University of Southern Queensland
Faculty of Health, Engineering & Sciences

Recyclable Disposable Helmet Design

Submitted by

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Abstract

Throughout recent history numerous changes have been made to the modern bicycle helmet and the laws surrounding this protective equipment. This study develops a recyclable disposable helmet design which can be implemented into a bicycle sharing scheme, (Brisbane's City Cycle). The helmets requirements are for it to be produced with only recyclable material and manufactured in a moderate amount of time at a low cost. The main scope of the following study is to select and verify a possible material, test the impact energy absorption and load distribution of the material in the form of a helmet. The tests conducted were in accordance with the Australian New Zealand standards AS/NZS 2063:2008.

The investigation includes, current research and implementation of recyclable materials and leads into the analysis of conceptual designs for the helmet. Material analysis has been undertaken with samples of the desired material manufactured and tested to compare with the most common materials currently used. The testing of the final helmet design is then analysed with the outcome and future work for the project discussed.

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Nomenclature

$a(t)$	- Linear acceleration, measured in the gravity of the head
F	- Force
g	- Acceleration Due to Gravity (9.81 m/s^2)
m	- Mass
s	- Displacement after impact
t_1	- Initial time of impact
t_2	- Final time of impact
v	- Velocity
σ	- Stress
ε	- Strain

Chapter - 1 Introduction

1.1 Outline of the study

The introductory chapter introduces the purpose and research objectives of the project and provides an understanding to the current industry of helmets. The main objective within this study is to investigate bike sharing schemes throughout the world and their solution to a helmet option with a main concentration to Brisbane's, CityCycle, and to design and test a helmet to the current Australian standards with the intention of implementing the working design into this scheme.

1.2 Project topic

The disposable recyclable helmet design is targeted for the Brisbane CityCycle and also for the various Bicycle rental programs throughout the nation and potentially internationally (depending on testing criteria). The outcome of the project is to design a disposable helmet which does not only use recyclable materials but also previously used helmets of the same material which will be used to continue the manufacturing process. This process will allow the product to be disposed of after each uses into a recycling bin at each station and for the material costs to be as low as possible. The helmet being recyclable will also allow all users of the CityCycle scheme to have unlimited access to a helmet (due to expected price). The helmet will abide by all national requirements and standards to ensure its safety. The design and its disposable qualities in theory are considered a more health considerate approach to sharing helmets than the current solution.

1.3 The Problem

CityCycle, Brisbane's public bike share scheme, is an active and sustainable type of public transport that encourages more people to cycle around the inner city. (Brisbane Council). The scheme was first introduced by previously elected

Introduction

Lord Mayor of Brisbane, Campbell Newman in September 2010. The initiative of the scheme was introduced to aid in the Brisbane City Council's plan to help reduce traffic congestion and ease parking pressures in central Brisbane. (Brisbane Council). CityCycle gives different options in the hiring of bikes and helmet options offered, CityCycle bike hiring is currently available 24 hours 7 days a week. Within the agreement of hiring a CityCycle bicycle there are various road safety requirements when using the bike. One of the most crucial and controversial rule, is to

- Always wear an Australian standards approved bike helmet. (CityCycle 2012)

This rule is a main consideration for the outcome and the major basis for a recyclable disposable helmet design, to provide an eco-friendly and safe helmet to riders. This factor has been heightened as more advocates are pushing for a no helmet law for the bike sharing scheme as all other options of helmets to date, have been met with a negative response. (Freedom 2015). This is an unsafe solution to the problem, a low cost sustainable protective helmet is a more desirable solution as safety of the wearer is the number one concern.

1.4 Project objectives

The objectives of the project have outlined the sequence of the investigation, to present a logical layout of the project, these objectives are to:

- Investigate the need within the CityCycle scheme;
- Investigate the current Australian standards required for a helmet,
- Investigate the materials currently proposed with recyclable qualities,
- Test samples of the material chosen, produce various conceptual 3D designs,
- Create multiple helmets of a final designs and test to the Australian standards which are required for a helmet to be sold in Australia.

The end product will also be assessed on various qualities to determine if the design is viable for the market.

1.5 Research Aim and Objectives

(ACCC 2015) states, the design of a helmet must consist of a,

- Means of absorbing impact energy
- Means of distributing the load
- Retention system.

The above points outline the requirements for a helmet design and the material used, these factors have guided the research aims and objectives of the project. This has pushed the research into defining the characteristics of the proposed material (refer to Chapter 8) as the focus is to design a feasible disposable helmet with recycled material. The material analysis and selection of current recyclable materials is a main focus. The helmet must meet all Australian standards within the scope of the project, while also being a cost effective and easily recycled, this requirement of the design is defined as the main research main. The background research will also include the justification of the current materials used, the development of materials and the current helmets using recycled materials.

1.6 Justification

The need for the project is derived from the CityCycle scheme itself. The public's view throughout the schemes life span is somewhat negative in nature, as the scheme has yet to produce a satisfying profit to the region.

> "At this rate it would have almost been cheaper to buy bicycles for everyone who purchased an annual or quarterly CityCycle subscription," Cr Sutton said. (SOPHIE ELSWORTH 2011).

This is just one of the negative remarks made about the implementation of the scheme. This is also due to the fact that 70 per cent of Brisbane's free yellow CityCycle helmets have gone missing since they were introduced last year. (Feeney 2012). This statistic is one of the more dramatic concerns for a need of an alternative solution to the problem. The CityCycle scheme when initiated had limited option for helmet use and the free yellow helmets was then implemented as a council initiative. Due to vandals and theft of the free helmets this option is considered to be a failure and not a continuous solution which has now allowed the opportunity for an alternative solutions, hence the disposable recyclable helmet design.

1.7 Scope

As the purpose of the project is predominantly to design a disposable recyclable helmet for the Brisbane CityCycle scheme and test the helmet the research scope of this dissertation will include investigation into which standards for bicycle helmets as well as the material analysis and material selection. Further investigation into the results and discussion are had to determine the outcome of the product. The helmets were tested to, AS/NZS 2512.9, Method 9: Determination of Load Distribution and, AS/NZS 2512, Method 3 Impact Energy Testing. These are outlined within section 2.5.

1.8 Deliverables

The following tasks completed.

- Review of Literature encompassing the current CityCycle scheme, national standards and requirement.
- Current designs and conceptual designs for the final product
- 3-D CAD drawings of conceptual designs
- Material analysis and selection
- Methodology of the design and testing procedures
- 3-D clay model of final design
- Testing procedures and outcomes
- Validation of end result including a comparison of design and material with current on the market helmets.

1.9 Dissertation Overview

The following dissertation is an investigation into a suitable recyclable material, which is then implemented into a recyclable disposable helmet design and tested. Included is the investigation into the relevant Australian standards which a helmet is required to undertake to be certified within Australian. The investigation continues into, current research and implementation of recyclable materials and leads into the analysis of conceptual designs for the helmet. Material analysis has been under taken with samples of the desired material manufactured and tested to compare to the most common materials currently used. The testing of the final helmet design is then discussed with the outcome and future work.

Chapter - 2 Review of Literature

2.1 Chapter Overview

The review of literature contains background on the CityCycle scheme and the law regarding wearing helmets. Other impact testing strategies are discussed to compare the Australian testing with a global scale. Two test have been chosen which will determine how affective the material acts during impact and if it will distribute the force throughout the head. These tests are explained and the requirements of each clearly stated.

2.2 Brisbane CityCycle Scheme

The CityCycle scheme is a bicycle hiring campaign designed to lower the inner city congestion during peak hours within the city. The main concept of the scheme is that people who work within the city will park their cars further from work and ride a bike to work. The other concept which is implied within the CityCycle project is for tourist to be able to explore the city whilst riding. The scheme encourages physical activity and lowering the use of cars within the city. Many other cities have adopted this tourist attraction in the hope to lower vehicle congestion. As these schemes become more popular the need for a sustainable solution to a helmet is required, hence the need for a recyclable helmet.

Figure 2.1City Cycle Bike and Terminal (Council 2015)

2.2.1 Introduction into the services

More than 500 cities in 49 countries host advanced bike-sharing programs, with a combined fleet of over 500,000 bicycles. The introduction of a bicycle rental scheme starting with the introduction of 50 white bicycles scattered within Amsterdam for free use in 1965.(Larsen 2013)

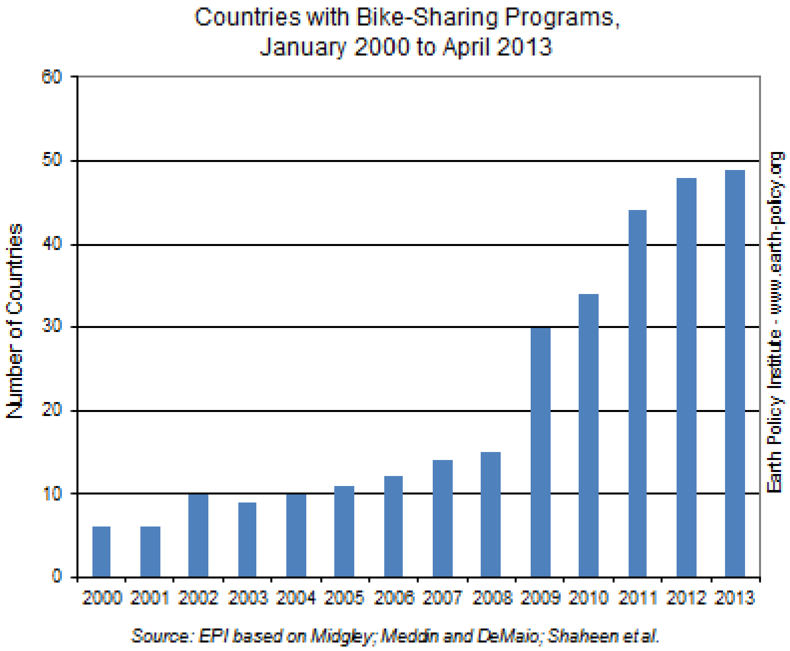


Figure 2.2 Countries with Bike-Sharing Programs(Larsen 2013)

In 2010 after increasing popularity in global bicycle rental schemes two major cities within Australia started the developing stages of their own rental schemes. Both Brisbane, CityCycle scheme and Melbourne's bike share started construction to be a part of the international phenomenon of, city bike-sharing programs.(Brisbane Council 2015; Victoria 2015). The scheme was first introduced by the previously elected Lord Mayor of Brisbane, in September 2010 Campbell Newman. The initiative of the scheme was introduced to aid in the Brisbane City Council's plan to help reduce traffic congestion and ease parking pressures in central Brisbane. (Brisbane Council).

The initial conditions of the scheme included various rules and regulations that must be abided too when in use of the CityCycle bikes. These rules include that the rider must;

- Wear a helmet,
- be 17 years or over and fit,
- The rider must ensure to check the bike before they ride it, for any defects or damages.
- The payment of the hire is for an excess of 30minutes (from check out to lock in) and
- the bikes cannot be hired for a period longer than 24 hours (after 24 hours we will treat the Bike as lost or stolen and debit you accordingly); (Brisbane Council 2013)

These have been stated by the Brisbane City Council in the City Cycle User Agreement. During the introduction the scheme applied other rules which included a curfew of the bikes and they were only available for use on certain days of the week. The pricing of the hire times was considerably larger than the current asking price and there was no helmet option available for riders. Brisbane city council developed and implemented various solutions to the identified problems due to the large backlash to various aspects of the program by the public.

2.2.2 Altercations to the initial scheme

The changes which have been applied include a dramatic cost reduction of hires, linking the service with the Trans Link Go Card and, the introduction of student subscriptions.(Moore 2013) Below outlines the seven- point plan the city council implemented after backlash to the scheme.

Seven-point plan to boost CityCycle

- Daily subscriptions reduced to $2 (from $11)
- Weekly subscriptions introduced at $11
- 400 free helmets to be distributed to key stations
- Web-mobile access to allow people to subscribe using a smartphone or tablet

- CityCycle Express Cards introduced, meaning no wait for a CityCycle card in the mail. The express cards are only available for quarterly and annual subscriptions.
- Corporate subscriptions introduced to allow companies to register multiple cards under one company name with charge back to one common credit card.
- Allow users to agree to the terms and conditions at the terminal over the phone when they use their card for the first time (Times 2011)

The council was pressured due to the lack of support and the new plan was to validate the success of the program for years to come.

2.2.3 Current helmet options and requirements

Participants are encourage to provide their own helmet whilst using the services yet many believe this to be a burden.

> "When you ride a bicycle, you must wear an Australian Standard-approved bicycle helmet. You must securely fit and fasten it." Stated (Queensland 2015).

Above is the Queensland Government Transport and safety's rule for when riding a bike. Therefore all CityCycle riders are required to abide by this rule.

> "By law, it is a condition of hire that helmets are worn by users. For further information please visit the Queensland Department of Transport website. Users are encouraged to use their own helmets, or annual and 3-month subscribers can purchase a helmet at the time of subscription." (Brisbane Council 2015)

The direct answer from CityCycle to, the question "Do I need to wear a helmet?"

Throughout the construction of the scheme the council has introduced their solutions to CityCycles' problems such as, for the users required to wear a helmet. These solutions includes the above proposal for subscribers to purchase a helmet at time of subscription or another purchase. This solution does not allow for the one off user or the fact that carrying around a helmet is an inconvenience to users, therefore the council introduced yellow free helmets for users.

In 2012 the council introduced 1500 yellow CityCycle helmets into the scheme which were held within the basket of the bikes at key locations for a free helmet option which would overcome the issue of one time users required to purchase a helmet. (Feeney 2012) states,

> "About 70 per cent of Brisbane's free yellow CityCycle helmets have gone missing since they were introduced last year."

Unfortunately for the council this idea of a free helmet has been crushed by the very apparent destruction of the free helmets in various ways of either vandalism or theft. The free helmet idea also had no consideration to the health issues associated with using frequently shared helmets between riders. This is leaving the council with a very high bill regarding helmets and not delivering a reliable helmet option for riders.

2.2.4 Demographic

The CityCycle scheme is designed to increase the physical activity of people within the city and to ease congestion on the roads as more people will be riding. CityCycle has stated that if over the age of seventeen then you are able to use the bicycles. Yet as previously stated within the User Agreement it is outlined as, Be 17 years or over and fit; this indicates that a certain level of fitness is required for the use of the bikes yet this fitness level is not stated. Apart from these the scheme has no direct demographic and is designed to be enjoyed by all. Therefore the study has a demographic of an adult, and is designed for an adult size helmet

2.3 National and interstate standards

Australia in many ways has led by example with introducing bicycle laws being one of the first countries in the world to enforce a rider to wear a helmet whilst riding. The laws were introduced between 1990 and 1992 when slowly, all states and territories one by one began to amend their current laws to ensure the safety of the riders, making Australia a world – leader in the process.(Neef 2013). Stated within the Brisbane CityCycle scheme the requirement of the rider is to wear a helmet at all times, this is also stated by (Queensland 2015) refer to section 2.2.3

2.3.1 The law

In accordance with Transport Operations (Road Use Management) Act 1995 section 256, (1),

> "The rider of a bicycle must wear an approved bicycle helmet securely fitted and fastened on the rider's head." (Queensland & Counsel 2015).

The law is there to ensure that all riders are safe when in control of the bicycle. Yet for those who disobey the law, a, maximum penalty—20 penalty units, is given to those who are caught in the wrong. The penalty unit value in Queensland is $113.85 (current from 1 July 2014). Therefore for not wearing a helmet the maximum penalty is $2,277.00. (Gvernment 2015). This is considerably large amount for a personal protective equipment when many people are currently advocating for the removal of helmet laws within Queensland. The legislation also states that the helmet is required to be an Australian Standard therefore if a helmet is purchased or brought from overseas then there is still a risk in being fined. There are exceptions to this by receiving a permit from local council. An international helmet can only be permitted if the Australian standard recognises the standard that the helmet is ranked at as an equivalent standard.

2.3.2 Requirements of a bicycle helmet

Within the current standards required for a helmet, there are various methods of testing and validating that a helmet is safe. Different methods and scales have been implemented by different organisations depending on where the helmet is to be sold. The Australian market has devised its own standards with testing for different elements of the helmets. The Australian standard can only be given by a select few companies. These companies are equipped to allocate products with an Australian Standard sticker and to ensure its quality.

The task of certification can cost in the thousands for a manufacture trying to get a product to meet the standards. The process does not only include initial testing, yet also focuses on the quality of the material and production to ensure the quality of the standard. This process is time consuming to both the certification company and the manufacture. If the quality of the product is found to be contradictory to the certified version of the product after production, then there can be a product recall. A messy and expensive process for all those involved in manufacturing, distributing and selling the helmet (Neef 2013).

The free CityCycle helmets which have been put into rotation within the scheme are identified as a road helmet, "a helmet designed for use by almost any bicycle rider, including those who ride on roads or paved trails. "(Institute 2015), and are in accordance with Australian Standards.

2.4 Various Criteria for Helmet standards

Throughout time there have been various considerations into the scale and standard in which a safe head impact can be recorded. The previous section (2.3) identifies that the law states, the helmet worn is required to be certified to Australian standards as the government has decided that this standard of safety is suitable.

The process of the project is too undeniably demonstrate that the process of a recyclable helmet is possible. To ensure that the dissertation provides a successful description of the outcome to determine further work other criteria are to be investigated. This will allow a wider range of validation and encourage further investigation internationally as the end product can be evaluated on multiple scales.

2.4.1 Severity Index

The first model historically was the severity index to determine a scale to measure head impacts. The following equation is a basic integration implementing the variables of, the duration of deceleration during the impact and the deceleration at time t. Equation 2.1 Severity Index (Bourne 2015a)

$$SI = \int_0^T \{a(t)\}^{2.5}\, dt \qquad (2.1)$$

The index 2.5 was chosen for the head and other indices have been allocated for the other parts of the body (usually based on possibly gruesome experiments on human or animal bodies). The severity index was found to be inadequate for various application and therefore researchers developed the Head Injury Criterion HIC. The HIC is a continuation of the Severity index and both are applied to the same corresponding fatality percentage based on the result, the fatality percentage is explained within the following section.

2.4.2 Head Injury Criterion (HIC)

The head injury criterion is a measure of the likelihood of head injury arising from impact. This is analysed by the mathematical formula below, the equation is calculated using the linear acceleration, and time interval of the peak acceleration of the impact. Equation 2.2 Head Injury Criterion (HIC)(Gaetano Bellavia 2007)

$$HIC = \max(t_1\, or\, t_2) \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right]^{2.5} \right\} \qquad (2.2)$$

The continuation of the development of the world recognised equation is the scaling and limitations of the equation. There has been vast amount of discussions regarding the limits in which the limit of a standard should be, currently the tolerance threshold proposed by Gadd, for crash with impact, is equal to 1000: the overcoming of this value indicates a greater probability than

95% of extended concussion. The HIC (Head Injury Criterion) is a new injury criterion for the head.

Various organisations are currently investigating if the 1000 is a safe enough value to strive for and many are calling for a decrease of the standard to increase to safety of head equipment.

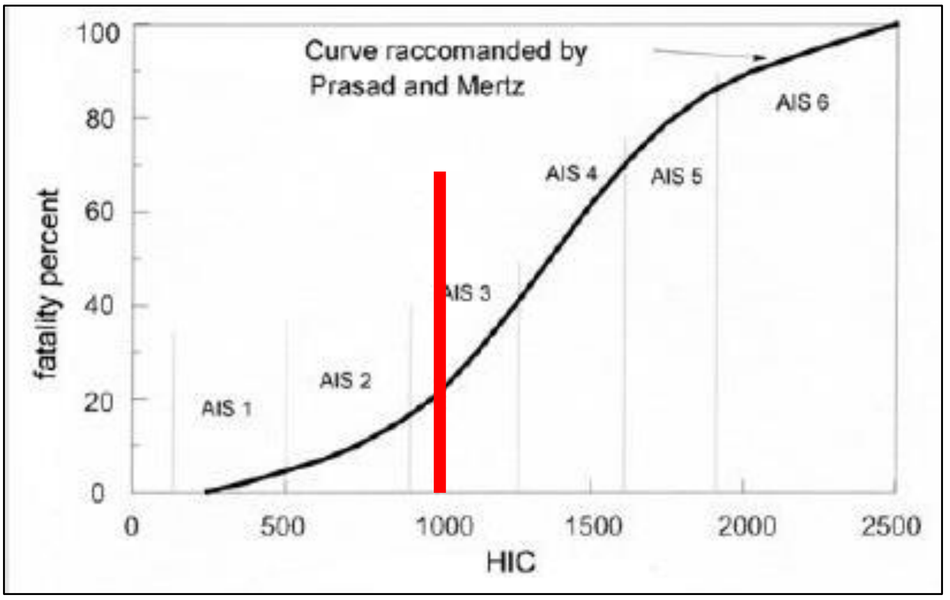


Figure 2.3Probability of fatality versus HIC (Gaetano Bellavia 2007)

The above figure is the curve recommend by Prasad and Mertz this is a representation of the likelihood of fatality of a head impact against the HIC value of the impact, and the red line represents the maximum before impacts are considered life threatening. Some crash test have low HIC values as low as 142, (an Audi8, with airbag, in 1998) (Bourne 2015b).

2.5 Bicycle Helmet Standards

The following standards are unlike the previous criteria which have been discussed, unlike the previous criteria the Australian standards use a peak deceleration over a maximum amount of time to determine if the helmet is within standard. These standards and the process of what each experiment determines is discussed throughout the following section.

AS/NZS 2063:2008 6

5 CONSTRUCTION

5.1 General

5.1.1 *Components*

The helmets shall consist of—

(a) a means of absorbing impact energy;

(b) a means of distributing load; and

(c) a retention system.

All components of the helmet shall be permanently attached. Removable comfort pads are not considered as part of the protective system.

Figure 2.4, Requirements of a Helmet design. (Zealand 2008)

The above figure is a statement from the Australian standards AS/NZs 2063:2008 which outlines the standards for an Australian bicycle helmet. Which linked in with other Australian and New Zealand Standards outline the acceptance level of products.

Within the AS/NZS 2063:2008 various other standards are referenced which relate to various attributes and conditions of the helmets and testing which the helmets are required to pass.

These standards stretch from AS/NZS 2512.1:2009 to AS/NZS 2512.9:2009 with a total 15 documents which outline everything from the designs of the tests mechanisms to the temperatures which the helmets are required to be tested at and also the test order for the helmets outlined below.

TEST ORDER FOR HELMETS

Sample No.	Conditioning	Test
1	Ambient temperature	7.2 Horizontal peripheral vision clearance test 7.7 Peak deflection test 7.3 Static stability test
2	Ambient temperature	7.4 Impact energy attenuation test 7.6 Dynamic strength of retention test
3	Ambient temperature	7.5 Load distribution test 7.6 Dynamic strength of retention test
4	High temperature	7.4 Impact energy attenuation test 7.6 Dynamic strength of retention test
5	High temperature	7.5 Load distribution test 7.6 Dynamic strength of retention test
6	Low temperature	7.4 Impact energy attenuation test 7.6 Dynamic strength of retention test
7	Low temperature	7.5 Load distribution test 7.6 Dynamic strength of retention test
8	Water immersion	7.4 Impact energy attenuation test 7.6 Dynamic strength of retention test
9	Water immersion	7.5 Load distribution test 7.6 Dynamic strength of retention test
10	Spare sample	

Table 1, Test order for helmets(Standard 2008)

Due to time constrictions of this project the following design testing will focus on the Impact Energy Attenuation Test and the Load Distribution Test. As these tests are required for conditions and focus on the materials properties and abilities to protect the head from injury. For the purpose of this dissertation these tests are consider to give more vital information about the material which will be considered, and therefore be the more important tests to provide the information of the outcome of this project.

These two tests combined will determine if the profile of the helmet combined with a material will be a suitable design which will then be able to be manufactured. Also discussed is the strength of retention test which will be a design consideration later within the process of manufacture and designs, which is outside the scope of this dissertation.

2.5.1 Methods of testing protective helmets AS/NZS 2512, Method 3 Impact Energy Testing

The Australian/ New Zealand Standards also include, the general requirements for the conditioning and preparation of the test specimens and laboratory conditions, Methods of testing protective helmets. Firstly the conditioning of the helmets must be conditioned at varying temperature to ensure that the product meet the standards on any given day. At least one of the products is required to be exposed to each of the Conditions

- Ambient temperature; between 18°C and 25°C for 4h to 30 h.
- Low temperature; -10 ± 2°C for 4 h to 30 h.
- High temperature; 50 ± 2°C for 4h to 30 h.
- Water immersion; at least one of the helmets shall be immersed in water at a temperature of 18°C and 25°C for 4h to 30 h.

(Zealand 2006)

Next is the Determination of impact energy attenuation – helmet drop test. “A complete helmet is mounted on an appropriately instrumented head form and dropped, in guided free fall, on to an anvil as specified in the product standard. The acceleration imparted to the assembly is measured.”(Standard 2007).

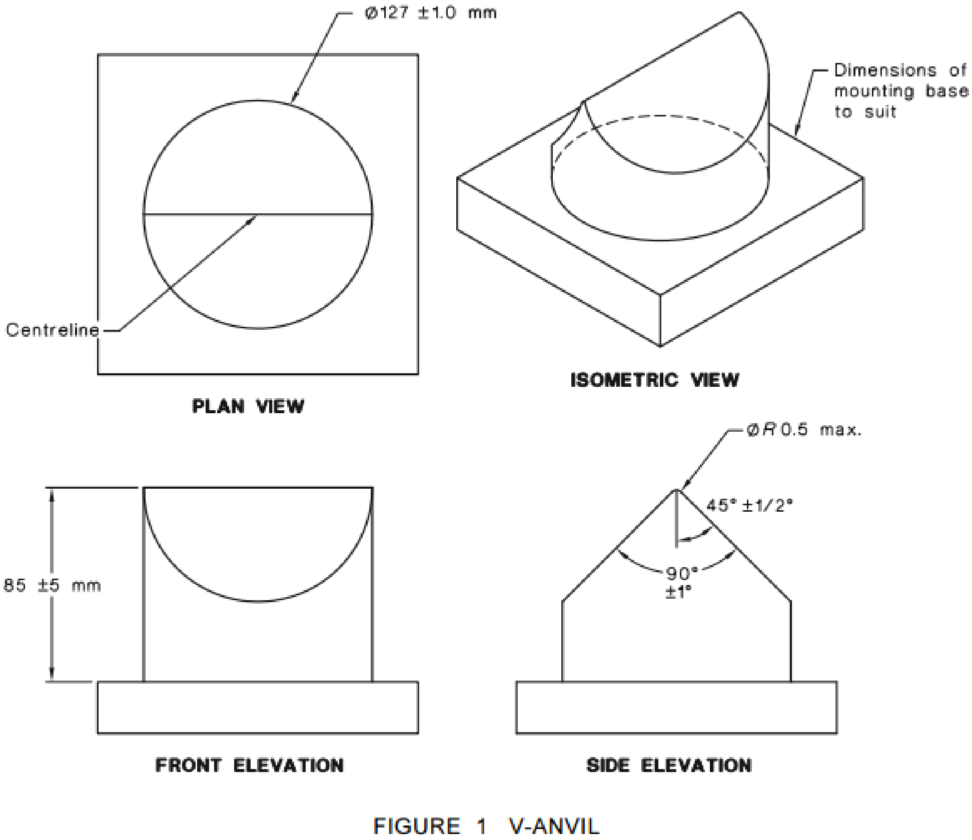


Figure 2.5 V- Anvil (Standard 2007)

In figure 3 it shows the required apparatus in which the test subject will be dropped on and a measured response will be recorded. The standard also notes that a material with a magnesium/ zirconium binary alloy with 0.3% to 0.8% zirconium is suitable for the anvil.(Standard 2007).

TABLE 1

MASSES OF IMPACT ENERGY ATTENUATION TEST DROP ASSEMBLIES

Test headform size	Mass of drop assembly kg
AA	2.5 ±0.05
A	3.1 ±0.05
E	4.1 ±0.05
J	4.7 ±0.05
M	5.6 ±0.05
O	6.1 ±0.05

Table 2, masses of impact energy attenuation test drop assemblies(Standard 2007)

For different manufactures different sizes will be produced and different sizes for each product is likely to be sold therefore there are varying weights in which are to be applied. As shown in table 1. Depending on the headform calculated for the helmet will depend on the mass use, (headforms are calculated using various formulas outlined in AS/NZS 2512.1).

The apparatus also is under strict verification, (Standard 2007) outlines, “the velocity of impact shall not differ by more than 3 % from the velocity of impact theoretically obtained in free fall in vacuum, within 50 mm of the point impact from the specified drop height.” The strict rules that govern these tests ensure that there is no confusion when testing and that the repeatability of the tests are all within tolerance.

Outlined by the standards (Standard 2007), is the procedure of the tests,

a) Condition and prepare the helmets in accordance with AS/NZS 2512.2.
b) Ensure that the laboratory conditions are as specified in AS/NZS 2512.2.
c) Position and secure the helmet as specified in AS/NZS 2512.2.
d) Perform the impact energy attenuation test(s) as specified in the product Standard, ensuring that the test site and centre of the anvil are lined.

e) Measure the acceleration resulting in each case.
f) Mark each helmet to ensure it does not entre service.

The last stage outlines all considerations taken into account with each of the tests such as the specific conditions of each helmet, masses used, etc. this is too ensure all data recorded is done in a professional manner with no margin of error when comparing data.

1. Identity of the helmet under test.
2. Details of headform.
3. Headform acceleration at intervals specified in the protect Standard.
4. Details of the detachment of protective components as a result of testing.
5. The number of the Standard used, Australian/ New Zealand Standard, AS/NZS 2512.3.1.

These above points are all to be reported for reach product which is tested,(Standard 2007).

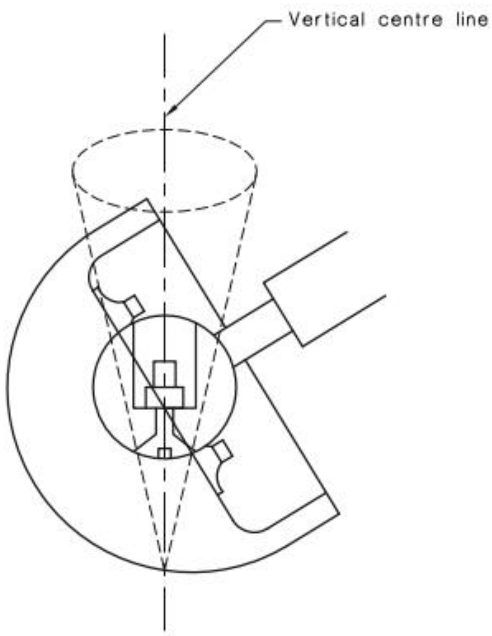


Figure 2.6, Centre of mass(Standard 2007)

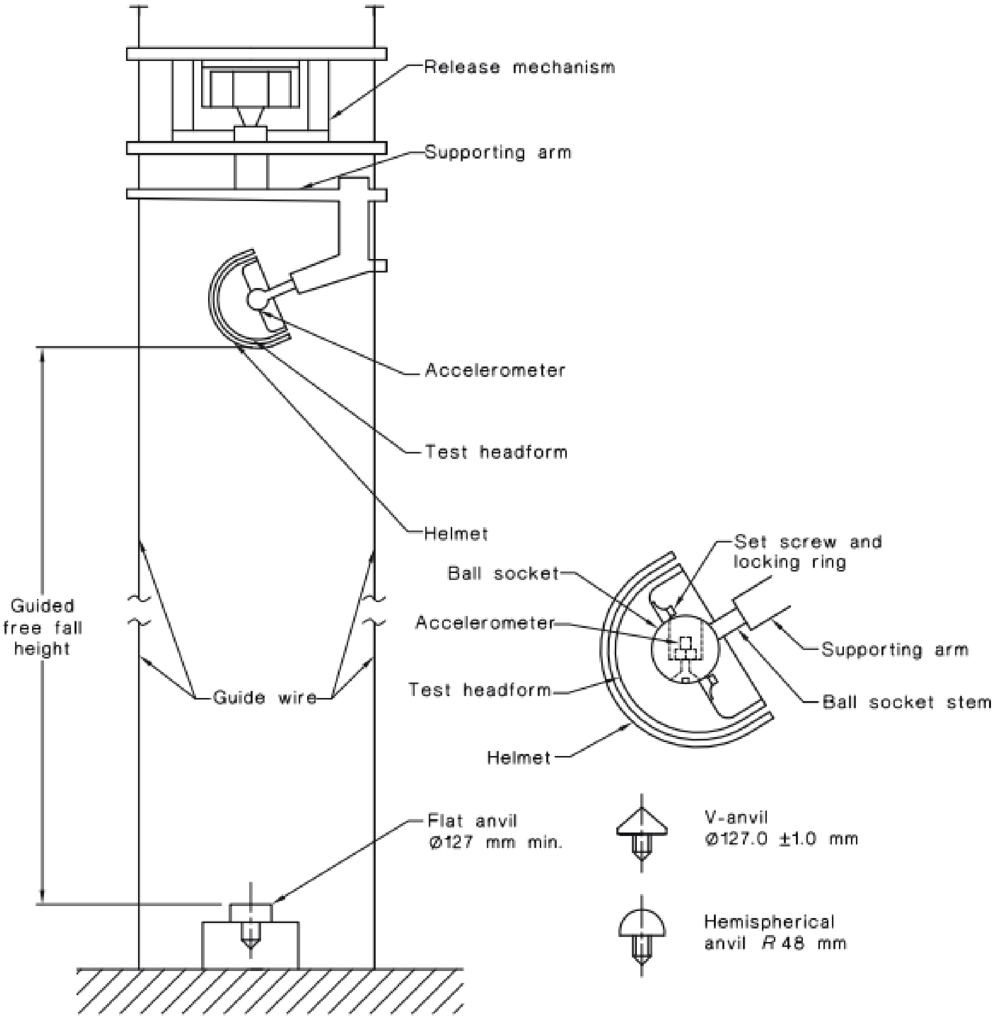


Figure 2.7, Typical Apparatus for impact energy attenuation test (Standard 2007)

Figure 5 graphically represents a typical apparatus used for impact energy attenuation tests, which shows the test helmet on a supporting arm which will be dropped onto the anvil at the bottom of the apparatus. Each anvil will show different results due to the different profiles, these are used to represent various surfaces which a rider may fall onto.

2.5.2 Methods of testing protective helmets AS/NZS 2512, Method 5 Determination of Strength of Retention System

The previous standards which are outlined in Method 3 are all aimed to test for impact energy absorption for a test helmet. The standard goes through all aspects of a helmet, the next portion which is of concern is Method 5, Determination of strength of retention system.

The typical tests for the retention system include a static and a dynamic test. The static test gradually applies an increasing load onto the retention system of a magnitude and durations specified in the product Standard. This force is applied normal to the basic plane of the headform. This test is designed to measure the increase in deflection of the loading device. Then the report of the test is made this report is similar to that previously outlined in Method 3 in a professional manner to decrease the chances of mixing the results.

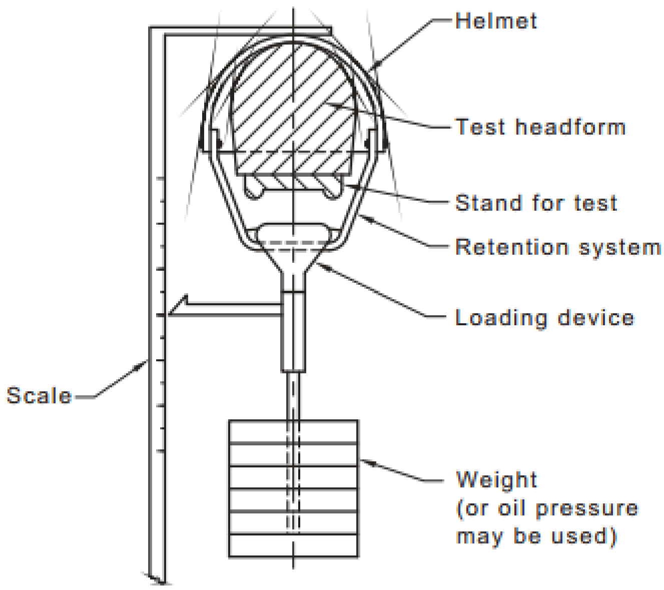


Figure 2.8, typical apparatus for static retention system (Standard 2008)

The second test is designed for a dynamic testing of the retention system, this test is designed so that when riding if the helmet has a force applied to it that the helmet will stay on the rider. The method applies to each individual component of a system in which the components can be independently fastened without securing the complete assembly.

The test is comprised of a loadbearing device which consists of a chin strap stirrup with a guide bar. A device to measure the dynamic and permanent displacement of the retention system, chin strap. This device is constrained to various limitations of dimensions and weight, to ensure all testing is accurate and repeatable similar to those previously discussed. (Standard 1998)

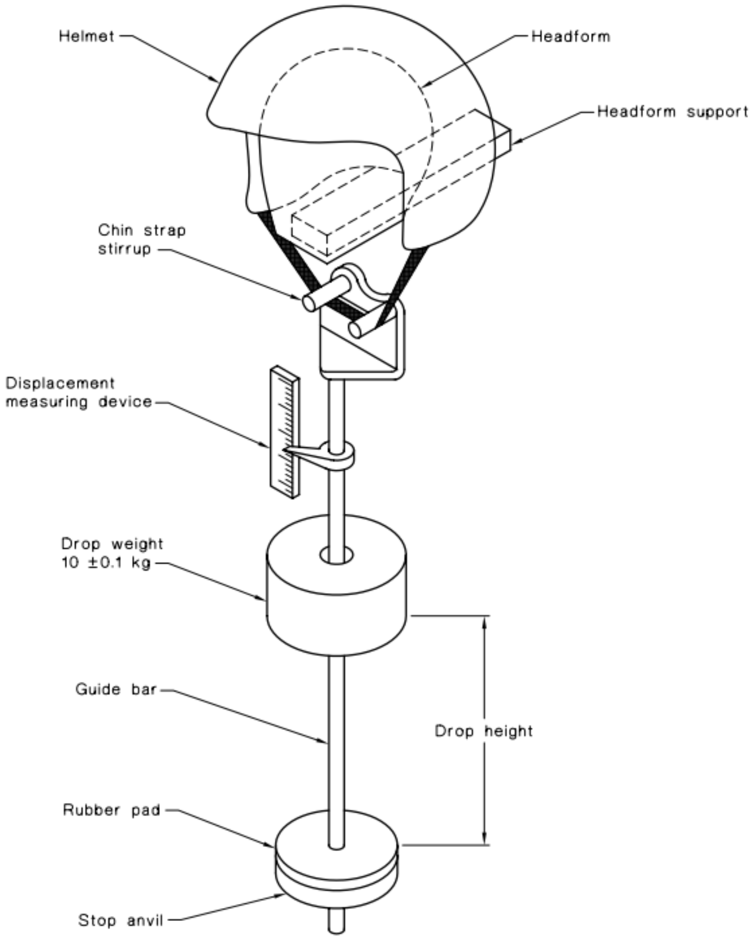


Figure 2.9, typical apparatus for dynamic retention test(Standard 1998)

2.5.3 Methods of testing protective helmets AS/NZS 2512.9, Method 9: Determination of Load Distribution

The last test which is outlined within the requirements of a helmet is the means of distributing the load therefore, this also requires a test to determine if the helmet meets the Australian Standards. This test is to determine if the load is distributed or not. The test is comprised of a suspended anvil which will be dropped onto a specific point on the helmet. This point will have strain gauges attached capable of measuring the force transmitted by a steel load transfer pin on the anvil. The anvil is dropped form the desired and specified height towards the outer surface of the helmet and the forces are measured. The below figures are outline form AS/NZ2512.9 as construction drawings.

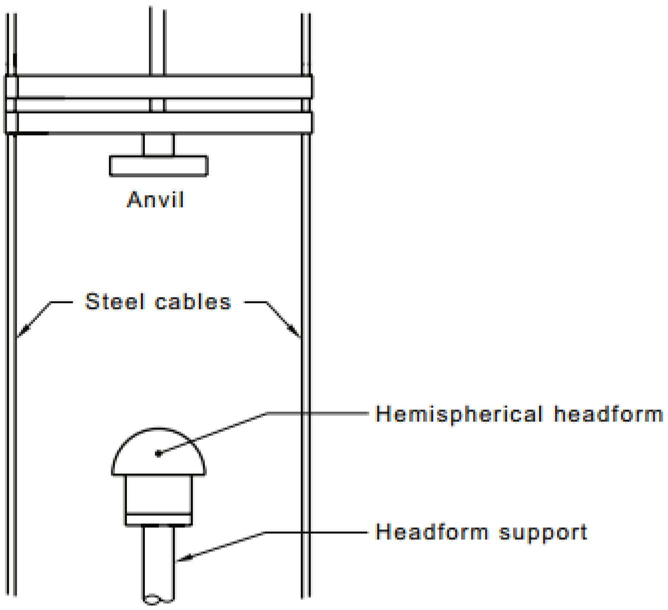


Figure 2.10, typical rig layout(Standard 1998)

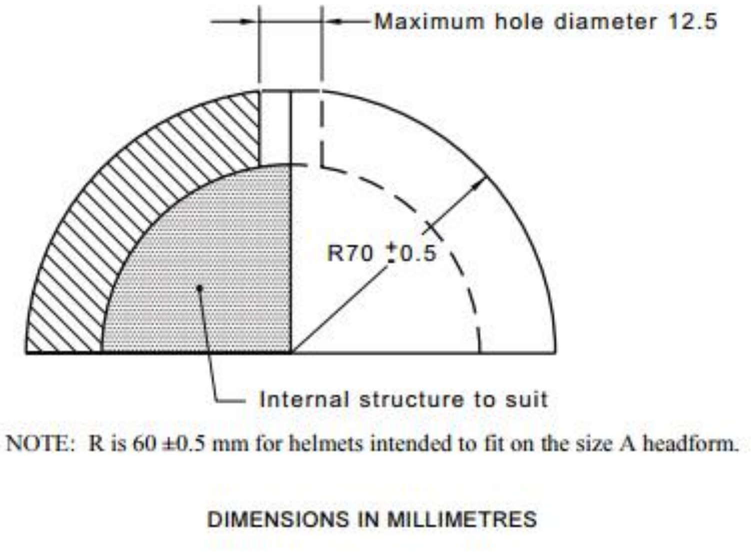


Figure 2.11, Hemispherical Headform Construction(Standard 1998)

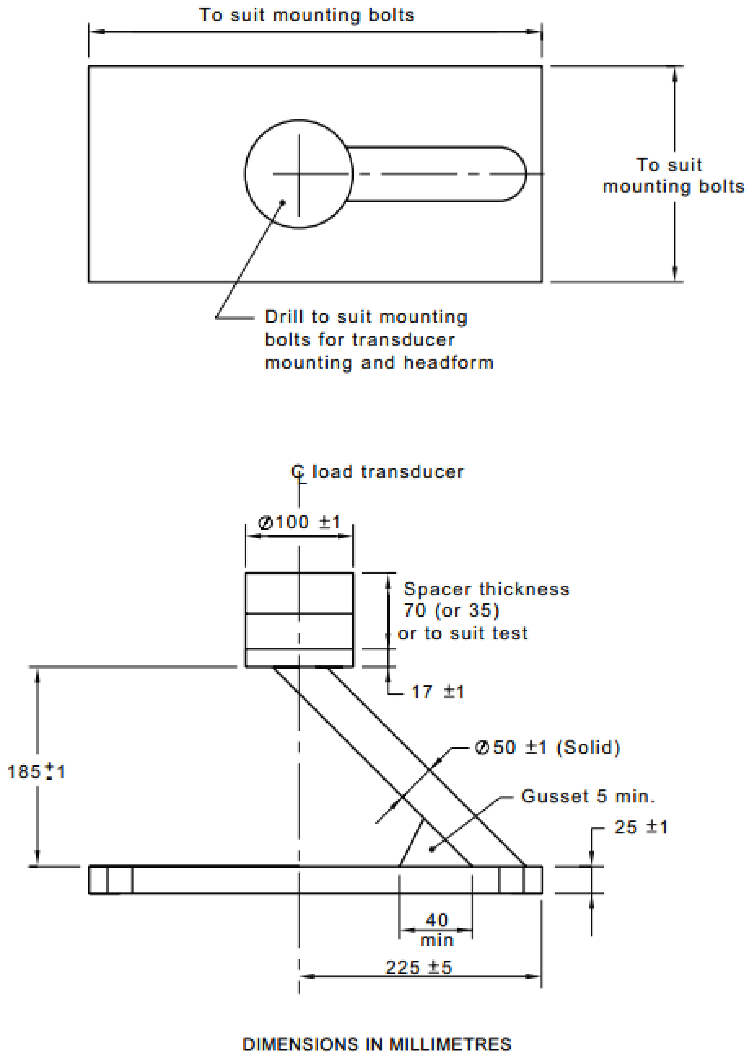


Figure 2.12, Head form Support(Standard 1998)

2.6 Requirements to pass the AS/NZS 2063:2008

The standards have been broken into various tests at various conditions as previously discussed. For each of these tests no matter of the condition the helmet which is being tested will be required to achieve a certain result.

2.6.1 Impact Energy Attenuation

When the helmet is tested using a flat anvil only and a free-fall height of 1500 +30, -5 mm the head form acceleration shall not exceed 250g peak. In addition, the cumulative duration of acceleration shall not exceed –

(a) 3.0 ms for acceleration greater than 200g
(b) 6.0 ms for acceleration greater than 150g

2.6.2 Load distribution

When the helmet is tested in accordance with AS/NZS 2512.9 using a fall height of 1000 +15, -5 mm, the following conditions shall be met:

(a) Loading measured by the force transducer shall not exceed 500 N measured over a circular area of 100 mm^2
(b) The anvil shall not contact the surface of the head form.

2.7 Requirements of the material used

As outlined throughout the standards there is no requirement of the material used or the way in which the material is manufactured as long as the end product can safely pass the tests outlined. Therefore the material used will need to be able to withstand all conditions outlined at ambient temperature, cold and hot temperatures and be able to be fully submerged in water. "EPS remains the choice for most bike helmets because it performs well in hard impacts and it is light, cheap, durable in use, reliable to manufacture and easy to ventilate."(Institute 2015). These are some reasons to why Expanded Polystyrene is one of the most wide spread foams in our society. Yet within Australia Currently there is little to no recycling of house hold EPS or high grade EPS used in bicycle helmets therefore without the ability to recycle this material a substitute is required for the purpose of the task of a disposable recyclable helmet.

Chapter - 3 Methodology

3.1 Chapter Overview

The dissertations Methodology is a reflection of the sequence in which the major tasks have been performed. The methods in which testing and results have been conducted will be investigated more in depth. The scientific method is the basis of the projects methodology. The method has been applied to ensure that all information is discussed and analysed objectively. The observations are recorded and analysed, the information is then used as evidence to back up the initial theory. The process of discussing the results objectively will disregard and pre-existing expectations, and produce only the facts.

3.2 Method of Experimental Procedure

The method of the experimental procedure is based off the Scientific Method. The diagram represents the rudimental steps involved in applying the method. The method has been utilised when performing both the material testing (refer to section 7.2.2), and the helmet tests (refer to section 10.2).

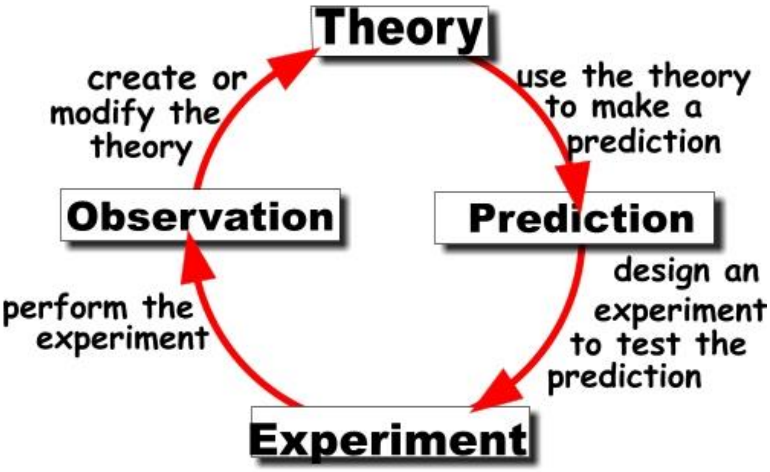


Figure 3.1, Scientific Method,(The Scientific Method)

The experimental method for, validation of the material samples includes

- The Theory that the material contains the required properties,

- The Prediction that the theory is correct the material meets the requirement depending on thickness
- The Experiment (refer to section 7.2) and
- The Observation and discussion of the results.

This procedure is similarly applied to the experimental testing of the helmets. Although the variables present during those test are considered to have a larger effect of the end results. The control variables which are required by the Australian standards include the temperature, design of head form, weight of design. These are all recorded to determine if the results have been affected by these variables for raw data and recordings of control variables (refer to Appendix E)

3.3 Design Considerations

The initial considerations were to produce a sustainable solution which is a disposable recyclable helmet. The design was intended to be marketable in various countries to influence the global market to start producing sustainable solutions to everyday objects. The physical considerations were to have an eye catching deign to increase word of mouth of the helmet as well as being as safe as possible. The overall design considerations were targeted at a final product to increase the possibilities of the helmet being brought to market, and for the safety to speak for itself shown in the final testing.

3.3.1 Test Rig Design

The test rig design had various design considerations, as the standards gave a general concept the design of the test rig which was manufactured was designed off that concept. The initial design was a single wire free fall drop, yet due to possible swaying of the helmets a similar two wire design was decided on. To ensure that the test rig was easy to assemble the test rig is designed to be clamped to an interior beam within the testing lab. This will eliminate any fastening of the test rig to a single point or the need to bolt the rig to anything. To ensure that the wires are tight the ends will be attached at the desired height then the wires will be lopped through hand tightened and fastened with loop clips and tightened with the threaded rod at the top end as shown in the below figure.

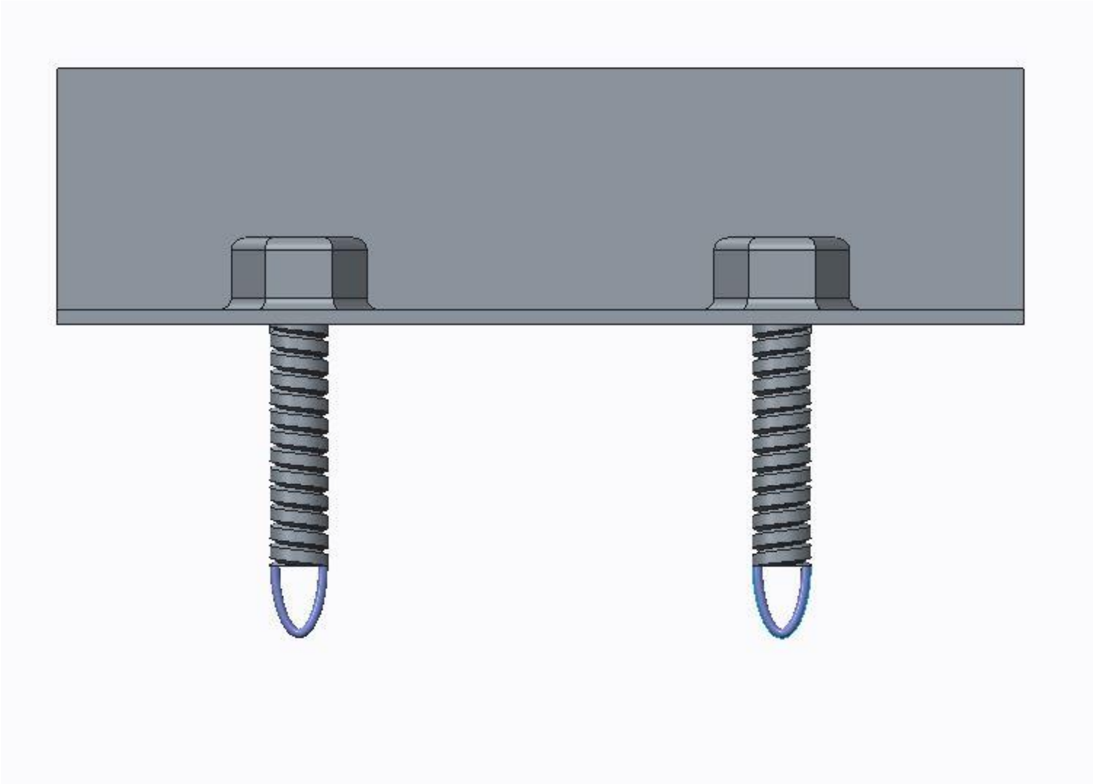


Figure 3.2, Test rig design

The threaded rod with half chain loops at the bottom allow the wire to be threaded through and then fastened once the wire is hand tight the threaded rod can be turned tightening the wire to ensure a straight drop into the nuts at the top of the angle.

This design will also allow for any desired height with an increase of wire between the top and bottom allowing for use both in the load distribution and impact energy absorption tests.

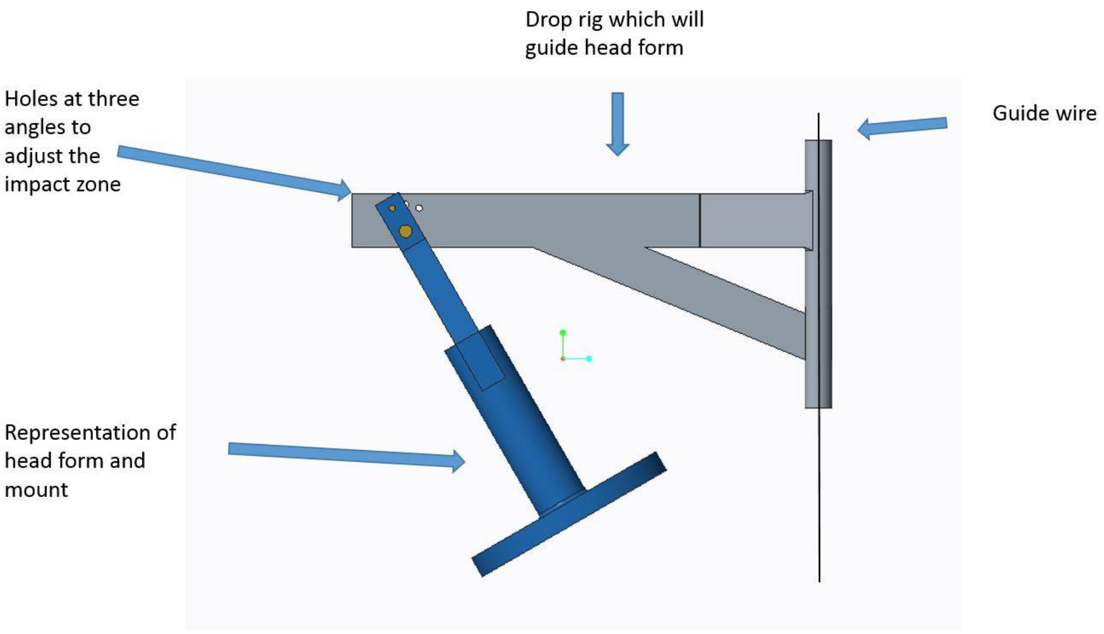


Figure 3.3 Test rig diagram

The above test rig diagram is a 3D model of the components of the drop rig to show how the different angle of the helmet will be achieved as well as giving a visual representation of the design and how it will operate before the manufacture of the rig.

3.3.2 Helmet Design

The established factors which highly contribute to the final designs features are based of the testing requirements of both impact energy and load distribution. As discussed further in section 6.4 and 8.3 the material is selected using a comparison of the current material for the impact energy absorption. The secondary consideration of load distribution is the more considerable factor of the two when considering shape and size of the design, as these factors are directly related to the potential load distribution of the helmet. For these considerations to be incorporated into the design a hand moulded design were created which incorporate design features to compensate for this. Furthermore

more plaster mould were than manufactured of the design and used for the end production of the design. The manufacturing by hand is complex operation which includes various mixing stages for further information refer to Appendix D.

When the manufacturing process of the helmet was design the control of variables were of high consideration such as weight, thickness and final material properties. Due to the nature of the material and manufacturing techniques the outlined considerations are difficult to control which therefore may contribute to differing results between helmets. The nature of these considerations and the influences which are attributed to those are discussed further within Chapter 9.

3.4 Project Time Line

The time line has been constructed to identify key elements of the dissertation and to ensure a consistent and logical sequence of the completion this allows all aspects of the dissertation to be completed in order. The project timeline also identifies the duration which the element can be completed in and also a desired starting date. The timeline has ensured that the work can be completed within the time allocated as well as allowing a visualisation of when each task is to completed, identified in Appendix A. The use of the timeline has implemented a logical time organisational tool which has been utilised throughout the duration of the project. This timeline would also be a unique tool in the reproduction of the outcome of the project.

3.5 Process of Validation

Various comments and discussion on the type of testing and material selection has been investigated, yet the chronological process and outcomes for continuation is required to be stated.

The Investigation of material analysis and selection is the first consideration in the continuation of the topic. It has been conducted to investigate the most probable method of manufacture which will provide a material with the desired properties, (refer to Chapter 6).

A contingency has been implemented to determine the material properties prior to the manufacture stage, (refer to Chapter 8). The testing of the material will validate the manufacture of a helmet of that material.

The process of manufacture is determined and the use of casted moulds have been used to produce the final helmet. Once the helmets are manufactured testing is completed and raw data is collected and analysed (refer to Chapter 9).

3.6 Assessment of Consequential effects

The effects of the information which is outlined within this dissertation may have various effects due to the nature of the project. This document is not certified to determine if the helmet meets Australian Standards, the testing which is completed is a reproduction of the Australian Standards and provides no certification to the design. The document only states that the outcome of the test is a representation of the Australian Standards and this is the likelihood of the design performing within the Australian Standard Testing. This is a major consequential effect of the information provided in the document and also if the results were to be perceived as a certification of the design. This assumption has major consequences which relate to legal liability and safety of the user. If the information were used to reproduce the helmets for production before being certified this document does not state they are suitable for use as a bicycle helmet. This document is an investigational document with the desired outcome of determine the likelihood of the proposed design.

Chapter - 4 Helmet Designs, Current Products and Conceptual Designs

4.1 Chapter Overview

The following chapter is intended to categorize the current design of bicycle helmets both with and without the use of recycled materials. Through the literature review process different helmets that incorporate a recycled material have been investigated. The advancements in the use of recycled materials are discussed referring to the incorporation of these designs within the project. The incorporation of a recycled materials unfortunately is not currently on the Australian market, although there is helmets which do incorporate such materials overseas. These designs are discussed due to the high value of insight regarding what designs can meet other market standards. Also the basic development of the current bicycle helmet and how the technology lead to the materials used is commented on.

The focuses is to determine a recyclable material which can be implemented into a helmet design which will perform satisfactory under testing. The design is one of the variables which will conclude if the helmet is a success. Within the following chapter various 3D models are shown to show the design process and the concepts which they have been derived from also displaying the final design and a discussion on the characteristics of the design. This process has been conducted throughout the investigation of current designs and the review of literature to show the development of ideas and designs.

4.2 Recyclable inspired designs

For a helmet to be fully recyclable and also practical the assumption is made that for a continuation of supply the helmet will need no dismantlement. This is to ease the reproduction process and make the recycled process desirable to an investor. Therefore the helmet would need to be manufactured of one element and for this reasoning the current helmet design of having multiple layers can be disregarded as a viable reproduction using recycled material, thus the investigation of different designs is required. Regarding to the material even though the EPS which is used in most bicycle helmets today is not recyclable it is still the most common used material for helmet production due to its cost of manufacturing and its performance qualities. Although it is a desirable material many designers and inventors are currently looking to find suitable recyclable alternatives.

4.2.1 The Kranium Helmet

The Kranium helmet was developed by Anirudha Surabhi a student from the Royal College of Art, in London. The design utilises a corrugated paper design, inspired from the natural bone structure found in the wood pecker. This design uses various interlocking rows of the material to shape the inner layer of the helmet as shown below.

Figure 4.1 the Kranium helmet

This design allows more flex throughout various points within the structure than a current EPS design and has a better impact of one third G-value during crash test when compare to a regular polystyrene helmet stated from the current design which is on the market.(Designs 2015). This design has currently been marketed with a combination of the cardboard and an EPS liner and plastic cover to protect from the weather. This designs innovation and creativity of using a structure found in nature deserves a mention due to the step forward into recycled materials being utilised in today's market.

4.2.2 The paper pulp Helmet

The paper pulp design is made from recycled newspaper and a food safe additive to make the helmet waterproof to up to 6 hrs. This design is an English design and is currently designed for one off uses in conjunction with a bike sharing scheme in London.

> "Helmets are intended for short periods of use and can be disposed of back into the waste system. The helmet and strap are fully recyclable and can be re-pulped into a new helmet without any degradation of the material." (Thomas 2013)

Figure 4.2Paper Pulp Helmet Design

This design was found during the investigation stages of recycled materials being used for helmets, the design has a very similar design role as the outline of this project. The design is named the paper pulp helmet yet uses the same material investigated within chapter 7 moulded paper. Unfortunately the above design has been produced by an Arts Collage and no engineering research or testing results has been release as well as any further continuation of the design since 2013. This helmet design gave an interesting outlook of the final conclusion of the project as the production of a fully recyclable helmet has been accomplished before. This design then drove the material selection process leading to the development of sample testing (refer to section 7.2.1). As the final conclusion is what standard can a fully recyclable helmet the selection process of the material is still required due to the lack of results given by the Paper Pulp Helmet.

4.3 Helmet designs and protective profiles

Many years of safety investigation and design has led to numerous designs and styles of helmets. The process of investigation and design has been applied through many different industries which require such safety considerations to the wearer, such as space travel. A main safety consideration has been high impact velocity as many activities require this application inside the head protection, these include;

- race car driving,
- motor cycling,
- sky diving,
- snow skiing and
- Snowboarding.

All of these activities include a high risk of major head injury due to the velocities which the person performing these acts travels at. This risk which people expose themselves to is the reasoning for the high level of investigation to the protective equipment used. This amount of investigation is a result of the difficulty of reducing the impact to the head through these protective helmets. This process requires investigation into different combinations of materials which can absorb this large amount of energy before translating through to the wearer’s skull.

There is also many designs for low impacts such as the bicycle helmets, skateboarding scooter helmets and various other activities. Yet the level of investigation into the protective equipment is lower in comparison to high velocity activities. The literature investigation made concludes that this is due to a combination of the level of risk and the founding of each specific activity. The low velocity designs are identified throughout this project as more applicable with the scope of the dissertation as the function of a bicycle helmet is at low velocities. The testing and calculations can also be directly linked to the requirements of the bicycle helmet outlined within the standards. Therefore the materials and technology which is currently being tested could possibly be transferred into the application of a bicycle helmet.

4.3.1 Current basic bicycle helmet design and evaluation

In the 1880's riding clubs became very popular which became strong advocates for the use of bicycle helmets, firstly the use of Pith helmets was common, with the Pith being an easily crushable plant material widely available at the time. At the beginning of the 20th century the apparent risk of head injuries was becoming more obvious to racing clubs.

> "Racers began to use helmets formed of a ring of leather around the head and a wool ring above that. Then the style evolved and the ring of leather was supplemented by strips of leather arranged longitudinally on the head. These offered a little better protection than the pith helmets, but still more was needed."(Davison 2015).

In the 1970's started the age of testing and analysing of bicycle helmets and in 1975, Bell Auto parts invented the first real helmet for cyclists. It consisted of a hard plastic shell padded with a foam-like material. This was the beginning of the modern helmet.(Davison 2015). The modern helmet is constructed out of a shell, liner and straps. The shell is usually made from a plastic to stop any penetration and used for protection from rain and other weather conditions. The linear is used to distribute the energy from the impact so that the head is protected during a crash. And the straps are used to ensure that the helmet stays on during the crash and riding process.

4.3.2 Helmet designs of high impact velocity

Even though the scope has been outlined that the low impact velocity designs are within the spectrum due to the similar physics high impact velocity designs have been discussed and investigated for creative purposes. The high impact velocity designs could also incorporate a more advanced method of manufacturing or design which could be implemented into a low velocity designed product.

There are various sports and activities which require helmets yet it seems to be only the sports with more money that gets the more advanced helmets, such as formula one. Formula one car racing is a multi-million dollar industry with Red Bull and Ferrari both having budgets in the region of £250m ($373m) a year.(Benson 2014). With the helmet being the only protection for a drivers head. There has been a lot of innovative elements put into modern helmets such as pull away visors to ensure 100% visibility when driving. With a bicycle helmet commonly formed from one inner liner while (Groote 2006)a common motorcycle helmet is constructed in three layers - padding, inside and outside shell - a Formula 1 helmet has no fewer than 17 layers. These advancements within these fields of motor sports and their helmet design make these design and the elements which they are made from outside the scope of this dissertation. This is due to the velocities which are experienced during these activities are to extreme compared with the low velocities that will be experienced in a bicycle accident that would be applied to the helmet.

4.4 Helmet designs of low velocity impact sports

There are many different styles and types of low velocity sporting helmets currently on the market. These can range from football, lacrosse, baseball to skate boarding and etc. These helmets and there technologies could be of use due the applications being similar in nature, this is because the impact velocities experienced within these sports are similar to those when riding a bicycle.

4.4.1 American Football Helmets (Gridiron)

American football helmets have been designed and changed over the years to overcome the impacts from tackles and helmet to helmet collisions. The current materials which these helmets are currently manufactured from include a hard plastic exterior with thick vinyl foam combination for the interior padding for the energy absorption. (*Football Helmets* 2014).

These materials that are utilised within this product have been classified as suitable for impact energy absorption with the helmets repeatedly tested against similar standards to that of the Australian Standards. These materials which are used for impact energy absorption are unfortunately not recyclable which regards the uses of them outside the scope of the project.

The characteristics of the football helmet are similar to those incorporated within a current bicycle helmet. Although being similar there is currently a lot of research and development into new technologies to reduce the likelihood of concussions to players. These new technologies include the development of new materials such as the Architected lattice being developed by UCLA. The UCLA- Architected materials group in November 2014 had started developing a novel, energy absorbing micro lattice material, with the intention of incorporating the material into Football Helmets. The material has been designed to replace the current vinyl foam used in current helmets and will help prevent concussions and traumatic brain injury by absorbing energy upon impact while limiting the peak loads which are experienced by the player. (Kisliuk 2014)

4.4.2 Lacrosse Helmets

The sport of lacrosse although the rules and playing strategies are somewhat different to that of football the head protection is still classed as similar in its practicality, as within the game low velocity impacts can occur. These impacts can be caused by other players and that of the ball and this is why the impact energy absorption of the helmets are of interest. Like football lacrosse receives a lot of research into the continuing development of the technology used and materials within the helmets. A study into lacrosse helmets has shown that the amount of impacts even with a new helmet can lead to concussion regardless of the direct magnitude of the impact. The results showed that lacrosse helmets decrease relatively rapidly. A lacrosse player can sustain many of these low-impact hits to the head over the course of a season, or even just a few practices. (Burke 2014). Yet the organisation which is in control of standards which lacrosse helmets are under have no regulations which are in regard to renewal or recertification of helmets. Therefore there is a high possibility of helmets which offer little to no protection.

The study shows that a newer helmet with less impacts to it, is considered as a higher protector from impacts, this is one of the considerations of the disposable recyclable helmet, as all helmets are only certified as a one-time use.

4.5 Conceptual designs and explanation of derivation

To explain the development of the conceptual design process, each design has been described outlining the main inspiration and how the design has continued from the past. Each of the designs have been discussed chronologically to show step by step the continuations of different ideas and how the final design has been reached. The original inspirations of all the designs incorporates current helmets on the market today combined with some creativity, to demonstrate an original design.

4.5.1 Design requirement

The current designs on the market have no identifiable requirements apart from those outlined within the standards which are to pass all tests outlined. Throughout the market there are many helmets which are designed for the sole purpose of being an eye catching helmet. This current fashion style of helmets is a marketing scheme to increase the price of helmets, yet just because a helmet is pleasing to the eye or that it is made with a different exterior material does not necessarily mean that it provides a better all-round protection to the rider. The main design features are the suitable strap design with appropriate ventilation this is for the comfort of the rider. Therefore with this information it gave full creative freedom of the design within the range of covering the head. Each of the designs outlined were then analysed on a practicality scale and using common sense combined with some creativity the final design was hand crafted.

4.5.2 Design One

The first design has been developed from a mix of current bicycle helmet ideas which are currently on the market and a basic idea which originated at the beginning of the project. The design that has been put forward is derived from the Kranium design which has previously been discussed. This design also incorporates key design features which many riders consider to be essential in a helmet including good ventilation. When considered as practical the thought that the recycled materials mechanical properties may be considerably less than that of EPS and the large amount of holes made the design probably too feeble therefore impracticable, which lead to a full design of design two

4.5.3 Design Two

This design is based on the principles of corrugation increasing the strength of a material which became a major thought after design one, and this will distribute the load throughout the profile of the helmet.

> “The compression curve of multi-layer corrugated boards present the three sections of linear elasticity, sub-buckling going with local collapse and densification. At the stages of sub-buckling, the stress always looks like as a long ascending plateau. The stress – strain curve of a multi – layer corrugated board can be simplified as the below fig. therefore, the energy absorption diagram of multi – layer corrugated boards can be modelled by sub section functions.”(Wang 2010)

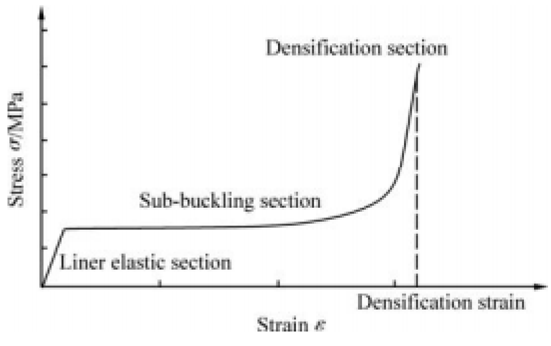


Figure 4.3 schematic diagram for compression stress-strain of multi - layer corrugated boards

This is the theoretical model of energy absorption which is being applied to the model this is also the basis for the sample testing which is referred to in section 8.1. With the above figure the densification strain represented by the dotted line determines the materials maximum energy absorption, as after this point is reached the material can no longer absorb energy. This is to say that at the end of the sub buckling section, the effective energy absorption per unit volume is the most. Therefore when comparing materials the compression test can be used to determine the maximum energy absorption.

The report referenced, continues to refer to the corrugation of the board increasing the sub buckling section of the stress – strain graphs and have determined that the energy absorption of the multi-layer corrugated boards is related with corrugated structure.

This corrugation of material has previously been used for the cranium design as the material of industrial corrugated paper is utilised to give maximum energy absorption. Due to the material currently being analysed of paper pulp which is not a corrugated material and the technologies which would be used to manufacture the material in that form is outside the scope of the project. For the design purposes the corrugation technique has been implemented into the exterior of the design to try and captivate this corrugation energy absorption. This design idea has also been used by the paper pulp helmet referred to in section 4.2.2, yet as stated no data has been produced on this design to confirm the quality of the design.

4.5.4 Design Three (Final)

The final design was inspired from all conceptual designs combined with the current helmet designs on the market. This design has been constructed with the use of modelling clay refer to section 7.3. This process has be used due to limitations of resources and time, if these were not apparent a model or moulds specifically would be produced using a CNC machine.

The design has been developed using the outline of the head form which is used within the test, this is too ensure that the helmet will fit. The model has then been built up from the base trying to use a similar corrugated design to that of design 2. This is to increase the strength of the material and to try and make the helmet appealing to the eye. The corrugation is a design consideration to increase the products ability to distribute the load which is not only a test in itself refer to section 2.6.2, but also a consideration of a helmet itself. This design should help the probability of the final design and material being a success.

4.6 3-D design CAD Drawings

The 3D Designs are to show a visualisation of the general concepts which have been developing throughout the process of the investigation of designs. Each design has been discussed in the previous section to relay the thought process of each design and how practical each design is. The conceptual designs have been presented to represent the design process throughout the different stages of design and how the development of ideas has carried through the designs as each design has been displayed chronologically.

The final design is not modelled as it is a continuation of the Design two with the combination of aesthetics which was hand modelled this process is explained in section 7.3.

4.6.1 Design 1

Taken from the most basic model of a child's helmet with a larger amount of ventilation holes to ensure the rider stays cool. Due to the materials investigated the design 1 would not compensate for such material properties refer to section 8.4.4.

Figure 4.4 Design 1

Design 2

Due to the enlightenment of the material properties as previously mentioned the paper pulp helmet design was investigated as that design also incorporated a corrugation strengthening technique.

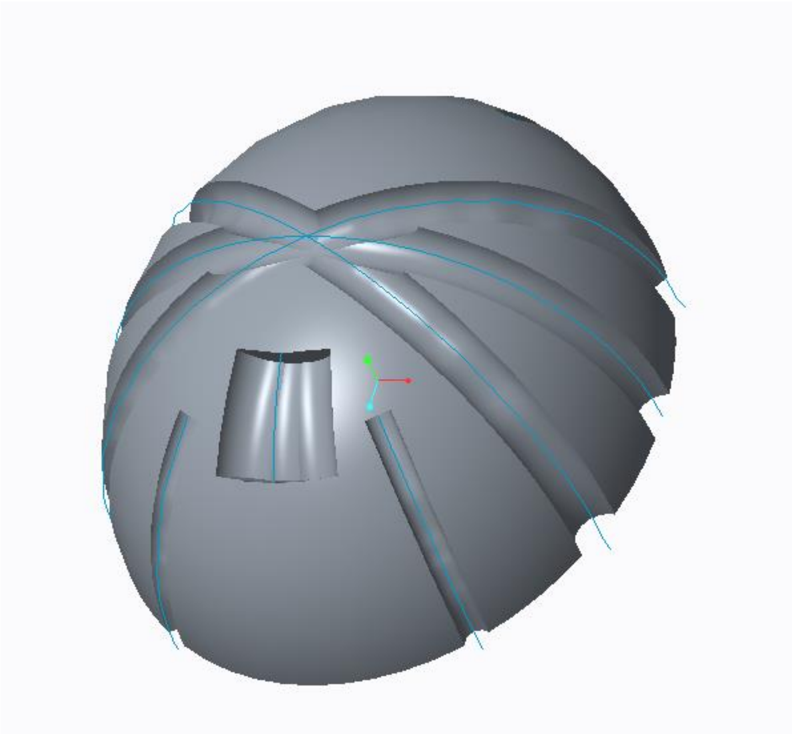


Figure 4.5, Design 1 top view

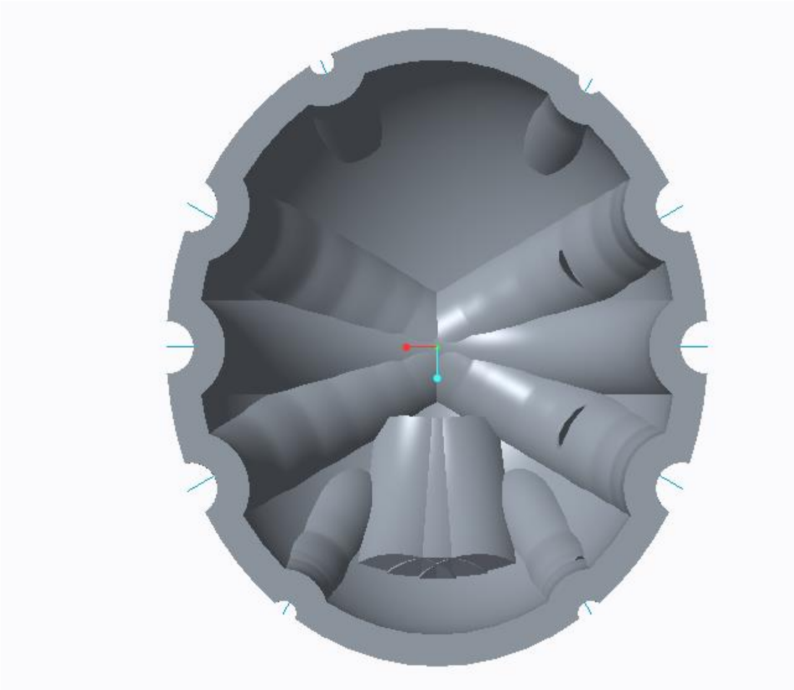


Figure 4.6 Design 2 bottom view

4.6.2 Final Design

The final design has been developed using the previous design whilst integrating a larger amount of creativity into the design, to demonstrate that the results with revolve around an original design utilising a recyclable disposable material.

Figure 4.7, top view of model

Figure 4.8, side view of model

Figure 4.9, Final Helmet Production

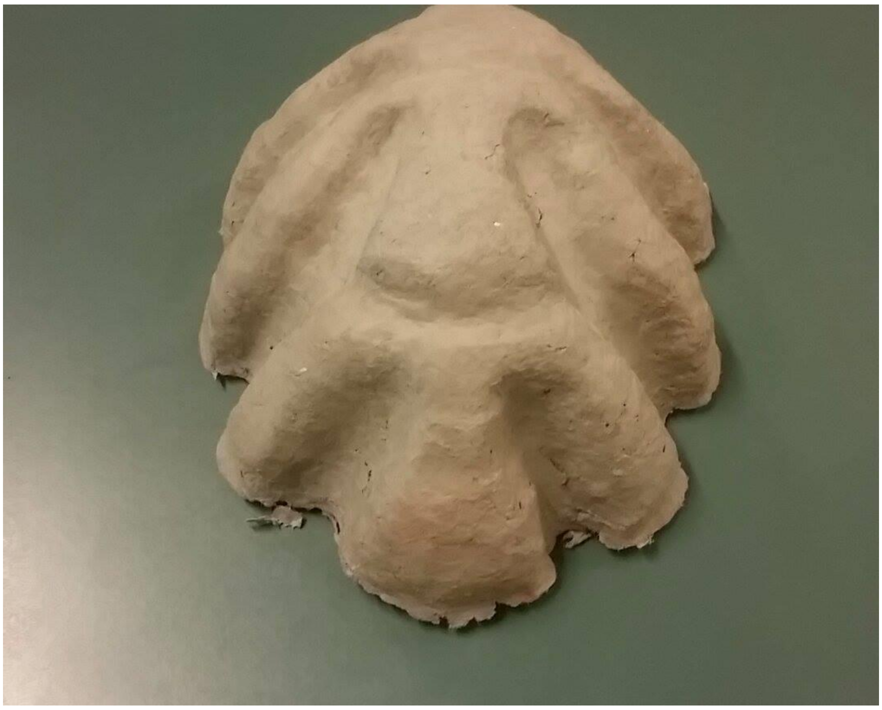


Figure 4.10, Final Helmet Production Top View

Chapter - 5 Material Analysis

5.1 Chapter Overview

The following will discuss different techniques which are utilised when determining a material for a desired purpose. Through the investigation of material analysis an example of impact energy absorption material selection has been discussed. The discovery of this analysis has then driven the material selection process for the helmet, as the analysis is for determining the impact energy which is outlined as a main feature of the material and also for the helmet test refer to 2.6.1. The Ashby charts which feature in section 6.2.1, give a comparison for recyclable material which have been investigated and a method for determining the likelihood of being compatible to current materials. The material analysis section 6.2, also outlines why the current materials are in use and why these are so widely produced. Within section 6.4 the decision of which material is selected for testing and furthermore the production of the helmets is outlined.

5.2 Material analysis

The most commonly used materials with a bicycle helmet are EPS for the interior material and a plastic liner of the exterior. But why are these used so universally? “The major impact-absorbing element of the helmet is a foamed polymer liner, commonly made of expanded polystyrene (EPS). Polymer foams are chosen because they are easily fabricated and because, unlike honeycombs, their ability to absorb energy is Omni-directional.” (*Materials for Bicycle Helmets* 2015) this is just one answer to the question, but this does not include the scientific analysis of the material. When designing a helmet there are three main design requirements which need to be considered,

- The Function: protective cycle helmet.
- The Objective: maximise energy absorption / unit volume.
- The Constraints: load on skull< damage load.

Material Analysis

These requirements allow the material selection process to have limitations to analyse which materials meet all requirements for a suitable helmet. Material selection is a crucial role within the design process, many think of the process solely depending on big considerations such as cost, availability and manufacturing capabilities. These are all considered in the process yet to firstly consider a material without previous knowledge there are various ways which this can be accomplished. The Ashby Charts developed by Professor Mike Ashby, are a series of charts which are used to compare common property combinations of different materials and is one of the most commonly used material selection within the design process. Many companies have taken these charts to make various material selection programs for engineers to use to make this process easier. "The CES Selector software makes it fast and easy to apply these concepts to practical problems—and training is also available to help you get up-to-speed quickly."(*Materials for Bicycle Helmets* 2015). This is referring to the industry standard approach to systematic materials selection. Through the investigation for current materials used an analysis of impact energy absorption using some of the Ashby Charts was found and is the starting point for the material analysis approach.

5.2.1 Material Analysis of a Bicycle Helmet

(*Materials for Bicycle Helmets* 2015) describes how a bicycle helmet liner performs two impacting mitigating factors. First, it redistributes a localised external force over a larger area, reducing the local stress on the skull. Second, it sets an upper limit to the magnitude of this distributed force, as determined by the plateau-stress of the foam. These two functions are the limitations when developing a material selection analysis for a helmet. These are also the contributing factors which are outlined within the Australian Standards which the helmet is to be tested against. Load distribution and impact energy, therefore it is only logical to maximise the results with making these the limitations of the material used.

> "The maximum tolerable deceleration, a, of the human head is approximately 300 g, provided it is applied for a few milliseconds only.

Longer impacts at this deceleration level cause irreversible injury. The mass m of a head is approximately 3 kg, so the maximum allowable force, from Newton's Law, is

$$F = m\,a = 9\ kN.$$

As the foam crushes between the obstacle (on the outside) and the skull (on the inside) it beds-down, distributing the load over a projected area A of order $10^{-2} m^2$. To prevent F rising above 9 kN, the foam must crush with a plateau stress of approximately:

$$\sigma\ (0.25) = F/A = 0.9\ MPa.$$

Impact mitigation depends on the ability to absorb energy."

This limitation of 0.9 MPa is the defining compressive Stress when comparing materials on the selection Charts for Impact Energy Absorption. When identifying which materials suit the considerations for a helmet liner the Ashby Charts are used.

Material Analysis

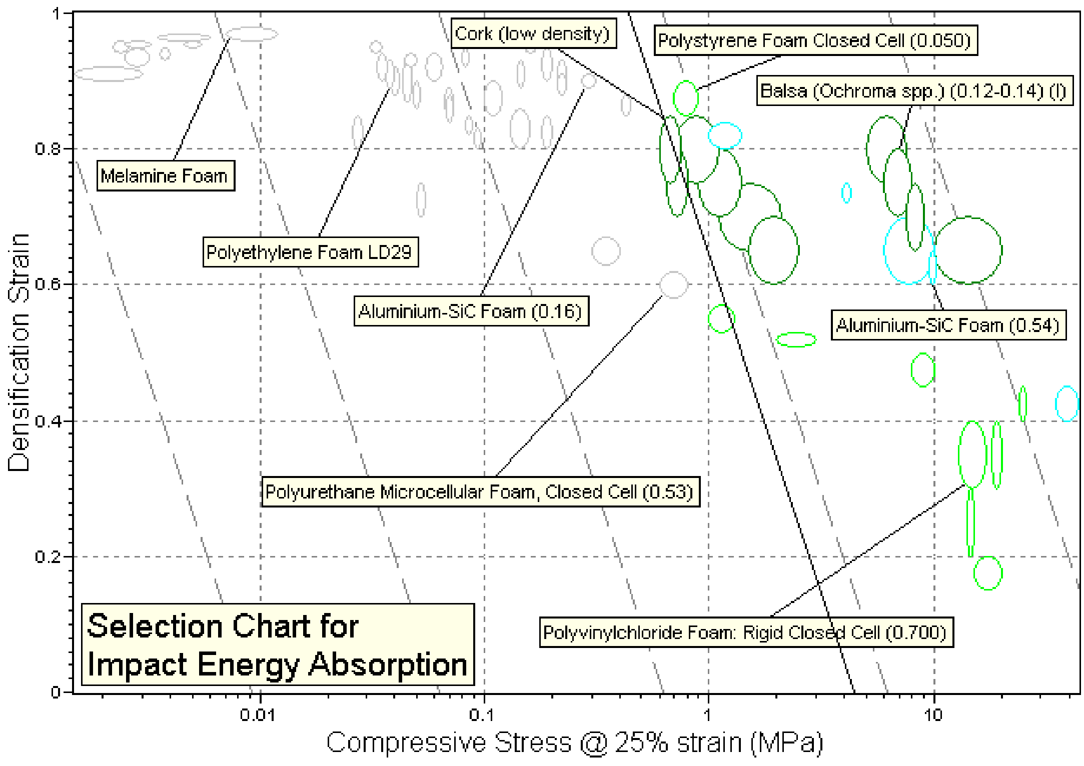


Figure 5.1 Densification strain plotted against plateau stress (which we take as the compressive strength at 25% strain) for commercially-available foams.(Materials for Bicycle Helmets 2015)

Figure 13 is a generated Ashby Chart using a program, the figure outlines which material can be considered for a liner using the above limitations. The highlighted materials above the selection line have high valued of energy absorption per unit volume on of the defined objectives.

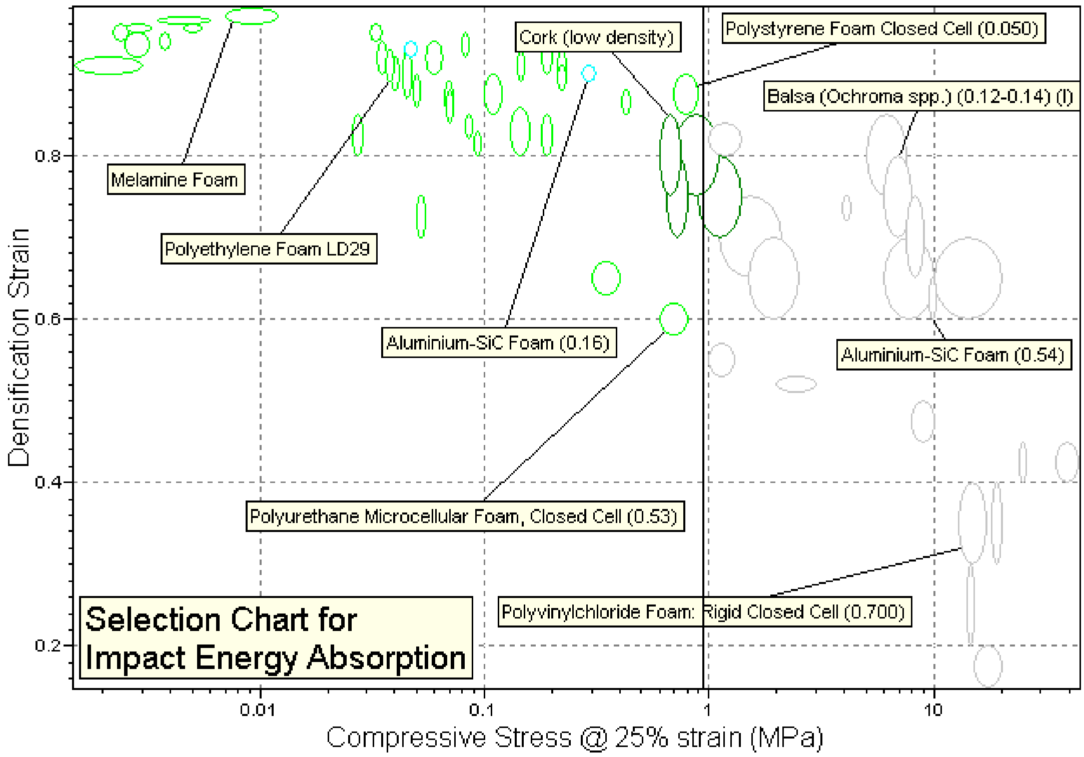


Figure 5.2 Densification strain plotted against plateau stress (which we take as the compressive strength at 25% strain) for commercially-available foams. The selection line delineates the constraint of a plateau stress of 0.9 MPa.(Materials for Bicycle Helmets 2015)

Figure 14 is the same chart yet the highlighted material are ones which absorb energy below the plateau stress outlined as 0.9 MPa. When comparing the above charts and identifying all materials which are highlighted in both cases, the materials which appear in both circumstances are the materials which meet all requirements.

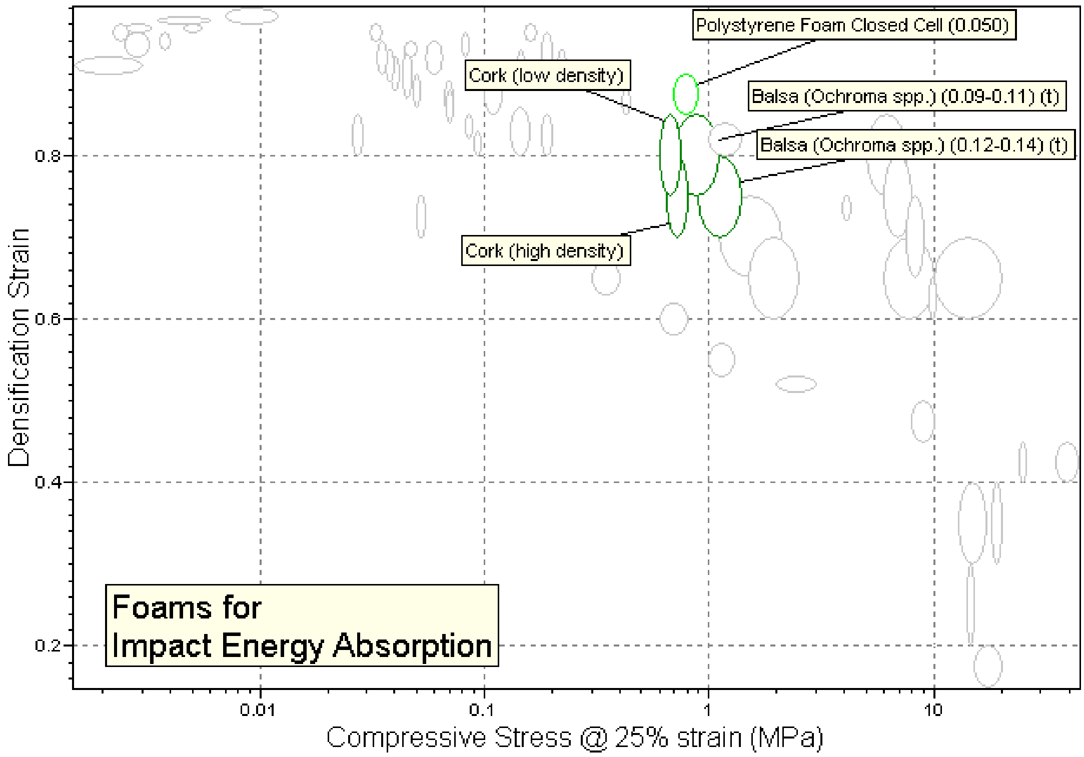


Figure 5.3 Densification strain plotted against plateau stress (which we take as the compressive strength at 25% strain) for commercially-available foams, showing the candidates that pass the selection.(Materials for Bicycle Helmets 2015)

Therefore with the analysis of the material properties and conditions applied for a compatible material for impact energy absorption, the identified materials fit all requirements outlined. Once these materials are identified then the process of their individual costs, availability and manufacturing abilities are then evaluated to provide the most suitable material.

This is the current method of material selection therefore within this dissertation the requirement of the material used will be to have similar material properties to the materials identified. Using the information regarding these Ashby Charts the chosen material will also be required to have similar properties to that of the outline materials and therefore with the range of densification strain of 0.7 to 0.9.

Results of Chart Analysis.

Material Analysis

Materials Passing All Stages
Balsa, ultra low density, perpendicular to grain
Cork
Polystyrene foam closed cell (0.050)

Table 3 Selection Results: Materials for bicycle helmets(Materials for Bicycle Helmets 2015)

5.3 Recycled Materials

Globally many companies and industries are now focusing on and allocating large amounts of resources and time to maintaining and improving the environmental impact which our modern society is causing with most industries. This is to ensure that the environment will be sustained with many catch phrases such as, Building a better tomorrow, saving the planet, and other campaigns. As this has become a major factor within our society there has been an increase in the recycling industry, as there is only a limited amount of resources in the world. This is one of the major factors of the recyclable helmet design as previous stated more cities are adopting a bicycle scheme and the large amount of land fill combined caused by the current bicycle helmets can be greatly reduce and could possibly change the industry by developing a recyclable helmet.

This dissertation focuses on paper as a major resource as this material is readily available and newspapers are in particular found in large quantities in major cities. In the following sections it is shown how newspaper can be manipulated in different ways to produce a desirable material for the helmet design. Further through the process the chosen material will be manufactured and tested to determine how valid the research on this material is for this particular purpose. The testing will be compared with the impact energy absorption and methods of distributing the load will be discussed.

Due to the main focus residing around paper the most commonly known production of a paper material is paper mache. This has been investigated yet all sources of the production of this material are have no scientific research. The process also includes a binding agent most commonly used is flour and water which would make the helmet no longer recyclable or able to be used back into the process and for this reasoning this method has been ignored as a desirable material.

5.3.1 Recycled Paper

Recycling paper begins by breaking down the product using either chemical or mechanical means to free the fibres and create pulp. The pulp is re-manufactured into paper products in a similar way to first production paper. When paper breaks down in landfill it creates methane, a major greenhouse gas with the global warming capacity 21 times more powerful than carbon dioxide.(Ark 2015). This is why many current designers are looking towards methods which include paper recycling as the current use is high, there is a high volume in circulation and the manufacturing abilities are wide when produced into a pulp form. As previously discussed there have been various paper based products that have either continued through to small manufacture or to selling the product on the market.

Current paper mills which use recycled paper as a resource to create other products do by using the recovered paper combined with water into a large vessel, similar to a blender called a pulper, to separate the fibres in the paper sheets from each other. The resultant slurry then moves through various separation processes to remove contaminants such as ink, clays, dirt, plastics and metals. The amount of containment allowed through the process depends on the desired paper which is being produced. Mechanical separation equipment which is used includes various machines such as screens (course and fine), centrifugal cleaners, and kneading units which are used to break apart ink particles. (EPA 2012)

5.3.2 Moulded pulp or moulded Fibre

Moulded paper pulp, which is also called moulded fibre, has been used since the 1930s to make containers, trays and other packages. Moulded pulp packaging experienced a decline in the 1970s after the introduction of plastic foam packaging. But more recently the use of moulded pulp packaging is increasing due to today's emphasis on environmental friendliness and sustainability of products. Moulded pulp can be manufactured within the range of thickness ½ inch, 12.7mm and smaller. (Stratasys 2015).

Material Analysis

This material is currently being researched for its practical use within the packaging industry. The material provides various cushioning properties which aid in the process of shipping and transport to keep the products safe. Due to the current research being conducted this material may be considered an interesting option for the material selection process for consideration into a recyclable disposable helmet design.

One company in particular has done research into the effectiveness of moulded pulp verses expanded polystyrene foam, these tests have been completed to test which material is better when a static load is applied and which absorbs more energy with dynamic loading. These tests are also dependant of the manufacturer of the material and the thickness, size and shape of the test sample.(Howe 2010)

The first test is a static load test showing how much acceleration in G's the test samples are able to absorb.

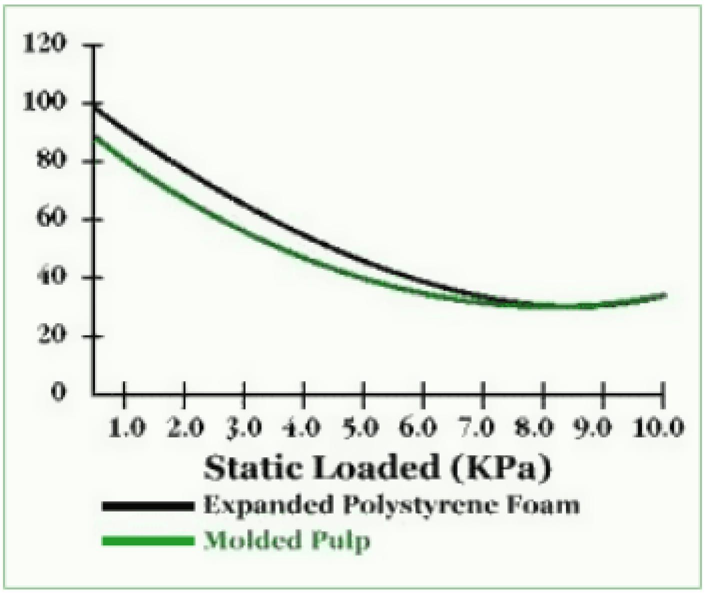


Figure 5.4 cushion curve, static load (Howe 2010)

The above figure represents the compared performance of the expanded polystyrene to moulded pulp. It measures the amount of acceleration, in G's the test sample is able to absorb over a range of static loading. As shown in the above figure when introduced into the static load of around, 7.5 KPa the

moulded pulp acts to the same standards and better than the polystyrene. Therefore at these loads the moulded pulp was a better protective material.
The second test illustrates if the test sample is exposed to shock pulses (dynamic load), measured in G's experienced during impact

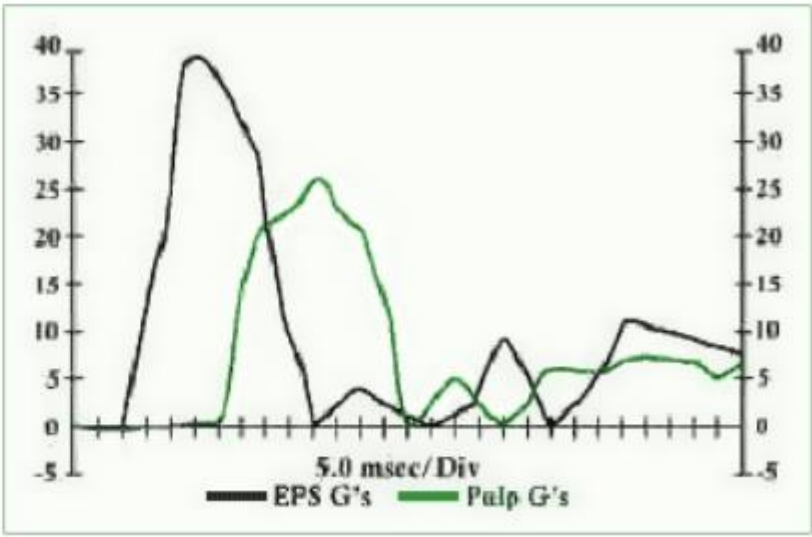


Figure 5.5 Drop Test, Dynamic loading (Howe 2010)

As shown in the above figure the moulded pulp test sample had lower peak acceleration than the expanded polystyrene showing that the moulded sample absorbed more of the impact. These test show that the Moulded Pulp could provide a reasonable material for a Recyclable Disposable Helmet as this is a key component of the design criteria.

The process which this material goes through when making products such as egg cartons includes, various processes to ensure that the end material is strong enough for the desired job. The recycled paper is blended with hot water between 43º - 65 ºC for a period of 20 minutes swelling the paper fibres and insuring that they are evenly mixed together. The next process includes the mould of the product, this is an important part of ensuring the strength especially when designing a helmet which is designed for impact and load distribution testing. The moulds are then dipped into the pulp with a stainless steel mesh to ensure that the pulp is spread evenly over the mould by a vacuum. After the paper pulp is produced onto the mould it is then transfer into an oven to be heated. This process dries out the product and bonds the paper fibres together hardening the end product. This process if chosen would be difficult to replicate and various parts of the process would be substituted with more easily accessible resources.

5.4 Material Selection

The recycled materials which have been investigated have all been based off other testing, results or conclusions after studies. As the material for this dissertation will be unlike any previously tested in this environment and no solid information through literature review have been reported the selection process will have to be analysed within the project. This will include a step which will determine if the material have the correct properties. This step is the comparison to the currently used EPS to a suggested material using the Ashby Charts (refer to section 6.2). This step is implemented to give the material used in the helmet some reasoning in the decision, this step will also give the outcome a better result and discussion as the material used will have a suitable level of impact energy.

To ensure that the material can withstands the loads and forces which will be applied during the testing stages a comparison to the most commonly used material will be conducted. This will be the initial stage of the material selection process, with the second being the standardised testing of the helmet. The test which will be conducted will be a compression test to compare the stress and densification strain previously discussed. All information on refer to section 8.4.

The material which has been tested first is the moulded pulp or moulded fibre, refer to section 6.3.2, this material has been chosen due to the vast testing currently being conducted by various companies as well as the material itself. The material requires no bonding agent which meets all criteria of the recyclable disposable helmet as well as various test comparing it as a better impact energy absorber than the current material EPS, due to these this is the first material which is to be tested. If the material passes the test with comparison to the EPS and other materials which meet the criteria the material will then be implemented into the production of the helmet. This test will also allow the material to give characteristics such as thickness and density of the material. Which will be integrated into the manufacturing of the helmet. These test will determine if the material is a compatible material as literature has stated. After the testing if the moulded Paper shows no promising results the material selection process of sourcing another material will be conducted for a second round of testing.

5.4.1 Retention system

The current material which the most common type of bicycle helmet use is nylon or polypropylene. These two material look very similar yet vary considerably in fabric, surface finish, wave and other characteristics.(*How Bicycle Helmets are Made* 2015) With a plastic buckle which can adjust to fit any size within a range. The Paper pulp helmet which has previously been discussed, refer to section 4.2.2, includes a strap which is reported to be made from a woven paper string which is fully recyclable.(Yang 2013).

The retention system is the next material selection process after the impact energy and load distribution testing. The same material selection process will be conducted as the materials investigated are recyclable there is limited information regarding the properties. Therefore the end results of the retention test will determine if the retention system is viable. The materials which will be investigated include a woven paper string, this material consists of make a lattice of paper to increase the collective strength of the material. Other material which have come to attention during the investigation process include biodegradable materials. These materials will be used in similar fashion to that of the woven paper, in using a lattice to increase the strength of the material. The use of the paper woven material will mean no dismantlement of the product is required therefore making this the most desirable material, and the other options will have to separately dismantled from the product prior to recycling but will also be environmentally friendly and within the parameters of this product.

Chapter - 6 Process of Samples, Moulds and Helmet

6.1 Chapter Overview

The following chapter includes the outline of the processes which have been utilised when constructing the samples, moulds and helmets. The three components have been identified as the three significant design and material selection processes. These are examined through the following section to illustrate the importance of their assistance to the outcome of the final product. These process will also affect the results and discussion of the end results, this is due to the difference in conducting each of these processes if time allowed or an increase to available resources.

6.2 Material Property evaluation

The process of conducting a test on the samples constructed is designed to identify material properties of the recyclable material refer to section 6.4. This is a major consideration to the material selection process, as the initial testing of the samples will determine if the material obtains the required properties for impact energy absorption.

To ensure that the material obtains the required properties for the necessary impact energy absorption, test samples are manufactured with different characteristics and compared with each other as well as the current material, polystyrene foam.

The test which all sample are conducted upon is a compression test with a resulting stress strain graph of each sample refer to section 8.4. The final graphs will be compared firstly with each sample and secondly with the Ashby chart which is outlined with chapter 5 material selection.

> “Energy absorption is the ability of the material to convert the kinetic energy into energy of some other form such as, heat, viscosity, visco-elasticity, friction etc. Energy absorption capability of foams depends on the stress and strain of the plateau in stress-strain curve.” (M. Altenaiji 2012)

The compression test that was conducted on all samples will be used to determine the stress strain curve used to define the densification strain and compressive stress. Using equations (7.1) and (7.2) to calculate the Stress and Strain respectively

$$\sigma = \frac{F}{A_o} \quad (7.1)$$

$$\varepsilon = \frac{L - L_o}{L_o} \quad (7.2)$$

The two equations will evaluate each sample to determine its positioning on the Ashby Chart which is then compared with the current material. The two equations above will also be the considering factors to determine if the samples meet the characteristics required for the energy absorption as well as a corresponding result as polystyrene foam.

6.2.1 Specimens for testing

The samples which have been used for the compression test were made using the material moulded paper. This process includes cutting newspaper into small sections and blending the paper dry this then ensures that almost all the paper is broken down into its fibres. Once enough material is at this stage the fibres are then mixed with warm water, Between 43 – 65 degrees Celsius. After the mix is ready it is then transferred into its mould, (a baking tray) and the process of vacuum pressurising is conducted. This process involves covering the tray with a plastic cover and attaching a vacuum which will then compress the material and extract almost all the water prior to the heating. This stage of the process is to mimic the mould being submerged into the material and a vacuum applying the material onto the mould. These specimens where then recorded depending on their average thickness and tested under the same conditions therefore the only variable was the thickness of the material. This gave a range in which the helmets thickness could be. Refer to Appendix D for the steps taken in preparing the samples.

6.2.2 Testing samples

The compressive test involved a separate test for each sample. The results will be collated and comprised as data points and comprised into a graph to be compared with the polystyrene which according to the Ashby charts will be at a compression strength of 0.9Mpa, densification strain should be within the range of 0.7 – 0.9, the sample with the greater strain at the 0.9Mpa strength is then the most desirable thickness for the helmet.

The below image is a photo taken before conducting the first compression test on a sample piece of 9mm.

Figure 6.1, Compression Test

Refer to Appendix D for the steps taken in testing of the samples and refer to Chapter 8 for results

6.3 Helmet Moulds

The helmet mould is constructed in three components, a hand moulded clay model of the helmet, a plaster cast of the clay model (exterior of helmet) and a plaster cast of the inside of the first plaster mould (interior of helmet).

The clay model was hand moulded as the design is an original helmet design and there is limitation to the facilities available, if these limitations and time restrictions were not apparent a CNC machine would be used to produce moulds preferably using stainless steel and utilising the similar methods to industry. This would also extend the life of the moulds and the accuracy of the design as well as increasing the production capabilities of the helmet. It should be noted that this could also hinder the results due to the human error which may occur during the hand moulding process. If the project was to be continued a 3D model and a manufacturing method such as CNC would be required otherwise there would be a vast difference in results. Yet for the purpose of determining if a recyclable disposable helmet is possible to meet the standards this method is suitable for the outcome.

Figure 6.2 Interior plaster mould of helmet

The model has been made constructed as an internal and external two part plaster moulds which when combined will illustrate the end helmet. The plaster mould of the exterior will be used to pour the moulded paper pulp mixture into, and the plaster mould of the interior will be used to press into the exterior to give an even thickness through the helmet. The interior mould has holes to allow the water through into to vacuum. The process has taken some variations in comparison to the initial design due to altercations yet this method produces a suitable product for testing. Refer to Appendix D under Hand Mould.

6.4 Helmet Manufacture

The helmets which have been used for testing have, as previously stated manufactured using the moulded paper pulp material and a vacuum compression technique. As stated in section 7.3 two plaster moulds have been produced to ensure an even thickness throughout the helmet. To ensure that each helmet is close to equal thickness the amount of the newspaper fibres are measured for each helmet and the amount of water added is recorded. This combined with spreading the mixture out and the compression of the interior mould will give some consistency to the thickness. It is to be noted that this method of production will have various variations involved throughout the process and if the project is continued the method of production is to be altered.

Figure 6.3, Vacuum compression technique of manufacturing helmets

Figure 6.4, Top view of helmet manufacture

Chapter - 7 Experimentation of Samples, Stress Strain results

7.1 Chapter Overview

In section 6.4 the material selection process defined the final selection process as a comparison to current material used within helmets, as this material has all desired properties required. Mould paper is the most desired material to proceed to this selection process. The material will be tested and compared to the EPS material properties discussed within the material analysis research. The compression test used to compare the two materials was conducted on various thickness to give a desired thickness for the helmet. Furthermore the thickness was restricted to 9mm as a result of the weight considerations of the helmet and materials capabilities. The amount of force applied to the sample and the difference in distance of the weight were recorded. Using the applied stress and strain which have been calculated, each sample was graphed and analysis using a trend line to determine actual and theoretical results per sample size.

7.2 The Test Parameters

The compression test which was conducted upon all specimen works with placing the specimen on a rigid base and lowering another plate. When the plate is lowered the force increases, this force can then be calculated into the stress which the sample is exposed to using F/A = Stress (refer to equation 7.1). Secondly as the secondary plate moves the downwards the adjustment in position is record with the corresponding force, using equation 7.2 this information can then be used to determine the strain applied to the sample. Therefore as the stress increases on to the sample the samples starts to deform and this deformation is then used to calculate the strain. Once the data was collected and the corresponding values of stress and strain where calculated the resulting graph was then produced with the corresponding trend line. Using the calculated data the strain at the stress value of 0.9Mpa is then recorded and this strain will then be compared with the Ashby charts previous discussed.

The compression test results will be in the form of the stress strain curve of the specimen, which is used to identify various material properties. The strain which the specimen reach will be compared with the compression strain reach by the current material EPS (refer to section 6.2). The comparison of the test will determine if paper pulp is a possible substitute for EPS.

As the final design has incorporated corrugation there are various points throughout the design that are not in direct compression which is experienced within the test therefore other material properties are to be used to identify these reactions, such as shear stress. Therefore the compression test determines that the recyclable material can be used as a substitute to the EPS which literature research suggest is the case and the final helmet design will determine that the material can be implemented into a working design. The compression test is only a comparison of the recycled material and currently used material performing similar and is no indication that the helmet design will be a success. The design has incorporated the corrugation as the test determines the material has the correct properties of impact energy absorption similar to that of the EPS but not of load distribution. The corrugations purpose is to compensate for the load distribution refer to section 5.2.4, as stated the corrugation of the final design has been incorporated to increase the probability of the material and design working in unison to be considered as a success.

7.3 Identification of Important Characteristics

Throughout the investigation into moulded paper and the total research of the project there has been no hard evidence of a scientific testing of moulded paper. The only known reasoning for which the material has been chosen is the accessibility of the raw material, the production is cheap and effective, and it fits all requirements which have previously been outlined and requires no bonding agent. Therefore the material selection process includes the step of testing each desirable material for the comparison of impact energy absorption. This step is to continue the sequencing of the project whilst giving a substantial reasoning for the decision. The test as stated will determine the required thickness of the end helmet to therefore exhibit the same impact energy absorption properties of the sample yet various characteristics will vary the end result due to how the material is made.

The characteristics of the samples in comparison to that of the helmets will also vary. These are to be considered as the variable properties of the material. These varying properties are properties that cannot be controlled through the production of the material due to either the production techniques or the raw materials.

The properties which are affected include density, which can then lead to varying weight and strength properties of the material which have a direct relationship to the densification strain at a given stress. This may then hinder the results of the testing. Due to being unable to change this the process is outlined the same way when producing all samples. One of the main considerations which has been under taken is to ensure that all of the newspaper is broken down into fibres prior to the mixing with water. This is to try and produce more of a homogenous material.

The raw material of newspaper is of major concern as there is no way to regulate the properties of newspaper, this in conjunction with the above concerns are the factors which are considered variable properties. These factors are to be taken into consideration when analysing the results of the compression tests.

7.4 Results of Tests

The results of the compression test have been displayed as graphs due to the large amount of data points recorded by the test. The graphs are the representation of the stress strain curve of the three most promising thicknesses 9,8.5 and 7mm. each graph has been analysed and the final result of strain at 0.9Mpa is discussed as well as the trend lines of all the curves. Each of the results both collected data and theoretical trend line are compared to the Ashby Charts to determine what thickness the material should be when the helmet is produced.

7.4.1 9mm Sample Results

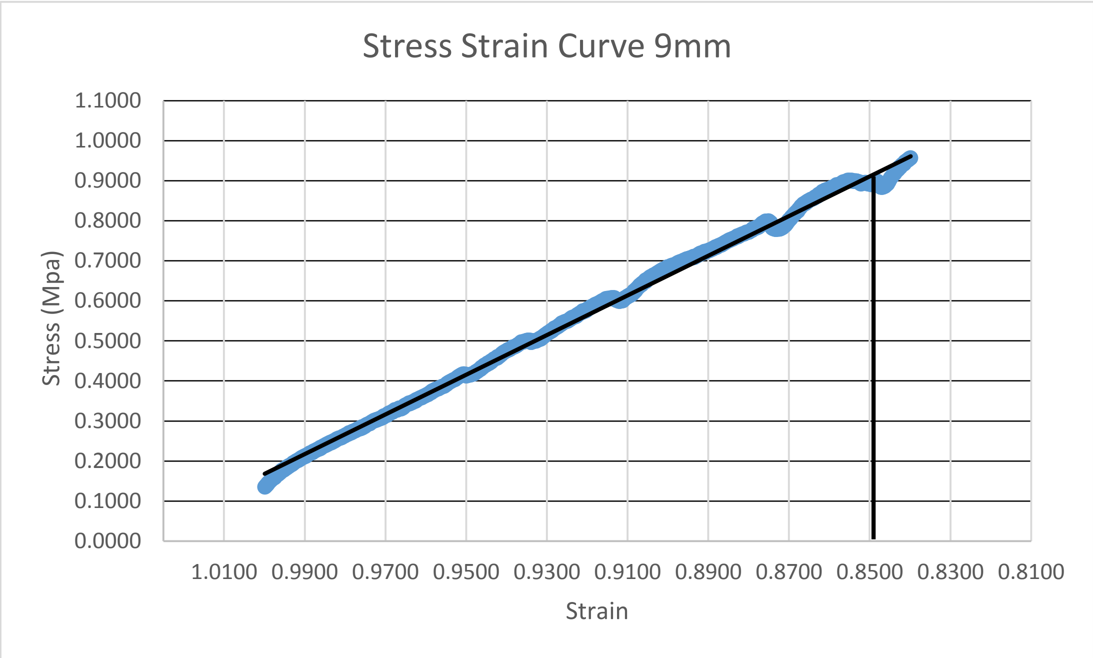


Figure 7.1, 9mm Sample Results

Stress Strain Curve of the 9mm sample compression test with a value of ε= 0.8452 at σ= 0.9002Mpa. Therefore at compression stress of 0.9Mpa the densification strain is 0.8452, close to the value of EPS and within the range outlined. Although the linear trend line of the test indicates a larger value of strain showing in the figure above as ε= 0.85100 also within range. This has identified that the average strain of the material is well in range of a suitable substitute to expanded polystyrene. This graph therefore predicts that the moulded paper is a suitable substitute to the EPS currently used with the average helmet.

7.4.2 8.5 mm Sample Results

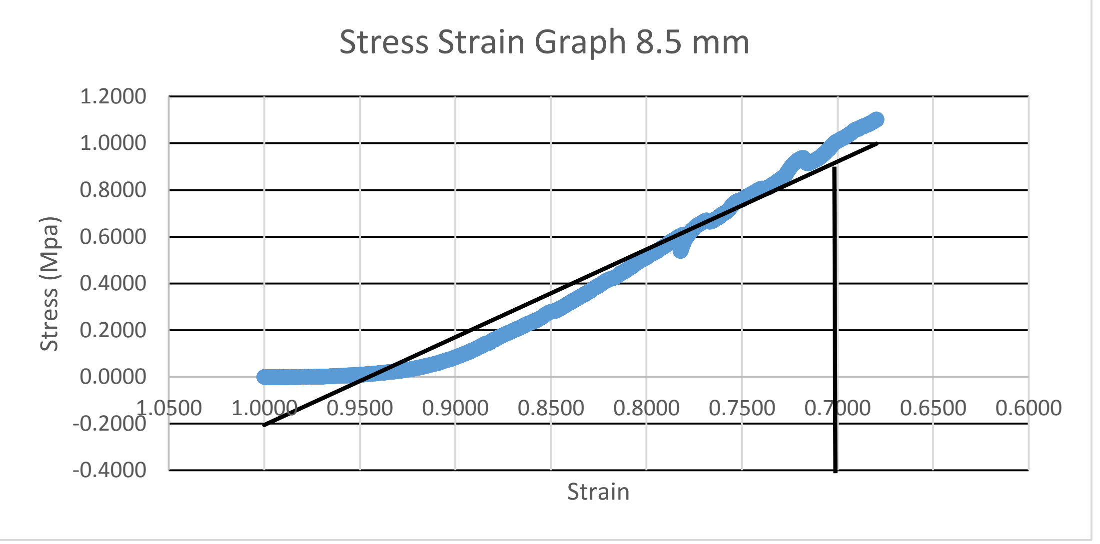


Figure 7.2, 8.5mm Sample Results

Stress Strain Curve of the 8.5mm sample compression test with a value of ε= 0.7239 at σ= 0.9043Mpa. Therefore at compression stress of 0.9Mpa the densification strain is 0.7239, close to the value of EPS and still within the range outlined. Yet the results from the thicker sample above provide a more desirable result. The linear trend line of the graph indicates that the average strain within the material is lower than that of the instant of 0.9 Mpa, with an average recorded as 0.7 according to the trend line.

This result of a lower linear trend result is caused by the initial results recorded, due to the strain being calculated from the displacement of the test piece these initial results may be caused by a small gap between the test sample and testing piece. With the sample and test piece not in full contact the results will show the strain increasing with little stress on the sample which has affected the overall results.

7.4.3 7 mm Sample Results

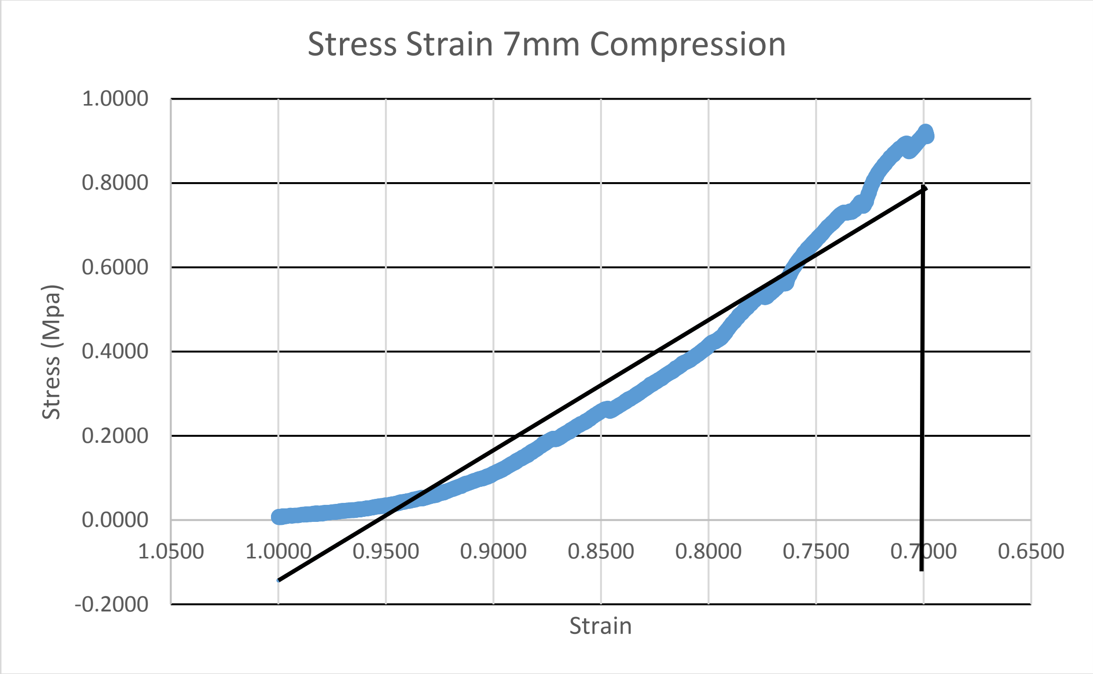


Figure 7.3 7mm Sample Result

Stress Strain Curve of the 7mm sample compression test with a value of ε= 0.7022 at σ= 0.9000Mpa. Therefore at compression stress of 0.9Mpa the densification strain is 0.7022. As displayed through the above graphs the relationship between the decease of the sample thickness and the densification strains are proportional as the further samples which were tested display lower results (refer to Appendix E)

7.4.4 Conclusion

The densification strains at 0.9Mpa are within the range outlined for all samples. With the result being conclusive of all sizes the helmets thickness could then be 7mm or larger as the increase of thickness has increased the strain at this point. As previously stated the above test results represent that the moulded paper can be can a substitute for EPS which is currently being done within the packaging industry. These results are now used as a guide for the introduction of moulded paper into the helmet design (refer to section 5.2.4).

Experimentation of Samples, Stress Strain results

The helmet design has utilised the use of corrugation into the design to compensate for the load distribution consideration of the design.

The rest of data collected was also converted into similar graphs refer to Appendix E. Concerns are still apparent weather the material will hold together under the large forces experienced during test yet the material.

Chapter - 8 Helmet Test

8.1 Chapter Overview

In Accordance to the standards outlined within chapter two, prior to testing multiple simulated conditions are required. The purpose of the following chapter is to investigate the importance and differences between said simulated conditions. Furthermore a theoretical dynamic analysis is discussed to identify the energy, forces and velocities which the helmets will experience.

The theoretical numerical analysis has incorporated data collected form the tests discussed in chapter ten, and will be further discussed in section 10.4 in the comparison of tests.

8.2 Set up of Test

The setup of the testing equipment includes the final assembly of the rig as well as the arrangements of each test and how they have been conducted. The test rig has been designed in compliance with the Australian standards refer to sections 2.5.1 and 2.5.3, and aligned with the specific anvil.

8.2.1 Test Rig

The test rig which has previously discussed in section 3.3.1, the rig is designed to perform in accordance with the outlined examples of a drop mechanism. For safety considerations the rig is setup against a column to reduce the danger area when completing the testing. For each test the corresponding anvil is to be placed in the path of the falling drop rig. As shown in the below diagram the test rig can be adjusted to three different angles as each test is required to be tested at different areas of the helmet.

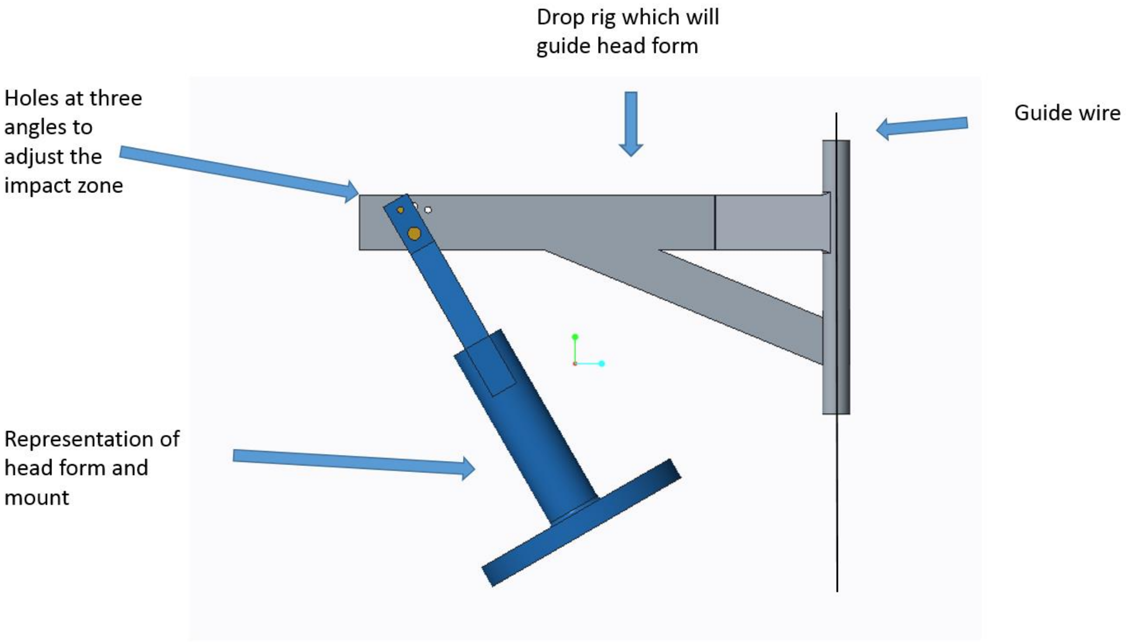


Figure 8.1 Drop Rig design

To make the process more efficient the anvils will be interchanged with the same weather condition, or until the helmet is no longer able to be tested due to extensive damage. This process is further explained in section 9.3.

8.3 Testing Procedures

The Australian standards have outlined a testing sequence which describes both the conditioning of the helmet prior to the test and the required number of tests per sample. This study as previous outlined focuses on the two test, impact energy and load distribution. The following table shows that for each of these tests a separate helmet is required. With this knowledge the testing sequence can then be altered as each test is considered independent of each other.

Helmet Test

TEST ORDER FOR HELMETS

Sample No.	Conditioning	Test
1	Ambient temperature	7.2 Horizontal peripheral vision clearance test 7.7 Peak deflection test 7.3 Static stability test
2	Ambient temperature	7.4 Impact energy attenuation test 7.6 Dynamic strength of retention test
3	Ambient temperature	7.5 Load distribution test 7.6 Dynamic strength of retention test
4	High temperature	7.4 Impact energy attenuation test 7.6 Dynamic strength of retention test
5	High temperature	7.5 Load distribution test 7.6 Dynamic strength of retention test
6	Low temperature	7.4 Impact energy attenuation test 7.6 Dynamic strength of retention test
7	Low temperature	7.5 Load distribution test 7.6 Dynamic strength of retention test
8	Water immersion	7.4 Impact energy attenuation test 7.6 Dynamic strength of retention test
9	Water immersion	7.5 Load distribution test 7.6 Dynamic strength of retention test
10	Spare sample	

Table 4, Test order for helmets (Standard 2008)

As stated above each temperature condition requires 2 helmet samples with one spare sample, this makes the total helmets required to 9 helmets, due to the uncertainty of the helmets performance a limited number of helmets has been allocated to each individual test. As previously stated each of the tests are to be conducted on various points on the helmet, this is the reasoning for creating three different angles which the helmet can be adjusted to on the test rig.

Sample number	Conditioning	Test
1	Ambient Temperature 18-25 °C	Impact Energy Absorption 3 Angles 3 Anvils
2	Low Temperature -10 ± 2°C	Impact Energy Absorption 3 Angles 3 Anvils
3	High temperature 50 ± 2°C	Impact Energy Absorption 3 Angles 3 Anvils
4	Water Immersion 18-25 °C	Impact Energy Absorption 3 Angles 3 Anvils
5	Ambient Temperature 18-25 °C	Load Distribution
6	Low Temperature -10 ± 2°C	Load Distribution
7	High temperature 50 ± 2°C	Load Distribution
8	Water Immersion 18-25 °C	Load Distribution

Table 5 New Test Sequence

The above table outlines the new testing sequence, this new order has been designed to be more time efficient. Conducting the impact energy test for all conditions will reduce the setup time between each of the test. The sequence of the test will involve testing the ambient temperature sample on the first anvil changing the angle, then changing the anvil and continuing until all 9 tests are completed and moving to the next condition sample. This process will include 36 impact energy absorption test results and 4 load distribution. If a helmet sample fails one of the test a secondary sample is allocated to continue the test, if that sample breaks the helmet is considered to have failed that test and the next test is performed. It is stated that only 10% of the sample can break off before being considered a fail.

8.4 Explanation of Conditions and Angles of drop.

Each aspect of the drop has been explain within this section prior to the results to give an understanding of the conditions and the desired outcome. The impact energy test is design to replicate multiple weather conditions which are experienced within Australia. These include the extreme cold fronts experienced within the southern states to the extreme heat waves in the north.

8.4.1 Ambient Temperature

The ambient temperature is used for a control situation as this condition is the most common scenario that a helmet would be used in in Queensland. The control test will also give information regarding the other conditions if the samples pass the control ambient test yet fail the others, further investigation into the conditioning of the materials is required.

8.4.2 Low Temperature

The low temperature focuses on the materials behaviour when experienced to the extreme cold, the material is expected to have a brittle behaviour when exposed to the cold weather which will impede the results. These test will strains the materials bonding behaviour and identify defects within the design. This test is of major concern due the products ability to be applied worldwide and not only to northern Australia, for the product to be implemented into other bicycle rental schemes the helmet must produce a safe results for when experienced to the cold.

8.4.3 High Temperature

The high temperature is the opposite of the previous condition and can be considered more of a consideration within Queensland as the weather is commonly hot, and for the helmet design to be implemented into the Brisbane City Cycle this condition is of high consideration. The helmet is predicted to be more malleable and therefore may absorb more of the applied forces.

8.4.4 Water Immersion

The water immersion test is designed to mimic wet weather, due to the material being used, recycled newspaper, this is a major concern. To compensate for the water immersion the helmets will be coated in an outdoor enamel, this will protect the helmet from the water without effecting the properties of the material. The enamel paint will reportedly give a period of protection from the outside weather of four months, due to the limitations of the dissertation the study of the effects of the enamel paint has been excluded from this research. Within the continuation of the project the investigation into water protection life is required with an allocation of use by date during production.

8.4.5 Angle 90 Degrees

The 90 degree drop test is designed to simulate a direct impact to the top of the head. This scenario may seem unlikely yet if the rider is to fall over the handle bars it is very common that the top of the riders head will impact the ground first. With the thickness of the helmet being greatest at this point, the expectations are for the helmet to produce its best results during this angle. The results gained from this test may validate if the bulk of the helmet is considered viable.

8.4.6 Angle 30 Degrees (FRONT)

The 30 degree front has been selected for analysis due to the high probability of falling forward, this angle will determine the effectiveness of the front of the helmets frontal design. Due to the rim of the helmet being the weaker points both the front and back are vital to determine the outer strength of the helmet

8.4.7 Angle 30 Degrees (BACK)

The 30 degree back has been selected for analysis due to the probability of falling backwards, this angle will determine the effectiveness of the rear of the helmets design. And is chosen for similar reasons to that of the front.

8.5 Dynamic analysis of impact.

Dynamic analysis is the theoretical calculation of various properties of the system. These properties include the kinetic energy, the impact forces and the impact velocity of the falling object (headform and helmet). This analysis is to determine the theoretical results prior to testing to receive an understanding of what forces will act upon the helmets.

8.5.1 Equations used within analysis

The following equations which are applied when analysing the impact energy and load distribution test can only be applied with various assumptions to determine the accuracy of the results. The assumptions which are assumed when using the following equations include:

- A frictionless fall (free fall)
- A direct vertical drop onto the target
- Neglect wind resistance
- Constant value of gravity ($9.81\frac{m}{s^2}$)

As these assumptions cannot be replicated in a real world scenario it is known that there is a level of inaccuracy when calculating these results.

8.5.1.1 Kinetic Energy

Equation 9.1 was developed by Gottfried Wilhelm Leibniz, which describes the kinetic energy of a falling object which is now most commonly grouped with energy and momentum under the blanket of Newtonian mechanics. (Look 2015)

$$KE = \frac{1}{2}mv^2 \tag{9.1}$$

KE= kinetic energy

m = mass of object

v = maximum velocity

8.5.1.2 Maximum Velocity of object

Equation 9.2 is the impact velocity, which calculates the maximum velocity of the object which occurs just prior to the impact.(*Impact Force* 2015)

$$v = \sqrt{2 * g * h} \tag{9.2}$$

v = velocity

g = acceleration due to gravity

h = height of object when velocity is zero.

8.5.1.3 Force of impact

The force of the impact will be experienced both by the helmet and anvils, as stated by newtons laws, “the forces are equal and opposite”. When calculating the force acting onto the helmet the distance after impact which the object travels is required (s), this distance is assumed due to the limitations of the testing conducted. (*Impact Force* 2015)

$$F = \frac{m * g * h}{s} \qquad (9.3)$$

F= Force of impact

m = mass of object

g = acceleration due to gravity

h = height of object when velocity is zero

s = slow down distance.

8.5.2 Numerical Analysis

Numerical analysis has been calculated for both the impact energy and load distribution which describes the theoretical energy, forces and velocities acting on the helmets during the drop. The results of the calculations are theoretical results which will be compared to the results of the test, these results are calculated with the assumptions previous discussed applied.

8.5.2.1 Impact Energy Absorption

Impact velocity of helmet at the instant of impact using equation 9.2

$$v = \sqrt{2 * g * h}$$

$$v = \sqrt{2*9.81*1.5}$$

$$v = 5.425$$

Kinetic Energy applied onto the helmet using equation 9.1

$$KE = \frac{1}{2} m v^2$$

$$KE = 0.5*4.7*5.425^2$$

Helmet Test

$$KE = 69.1619J$$

Force of impact applied to the helmet at the instant of impact using equation 9.3

$$F = \frac{m*g*h}{s}$$

$$F = \frac{4.7*9.81*1.5}{.060}$$

$$F = 1152.67N$$

$$F = 1.152kN$$

8.5.2.2 Load Distribution

Impact velocity of helmet at the instant of impact using equation 9.2

$$v = \sqrt{2 * g * h}$$

$$v = \sqrt{2*9.81*1}$$

$$v = 4.429$$

Kinetic Energy applied onto the helmet using equation 9.1

$$KE = \frac{1}{2}mv^2$$

$$KE = 0.5*4.7*4.429^2$$

$$KE = 46.097J$$

Force of impact applied to the helmet at the instant of impact using equation 9.3

$$F = \frac{m*g*h}{s}$$

$$F = \frac{4.7*9.81*1}{.050}$$

$$F = 922.14N$$

The theoretical numerical analysis will be discussed further within section 10.4, were the results of both tests have been discussed and conclusions regarding the helmet are made.

8.6 Risk Assessment

There are many risks associated with both the performance of experiments, and the continuation of the project. Appendix C contains the standard USQ generic risk assessment and mitigation strategies regarding the tasks associated with the project. This appendix is only an assessment of the immediate risks associated to the people involved in performing the tasks. The risk assessment does not include an analysis of the product if it were to continue on to the open market. If the product were to become a sellable product various aspects of the helmet will be required to be assessed and the further work outlined in section 10.5 will have to be completed.

The helmet is designed to be a disposable one time use helmet, there is a large possibility of riders to use the helmets for an extend amount of time. The risks associated with a prolonged use of the helmet is the safety standard of the helmet will decrease over time and may be considered useless in an accident. To mitigate this potential risk, when manufactured the helmets will be required to have a "use by date" stamped into it. This will not stop riders using the helmets for prolonged periods of time, but will inform then when the helmet is no longer safe to use and the continuation of use is at their own risk. The period of time which the "use by date" is allocated will depend on testing of both the enamel paint and secondary testing of the helmet at a different periods of time exposed to different weather conditions.

Chapter - 9 Results and Discussion

9.1 Chapter Overview

The results of the tests have been displayed according to the pre-test conditioning of the helmet. Each test which has been conducted per anvil has been displayed together to represent the collective result of the helmets. As a result of extensive damage not all angles or anvils have been tested, for these situations the requirements within the standards have not been achieved. Graphs to illustrate the results of the test have been produced using MATLAB, the MATLAB code used to interoperate the data refer to Appendix F. The LMS data acquisition system has collected the acceleration, and calculated the distance travelled of the accelerometer in real time.

9.2 Impact Energy Absorption Results

The impact energy absorption tests are conducted to accurately determine that the material can absorb the energy transferred during a fall. The test is recorded in a measurement of G's over time. G's is a measurement of acceleration. Hence, 2 G's is a measurement of twice the acceleration due to gravity. The peak acceleration of the impact will determine the likelihood of a fatal impact to a human head.

The crucial measurement of the experiment is the maximum acceleration which the headform is experienced to, and the period of this acceleration, as these combined define the human body's limitations of an impact. The helmet is tested at a free-fall height of 1500 +30, -5 mm the head form acceleration shall not exceed 250g peak. In addition, the cumulative duration of acceleration shall not exceed the following conditions:

(a) 3.0 ms for acceleration greater than 200g
(b) 6.0 ms for acceleration greater than 150g

These limitations are the indicators of a likely pass or fail of the Australian standards, however these are not the deciding factors which state if the material and design are viable for further investigation and implementation into the market in the future. The outcome of the testing will determine the possibilities of the material and design being viable to further investigation

9.2.1 Ambient Air Temperature

Due to the conditions of this experiment no action was compulsory for the replication of ambient air temperature. The test is comprised of three angles for each anvil situation.

9.2.1.1 Flat Anvil Test

The flat anvil test is design to reproduce the situation of a rider falling onto a flat surface.

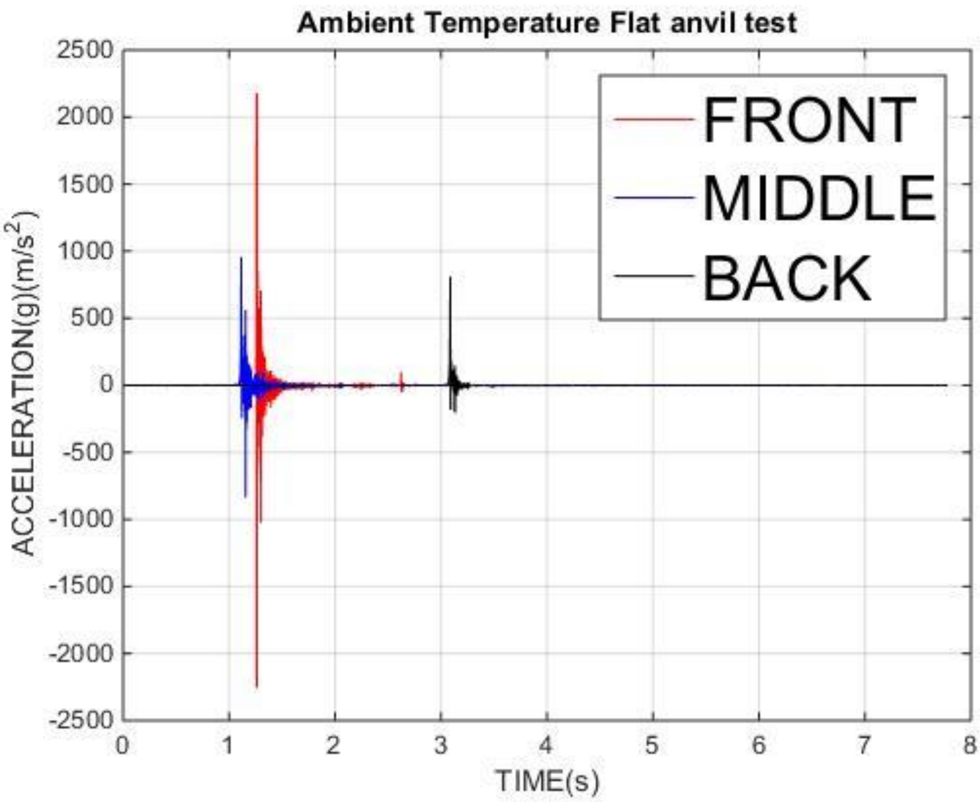


Figure 39, Ambient Temperature Flat Anvil Test

Results and Discussion

The above graph displays all three angle results on the same scale to display the comparison of the different areas on the helmet. The values of test are recorded below.

- The maximum acceleration of the front of the helmet: 2178.87 g
- The maximum acceleration of the middle of the helmet: 956.43 g
- The maximum acceleration of the back of the helmet : 810.56 g

Due to the vast amounts of acceleration which was experienced during the test the helmet was declared a non-compliance with the Australian standards. The maximum acceleration is of interest as the middle and back sides of the helmet have produced similar results. The result recorded of the front is dramatically high in comparison, this could be due to a miss alinement when conducting the test resulting in less of the helmet being under the head during the impact.

The below graph is a representation of the distance in which the head moved after the resulting impact, these results will be discussed within the numerical analysis.

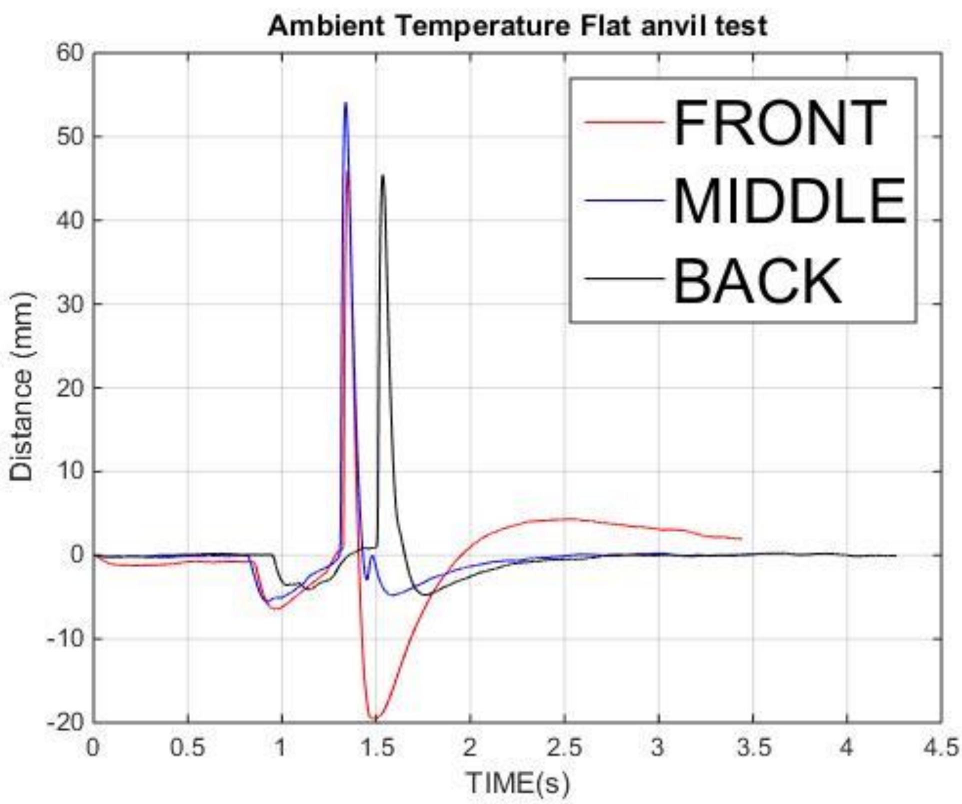


Figure 40, Ambient Temperature Flat Anvil Distance after impact results

The results of the displacement of the helmet during the test are:

- The max displacement after impact of Front: 45.89 mm
- The max displacement after impact of Middle: 54.12 mm
- The max displacement after impact of Back: 45.44 mm

These results are tabulated and used when comparing the numerical analysis. As expected, the results display almost a linear drop with a large displacement during impact and slight bouncing until the headform becomes fully stationary.

9.2.1.2 Angles Anvil Test

The angled anvil test is design to reproduce the situation of a rider falling onto a sharp surface such as, the corner of a curb or a sharp object.

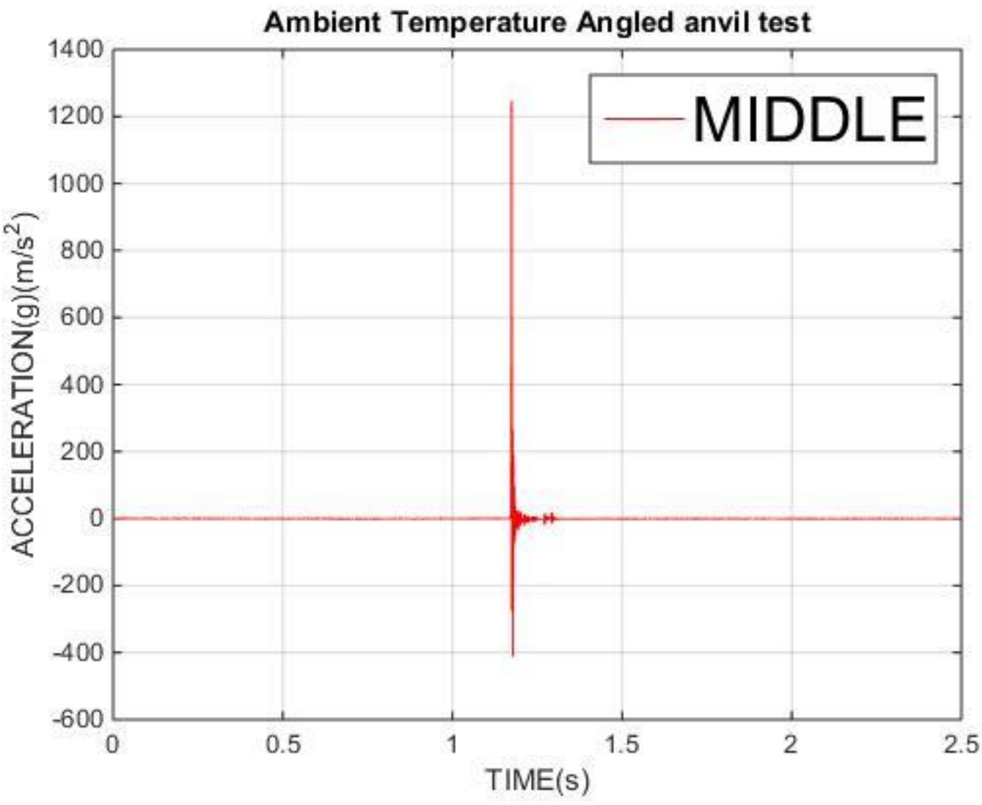


Figure 41, Ambient Temperature Angled Anvil Test

The graph displays only the middle results as each temperature had a limited number of helmets and once all helmets were no longer viable to test that temperature is considered a fail. Unfortunately when conducting this test the helmet was cut in half and was no longer able to be tested. The maximum acceleration which the angled anvil is;

- The maximum acceleration of the Front of the helmet: 1245.85 g

Due to the high value and the helmet break the helmet does not meet the standards.

The below graph is a representation of the distance in which the head moved after the resulting impact, these results will be discussed within the numerical analysis.

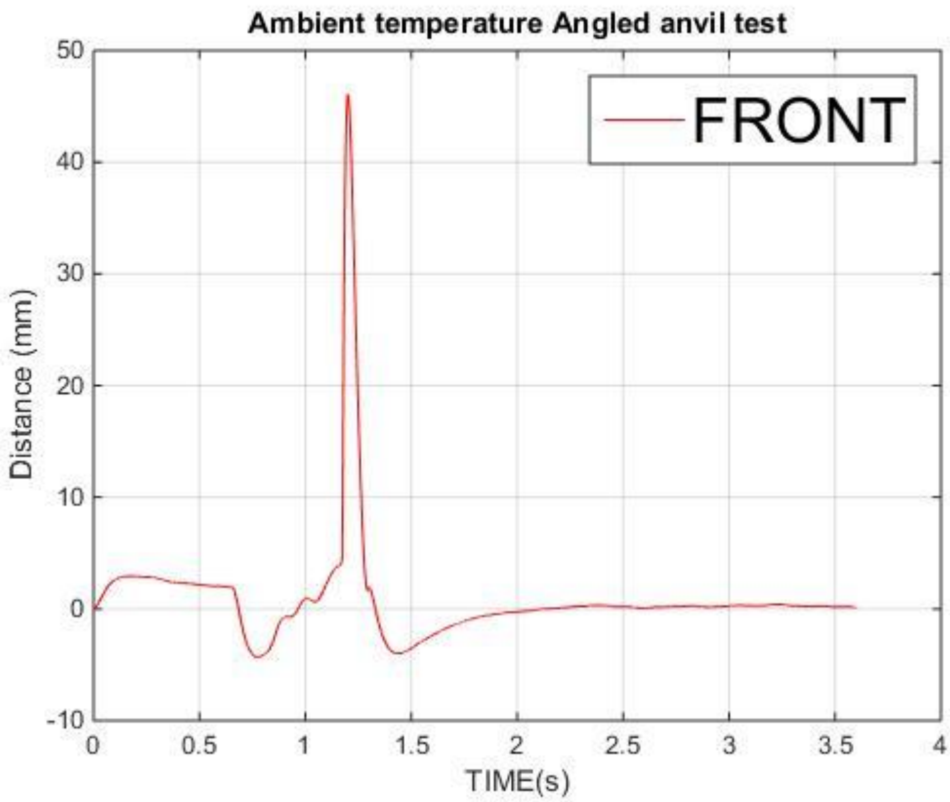


Figure 8, Ambient Temperature Angled Anvil Distance after impact results

The results of the movement of the helmet during the test are:

- The max displacement after impact of middle: 46.08 mm

The results of this displacement graph are similar to the expectations of all test, the results are displayed more clearly when only comparing one drop test.

9.2.1.3 Spherical Anvil Test

The spherical anvil test is design to reproduce the situation of a rider falling onto a sharp surface such as, the corner of a curb or a curved object.

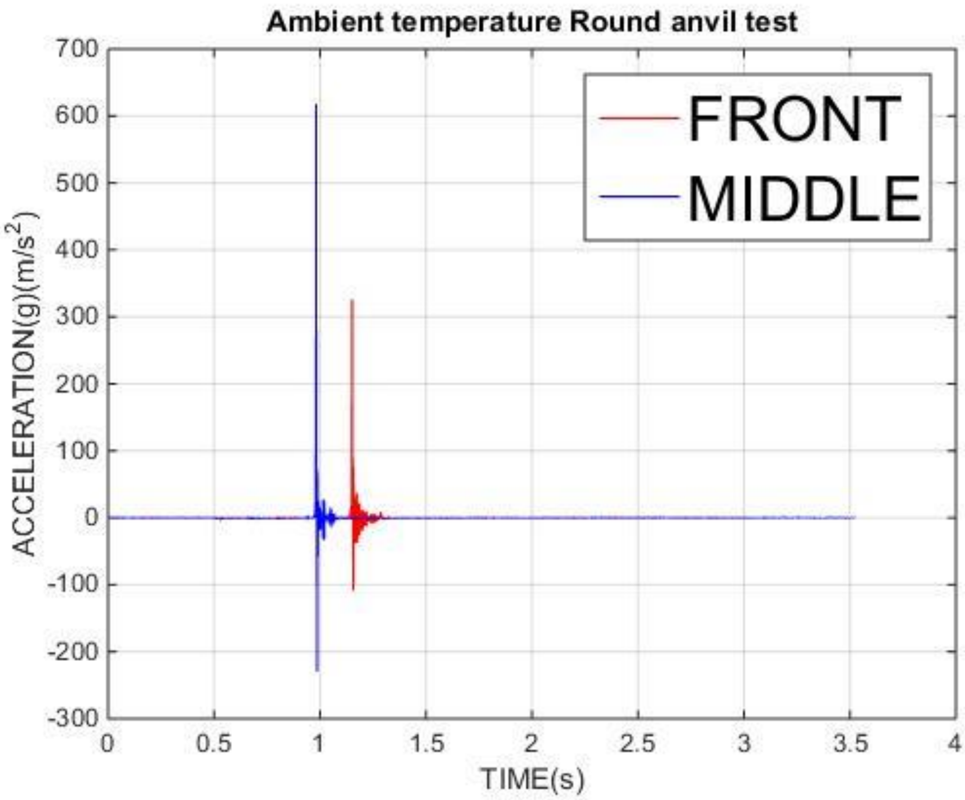


Figure 43, Ambient Temperature Round Anvil Test

The above graph displays only two angles and the corresponding results, this is due to the helmet braking during the testing. Due to time constraints and the parameters involved in the testing, and a limited number of helmets were allocated to each temperature. Once all helmets could no longer be tested, the temperature was considered a fail. Although the ambient temperature is considered a fail according to the Australian Standards, there are some promising results found within the testing, which are displayed below:

- The maximum acceleration of the Front of the helmet: 326.56 g
- The maximum acceleration of the Middle of the helmet: 617.85 g

Results and Discussion

As previously stated, the maximum acceleration a human head can safely experience is 300g. However, the front of the round anvil test demonstrated a maximum of only 326.25g. This small variance concludes that the design has shown some promise and the material is capable of producing a sound result.

The below graph is a representation of the distance in which the head moved after the resulting impact. These results will be discussed within the numerical analysis.

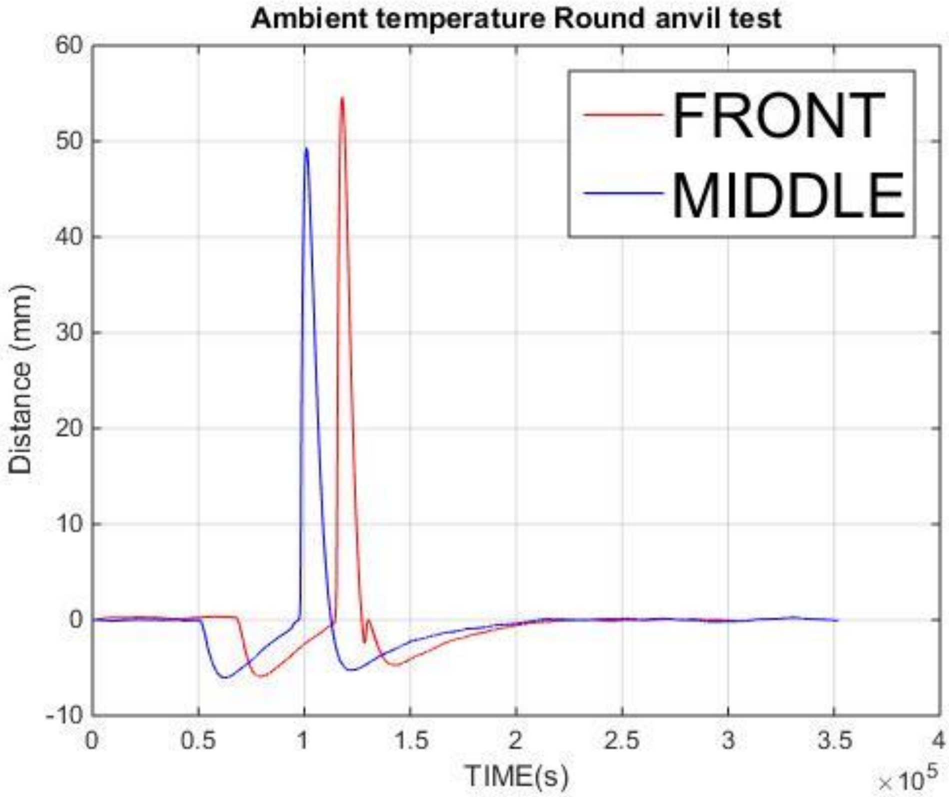


Figure 10, Ambient Temperature Round Anvil Distance after impact results

The results of the movement of the helmet during the test are:

- The max displacement after impact of Front: 54.6 mm
- The max displacement after impact of Middle: 49.31 mm

Similar results to the previous tests, the repetition of the maximum displacement shows equal performance throughout the tests and can be used to determine if the results can be disregarded if the results show a major difference.

9.2.1.4 All Ambient Drop Tests Compiled

To display the results of the ambient air temperature tests, the results have been compiled to show any reoccurring results and outliers of the testing. The graph shows the peak acceleration that was experienced.

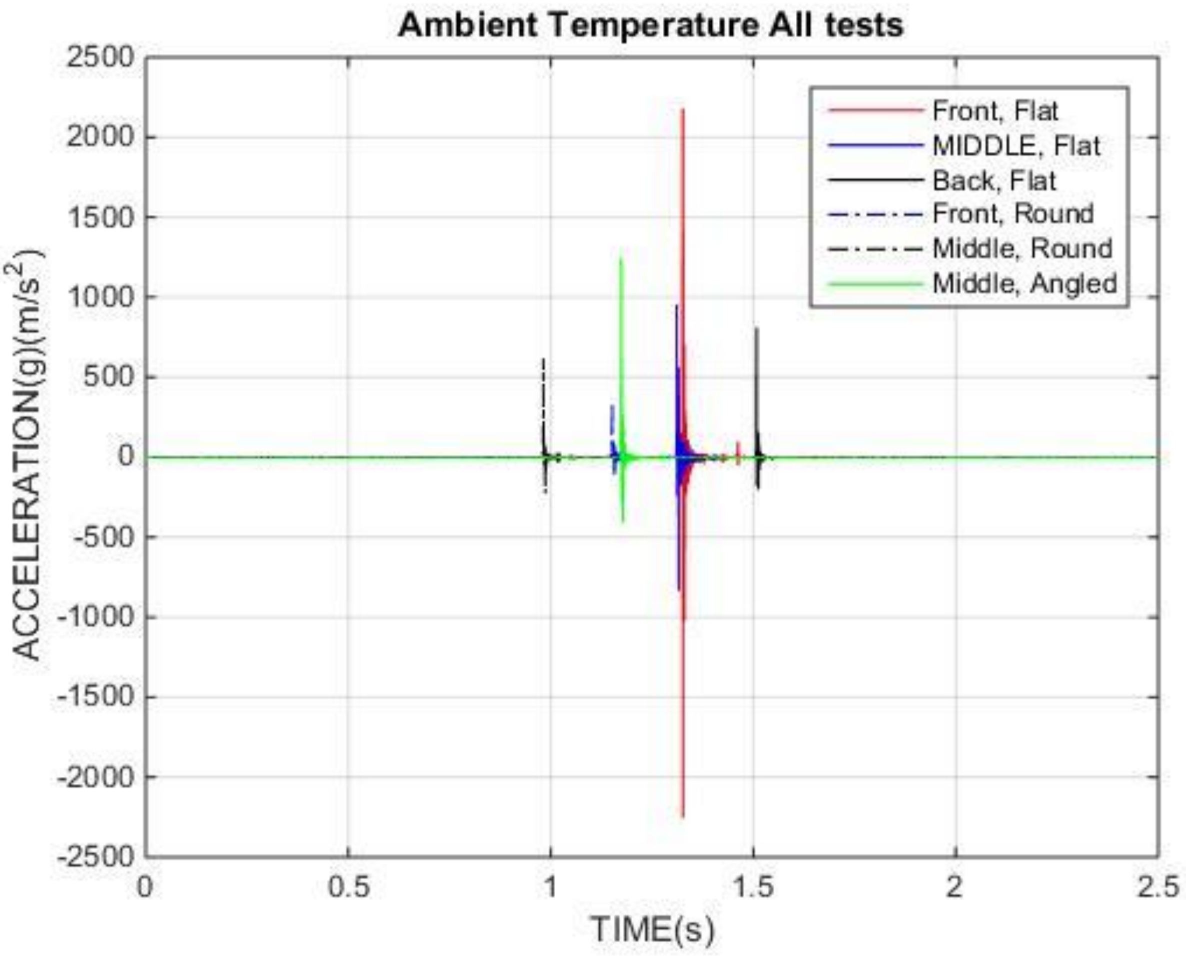


Figure 45, all ambient Temperature Results

From the above graph and previous graphs discussed it is evident that the lowest recorded accelerations are when the helmet is dropped onto the round anvil. With the smallest result being 326.56 g. The Front Flat anvil test can be considered an outlier, due to all the other results producing a similar outcome. This outlier could be due to an insufficient loading of the helmet or the helmet slipping during the test, this result is considerably larger than the other weather condition flat anvil results. During all tests, it was observed that a certain amount of damage was done to the helmet and parts of the helmet were broken this alone will determine that the helmet does not meet Australian standards.

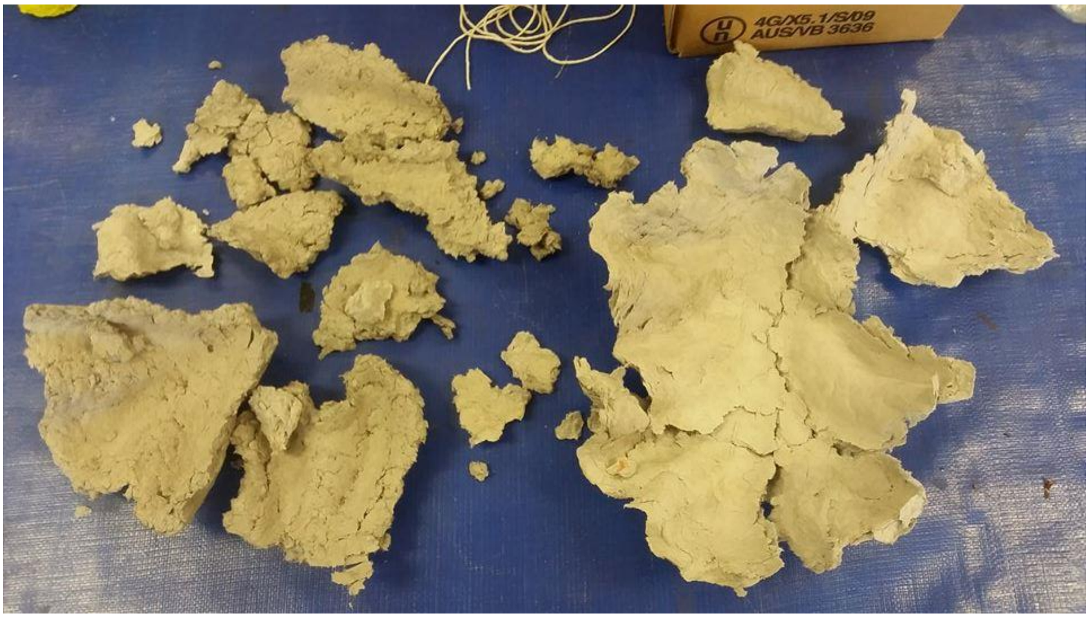


Figure 46, Damaged Helmets after testing

9.2.2 Low Temperature

Due to the conditions of this experiment, the samples are required to be at -10 degrees for four hours prior to testing. For this condition, the samples had been put into a freezer and the temperature when tested is recorded. The test for the low temperature has only been conducted for the Flat anvil, this is due to the limited number of helmets per temperature.

9.2.2.1 Flat Anvil Test

The flat anvil test is design to reproduce the situation of a rider falling onto a flat surface.

Results and Discussion

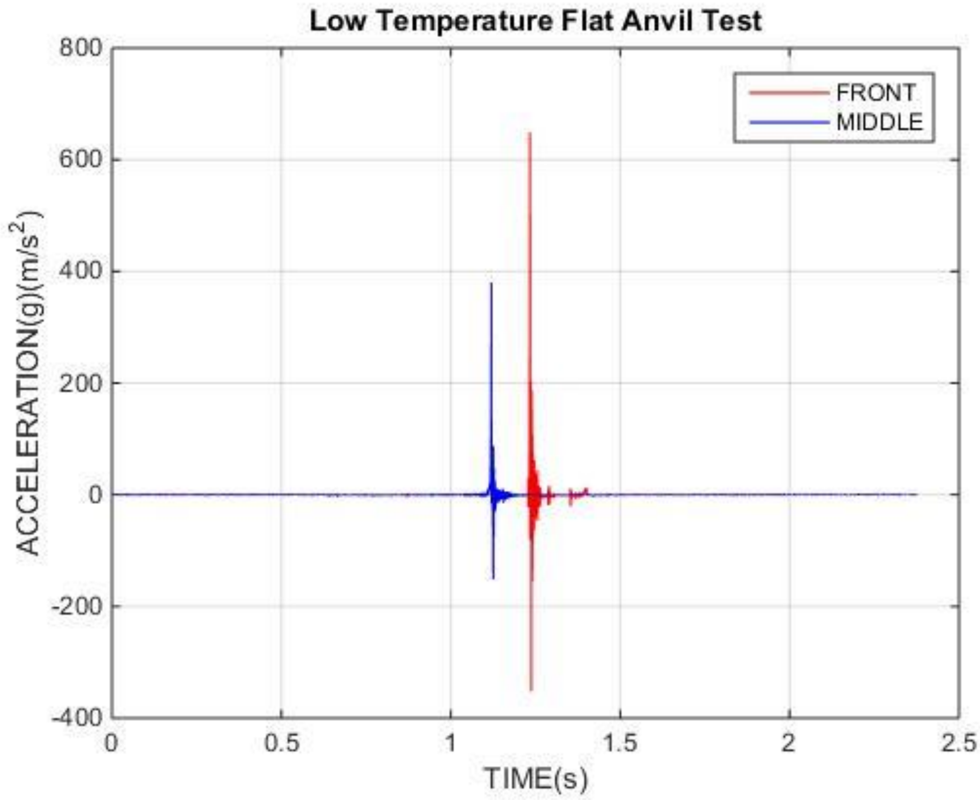


Figure 13, Low Temperature Flat Anvil Test

The above graph displays only two angles due to the damage caused to the allocated helmets. Therefore, no further testing could be conducted under these conditions. The values of the results are:

- The maximum acceleration of the Front of the helmet: 648.96 g
- The maximum acceleration of the Middle of the helmet: 380.18 g

When compared to the ambient temperature, the front of the helmet produces a higher result to the middle, yet the low temperature condition produces a lower acceleration and is therefore safer. The middle also produces a safer result which indicates the need for modifications to the front and back of the helmet.

The helmets which were used within these tests were destroyed on impact, making the biding agent of the helmet a concern.

The below graph is a representation of the distance in which the head moved after the resulting impact, these results will be discussed within the numerical analysis.

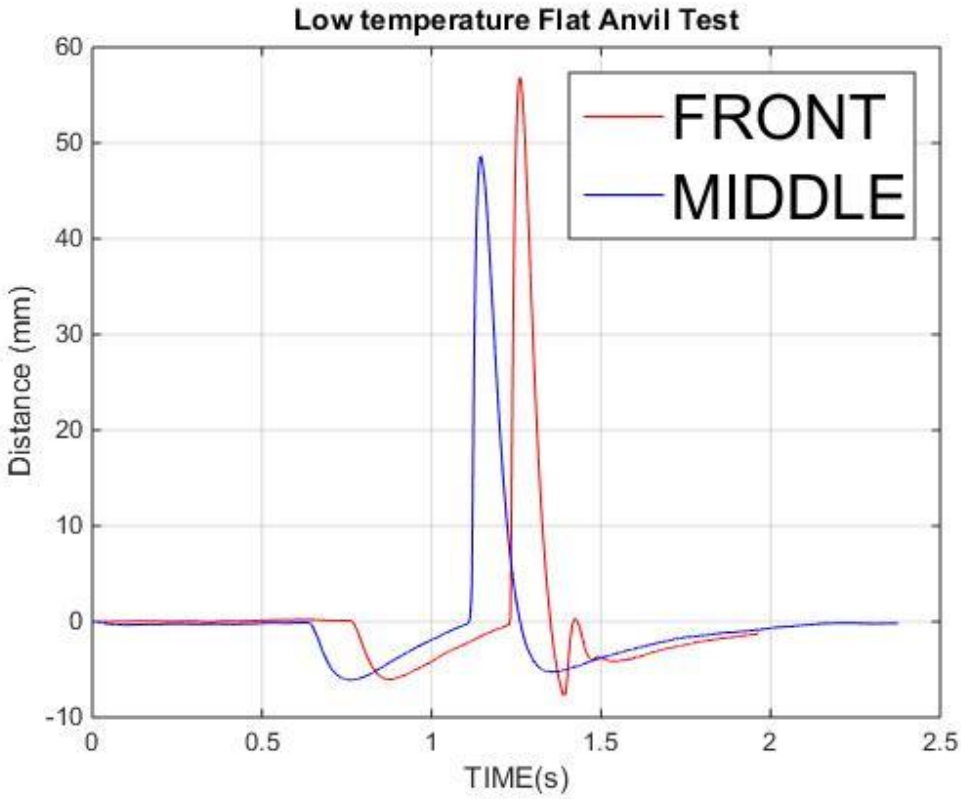


Figure 14, Low Temperature Flat Anvil Distance after impact results

The results of the movement of the helmet during the test are:

- The max displacement after impact of Front: 56.87 mm
- The max displacement after impact of Middle: 48.63 mm

9.2.3 High Temperature

Within the experiment, the samples will be placed within an oven which is at a constant temperature of 50 degrees for four hours. The testing has been conducted only on two anvils and two angles for each, due to the limited number of helmets allocated. The high temperature produced all helmets to be destroyed within the process similar to the previous weather conditions.

9.2.3.1 Flat Anvil Test

The flat anvil test is design to reproduce the situation of a rider falling onto a flat surface.

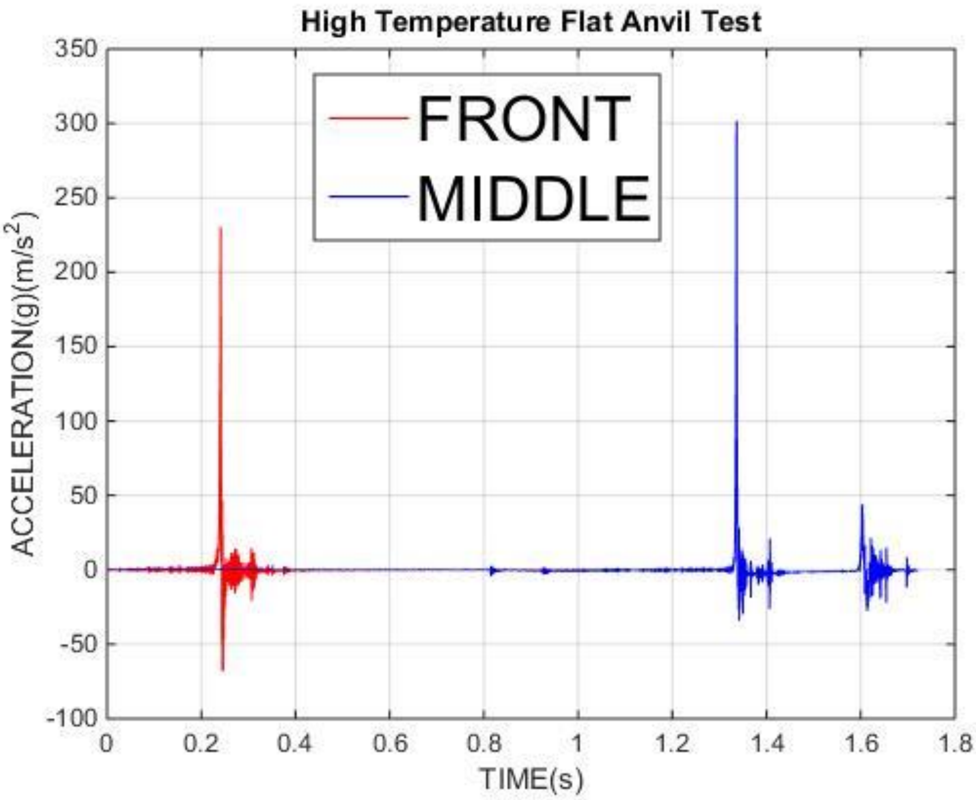


Figure 15, High Temperature Flat Anvil Test

The above graph displays only two of the angles unlike previous results the front of the helmet has decelerated the helmet considerably well with both results being low.

- The maximum acceleration of the Front of the helmet: 230.45 g
- The maximum acceleration of the Middle of the helmet: 301.86 g

It can be said that the results obtained display an acceptable standard since a human could withstand the impact of the front of the helmet. According to these results, the design can provide some safety during an impact.

The below graph is a representation of the distance in which the head moved after the resulting impact. These results will be discussed within the numerical analysis.

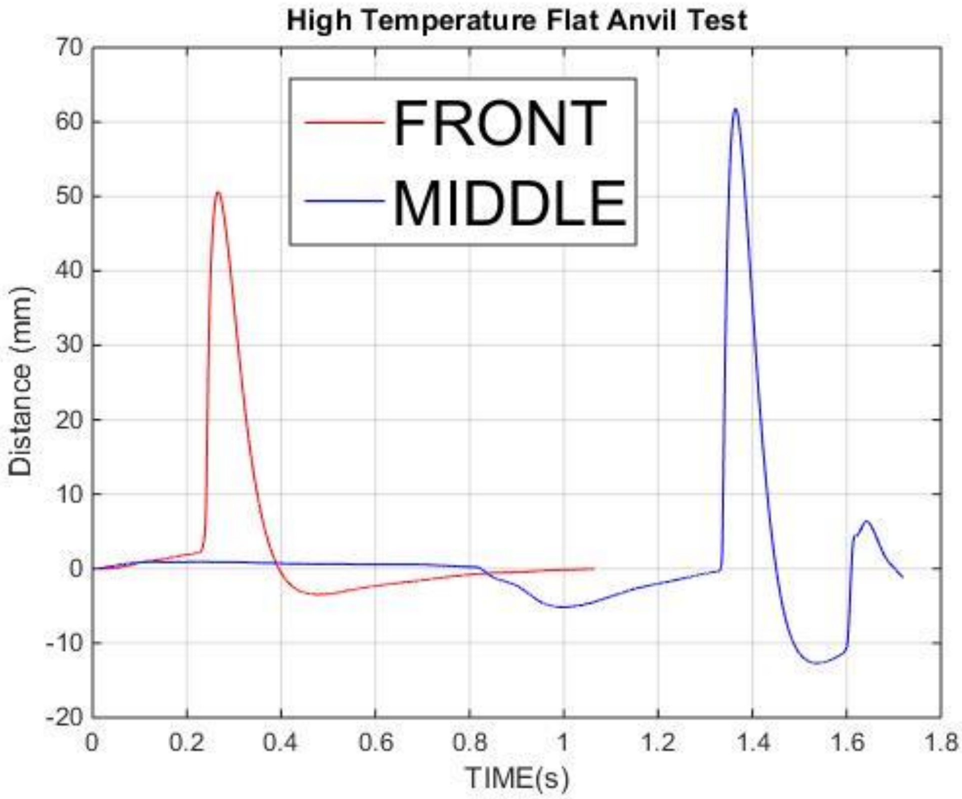


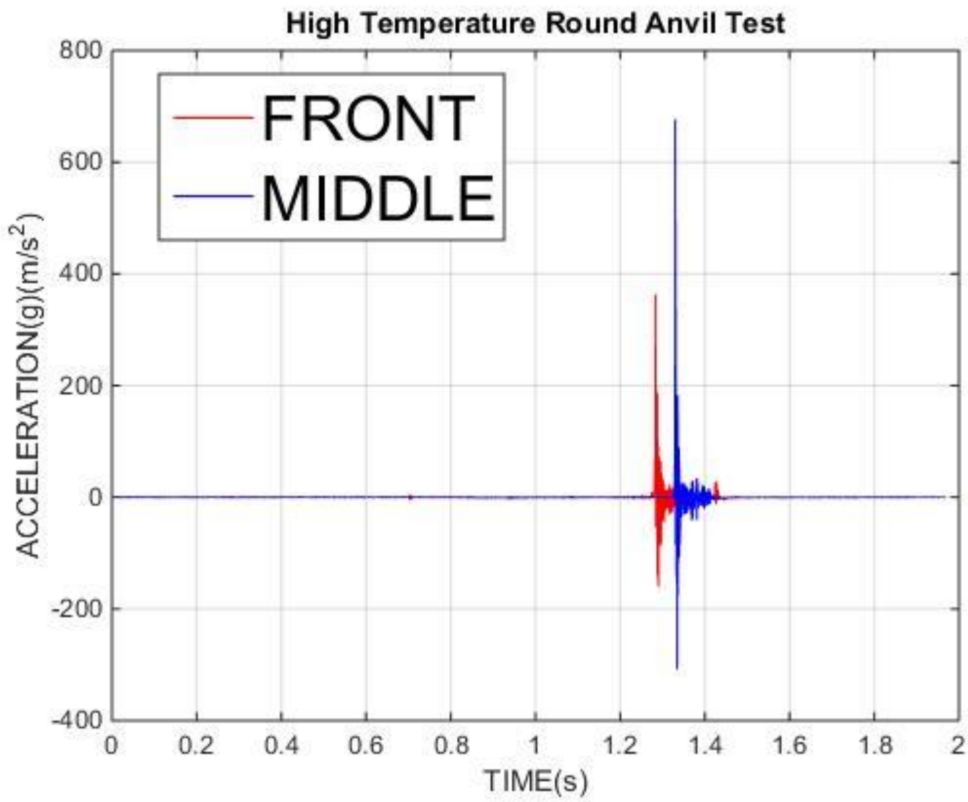
Figure 16, High Temperature Flat Anvil Distance after impact results

The results of the movement of the helmet during the test are:

- The max displacement after impact of Front: 50.63 mm
- The max displacement after impact of Middle: 61.8 mm

9.2.3.2 Spherical Anvil Test

The spherical anvil test is design to reproduce the situation of a rider falling onto a sharp surface such as, the corner of a curb or a curved object.



The above graph displays two angles due to the helmet being destroyed during this test. The graph is similar to the flat anvil as both have the front of the helmet produce a better results and values which are recorded are almost half of the ambient temperature.

- The max of Front: 364.16 g
- The max of Middle: 676.47 g

The below graph is a representation of the distance in which the head moved after the resulting impact, these results will be discussed within the numerical analysis.

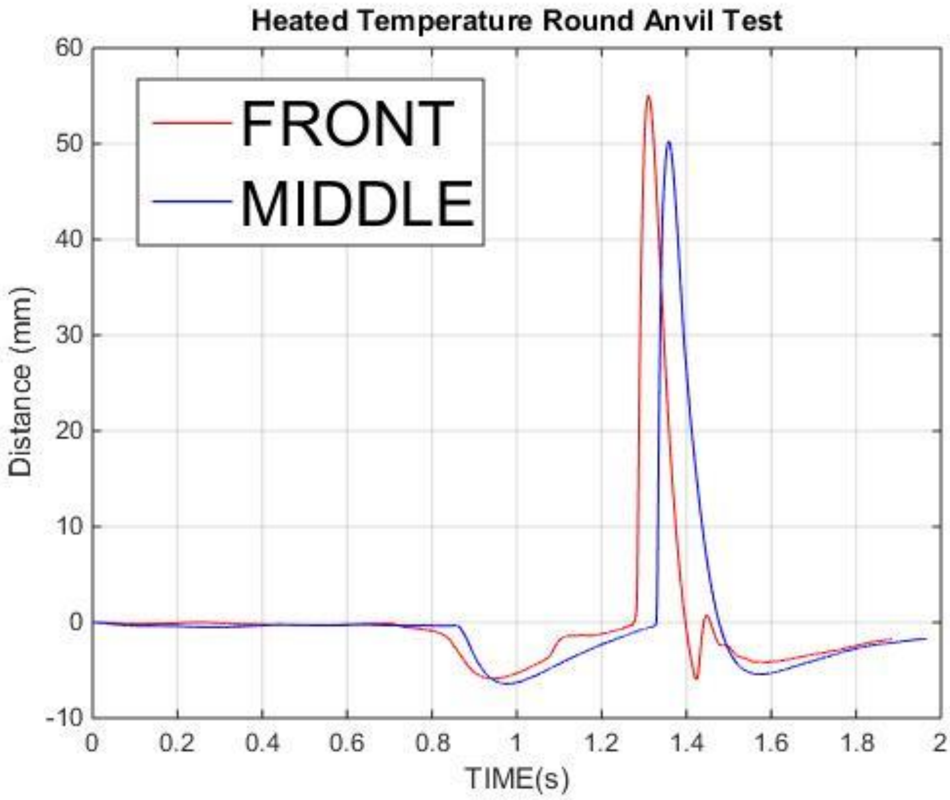


Figure 17, High Temperature Round Anvil Distance after impact results

The results of the movement of the helmet during the test are:

- The max displacement after impact of Front: 55.06 mm
- The max displacement after impact of Middle: 50.24 mm

9.2.3.3 All High Drop Tests Compiled

To display the results of the high temperature tests, the results have been compiled to show any reoccurring results and outliers of the testing. The graph shows the peak acceleration that was experienced.

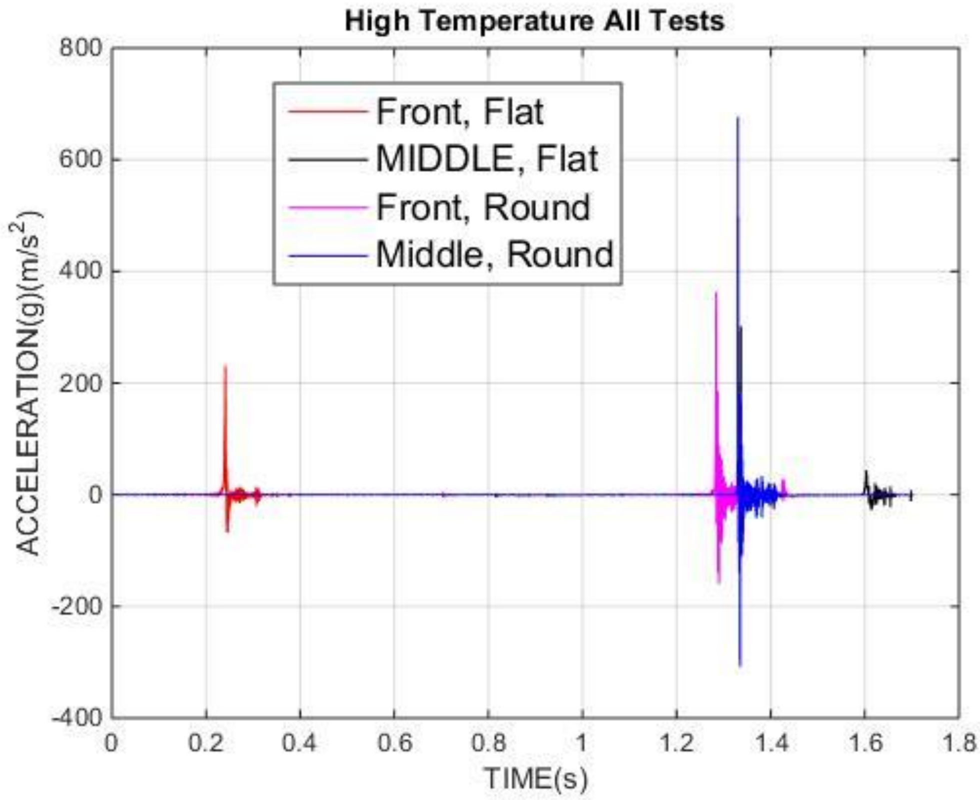


Figure 18, All High Temperature Results

As displayed above unlike the ambient temperature the flat anvil results of the High temperature are a larger than the round. Although the middle of the helmet dropped onto the spherical anvil both in the high and ambient temperatures produced a similar result. As the middle of the helmet is the most symmetrical in x and y directions, this location is most likely to produce a consistent result. Based on these results, further testing conducted on the middle of the helmet can be considered to produce the same result in both high and ambient temperatures, this could be used to reduce testing required within the future.

9.2.4 Water Immersion

Due to the conditions of this experiment, the samples are placed into a container of still water at room temperature for four hours. As previously stated, the samples are coated in an enamel paint. Due to time constraints, the enamel paints effectiveness on the material was not able to be tested. The water immersion test was conducted on the flat anvil only due to the catastrophic results to the helmet and the extreme data which was collected.

9.2.4.1 Flat Anvil Test

The flat anvil test is design to reproduce the situation of a rider falling onto a flat surface.

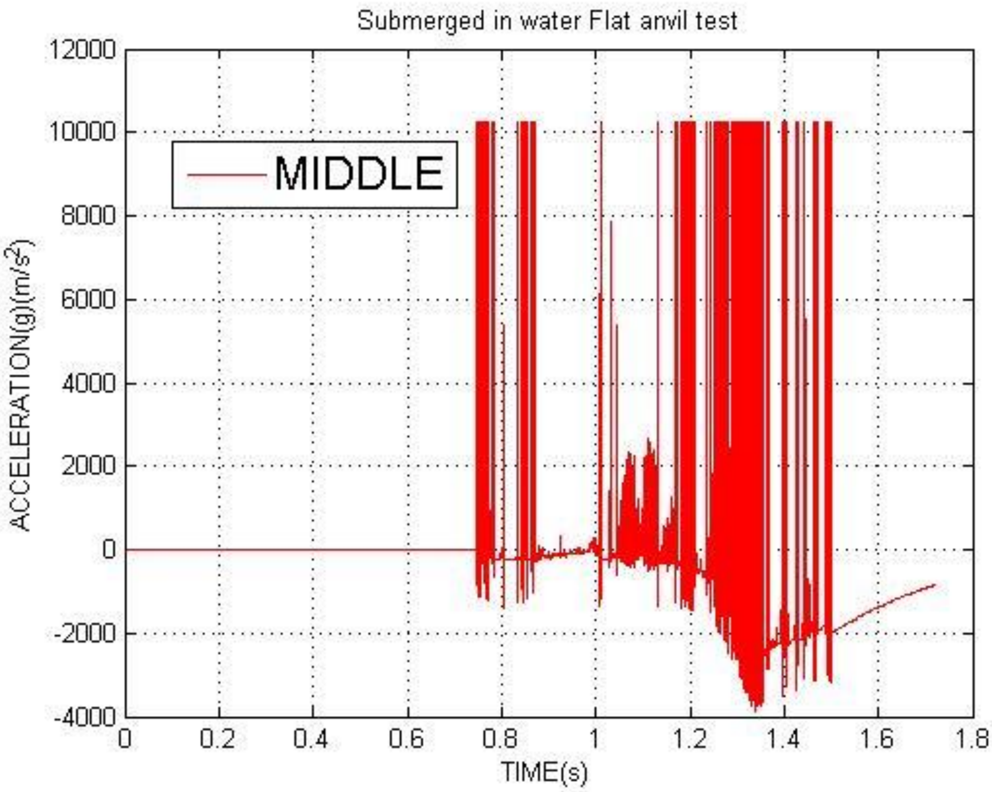


Figure 53, Submerged in water Flat anvil test

The test was only conducted once, during the experiment unusual data was collected which can only be explained by a miss reading of the accelerometer. The miss reading could have occurred if the accelerometer became loose within the head form and bounced around, which would therefore produce inaccurate data shown above. During the test, the helmet was instantly obliterated into many pieces this occurred due to the submersion in water. After the helmet was removed from the soak the helmet was malleable and it was obvious the integrity was lost. These results will be excluded from the outcome of the helmet as a result of the inadequate data.

- The maximum acceleration of the Front of the helmet: 10239.96 g

This value is five times greater than the allowable acceleration. However, the data has been disregarded due to the obvious incorrect data of the movement of the accelerometer. The movement is calculated by the second integration of the real time acceleration which is collected.

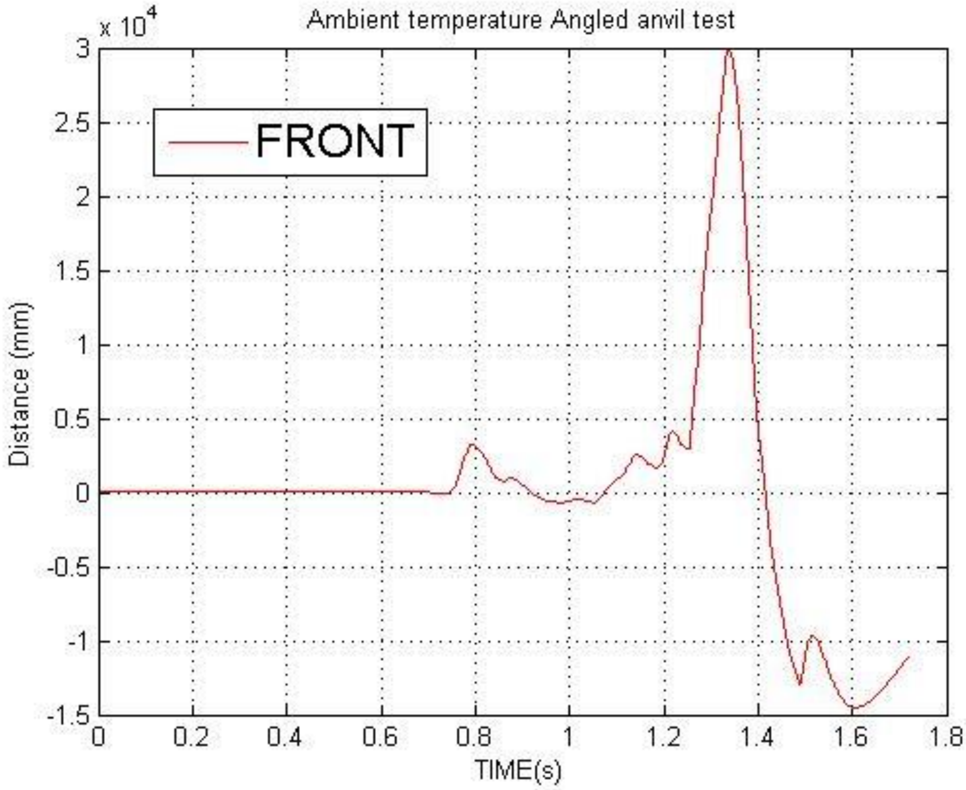


Figure 54, displacement during drop test of submerged flat anvil test

The maximum displacement after impact of middle is 29987.21 mm. this results is physically not possible as the data collected states that the head form bounced at twice the height at which it fell, and according to the conservation of energy this is impossible.

9.3 Load distribution

The load distribution tests are designed to measure the amount of force which is transferred through the helmet and onto the rider's skull. This is a vital safety consideration due to the limitations of the human body. The force which is applied onto the helmet is required to be distributed through the helmet to produce a small stress onto the head to reduce the injury of the rider. When the helmet is tested in accordance with AS/NZS 2512.9 using a fall height of 1000 +15, -5 mm, the following conditions shall be met:

(a) Loading measured by the force transducer shall not exceed 500 N measured over a circular area of 100 mm^2

(b) The anvil shall not contact the surface of the head form.

These are the limitations are which each graph are compared to, to determine the result of the sample. Each limitation is identified on the graph and the difference between the limitation either under or over is recorded. This difference between the limitation and recorded result will determine the amount of discussion of the helmet and the further investigations required.

Results and Discussion

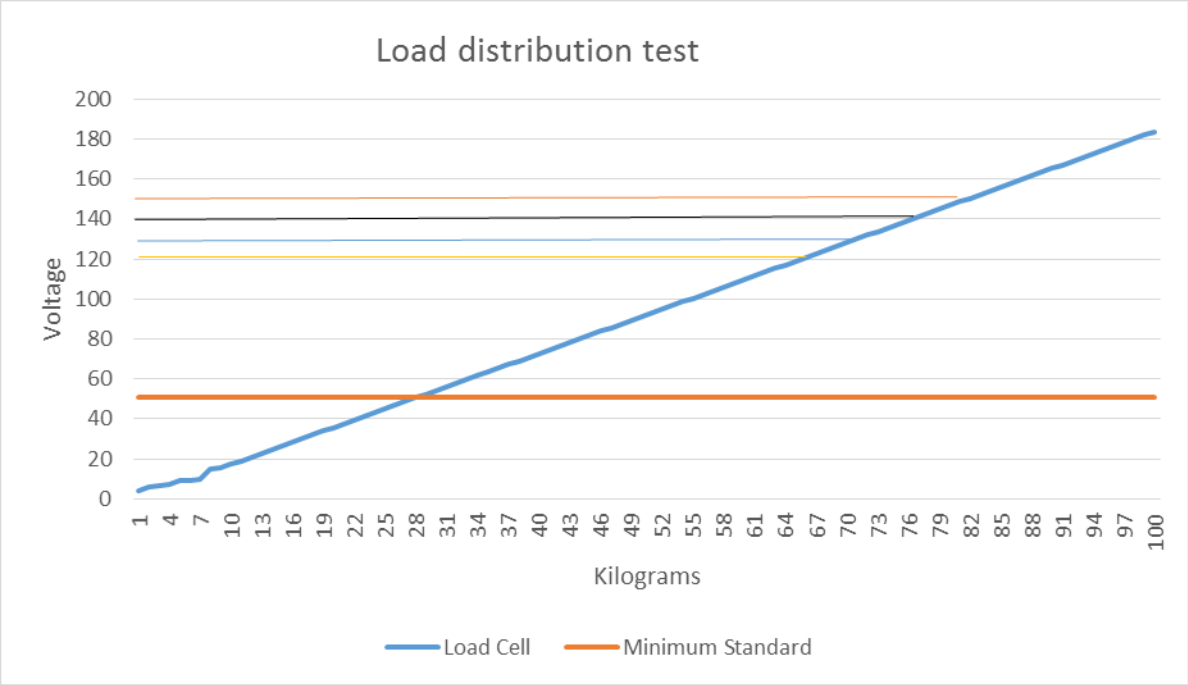


Figure 21, Load distribution Test

The load distribution graph is a representation of the results from the load cell used in the experiment. The load cell produces a voltage depending on the amount of weight applied and from the calibration function (load cell) the voltage which is produced during the test can then be used to determine the corresponding force.

- The yellow line represents the high temperature test.
- The blue line represents the ambient temperature test.
- The black line represents the high temperature test.
- The orange line represents the submerged in water test.

Using the voltage graph and determining the equivalent weight which was applied onto the load cell and converting into a force using the acceleration due to gravity the corresponding force was calculated.

- Ambient Temperature : 1255.68N
- Low Temperature : 1348.87N
- High Temperature : 1177.2N
- Submerged Helmet : 1432.26N

These results are higher than the standards allow for and can therefore be determined as not suitable.

9.4 Discussion of results

The information gathered from the impact testing is tabulated to visualise both the acceleration and displacement results. The test data tables identify the largest and smallest results. The important results, including the outliers previous discussed, are highlighted. The discussion of the result identifies the helmet's strengths and weaknesses. This has identified the areas to focus on for future work.

9.4.1 Impact Energy Discussion

The tabled results identify the promising results which support judgement that the helmet has potential to be a successful project.

The tables have been laid out to show all results for each condition, anvil and angle. The averages of the results as well as the maximum and minimum have been identified.

Acceleration Test Results (g)				Force calculations (N)
Ambient Temperature	Flat	Front	2,178.87	10,240.69
		Middle	956.43	4,495.22
		Back	810.56	3,809.63
	Angled	Middle	1,245.85	5,855.50
	Spherical	Front	326.56	1,534.83
		Middle	617.85	2,903.90
Low Temperature	Flat	Front	648.96	3,050.11
		Middle	380.18	1,786.85
High Temperature	Flat	Front	230.45	1,083.12
		Middle	301.86	1,418.74
	Spherical	Front	364.16	1,711.55
		Middle	676.47	3,179.41
Submerged in Water	Flat	Front	10,239.96	48,127.81
		Maximum value	1,245.85	5,855.50
		Minimum Value	230.45	1,083.12
		Average	596.30	2,802.62

Table 6, Acceleration Test Results

The yellow cells are the disregarded results, for reasons discussed in section 9.2, the green cells represent the best performing tests. The red cells are the worst performing results and the blue cells identify the tests that are the most comparable to the forces calculated by the displacement table. The force has been calculated using F=ma using the mass of the drop rig and the maximum acceleration experienced.

Displacement Test Results (mm)				Force Calculation (N)
Ambient Temperature	Flat	Front	45.89	1,507.09
		Middle	54.12	1,277.91
		Back	45.44	1,522.02
	Angled	Middle	46.08	1,500.88
	Spherical	Front	54.6	1,266.68
		Middle	54.6	1,266.68
Low Temperature	Flat	Front	56.87	1,216.12
		Middle	48.63	1,422.18
High Temperature	Flat	Front	50.63	1,366.00
		Middle	61.8	1,119.10
	Spherical	Front	55.06	1,256.09
		Middle	50.24	1,376.60
Submerged in Water	Flat	Front	29987.21	2.31
		Minimum Value	45.44	1,522.02
		Maximum value	61.80	1,119.10
		Average	52.59	1,325.03

Table 7, Displacement Test Results

The displacement table has been set out similarly to the acceleration table, with the force calculated using equation 9.3. The forces which are calculated using equation 9.3 are mostly smaller than the acceleration forces, this is due to the force being calculated using the peak acceleration which will give a maximum force experienced on the helmet during the test. Whilst the force using equation 9.3 is the theoretical force utilising the displacement of the falling helmet during impact. These results are within the theoretical result of $1152.67N$ as a peak force assuming a theoretical peak acceleration was not calculated. This wasn't not completed as the outcome of the tests were completely unknown and the assumption of a desired result was not required.

The lowest recorded tests are the high temperature flat anvil, front and middle. The acceleration experienced by the front of the helmet is lower than the overall peak acceleration allowed for the Australian test, yet due to more than 10% of the helmet breaking the test was considered a fail.
This test was well under the allowable fatal acceleration which an average human can withstand (300 g), therefore this test would provide substantial

protection during an impact. This result is promising, showing that both this material and design has potential to be a safe product in the market.

The worst performing test identified is the ambient temperature angled anvil middle. During the test it was observed that the angled anvil split the helmet and there was a physical impact with the anvil and headform. This result could be improved with an increase in helmet thickness to stop the cutting affect which this anvil had on the helmet.

9.4.2 Load Distribution Discussion

The load Distribution test results have also been tabulated to display not only the recorded voltages but also the forces which have been calculated using the corresponding weight from figure 55.

Load Distribution Test Results (V)				Equivalent (kg)	Force Calculation (N)	Limit (N)
Ambient Temperature	Flat	Middle	128	70	1,255.68	500
Low Temperature	Flat	Middle	137.5	75	1,348.87	500
High Temperature	Flat	Middle	120	66	1,177.20	500
Submerged in Water	Flat	Middle	146	80	1,432.26	500

Table 8, Load Distribution Test Result Table

The results of the load distribution test are comparatively equivalent to the impact tests as the conditions performed in a similar manner with the high temperature performing the best. Therefore if the project was to continue the impact test could be treated as an indicative test. This may be a productive option, reducing the testing time and cost. Confirmation test using load distribution would be carried out to complete the certification testing of the developed design.

9.5 Conclusion and Recommendations

The study is aimed to demonstrate the possibility of producing a solution to the bicycle helmet industry by developing a recyclable disposable helmet design. This study has achieved the initial stages of this process by the investigating recyclable materials, the implementation of the chosen material into an original bicycle helmet design and the testing of the helmets to the requirements outlined within the Australian standards.

This material was tested and compared to the current material EPS, to confirm the material as a possible substitute for an impact energy absorption material. The testing of this material produced promising results and the material was then used in the helmet design. The helmets were then manufactured and tested. The results of the test concluded that the current helmet design and material combination was not successful in providing adequate protection for the rider. The testing did however produce substantial evidence of the potential for the material to be implemented into a design and potential to produce a successful result. One test recorded within the limit required by the standards. The results have also indicated a need for an additional bonding agent due to the current brittle nature of the material.

The helmet will require a redesign with a thicker and more homogenous wall thickness. This can be achieved with a modified manufacturing technique.

Future work required if the study was to continue will include the investigation into a naturally decomposing binding agent, this will increase the strength of the paper fibres and ensure that the recyclable aspect of the product is not compromised. This study would be incorporate tensile testing of the material using various bonding agents which deteriorate over time and then determining a life span of the bonding agent when introduced to various weather conditions. Other future work will be to investigate and test long term non-invasive water proofing of the material. This would consist of multiple tests comprised of

multiple material samples with numerous water proofing substances which will not compromise the ability to recycle the helmet.
Once these issues have been overcome, further testing to the Australian standards would be conducted and further observations would then dictate the future work of the study.

The work of engineers is to produce a sustainable solution to the problems which we encounter, the study which has been conducted is the first step into producing a sustainable solution to the current helmet problem regarding bicycle rental schemes. The study provides the possibilities of a long term cost effective solution to ensure safety of the users. This product could also possibly introduce the applications of a recyclable material into other industries and improve the creativity of material selection for everyday objects.

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Appendices

Appendix A Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111 Research Project Part 1

PROJECT SPECIFICATION

TOPIC: Recyclable disposable helmet design

PROJECT AIM: To design a low cost easily accessible, recyclable, disposable helmet for the Brisbane City Cycle Bicycle Rental Service for safe bike riding 24/7.

1. Research the objectives of the City Cycle Bicycle Rental Service
   - Their ideals, why it was introduced, how much it cost, other rental schemes that have been put into place in other cities, current helmet options
2. Research national and interstate standards and requirements of helmets
   - The material requirements, stress standards, manufacturing standards, the legislation requirements
3. Research current helmet designs
   - The different parts within the helmet, different concept designs and shapes
4. Research required, recyclable, cost-effective materials of the helmet which are currently available
5. Research the most protective profile for head protection
6. Research manufacturing requirements of various materials
7. Computer design a 3D model analysing the model for impact analysis and energy dispersion with various materials
8. Analyse the results to see which materials meet the national standard, if not look at change of design or change of material and re test until a compatible result is found
9. Develop a decision matrix, consisting of materials which meet the standards previously outlined, the availability, production capabilities and the aesthetics of the design

As time permits

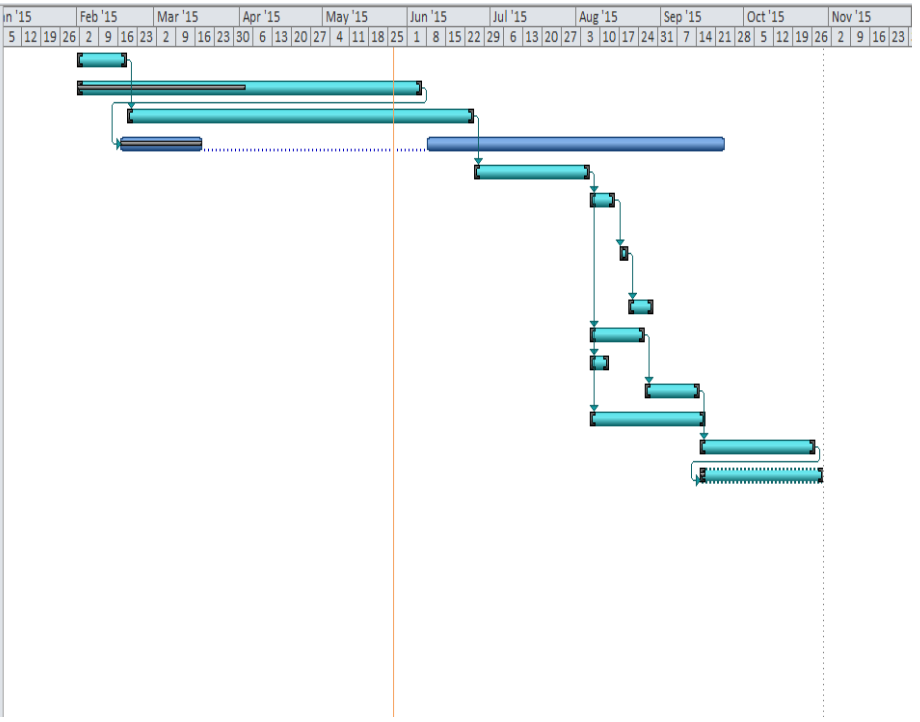
10. Analyse practical implications of introducing the helmet into the City Cycle Bicycle Rental service, including cost, customer satisfaction, implementation of a disposal system and up keep of the system.
11. Make a prototype of the design

Appendices

Appendix B Timeline

Timeline

		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			Introduction Chapter	14 days	Sun 1/02/15	Wed 18/02/15	
2			literature review	91 days	Sun 1/02/15	Sat 6/06/15	
3			Material Anaylsis	90 days	Thu 19/02/15	Wed 24/06/15	1
4			Conceptual designs	100 days	Mon 16/02/15	Wed 23/09/15	2
5			methodolgies	30 days	Thu 25/06/15	Wed 5/08/15	3
6			Making material Samples	7 days	Thu 6/08/15	Fri 14/08/15	5
7			Testing material Samples	3 days	Mon 17/08/15	Wed 19/08/15	6
8			Concluding results	7 days	Thu 20/08/15	Fri 28/08/15	7
9			Making Helmets	14 days	Thu 6/08/15	Tue 25/08/15	5
10			Constrcution of test rig	5 days	Thu 6/08/15	Wed 12/08/15	5
11			Conduct test of helmets	14 days	Wed 26/08/15	Mon 14/09/15	9
12			Dynamic anaylsis	30 days	Thu 6/08/15	Wed 16/09/15	5
13			Conclude results	30 days	Tue 15/09/15	Mon 26/10/15	11
14			Construct Final Dissertation	33 days	Tue 15/09/15	Thu 29/10/15	13



Appendices

Appendix C Risk Assessment

University of Southern Queensland

Generic Risk Management Plan

Workplace (Division/Faculty/Section): Engineering and Built Sciences		
Assessment No (if applicable): 1	Assessment Date: 08/05/2015	Review Date: (5 years maximum) 01/05/2016
Context: What is being assessed? Describe the item, job, process, work arrangement, event etc: Impact drop testing of a bicycle helmet.		
Assessment Team – who is conducting the assessment?		
Assessor(s): Samuel McQuade Others consulted: (eg elected health and safety representative, other personnel exposed to risks) Dr Ray Malpress		

Appendices

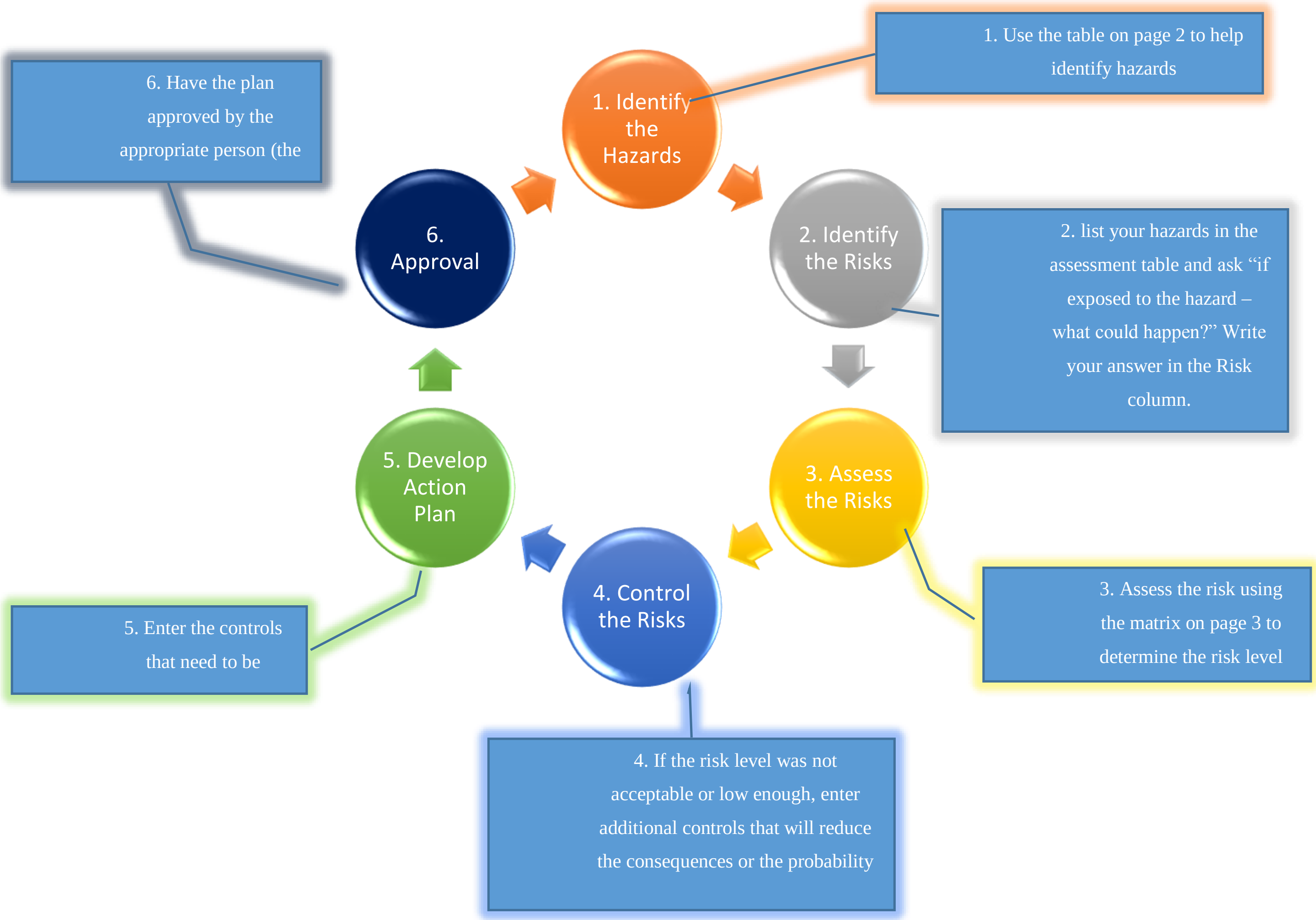


Figure 0.1, Risk Assessment Process

Step 1 - Identify the hazards (use this table to help identify hazards then list all hazards in the risk table)

General Work Environment		
☐ Sun exposure	☐ Water (creek, river,	☒ Sound / Noise
☐ Animals / Insects	☐ Storms /	☒ Temperature
☐ Air Quality	☐ Lighting	☐ Uneven Walking
☒ Trip Hazards	☐ Confined Spaces	☐ Restricted
☐ Pressure	☐ Smoke	☐
Other/Details:		
Machinery, Plant and Equipment		
☒ Machinery (fixed	☐ Machinery (portable)	☒ Hand tools
☐ Laser (Class 2 or	☐ Elevated work	☐ Traffic Control
☐ Non-powered	☐ Pressure Vessel	☒ Electrical
☐ Vibration	☒ Moving Parts	☒ Acoustic/Noise
☐ Vehicles	☐ Trailers	☐ Hand tools
Other/Details:		
Manual Tasks / Ergonomics		
☐ Manual tasks	☐ Working at heights	☐ Restricted space
☐ Vibration	☒ Lifting Carrying	☐ Pushing/pulling
☐	☐ Repetitive Movement	☐ Bending
☐ Eye strain	☐ Machinery (portable)	☐ Hand tools
Other/Details:		
Biological (e.g. hygiene, disease, infection)		
☐ Human tissue/fluids	☐ Virus / Disease	☐ Food handling
☐ Microbiological	☐ Animal tissue/fluids	☐ Allergenic
Other/Details:		
Chemicals Note: Refer to the label and Safety Data Sheet (SDS) for the classification and		
☐ Non-hazardous	☐ 'Hazardous' chemical (Refer to a completed hazardous	
☐ Engineered	☐ Explosives	☐ Gas Cylinders
Name of chemical(s) / Details:		
Critical Incident – resulting in:		
☐ Lockdown	☐ Evacuation	☐ Disruption
☐ Public	☐ Violence	☐ Environmental
Other/Details:		
Radiation		
☐ Ionising radiation	☐ Ultraviolet (UV)	☐ Radio
☐ infrared (IR)	☐ Laser (class 2 or	☐
Other/Details:		
Energy Systems – incident / issues involving:		
☐ Electricity (incl.	☐ LPG Gas	☐ Gas / Pressurised
Other/Details:		
Facilities / Built Environment		
☒ Buildings and	☐ Driveway / Paths	☒ Workshops /

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☐ Playground	☐ Furniture	☐ Swimming pool
Other/Details:		
People issues		
☒ Students	☒ Staff	☐ Visitors / Others
☐ Physical	☐ Psychological / Stress	☐ Contractors
☐ Fatigue	☐ Workload	☐ Organisational
☐ Workplace	☐ Inexperienced/new	☐
Other/Details:		

Risk Matrix

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Recommended Action Guide
E=Extreme Risk – Task ***MUST NOT*** proceed
H=High Risk – Special Procedures Required (See USQSafe)
M=Moderate Risk – Risk Management Plan/Work Method Statement Required
L=Low Risk – Use Routine Procedures

Appendices

Risk register and Analysis

Step 1 (cont)	Step 2	Step 2a	Step 3			Step 4				
Hazards: From step 1 or more if identified	The Risk: What can happen if exposed to the hazard with existing controls in place?	Existing Controls: What are the existing controls that are already in place?	Risk Assessment: (use the Risk Matrix on p3) Consequence x Probability = Risk Level			Additional controls: Enter additional controls if required to reduce the risk level	Risk assessment with additional controls: (use the Risk Matrix on p3 – has the consequence or probability changed?)			Controls Implemented? Yes/No
			Consequence	Probability	Risk Level		Consequence	Probability	Risk Level	
Example										
Working in temperatures over 35^0 C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	Regular breaks, chilled water available, loose clothing, fatigue management policy.	catastrophic	possible	high	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Manufacturing of helmet moulds	allergic reaction to plaster/ plaster spilling or over flowing the mould	PPE	Moderate	Rare	Low	Read information provided and call information line if concerned. Wear protective protection equipment; Gloves and protective clothing. Assistance when pour mix into mould	Insignificant	Unlikely	Low	Yes
Manufacturing of material samples	allegic reaction to paper mix/ exposed to hazardous fumes in P11 Fibre composite mixing room	PPE	Moderate	Possible	Low	Follow all safety instruction given during P11 safety induction. leave the room if overwhelmed	Minor	Unlikely	Low	Yes
Testing of Samples	Cut self/crushing of hand during compression testing	protective sheild	Moderate	Unlikely	Moderate	Communication between operator and putting in the samples.	Insignificant	Rare	Low	Yes
Manufacturing of Helmet	allegic reaction to paper mix/ exposed to hazardous fumes in P11 Fibre composite mixing room	PPE	Moderate	Possible	Low	follow all safety instruction given during P11 saefty induction. leave the room if overwhelmed	Minor	Unlikely	Low	Yes
Testing of Helmet	Loud Noises/falling objects/lifting objects/flying debris/other people conducting experiments	PPE	Moderate	Possible	Moderate	Ear plugs, temporary shield, communication and reduction of lifting rig whilst people nearby, correct lifting demonstrated, communication between experiments	Minor	Unlikely	Low	Yes
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No

Appendices

Step 5 – Action Plan (for controls not already in place)			
Control Option	**Resources**	**Person(s) responsible**	**Proposed implementation date**

Step 6 – Approval

Drafter's Comments:

Drafter Details:

Name: Signature: Date: / /

Assessment Approval: (Extreme or High = VC, Moderate = Cat 4 delegate or above, Low = Manager/Supervisor)

I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.

Name: Samuel Robert. Mcquade Signature: Date: 02/06/2015

Position Title: Student

Appendix D instructions for Samples, mould and helmet manufacture and testing

Procedure for making samples.

The outcome of the testing the samples is to determine if the material has suitable energy absorption properties. Therefore to change the energy absorption properties the sample properties will have to vary. These changing characteristics of the samples will include:

- Thickness
- Paper to water Ratio

Therefore to ensure that the end result helmets are to be manufactured with almost equal properties these factors will need to be recorded. These Samples will be the closet representation of the material properties and some variations is expected as many aspects of the recycled paper will affect the material properties. So that the reproduction of the process can be completed with as many variables being the same in both cases. Such as the mixing water temperature being between 43 – 60 degrees Celsius.

In the initial concept for the samples, the consideration of water to paper ratio was a major consideration as the ratio would make the samples to crumbly or too soft. To overcome this the method in which the samples were made uses a vacuum compression technique which at the sample time as evenly apply pressure to the sample also sucks out all excess water within the mixture. Therefore the consideration was then negligible as all mixes were with excess water.

After this was confirmed three samples of three different thickness where made the process is as follows.

Appendices

1. Shred paper in a blender for 20 minutes, making sure it shreds down too its fibres.
2. Blend heated water and paper for 5 minutes ensure a watery consistency.
3. Place pulp into moulds.
4. Apply covering (which allows even compression and no leaking of fibres into the vacuum)
5. Apply vacuum and ensure no leaks in the plastic
6. Apply desired pressure (60 Psi) for 15 minuets
7. Remove all coverings and tape
8. Heat for 1 hour at 150 degrees
9. Measure height of end result

The above steps were taken for all samples to ensure the process was repeatable for the following stages and so that another material could be tested against paper pulp.

Experimental Procedure of samples

1. Cut to size (100mm x 100mm), this is to ensure current amount of pressure.
2. Measure thickness before test
3. Conduct compression test
4. Record data
5. Measure thickness after
6. Conclude results

Procedure for making moulds

Hand Mould

1. Make an outline of head form as a starting point
2. Use a bowl smaller than head form as a starting point (this is to reduce amount of clay required.
3. Prepare model on to the bowl and mould into the required shape
4. Allow to dry slightly

Appendices

Plaster Moulds Exterior

1. Surround clay model with wooden panels to make a container
2. Seal all edges with clay so that the plaster dose not run out, also edge off the corners with clay to reduce overall weight
3. Mix and pour plater into container
4. Allow to dry
5. Remove wooden panel and remove clay model

Figure 0.2 Wet and Dry interior mould

Plaster Mould Interior

1. Cover exterior plaster mould
2. Pour plaster into cavity
3. Allow to dry
4. Remove interior mould
5. Drill holes through mould

Procedure of final Helmets (Paper Pulp)

1. Ensure plaster mould is clean
2. Mix paper pulp to instructions of samples (using 8 compressed cups of fibres/helmet.)
3. Pour into exterior moulds
4. Place covers on top of moulds
5. Place interior mould on top of mix
6. Apply plastic cover and vacuum
7. Remove vacuum
8. Place in kiln for 70 degrees for 5 hour.

Appendix E Experimental Raw Data

Stress Strain Results

Graphed results from five different sample sizes:

- 9mm
- 8.5mm
- 7mm
- 3mm
- 2mm

Identifying the densification strain with a black marker.

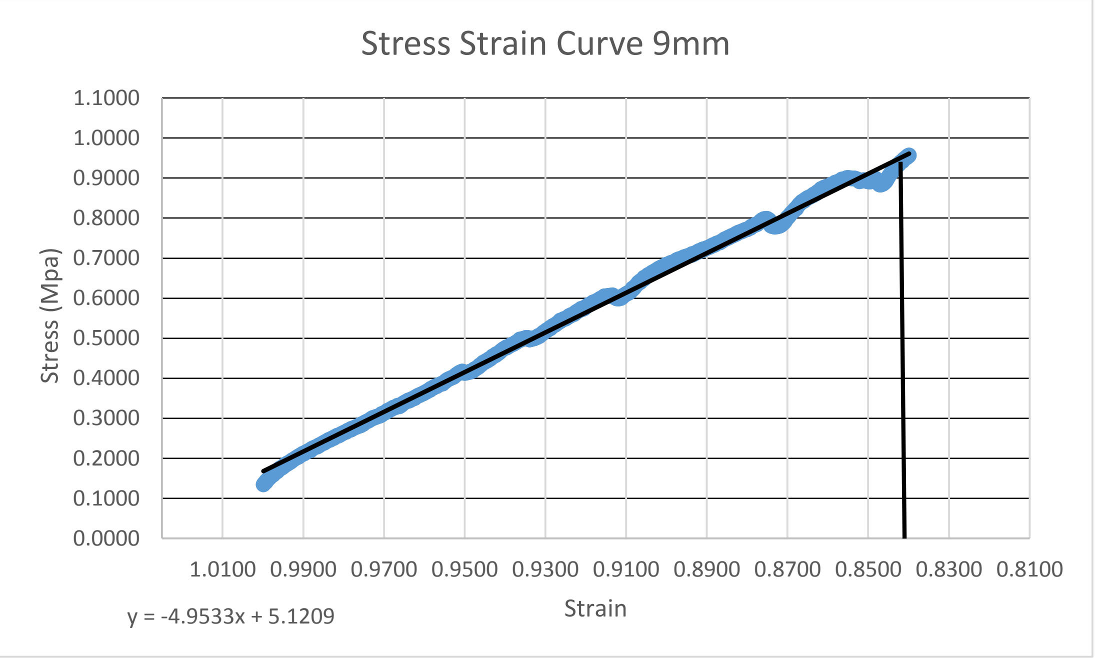


Figure 0.3, 9mm Stress Strain Curve

9mm Results

Experimental Results	ε=0.8452, σ = 0.9002
Trend line Results	ε=0.8521, σ = 0.9

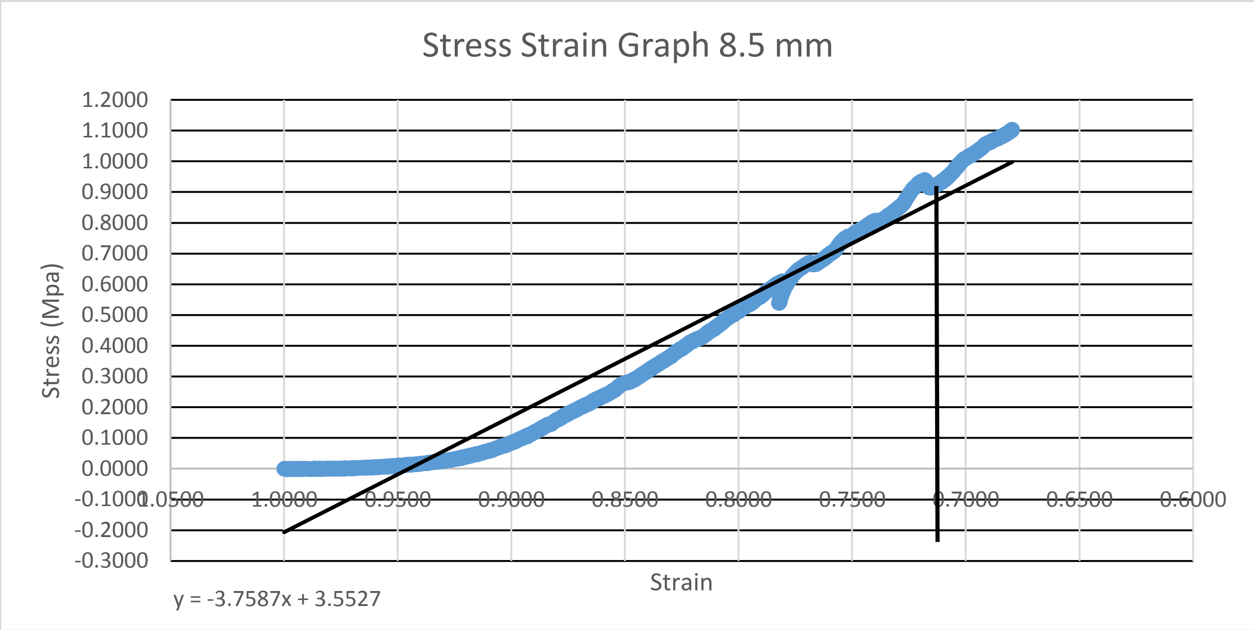


Figure 0.4, 8mm Stress Strain Curve

8.5mm Results

Experimental Results ε=0.7239, σ = 0.9043

Trend line Results ε=0.7057, σ = 0.9

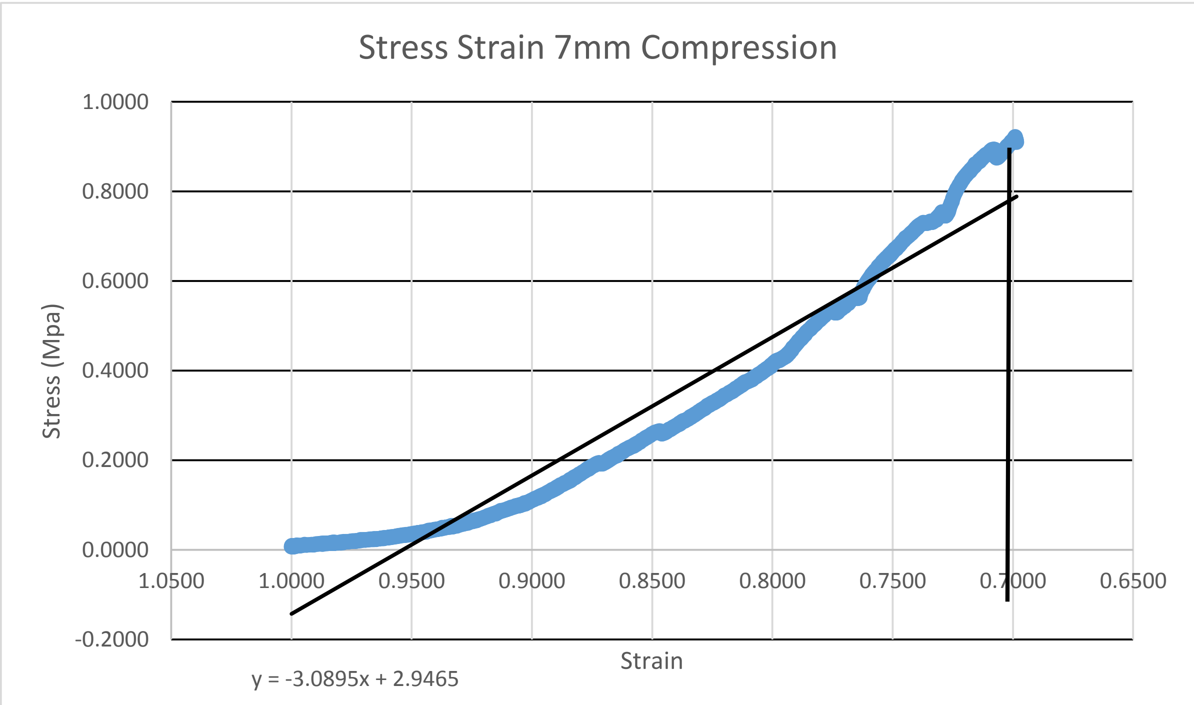


Figure 0.5,7mm Stress Strain Curve

7mm Results

Appendices

Experimental Results ε=0.7022, σ = 0.9000

Trend line Results ε=0.6624, σ = 0.9

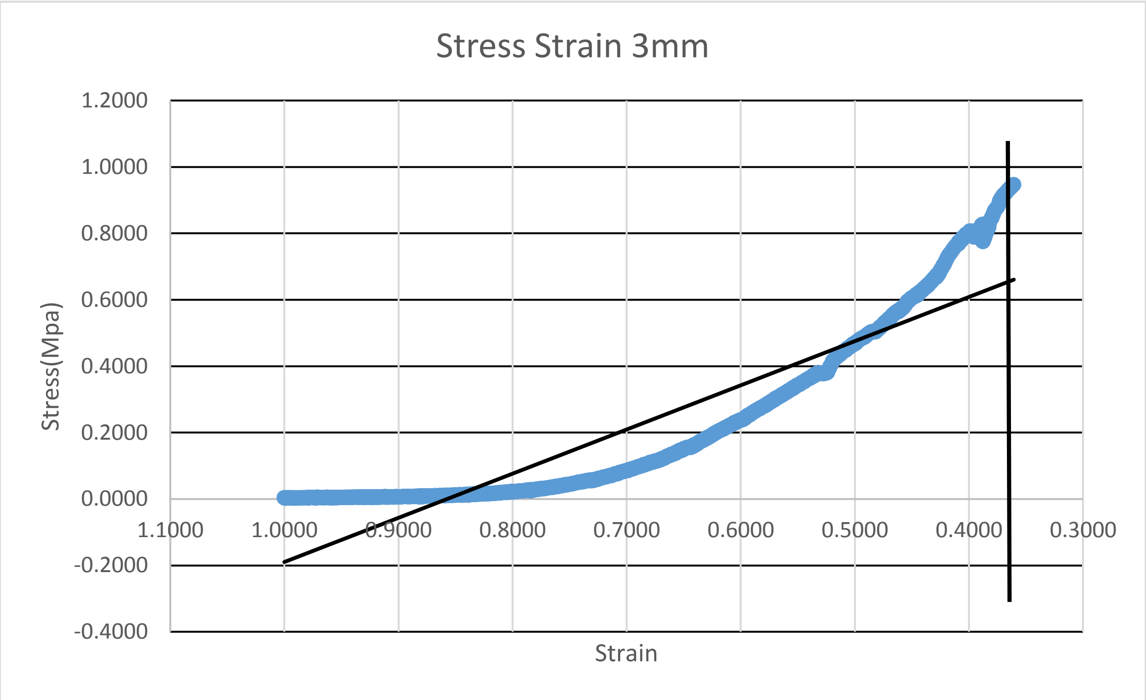


Figure 0.6, 3mm Stress Strain Curve

3mm Results

Experimental Results ε=0.3723, σ = 0.9014

Trend line Results ε=0.1807, σ = 0.9

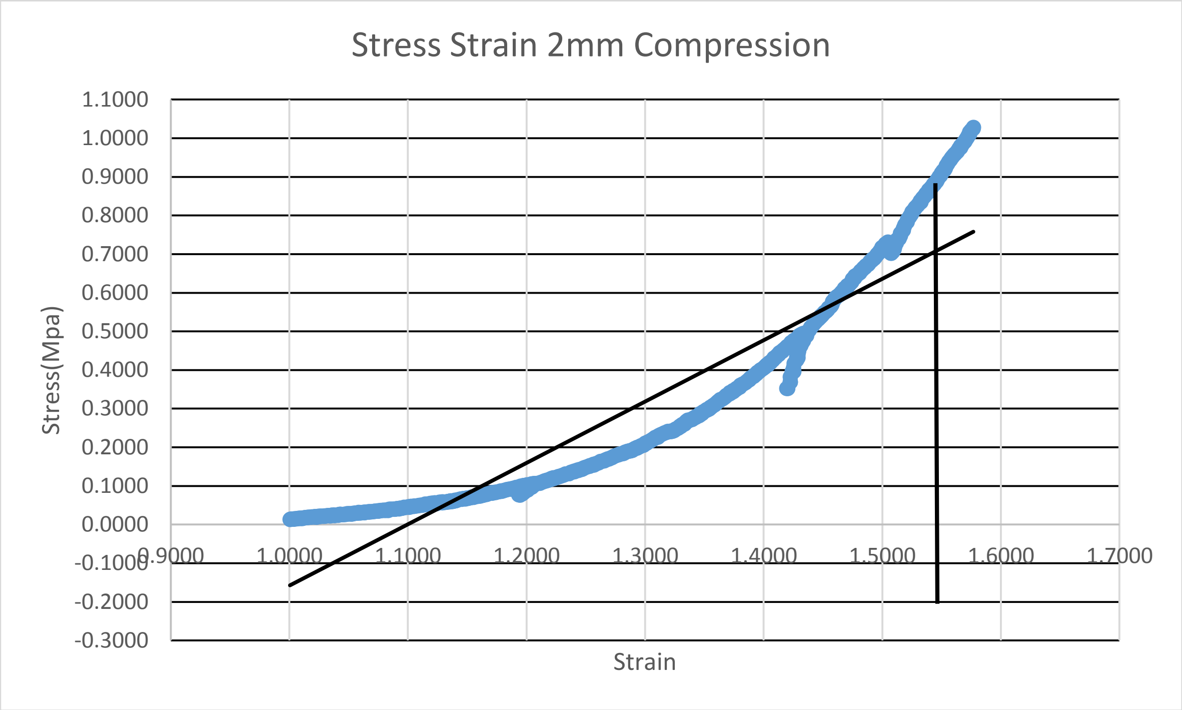


Figure 0.7, 2mm Stress Strain Curve

2mm Results

Experimental Results	ε=0.15480, σ = 0.9006
Trend Line Results	ε=0.1666, σ = 0.9

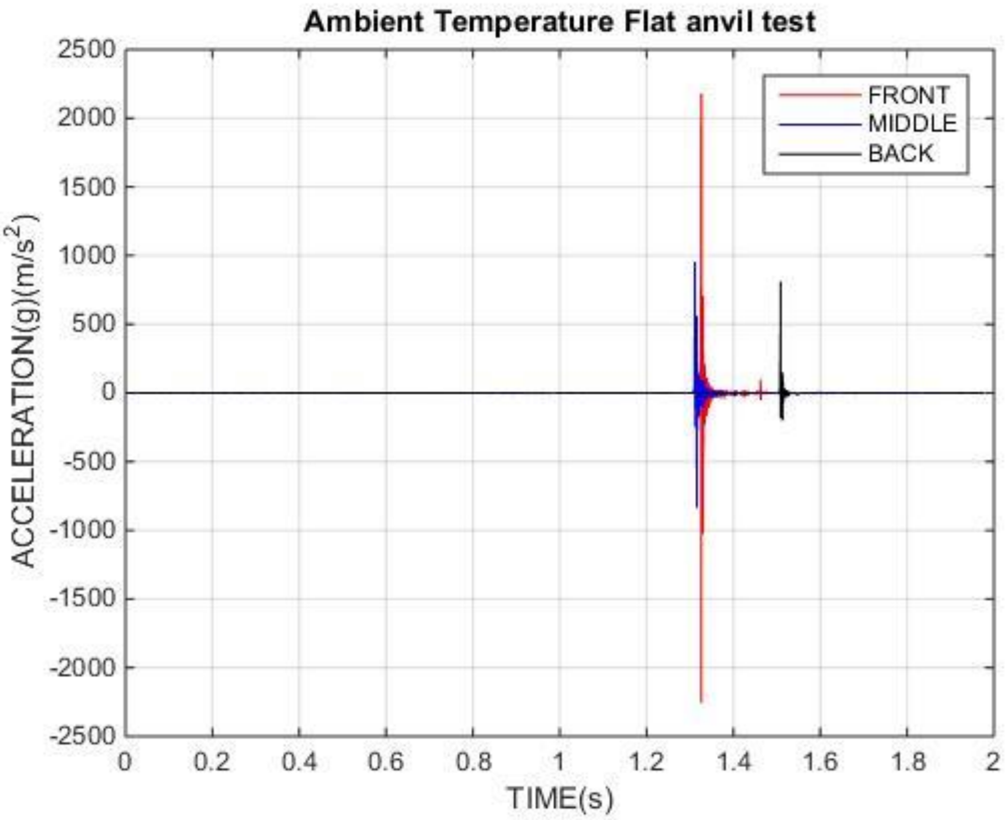
Appendix F MATLAB SCRIPTS


```
%Disposable Recyclable Helmet Design,
%Samuel Robert McQuade 0061033119
```

Ambient Temperature Flat Anvil Acceleration Graph

```
am1=xlsread('Ambient Temps.xlsx');
a1=am1(12:250000,6);
a2=am1(12:250000,7);
a3=am1(12:250000,8);
figure (1)
time=(1:length(a1))/1e5;
plot(time,a1,'r-')
hold on
plot(time,a2,'b-')
plot(time,a3,'k-')
grid
on,legend('FRONT','MIDDLE','BACK'),xlabel('TIME(s)'),ylabel('ACCELERATION(g)(m/s^2)')
,...
    title('Ambient Temperature Flat anvil test')
hold off
disp(' Ambient Temperature Flat Anvil Acceleration Graph ')
disp('------------DISSERTATION---------------')
disp(' ')
disp(['The max of Front: ',num2str(max(a1)),' g'])
disp(' ')
disp(['The max of Middle: ',num2str(max(a2)),' g'])
disp(' ')
disp(['The max of Back: ',num2str(max(a3)),' g'])
disp(' ')
disp('===============The End===========================')
```

```
 Ambient Temperature Flat Anvil Acceleration Graph
------------DISSERTATION---------------

The max of Front: 2178.87 g

The max of Middle: 956.43 g

The max of Back: 810.56 g

===============The End===========================
```



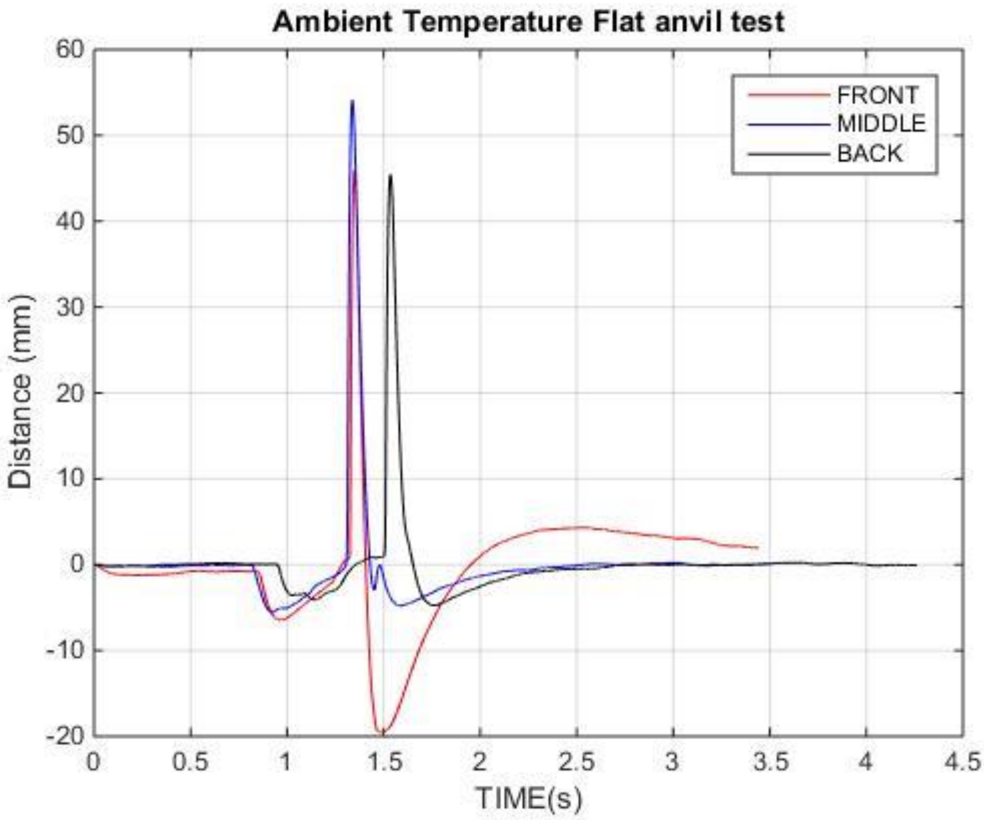
Ambient Temperature Flat Anvil Displacement Graph

```
am2=xlsread('Ambient                                                    Temps.xlsx');
b1=am2(12:end,10);
b2=am2(12:end,11);
b3=am2(12:end,12);
figure                                                                          (2)
time=(1:length(b1))/1e5;
plot(time,b1,'r-')
hold                                                                             on
plot(time,b2,'b-')
plot(time,b3,'k-')
grid on,legend('FRONT','MIDDLE','BACK'),xlabel('TIME(s)'),ylabel('Distance (mm)'),...
    title('Ambient          Temperature          Flat          anvil          test')
hold                                                                            off
disp('------------DISSERTATION---------------')
disp('    Ambient    Temperature    Flat    Anvil    Displacement    Graph         ')
disp(['The  max  displacement  after  impact  of  Front:  ',num2str(max(b1)),'  mm'])
disp('                                                                             ')
disp(['The  max  displacement  after  impact  of  Middle:  ',num2str(max(b2)),'  mm'])
disp('                                                                             ')
disp(['The  max  displacement  after  impact  of  Back:  ',num2str(max(b3)),'  mm'])
disp('===============The End===========================')
```

```
------------DISSERTATION---------------
 Ambient         Temperature        Flat        Anvil        Displacement        Graph
The      max      displacement     after     impact     of     Front:     45.89     mm

The      max      displacement     after     impact     of     Middle:     54.12     mm
```

Appendices

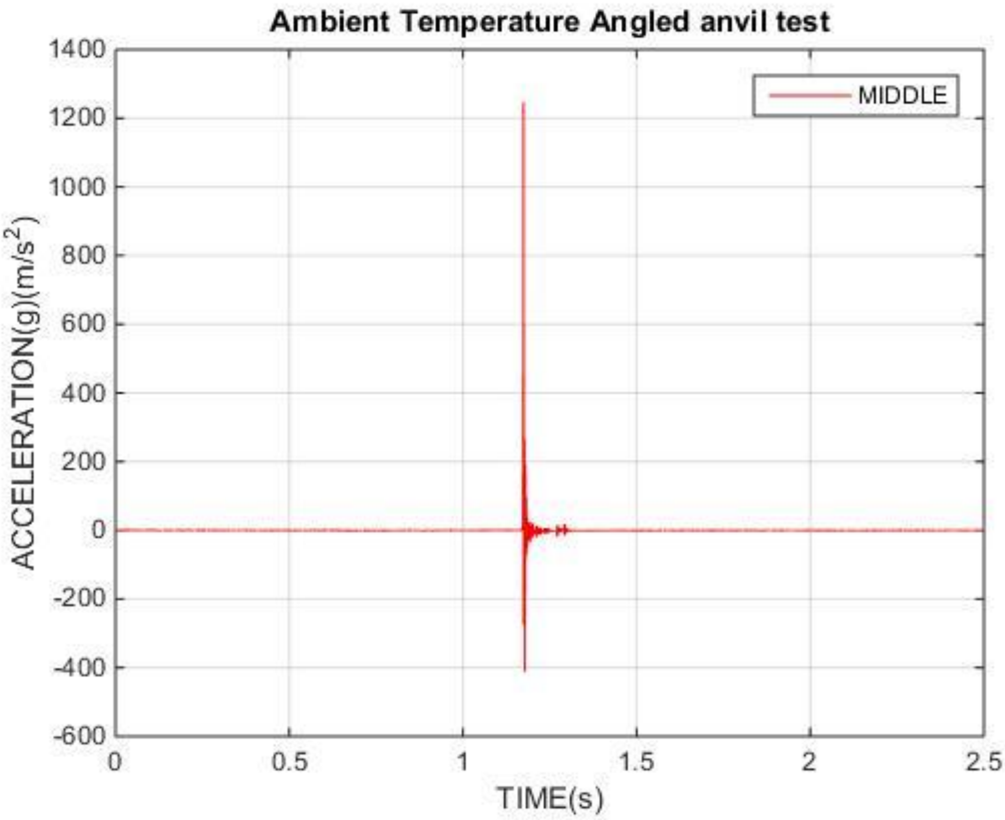
```
The max displacement after impact of Back: 45.44 mm
===============The End===========================
```



Ambient Temperature Angled Anvil Acceleration Graph

```
am3=xlsread('Ambient Temps Angle.xlsx');
d1=am3(12:250000,2);


figure (3)
time=(1:length(d1))/1e5;
plot(time,d1,'r-')
hold on


grid on,legend('MIDDLE'),xlabel('TIME(s)'),ylabel('ACCELERATION(g)(m/s^2)'),...
    title('Ambient Temperature Angled anvil test')
hold off
disp('------------DISSERTATION--------------')
disp('    Ambient    Temperature    Angled    Anvil    Acceleration    Graph        ')
disp(['The max of Front: ',num2str(max(d1)),' g'])
disp('                                                                              ')
disp('===============The End===========================')
```

```
------------DISSERTATION--------------
 Ambient     Temperature     Angled     Anvil     Acceleration     Graph
The max of Front: 1245.85 g

===============The End===========================
```

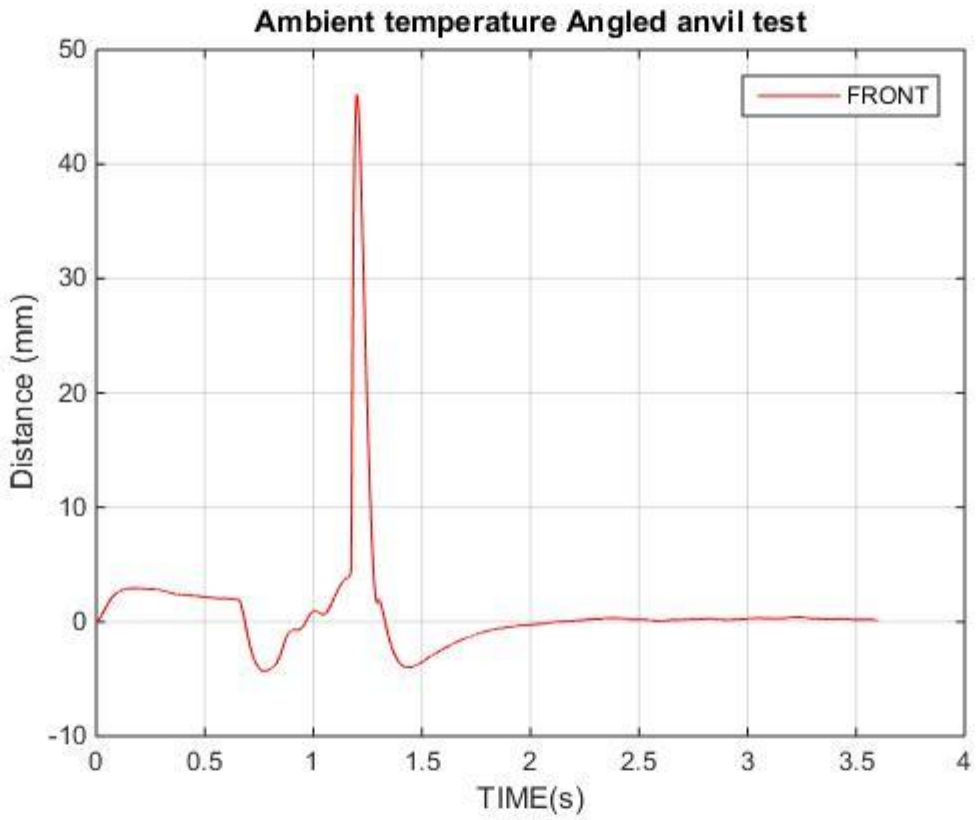


Ambient Temperature Angled Anvil Displacement Graph

```
am4=xlsread('Ambient Temps Angle.xlsx');
e1=am4(12:end,4);


figure (4)
time=(1:length(e1))/1e5;
plot(time,e1,'r-')
hold on


grid on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('Distance (mm)'),...
    title('Ambient temperature Angled anvil test')
hold off
disp('------------DISSERTATION---------------')
disp(' Ambient Temperature Angled Anvil Displacement Graph ')
disp(['The max displacement after impact of middle: ',num2str(max(d1)),' mm'])
disp(' ')
disp('===============The End===========================')
```

```
Warning: Ignoring extra legend entries.
------------DISSERTATION---------------
 Ambient Temperature Angled Anvil Displacement Graph
The max displacement after impact of middle: 1245.85 mm

===============The End===========================
```

Appendices



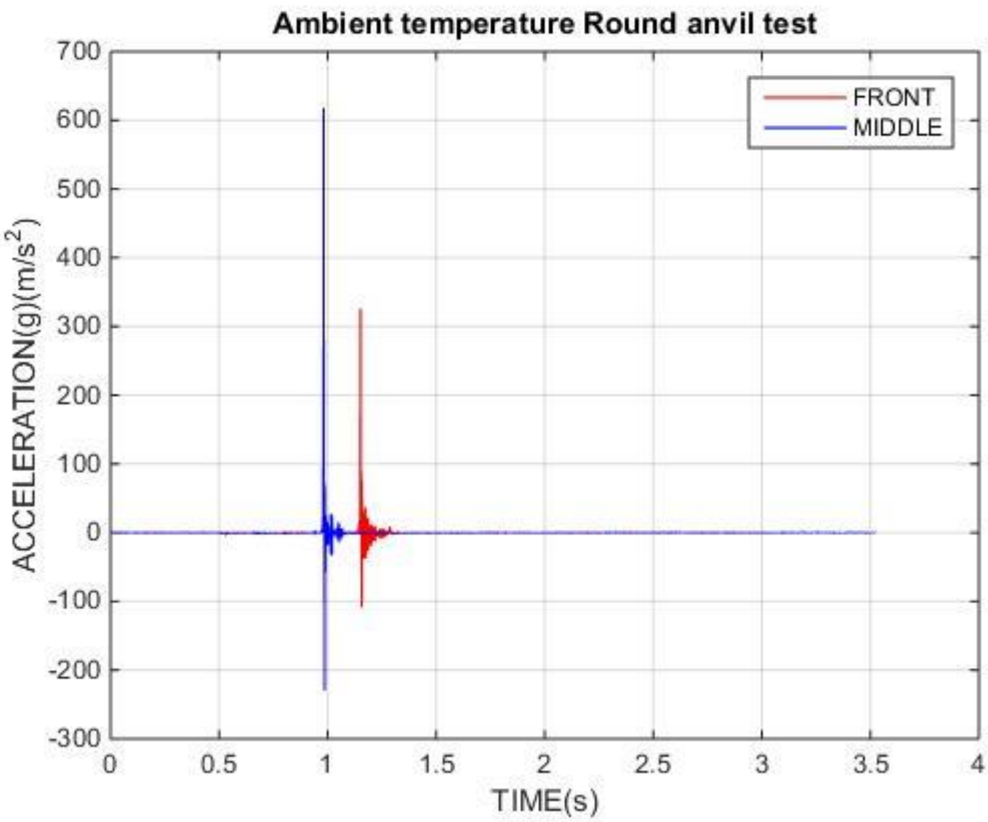
Ambient Temperature Round Anvil Acceleration Graph

```
am5=xlsread('Ambient                    Temps                    Round.xlsx');
f1=am5(12:end,6);
f2=am5(12:end,7);

figure                                                                    (5)
time=(1:length(f1))/1e5;
plot(time,f1,'r-')
hold                                                                       on
plot(time,                                                          f2,'b-')

grid
on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('ACCELERATION(g)(m/s^2)'),...
    title('Ambient         temperature         Round         anvil         test')
hold                                                                      off
disp('------------DISSERTATION---------------')
disp('    Ambient    Temperature    Round    Anvil    Acceleration    Graph    ')
disp(['The        max        of        Front:        ',num2str(max(f1)),'        g'])
disp('                                                                         ')
disp(['The        max        of        Middle:        ',num2str(max(f2)),'        g'])
disp('                                                                         ')
disp('===============The End===========================')
```

```
------------DISSERTATION---------------
 Ambient        Temperature        Round        Anvil        Acceleration        Graph
The             max                of           Front:            326.56              g

The             max                of           Middle:           617.85              g
```

Appendices

```
===============The End===========================
```

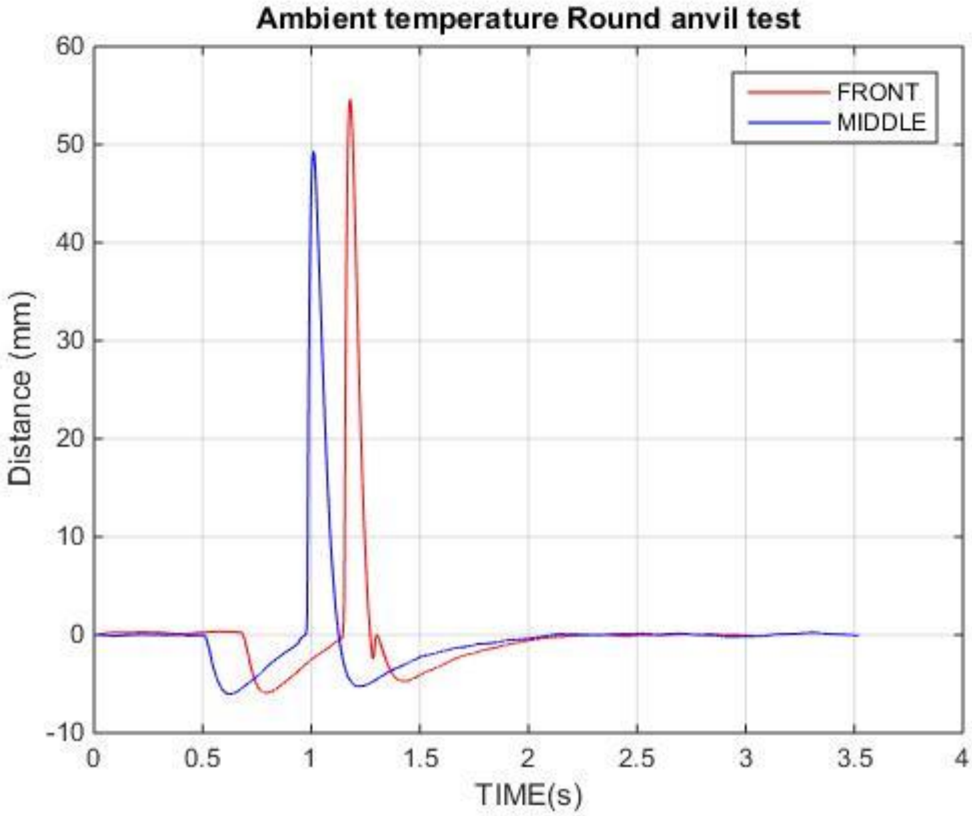


Ambient Temperature Round Anvil Displacement Graph

```
am6=xlsread('Ambient Temps Round.xlsx');
g1=am6(12:end,9);
g2=am6(12:end,10);

figure (6)
time=(1:length(g1))/1e5;
plot(time,g1,'r-')
hold on
plot(time,g2,'b-')

grid on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('Distance (mm)'),...
    title('Ambient temperature Round anvil test')
hold off
disp('------------DISSERTATION--------------')
disp('        Ambient    Temperature    Round    Anvil    Displacement    Graph    ')
disp(['The max displacement after impact of Front: ',num2str(max(g1)),' mm'])
disp('                                                                              ')
disp(['The max displacement after impact of Middle: ',num2str(max(g2)),' mm'])
disp('==============The End==========================')
```

```
------------DISSERTATION--------------
  Ambient    Temperature    Round    Anvil    Displacement    Graph
The max displacement after impact of Front: 54.6 mm
```

```
The max displacement after impact of Middle: 49.31 mm
===============The End===========================
```



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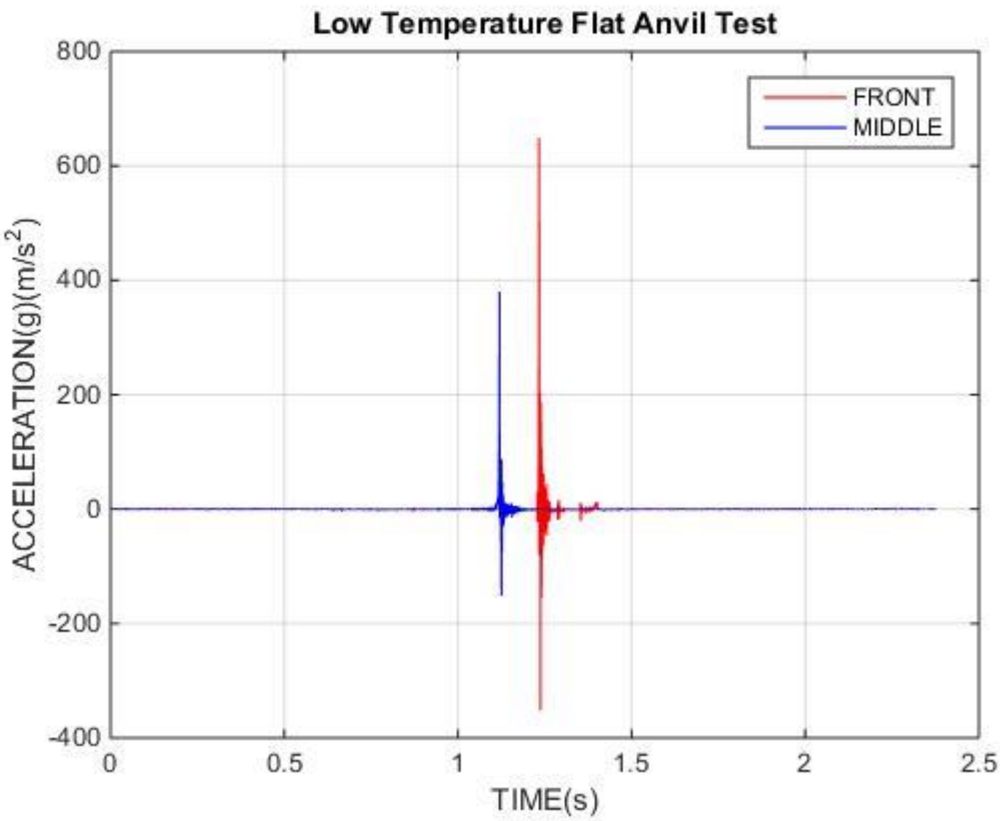
```
%Disposable Recyclable Helmet Design,
%Samuel Robert McQuade 0061033119
% Low Temperature Testing
```

```
am1=xlsread('Cold Head Drops.xlsx');
a1=am1(12:end,6);
a2=am1(12:end,7);

figure (1)
time=(1:length(a1))/1e5;

plot(time,a1,'r-')
hold on
plot(time,a2,'b-')

grid
on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('ACCELERATION(g)(m/s^2)'),...
    title('Low Temperature Flat Anvil Test')
hold off
disp('------------DISSERTATION---------------')
disp(' ')
disp(['The max of Front: ',num2str(max(a1)),' g'])
disp(' ')
disp(['The max of Middle: ',num2str(max(a2)),' g'])
```

```
disp('                                                                          ')
disp('===============The End===========================')
```

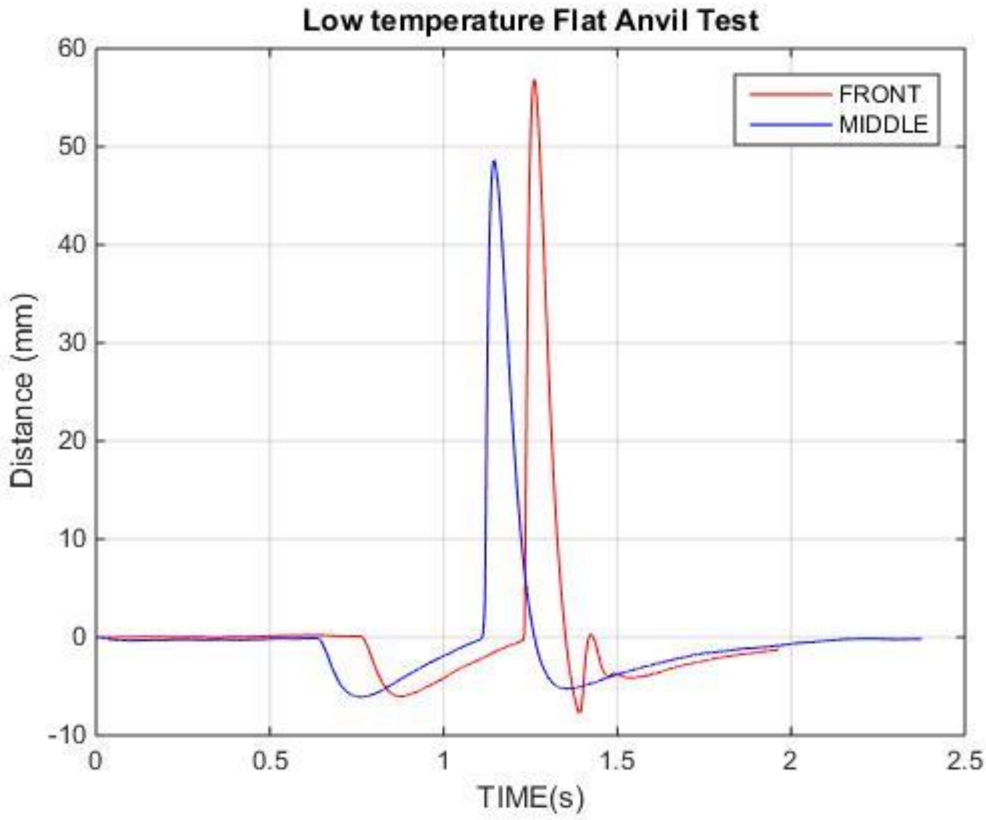
```
------------DISSERTATION--------------

The max of Front: 648.96 g

The max of Middle: 380.18 g

===============The End===========================
```




```
am=xlsread('Cold Head Drops.xlsx');
c1=am(12:end,9);
c2=am(12:end,10);

figure (2)
time=(1:length(c1))/1e5;

plot(time,c1,'r-')
hold on
plot(time,c2,'b-')

grid on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('Distance (mm)'),...
    title('Low temperature Flat Anvil Test')
hold off
disp('------------DISSERTATION--------------')
disp('                                                                          ')
disp(['The max displacement after impact of Front: ',num2str(max(c1)),' mm'])
disp('                                                                          ')
```

```
disp(['The max displacement after impact of Middle: ',num2str(max(c2)),' mm'])
disp('===============The End==========================')
```

```
------------DISSERTATION--------------

The max displacement after impact of Front: 56.87 mm

The max displacement after impact of Middle: 48.63 mm
===============The End==========================
```



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```
%Disposable Recyclable Helmet Design,
%Samuel Robert McQuade 0061033119
% High Temperature Testing
```

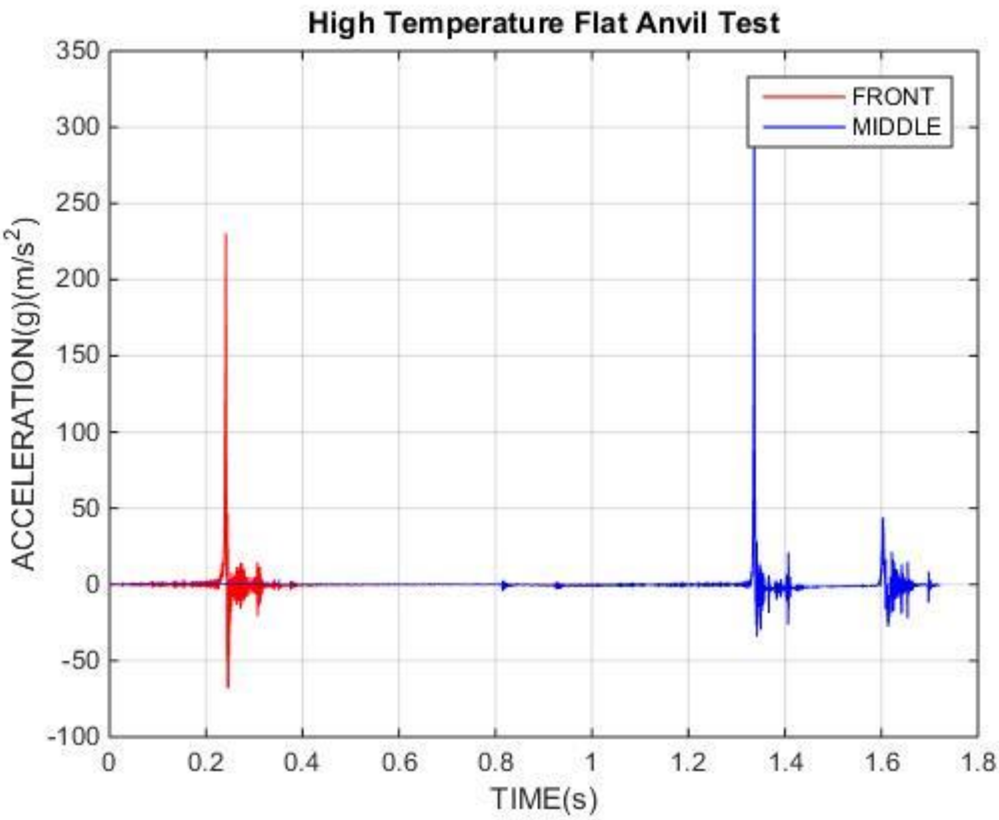
High Temperature Flat Anvil Test Acceleration Graph

```
am1=xlsread('Hot Head Drops.xlsx');
a1=am1(12:end,6);
a2=am1(12:end,7);
```

Appendices

```
figure                                                              (1)
time=(1:length(a1))/1e5;
plot(time,a1,'r-')
hold                                                                 on
plot(time,a2,'b-')

grid
on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('ACCELERATION(g)(m/s^2)'),...
    title('High          Temperature          Flat          Anvil          Test')
hold                                                                off
disp('------------DISSERTATION--------------')
disp('                                                                   ')
disp(['The        max        of        Front:        ',num2str(max(a1)),'        g'])
disp('                                                                   ')
disp(['The        max        of        Middle:        ',num2str(max(a2)),'        g'])
disp('                                                                   ')
disp('===============The End==========================')
```

```
------------DISSERTATION--------------

The          max          of          Front:          230.45          g

The          max          of          Middle:          301.86          g

===============The End==========================
```

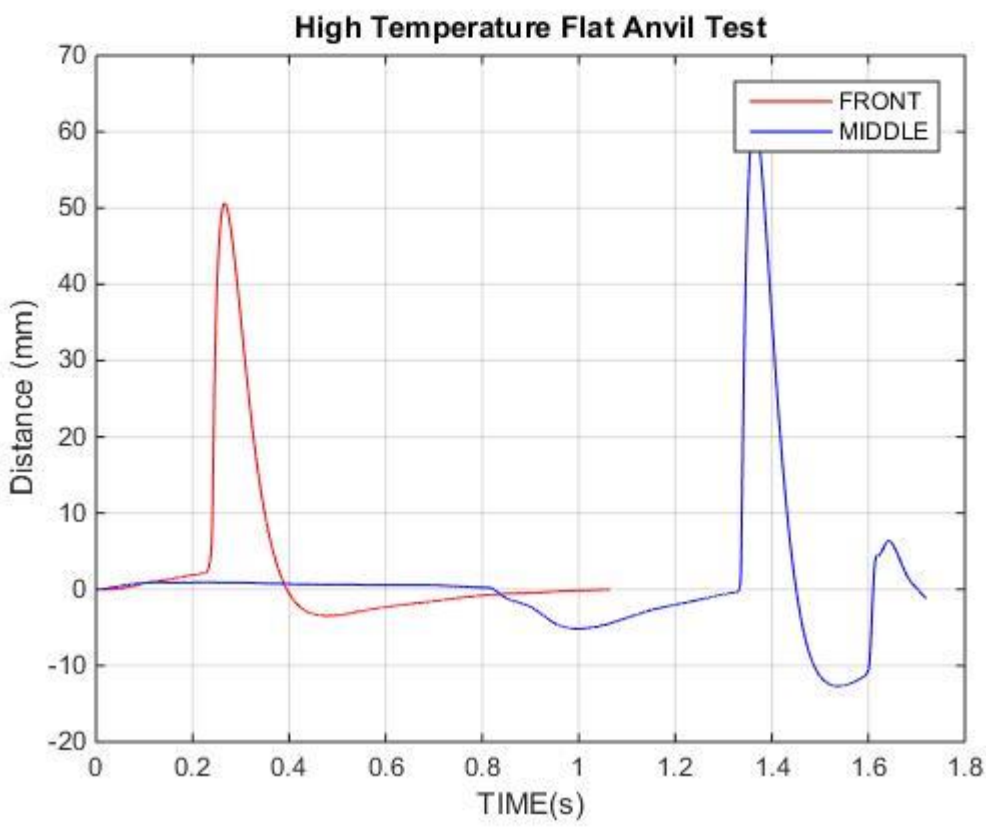


Appendices

High Temperature Flat Anvil Displacement Graph

```
am2=xlsread('Hot Head Drops.xlsx');
b1=am2(12:end,9);
b2=am2(12:end,10);

figure
time=(1:length(b1))/1e5;
plot(time,b1,'r-')
hold on
plot(time,b2,'b-')

grid on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('Distance (mm)'),...
    title('High Temperature Flat Anvil Test')
hold off
disp('------------DISSERTATION---------------')
disp(' ')
disp(['The max displacement after impact of Front: ',num2str(max(b1)),' mm'])
disp(' ')
disp(['The max displacement after impact of Middle: ',num2str(max(b2)),' mm'])
disp('===============The End===========================')
```

```
------------DISSERTATION---------------

The max displacement after impact of Front: 50.63 mm

The max displacement after impact of Middle: 61.8 mm
===============The End===========================
```

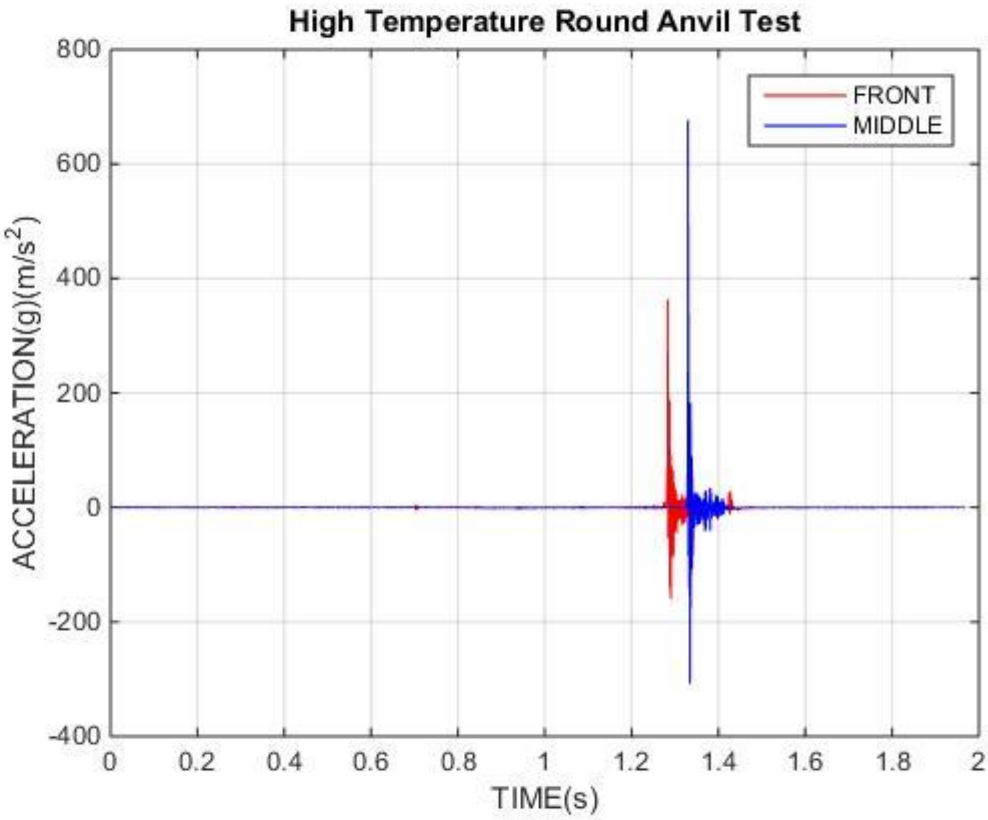


Appendices

High Temperature Round Anvil Acceleration Graph

```
am=xlsread('Hot Head Drops Round.xlsx');
c1=am(12:end,6);
c2=am(12:end,7);

figure
time=(1:length(c1))/1e5;
plot(time,c1,'r-')
hold on
plot(time,c2,'b-')

grid
on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('ACCELERATION(g)(m/s^2)'),...
    title('High Temperature Round Anvil Test')
hold off
disp('------------DISSERTATION---------------')
disp(' ')
disp(['The max of Front: ',num2str(max(c1)),' g'])
disp(' ')
disp(['The max of Middle: ',num2str(max(c2)),' g'])
disp(' ')
disp('===============The End===========================')
```

```
------------DISSERTATION---------------

The max of Front: 364.16 g

The max of Middle: 676.47 g

===============The End===========================
```

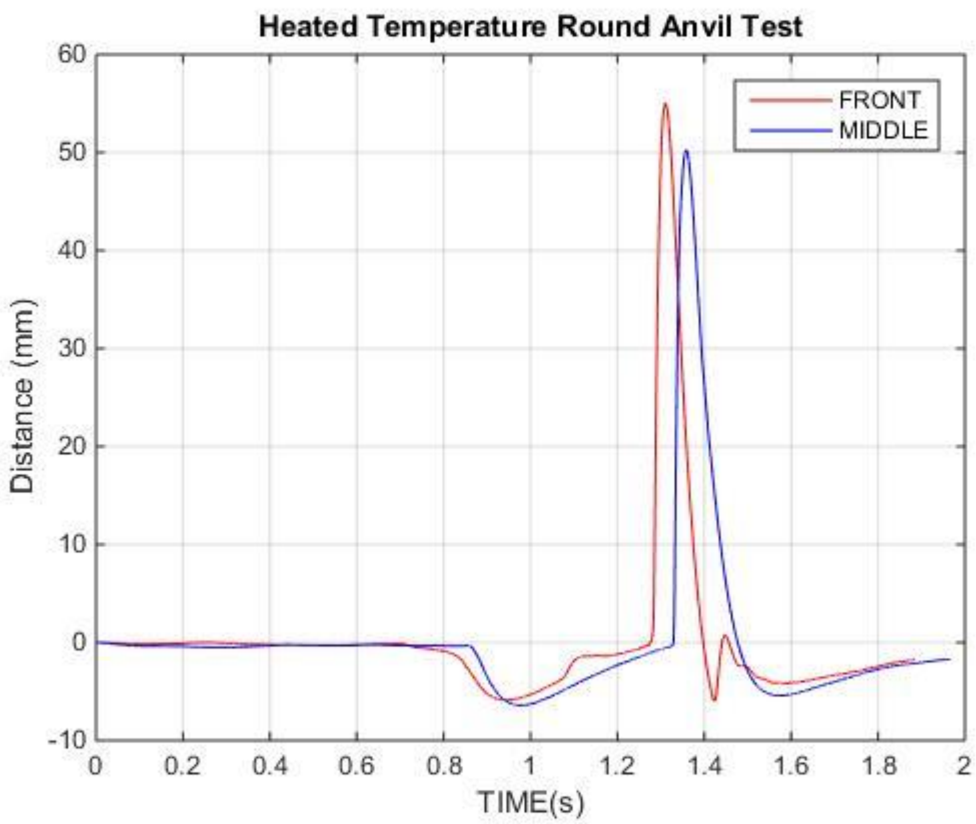


High Temperature Round Anvil Displacement Graph

```
am=xlsread('Hot Head Drops Round.xlsx');
c1=am(12:end,9);
c2=am(12:end,10);

figure
time=(1:length(c1))/1e5;
plot(time,c1,'r-')
hold on
plot(time,c2,'b-')

grid on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('Distance (mm)'),...
    title('Heated Temperature Round Anvil Test')
hold off
disp('------------DISSERTATION---------------')
disp(' ')
disp(['The max displacement after impact of Front: ',num2str(max(c1)),' mm'])
disp(' ')
disp(['The max displacement after impact of Middle: ',num2str(max(c2)),' mm'])
disp('===============The End===========================')
```

```
------------DISSERTATION---------------

The max displacement after impact of Front: 55.06 mm

The max displacement after impact of Middle: 50.24 mm
===============The End===========================
```

Appendices



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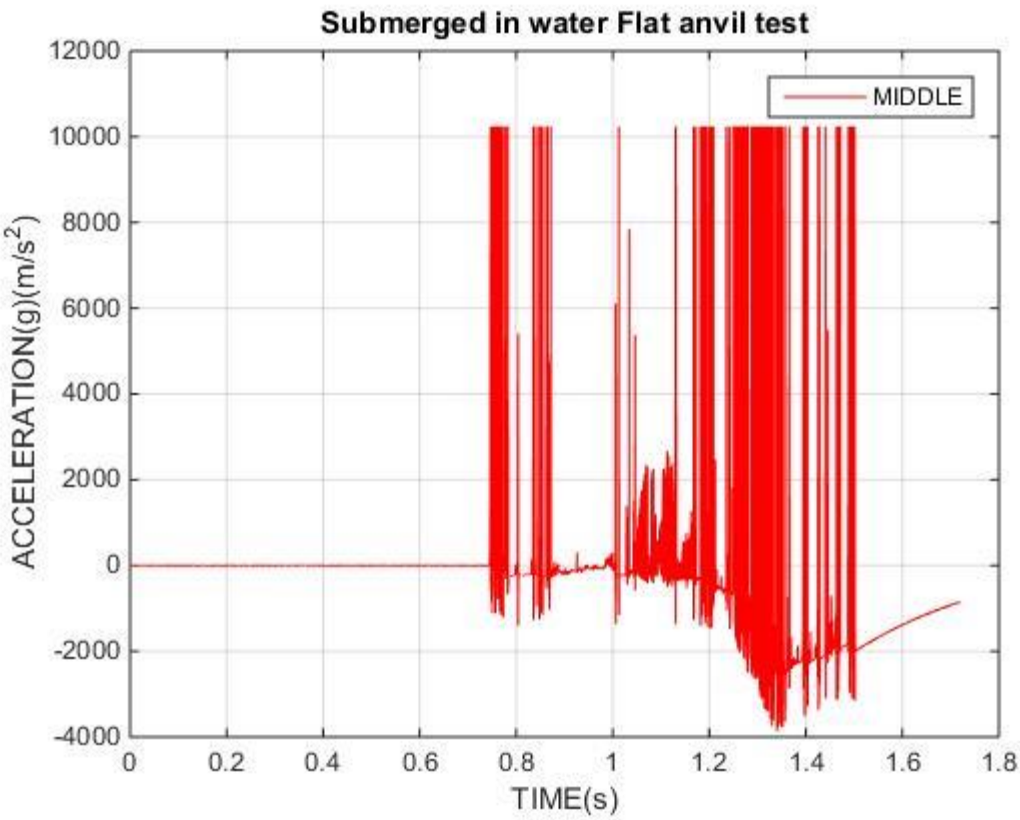
```
%Disposable                  Recyclable                  Helmet                  Design,
%Samuel                    Robert                    McQuade                    0061033119
% Submerged in Water Temperature Testing
```

Submerged Flant Anvil Accleration Graph

```
am1=xlsread('Wet                          Head                          Drops.xlsx');
a1=am1(12:end,2);


figure                                                                             (1)
time=(1:length(a1))/1e5;
plot(time,a1,'r-')
hold                                                                                on


grid       on,legend('MIDDLE'),xlabel('TIME(s)'),ylabel('ACCELERATION(g)(m/s^2)'),...
    title('Submerged        in        water        Flat        anvil        test')
hold                                                                               off
disp('------------DISSERTATION---------------')
disp('                                                                              ')
disp(['The        max        of        Front:        ',num2str(max(a1)),'        g'])
```

```
disp('                                                                    ')
disp('===============The End==========================')
```

```
------------DISSERTATION--------------

The max of Front: 10239.96 g

===============The End==========================
```

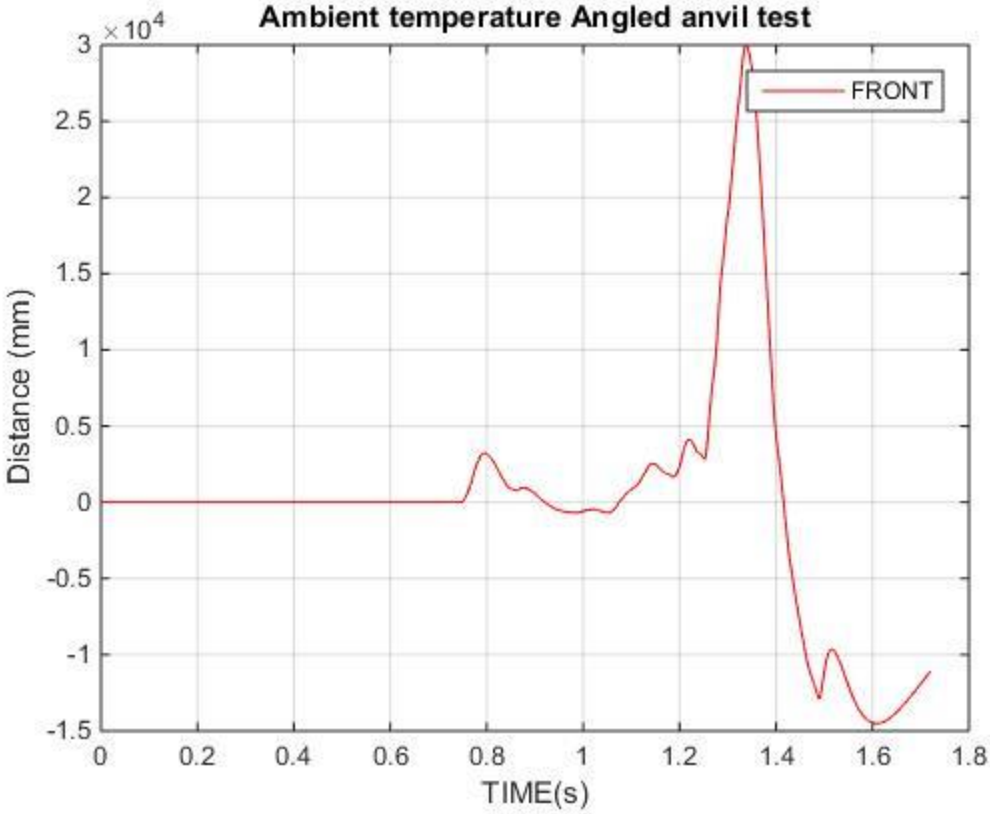


Submerged Flant Anvil Displacement Graph

```
am=xlsread('Wet Head Drops.xlsx');
c1=am(12:end,4);


figure (2)
time=(1:length(c1))/1e5;
plot(time,c1,'r-')
hold on


grid on,legend('FRONT','MIDDLE'),xlabel('TIME(s)'),ylabel('Distance (mm)'),...
    title('Ambient temperature Angled anvil test')
hold off
disp('------------DISSERTATION--------------')
disp('                                                                    ')
disp(['The max displacement after impact of middle: ',num2str(max(c1)),' mm'])
disp('                                                                    ')
disp('===============The End==========================')
```

Appendices

```
Warning: Ignoring extra legend entries.
------------DISSERTATION--------------

The max displacement after impact of middle: 29987.21 mm

===============The End==========================
```



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