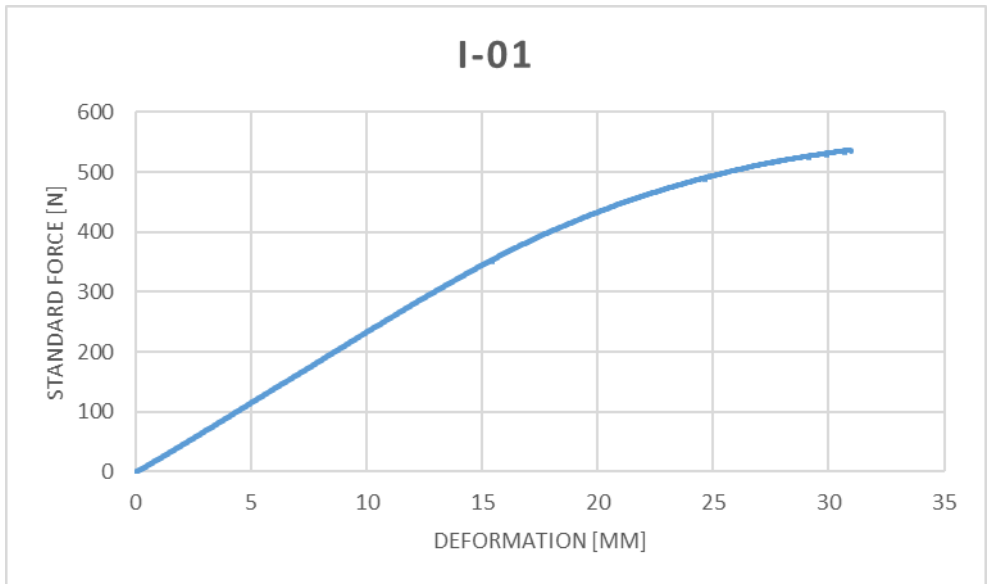


Figure 245 - I Bending Results

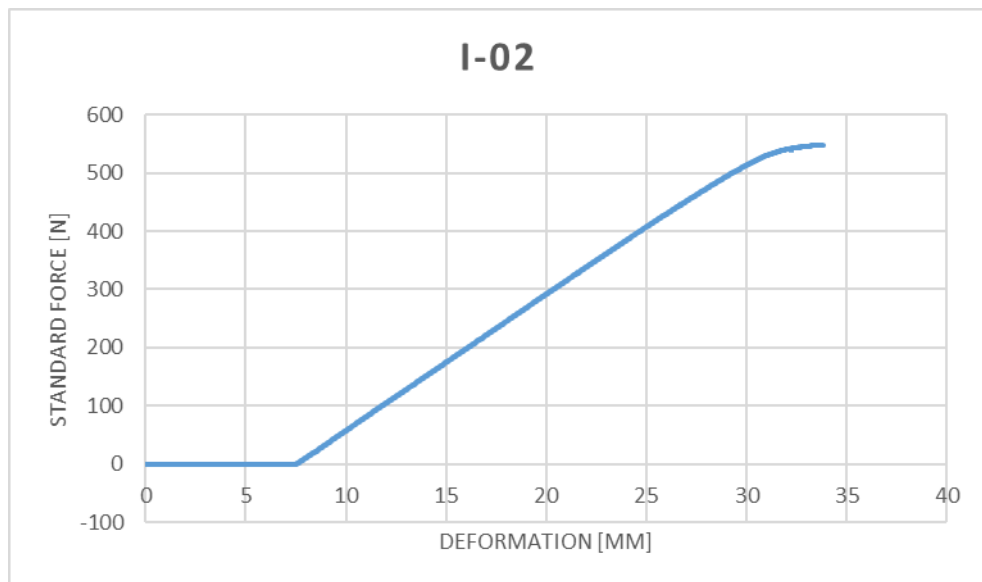


Figure 246 - I Deformation Results

12.2.1 WELDMENTS ANALYSIS

12.2.1.1 TEST PROCEDURE

SETTING UP A WELDMENTS LIBRARY

Create a folder for custom folders in the location where the weldment profiles are currently homed:

C:\Program Files\SOLIDWORKS Corp\SOLIDWORKS\lang\english\weldment profiles

1. Draw a sketch on the right plane of the profile
2. Draw construction lines and create a point in the middle of profile



Figure 247 - Weldments Profile

3. Add the dimensions needed
4. Note down the dimension number and sketch number e.g. D1@Sketch 1, for each dimension

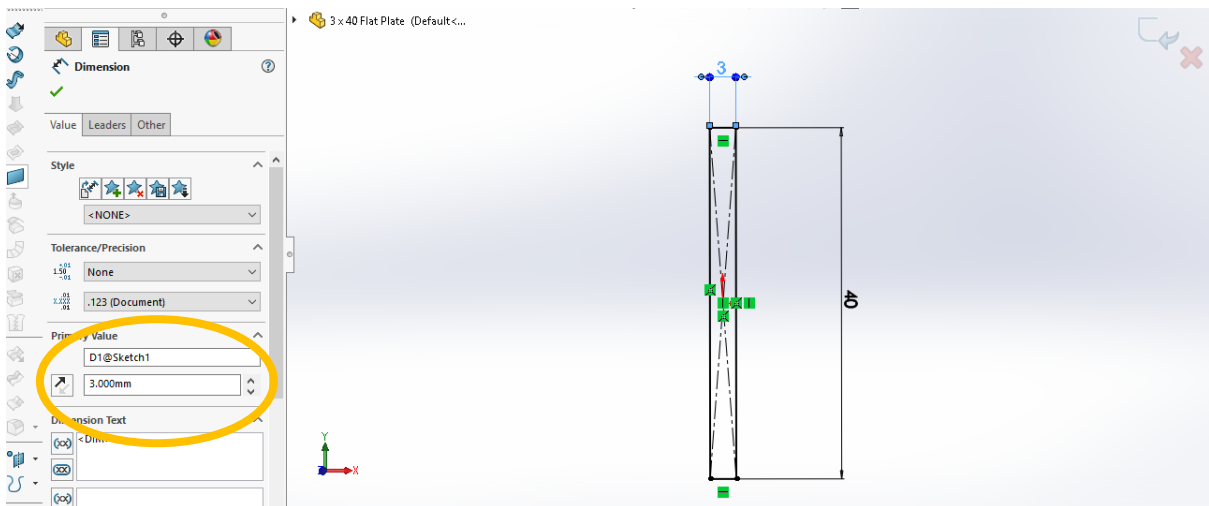


Figure 248 - Weldments profile dimensions

- In the file properties, rename the description as “L ‘D1@Sketch1@40 x 3.SLDPRT’ X ‘D2@Sketch2@40 x 3.SLDPRT’ “– one for each dimension; the coloured items should change depending on the sketch. The X is added between every dimension.

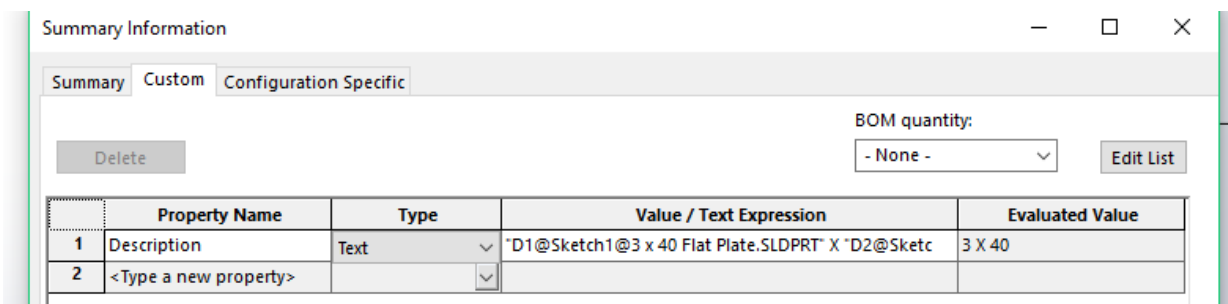


Figure 249 - Weldments BOM Description

- Save the profile in a different location and paste into the folder – due to the program file rights. (Make sure to save as .sldlfp file)

12.2.2 TOOL CATEGORY BREAKDOWN

The new tool categories were broken down and manipulated to be inputted into the tool matrix and the database. These were taken from the standard LPS 1175: Issue 8.

Type	Maximum dimension / power / weight	Quantity ²
Adhesive tape (reel)	75 mm wide	1
Cable cutter	200 mm long	1
Cargo strap (selection)	25 mm wide strap with cam buckle	1 ³
Electric cable (Single core)	1.2 mm diameter wire / 1 m long	1
Engineers hooks (selection)	-	1 ³
Firefighter's key	-	1
Fishing line (e.g. polypropylene multi fibre)	Reel	1
Fishing hooks (selection)	-	1 ³
Flexible plastic coupon	-	1
Glass cutter	-	1
Hexagon wrenches (selection)	200 mm long	1 ³
Knife	125 mm long x 3 mm thick blade	1
Lever (including nail pullers, prybars and utility bars)	300 mm long / 0.7 kg	1
Pliers (selection, including self-gripping and cutting)	200 mm long	1 ³
Punches (selection, including flat and pointed tipped)	200 mm long	1 ³
Rope (selection, non-metallic)	20 mm diameter	1 ³

Type	Maximum dimension / power / weight	Quantity ²
Screwdriver	6.5 mm diameter / square x 200 mm long	1
Scriber (selection)	200 mm long	1 ³
Socket/screwdriver set (selection)	150 mm long ratchet arm	1 ³
Spanners (selection)	150 mm long	1 ³
Traction screws ²²	5.5 mm diameter x 60 mm long	2 ³
Tweezers (selection)	-	1 ³
Universal key	-	1
Wire (selection)	3 mm diameter	1 ³
WD40	400 ml	1
Wood/plastic wedges (selection)	200 mm long x 50 mm wide	6

Figure 250 - Tool Category A

Type	Maximum dimension / power / weight	Quantity ²
Battery	3.6 V	1
Bolt cutter	350 mm long	1
Claw hammer	350 mm long / 1 kg	1
Drill bit (HSS / HSCO / Masonry)	6 mm diameter jobber	1
Drill/driver	3.6 V (complete with drill bit adaptor)	1
Electric cable (Single core)	2.1 mm diameter wire / 1 m long	1
Junior hacksaw	-	1
Junior hacksaw blades (HSS)	-	2
Metal plate shears	200 mm long	1
Multiple slip joint pliers	250 mm long	1
Pipe wrench	250 mm long	1
Pliers (selection, including self-gripping)	250 mm long	1 ³
Ratchet strap (selection)	25 mm wide strap with 200 mm long ratchet mechanism ²¹	1 ³
Screwdriver	7 mm diameter/square x 250 mm long	1
Screwdriver	14 mm diameter/square x 400 mm long	1
Socket set (selection)	250 mm long ratchet arm	1 ³

Type	Maximum dimension / power / weight	Quantity ²
Tube	50 mm outer diameter with 4 mm wall thickness x 300 mm long	1

Figure 251 - Tool Category B

Tool category A and B plus:

Type	Maximum dimension / power / weight	Quantity [†]
Axe	350 mm long / 1.5 kg	1
Battery	12 V	1
Bolt cutter	400 mm long	1
Brick bolster	250 mm long x 75 mm wide blade	1
Cold chisel	250 mm long x 28 mm wide blade	2
Crowbar	700 mm long / 2.5 kg	1
Drill ^{††}	12 V	1
Drill bit (HSS / HSCO / Masonry)	10 mm diameter jobber	1
Fluorocarbon based freeze spray	400 ml	1
Gas torch (Butane / Propane)	175 g	1
Hacksaw	-	1
Hacksaw blades (HSS / bimetal)	-	2 [‡]
Hammer (3 lb / 1.36 kg nominal head weight)	300 mm long / 1.8 kg	1
Pad saw	-	1
Pad saw blades (HSS / bimetal)	-	2 [‡]
Scissor jack	1500 kg capacity, 100 mm minimum retracted, 200 mm stroke	1
Wood chisel	250 mm long x 25 mm wide blade	1 [‡]

Figure 252 - Tool Category C

Tool category A, B and C plus:

Type	Maximum dimension / power / weight	Quantity [†]
*A-tool" lock puller	500 mm long	1
Battery	12 V	2 ^{‡‡}
Bolt cutters	500 mm long	1
Drill bits (HSS / HSCO / Masonry / Tungsten Carbide)	10 mm diameter jobber	5
Felling/fire axe (7 lb / 3.18 kg nominal head weight)	900 mm long / 4.5 kg	1
General purpose saw	750 mm long	1
Grinder	12 V	1
Grinder discs	100 mm diameter	3
Hole saw	50 mm diameter	1
Hooligan bar	760 mm long / 5 kg	1
Jigsaw	12 V	1
Jigsaw blades (HSS / HSCO / Carbide)	-	3
*K-tool" lock remover	-	1
Plate shears	300 mm long	1
Sledgehammer (7 lb / 3.18 kg nominal head weight)	900 mm long / 4.5 kg	1
Steel wedges	150 mm long x 50 mm wide	10
Tube	75 mm outer diameter with 6 mm wall thickness x 500 mm long	1

Figure 253 - Tool Category D

Tool category A, B and C plus:

Type	Maximum dimension / power / weight	Quantity [†]
"A-tool" lock puller	500 mm long	1
Battery	18 V	2 ^{***}
Bolt cutters	500 mm long	1
Circular saw	18 V	1
Circular saw blades	200 mm diameter	3
Drill (rotary and hammer action)	18 V	1
Drill bits (HSS / HSCO / Masonry / Tungsten Carbide)	13 mm diameter jobber	5

Type	Maximum dimension / power / weight	Quantity [†]
Felling/fire axe (7 lb / 3.18 kg nominal head weight)	900 mm long / 4.5 kg	1
General purpose saw	750 mm long	1
Grinder (cordless)	18 V	1
Grinder discs	125 mm diameter	3
Hole saw	50 mm diameter	1
Hooligan bar	760 mm long / 5 kg	1
Jigsaw	18 V	1
Jigsaw blades (HSS / HSCO / Carbide)	-	3
"K-tool" lock remover	-	1
Plate shears	300 mm long	1
Reciprocating saw	18 V	1
Reciprocating saw blades (HSS / HSCO / Bimetal / Carbide)	Standard series	3
Sledgehammer (7 lb / 3.18 kg nominal head weight)	900 mm long / 4.5 kg	1
Steel wedges (selection)	150 mm long	6
Tube	75 mm outer diameter with 6 mm wall thickness x 500 mm long	1

Figure 254 - Tool Category E

Tool category A, B, C and E plus:

Type	Maximum dimension / power / weight
Battery	36 V
Chisel bits (SDS-Plus)	300 mm long
Circular saw	36 V
Circular saw blades	200 mm diameter
Disc grinder	36 V
Drill (rotary, hammer action and/or SDS)	36 V
Drill bits (HSS / HSCO / Masonry Tungsten Carbide)	13 mm diameter jobber and long series
Drill bits (SDS-Plus)	300 mm long
Drill bits (step drill / cone cutter)	30 mm diameter
Drill bits (tile / glass)	10 mm
Drill saw	6 mm diameter
"Glasmaster" saw	-
Grinder discs	125 mm diameter
Hole saw	>50 mm diameter
Jigsaw	36 V

Type	Maximum dimension / power / weight
Maul - wood splitting (8 lb / 3.63 kg nominal head weight)	1200 mm long / 5 kg
Pick axe (5 lb / 2.27 kg nominal head weight)	1200 mm long / 4 kg
Pinch bar	1500 mm long
Reciprocating saw	36 V
Reciprocating saw blades (HSS / HSCO / Carbide)	310 mm long
Sledgehammer (10 lb / 4.54 kg nominal head weight)	1200 mm long / 6 kg
Steel wedges	300 mm long
Tube	75 mm diameter x 1000 mm long
Wood boring spade bits (selection)	40 mm

Figure 255 - Tool Category F

Tool category A, B, C, E and F plus:

Type	Maximum dimension / power / weight
Battery	54 V
Chisel bits (SDS-Plus)	600 mm long
Chainsaw (2-stroke)	3 kW with full fuel tank / 400 mm bar length / single chain
Circular saw	54 V
Disc grinder	54 V
Drill (rotary, hammer action and/or SDS-Plus)	54 V
Drill bits (HSS / HSCO / Masonry / Tungsten Carbide / SDS-Plus)	20 mm diameter / 600 mm long
Enforcer	450 mm long / 12 kg
Grinder (2-stroke)	3.7 kW with full fuel tank
Grinder discs	300 mm diameter
Hooligan bar	910 mm long
Reciprocating saw	54 V
Trolley jack	4 tonne
Tube	75 mm diameter x 1500 mm long

Figure 256 - Tool Category G

Tool category A, B, C, E, F and G plus:

Type	Maximum dimension / power / weight
Arcair	240 V / 80 psi oxygen supply
Arcair rods (selection)	1200 mm
Concrete chainsaw (2-stroke)	5 kW with full fuel tank / 350 mm bar length / single chain / 15 kg
Grinder (2-stroke)	5 kW with full fuel tank / 15 kg
Grinder discs	400 mm diameter
Diamond core drill bit	125 mm diameter
Enforcer	600 mm long / 18 kg
Hydraulic head and toe jack ("Rabbit tool")	15 kg / 5 tonne (S.W.L) output / 180 mm spread
Oxyacetylene cutting kit	250 l/min oxygen consumption ^{†††}
Rescue chainsaw (2-stroke)	4.5 kW with full fuel tank / 510 mm bar length / single chain
Ring saw (2-stroke)	5 kW with full fuel tank
Ring saw blades	400 mm diameter

Figure 257 - Tool Category H