Effects of Sa 2 and Sa 2.5 Blast Cleaning Surface Preparation on the Adhesion and Corrosion Protection Properties of Coating

by

Muhammad Munzir Bin Amirrudin

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the requirements for the
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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme
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Approved by,

(Assoc. Prof. Dr. Mustafar Bin Sudin)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD MUNZIR BIN AMIRRUDIN

ABSTRACT

Corrosion is a major problem for oil and gas operators as the cost consumed each year in fighting corrosion are staggeringly high. Along with the implementation of cost-effective corrosion prevention methods, the race for reducing cost consumption still goes on. Protective coating is considered to be one of the most economical methods there is. However, in the application of protective coating, the cost allocated for surface preparation exceeds the coating material costs itself by 21%. The typical standards currently used by PETRONAS required the steel substrates to be blast cleaned to the ISO cleanliness standard of Sa 2.5. Thus this project aims for the practice of a cheaper alternative of cleanliness standards which is Sa 2. Three samples (carbon steel) are blast-cleaned to the standard of Sa 2.5 and three others to the standards of Sa 2. All samples are coated based on coating system No. 1A in PTS. Corrosion test (ASTM B117-90) and adhesion test (scratch test) are conducted exclusively to measure the performance of coating system under different surface cleanliness standards. Four samples (two samples with Sa 2 and others with Sa 2.5 cleanliness standards) had undergone corrosion test. Remaining two samples, each with Sa 2 and Sa 2.5 cleanliness respectively, had undergone adhesion test. Calculation on corrosion rate using mass loss method and visual examination for evaluating the rust grade are done to determine the corrosion properties. Inspection using 3D non-contact measurement is conducted to confirm the critical load experienced by the coating thus determining the adhesion properties. Findings for corrosion test shows a equal performance of coating between samples prepared under Sa 2 and Sa 2.5 cleanliness standards – corrosion rate of 0 millimeter per year and a rust grade of 10. Findings for adhesion test shows the critical load experienced by sample prepared under Sa 2 is 51N and higher than the sample prepared under Sa 2.5 which is 43N. However, acoustic emission shows a higher intensity profile from the sample prepared under Sa 2 standards compared to the sample prepared under Sa 2.5. Thus, for the success implementation of surface cleanliness of Sa 2, the performance of the chosen coating system are to result in similar or better performance in comparison to the application of Sa 2.5.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 Problems of Corrosion

Corrosion (the deterioration of a metal or its properties) attacks every component at every stage in the life of every oil and gas field. From casing strings to production platform, from drilling through to abandonment, corrosion is an adversary worthy of all the high technology and research we can throw at it [1].

Because it is almost impossible to prevent corrosion, it has becoming more obvious that controlling corrosion rate may only be the most economical solution. Therefore, corrosion engineers are struggling in making the estimation the cost of their solutions of preventing corrosion in conjunction with estimating the useful life of the operating equipments in the production line.

1.1.2 Corrosion Rates and Common Affected Location

Thus, in the case of offshore oil rig, the analysis on where did corrosion most preferably to occur has been done as shown in Appendix A [1]:

1.1.3 Consequences of Corrosion

In the oil and gas production industries but not limited to it, the consequences of corrosion are many and varies, thus the effects of these on the safety, reliability and efficiency operation of equipment or structures are often more serious than the simple loss of a mass of metal.

Failures of various kinds and the need for expensive replacements may occur even though the amount of metal destroyed is quite small. Some of the major harmful effects of corrosion can be summarized as follows [2]:

1. Reduction of metal thickness leading to loss of mechanical strength and structural failure or breakdown. When the metal is lost in localized zones so as to give a crack-like structure, very considerable weakening may result from quite a small amount of metal loss.
2. Hazards or injuries to people arising from structural failure or breakdown.
3. Contamination of fluids in vessels and pipes.
4. Perforation of vessels and pipes allowing escape of their contents and possible harm to the surroundings. For example, corrosive sea water may enter the boilers of a power station if the condenser tubes perforate.
5. Loss of technically important surface properties of a metallic component. These could costs the ease of fluid flow over a pipe surface.
6. Mechanical damage to valves, pumps, etc, or blockage of pipes by solid corrosion products.
7. Added complexity and expense of equipment which needs to be designed to withstand a certain amount of corrosion, and to allow corroded components to be conveniently replaced.

1.1.4 Common Corrosion Prevention Methods

Generally, there are four necessary elements for metallic corrosion to occur:

1. An anode (the metal that's dissolving).
2. A cathode (the place where electrons are received to produce ions).
3. An electrical connection between the anode and cathode usually by physical contact (this is sometimes called the external circuit and provides for the flow of electrons).
4. A liquid medium, called the electrolyte, in contact with both the anode and cathode (which provides the means for transporting ions to and from the electrodes).

By retarding either the anodic or cathodic reactions, the rate of corrosion can be reduced. This can be achieved in several ways [2]:

Table 1: Methods to reduce corrosion rate

Concept	Main Methods	Applications
Conditioning the Metal	Coating the Metal	Organic Coating, Metallic Coating, Inorganic Coating
	Alloying the Metal	Stainless Steel
Conditioning the Corrosive Environment	Removal of Oxygen	Using strong reducing agents (i.e. sulphite)
	Corrosion Inhibitors	Anodic Inhibitors, Cathodic Inhibitors, Adsorption Type Corrosion Inhibitors, Mixed Inhibitors
Electrochemical Control	Difference in Metal Potential	Cathodic Protection, Anodic Protection

Of all the methods mentioned above, corrosion engineers have decided that conditioning the metal with the applications of protective coating is one of the most effective ways to fight corrosion.

1.1.5 Coating as Corrosion Preventer

Although coating is considered as one of the most effective method in preventing corrosion, the action of protective coatings is often more complex than simply providing a barrier between the metal and its environment. This is because paints may contain a corrosion inhibitor, zinc coating in iron or steel confers cathodic protection. In fact, the combination of those elements which made a coating system lives up to their reputation.

In fact, there are many different types of coating such as organic coating, inorganic coating, metallic coating and conversion coating which have various performance and usage on different application. Despite many new formulation of coating had been created to improved coating performance, the problems of corrosion are still significantly hard to solve.

The majority of paint and coating-related failures can be attributed to six primary causes. These causes are as follows [3]:

Table 2: Causes and descriptions of coating-related failure

Causes	Description
Improper surface preparation	• The substrate surface is not adequately prepared for the coating that is to be applied. • This may include cleaning, chemical pretreatment or surface roughening.
Improper coating selection	• Either the paint or coating selected is not suitable for the intended service environment, or it is not compatible with the substrate surface.
Improper application	• This can be a problem with either shop-applied or field applied coatings, and occurs when the required specifications or parameters for the application are not met.
Improper drying, curing and over coating times	• Again, this problem relates to a lack of conformance to the required specifications or parameters.
Lack of protection against water and aqueous systems	• This is a particularly serious problem with aqueous systems containing corrosive compounds such as chlorides.
Mechanical damage	• Results from improper handling of the painted or coated substrate, resulting in a breach in the paint or coating.

1.1.6 Surface Preparation Methods for Steel Substrates

Steel is the common material used for the construction of equipments such as pressure vessels and heat exchangers, as well as the structures of offshore platform. The applications of protective coating are most popular for protecting the equipments and structures from corroding. Prior to coating, steel should be cleaned by one or more of the nine surface preparations described below [4]:

1. Solvent Cleaning
2. Hand Tool Cleaning
3. Power Tool Cleaning
4. Near-White Blast Cleaning
5. White Metal Blast Cleaning
6. Commercial Blast Cleaning
7. Brush-Off Blast Cleaning
8. Power Tool Cleaning to Bare Metal
9. Water Blasting

Next, we will discuss the typical surface preparation methods that currently implemented by oil and gas operators such as PETRONAS.

1.1.7 PETRONAS Technical Standards (PTS)

In PTS, specifically PTS30.48.00.31-P which is a technical specification titled Protective Coating and Lining [5], one of the methods and standards of surface preparation that has been chosen to be applied in their coating system is by blast-cleaning. Table in Appendix X shows the surface preparation standards referred by PETRONAS.

Thus, from the above we know that the typical surface preparation methods that currently implemented by PETRONAS are blast cleaning, power tool cleaning and solvent cleaning.

1.1.8 Coating System based on PTS

There are many different coating systems which can be selected by PETRONAS according to various considerations such as [6]:

1. Coating characteristics.
2. Nature of substrates.
3. Basic function of coating on substrate.
4. Accessibility (time and space) and availability of appropriate equipment for satisfactory surface preparation and application.
5. Environmental factors.
6. Life cycle costs.

An example of a typical coating system which is implemented by PETRONAS is shown in Appendix B [5]. The coating system explains that prior to applying coating system no.1A, steel substrate has to be cleaned to the cleanliness standard of Sa 2.5.

1.1.9 Scenario in Surface Preparation Standards

The compliance of the surface condition of the steel substrate to the surface preparation standards are evaluated only by visual inspection. For example, an expert could say that a certain surface had been blast cleaned to an only Sa 2 standard. At the same time, a new painting inspector would say that the same surface had already adhered to the Sa 2.5 standards.

Thus, the differences in experienced, visual abilities and perception between painting inspectors will results in the selection of different surface preparation standards to be matched with the predetermined coating system. However, in this study, this scenario is not an important case.

There are no general rules of thumb when selecting a coating system in terms of types of coating and coating compositions which will always be sensitively affected by the variation of surface preparation methods applied. In most cases, the supplier of the coating will propose a specific coating system which will tell the consumer which types of coating should be used and the standard required to be adhered by the surface preparation methods.

However, in the fight against corrosion, many oil and gas operators has search for various ways to reduce the cost consumption thus making this the most important case for this project. Apart from choosing the most cost effective methods of preventing corrosion from happening, they can always go into the selection of cost-effective standards of surface preparation.

As for example, instead of considering using a blast cleaning to the standard of Sa 2.5, why not select the standard of Sa 2 which generally cost less? Of course, if it needs to be implemented, the blast cleaning to Sa 2 should provide similar or better coating performance in comparison with the Sa 2.5 standard.

1.2 PROBLEM STATEMENT

PTS requires a review to inspection standard of surface preparation for coating applications that yield cost effective operation without compromising its service life. The implementation of surface cleanliness standard of Sa 2 instead of Sa 2.5 will successfully achieve this requirement.

1.3 OBJECTIVES

Objectives of this project are:

1. To study the performance of coating upon the application of different surface preparation which meet the requirement of surface cleanliness standards of Sa 2 and Sa 2.5.
2. To propose a new cost-effective method of surface preparation based on PTS.
3. To study the effect of different surface condition to the adhesion properties of the coating on the metal surface based on PTS.
4. To study the effect of different surface condition to the corrosion protection properties of the coating on the metal surface based on PTS.

1.4 SCOPE OF STUDY

The material that will be used as one of the constant variable in this study is carbon steel material. The study is focused to the usage of carbon steel because of they are commonly used material in the construction of structures and operating equipments in the oil and gas industries. The carbon steel is used to construct the offshore platform structures and equipments such as heat exchangers and pressure vessels.

As for the testing methods, only adhesion and corrosion protection tests will be involved in this study. The reason being is that the equipments for conducting both tests are already provided here in UTP. If the study completes earlier than expected, one or two other testing methods will be conducted which hopefully will improve the results obtained for the study.

CHAPTER 2

LITERATURE REVIEW

2.1 COATING COST DISTRIBUTION

Generally, the raw material cost of any coating application is considered significant in estimating the total cost involved. However, it contributes to only a portion of the cost of a coating application project. The SSPC survey [16] indicated that, for example, for a typical aboveground crude oil storage tank, the total cost of coating is distributed as shown in Figure 1.

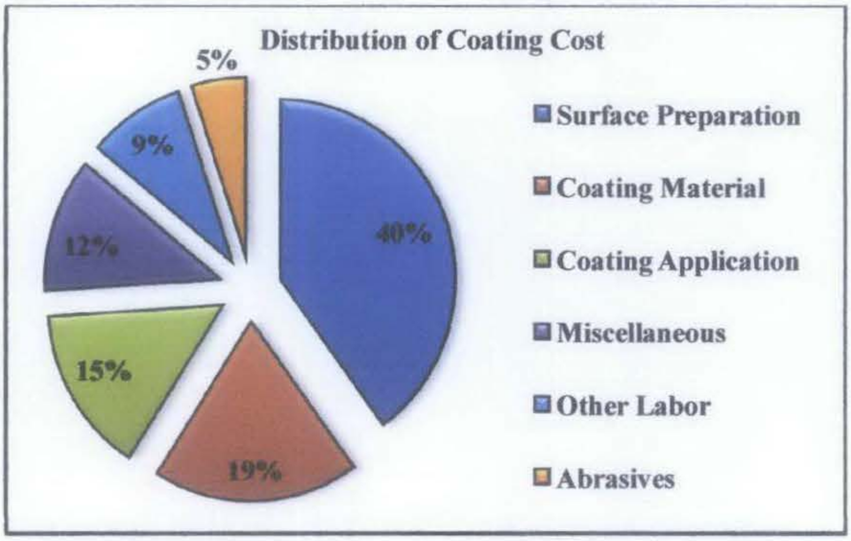


Figure 1: Cost distribution of a coating application on an aboveground storage tank

The above figure clearly demonstrates that surface preparation contributes to a considerably large percentage of cost compared to the coating material cost, let alone to the coating application cost.

2.2 PETRONAS Technical Standards (PTS)

In PTS, the purpose and the focus of the standards are explained in relation to coating performance. The purpose of the standards was to standardize and to improve the coating specification to optimize cost of painting without compromising the quality and coating performance [5].

The technical standards also focused on the methods of surface preparation. Specifically there are four methods of surface preparation [5]:

1. Pre-cleaning of surfaces and solvent cleaning.
2. Surface preparation by blast cleaning.
3. Surface preparation by hand and power tool cleaning.
4. Surface preparation and cleaning by water jetting.

However, as for this project, the study is only to compare the performance of a coating system upon the different blast cleaning surface preparation methods.

2.3 ADHESION TEST

2.3.1 Adhesion Measurement

Later in the methodology section, the adhesion tests chosen are the scratch test based on several criteria and requirements. The selection of adhesion measurement methods are guided by the following criteria [6]:

1. Quantitative - Gives numerical data that can be unambiguously interpreted.
2. Ease of sample preparation - Samples quickly and easily prepared with readily available equipment. If the sample is too complex, the test will not likely be implemented.
3. Results relevant to real world - Final data must have relevance to final use condition.

2.3.2 Scratch Tester [12]

Basics

The scratch tester moves a Rockwell diamond tip with a radius of 200μm across the coated surface of a substrate at a constant velocity while an increasing normal force is applied with a constant loading rate. The scratch test introduces stresses to the interface between coating and substrate causing delaminating or chipping of the coating. The critical normal force at which the first failure of the coating is detected is termed the critical load, L_c [12].

Failure detection [12]

The typical scratch tester has three methods of detecting coating failure which are:

1. A load cell to measure the change in friction.
2. Acoustic emission.
3. Observation of the scratch channel using an attached optical microscope.

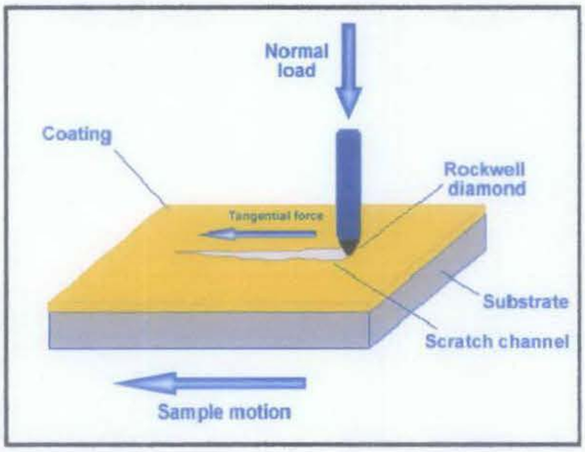


Figure 2: Diagram of an adhesion test [12]

The best scratch adhesion testers use all three methods of coating failure detection. The intensity of the acoustic emission is dependent on the type of coating failure during the adhesion test e.g. cracking, chipping (cohesive failure) and delaminating (adhesive failure). It is therefore important to observe the coating failure after the adhesion test using an optical microscope to confirm the critical load [12]. During the adhesion scratch tests of the coatings the damages observed in which P. Burnett divided as follows [24, 25]: spalling failure, buckling failure, chipping failure, conformal cracking, tensile cracking.

Possible substrates

The scratch tester can be used to assess the coating adhesion on many different types of substrates such as metal alloys, semiconductors, glass, and refractive materials but is the most accurate when assessing the adhesion of hard coatings onto relatively hard substrates >54 HRC [12].

2.3.3 Microscopic Examination

3D Non-Contact Measurement System [22]

It is a measuring microscope with image processing system. This machine has a manually or CNC-controlled vision measuring systems for reliable, non-contact precision measurement of surfaces and profiles. High-resolution, color CCD cameras provide high performance in these compact and mobile desktop instruments.

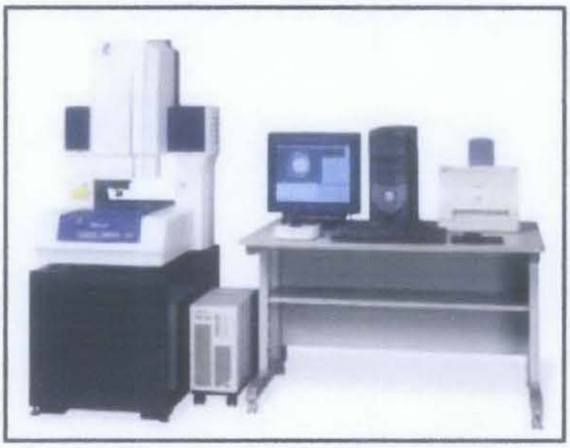


Figure 3: 3D Non-contact measurement system [21]

The system, Quick Vision provides numerous filter functions for enhanced measurement reliability, versatile illumination options and the ease and flexibility of QVBasic programming language. Quick Vision is ideal for vision measurement of parts with difficult to distinguish contours and surfaces.

Most of the measuring machine has an accuracy range between 0.3μm to 3μm.

2.4 CORROSION TEST

2.4.1 Salt-Spray Test

ISO [11] specifies the apparatus, the reagents and the procedure to be used in conducting the neutral salt spray (NSS), acetic acid salt spray (AASS) and copper-accelerated acetic acid salt spray (CASS) tests for assessment of the corrosion resistance of metallic materials, with or without permanent or temporary corrosion protection.

Figure 4: Salt-spray corrosion chamber facility in UTP

For this project, the NSS will be used. The salt spray tests are particularly useful for detecting discontinuities, such as pores and other defects in certain metallic, organic, anodic oxide and conversion coatings. The NSS test applies to [11]:

1. Metals and their alloys
2. Metallic coatings (anodic and cathodic)
3. Conversion coatings
4. Anodic oxide coatings
5. Organic coatings on metallic materials

2.4.2 Visual Examination

ISO 4628-3:2003 [15] describes a method for assessing the degree of rusting of coatings by comparison with pictorial standards. The pictorial standards provided in this part of ISO 4628 show coated steel surfaces which have deteriorated to different degrees by a combination of rust broken through the coating and visible underrust.

The pictorial standards [15] have been selected from the European rust scale published by the European Confederation of Paint, Printing Ink and Artists' Colours Manufacturers' Associations (CEPE), Brussels. The correlation between the ISO scale and the European rust scale and between the ISO scale and the rating system of ASTM D 610, Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces, is also provided.

2.5 SURFACE PREPARATION STANDARDS

2.5.1 Comparisons in Nomenclature

Worldwide, the surface preparation standards are being known with some different naming system by organization such as NACE, ISO and SSPC. NACE for example, is a leader in the corrosion engineering and is recognized around the world as the authority for corrosion solution controls. Appendix C shows the comparisons of nomenclature system between those organizations.

There are several standards within the blast cleaning surface preparation method in which four standards and their respective description are as shown in the next section.

2.5.2 Blast-Cleaning Standards Description

For this project, study will be done in comparing the performance of coating system upon the blast-cleaned surface to the standard of commercial blast-cleaning (Sa 2) and near-white metal blast-cleaning (Sa 2.5)

Near-White Metal Blast Cleaning – Sa 2.5 [8]

1. A Near White Blast Cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter, except for staining.
2. Staining shall be limited to no more than 5 percent of each square inch of surface area and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill scale, or stains of previously applied paint.
3. Before blast cleaning, visible deposits of oil or grease shall be removed by any of the methods specified in SSPC-SP 1 or other agreed upon methods.

Commercial Blast Cleaning – Sa 2 [8]

1. Staining shall be limited to no more than 33 percent of each square inch of surface area and may consist of light shadows, slight streaks, or minor discolorations caused by stains of rust, stains of mill scale, or stains of previously applied paint.
2. Before blast cleaning, visible deposits of oil or grease shall be removed by any of the methods specified in SSPC-SP 1 or other agreed upon methods.

SSPC-SP 1 is one of the methods of surface preparation by solvent cleaning [8]. The typical blast-cleaning activities are shown in Appendix D [19].

As for the pictorial or visual guide for the degrees of surface preparation by blast-cleaning methods [7], they are explained in the Appendix E. Appendix F shows the typical equipments types and parameters used in the process of blast-cleaning [7].

2.5.3 Sa 2.5 Versus Sa 2

Near-white blast cleaning (Sa 2.5) provides a greater degree of cleaning than commercial blast cleaning (Sa 2) but less than white metal blast cleaning (Sa 3) [18]. It should be used when a high degree of blast cleaning is required. The primary functions of blast cleaning before coating are [18]:

1. To remove material from the surface that can cause early failure of the coating system.
2. To obtain a suitable surface roughness and to enhance the adhesion of the new coating system.

The hierarchy of blasting standards in terms of the degree of cleanliness (higher level means higher degree in cleanliness) is as follows [18]:

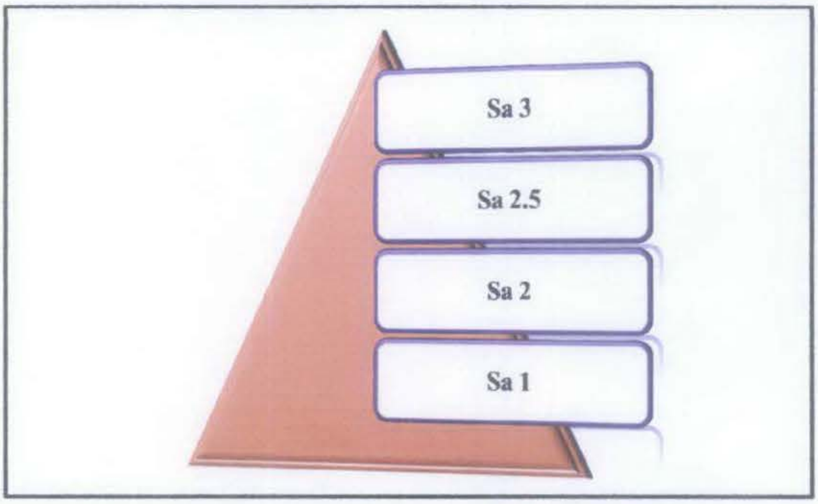


Figure 5: Hierarchy of blasting standards

2.6 SURFACE PROFILE

2.6.1 Blast-Cleaning Surface Profile

It is defined as the contour of an abrasive blast-cleaned surface. Profile is classified by its depth (height) and texture (rounded or angular). Profile is important because it gives paint additional surface area for adhering to the substrate and forming a good, tight bond. For steel, surface profile is a measurement of the average peak-to valley height of the roughness, and typically ranges from less than 1 mil up to 5 mils [17].

2.6.2 Blast Profile and Anchor Pattern

Based on PTS, the blast profile and angular anchor pattern shall be that recommended by the paint manufacturer to suit the minimum requirement of their respective primers; and the minimum peak-to-valley height shall be 25 microns. Roughness or anchor pattern [5] measurement shall be carried out by the painting contractor using instruments approved by Owners and in accordance with the procedures described in ASTM D 4417 [18].

Table 3: Relationship between coating thickness and anchor pattern [5]

Dry-Film Thickness	Anchor Pattern
125 – 200 m (5 – 8 mils)	25 – 50 m (1 – 2 mils)
200 – 500 m (9 – 20 mils)	50 – 75 m (2 – 3 mils)
500 m or more (over 20 mils)	5 m (3 – 5 mils)

Appendix G depicts the critical element of surface preparation on metal substrates specifically after blasting process before it undergoes the coating process [20].

CHAPTER 3
METHODOLOGY

3.1 PROJECT FLOW CHART

The project main activities are basically divided into two sessions. One is the activities that are conducted to evaluate the adhesion properties of coating and the other activities are conducted to evaluate the corrosion protection properties of coating. The activities breakdown for the project is shown in Figure 6 and Figure 7 below:

3.1.1 Adhesion Properties

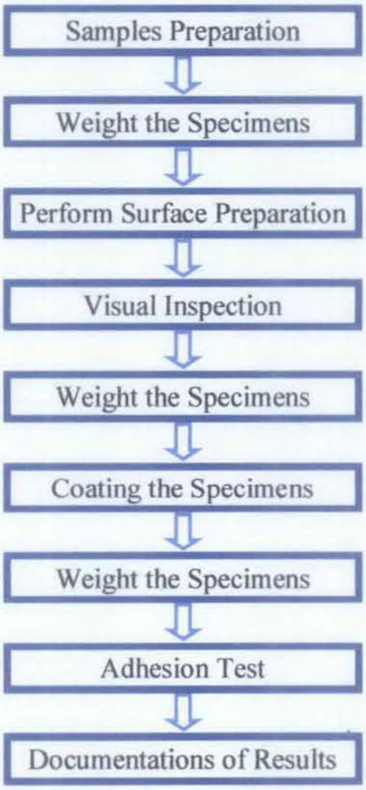


Figure 6: Project flow chart for testing of adhesion properties.

3.1.2 Corrosion Properties

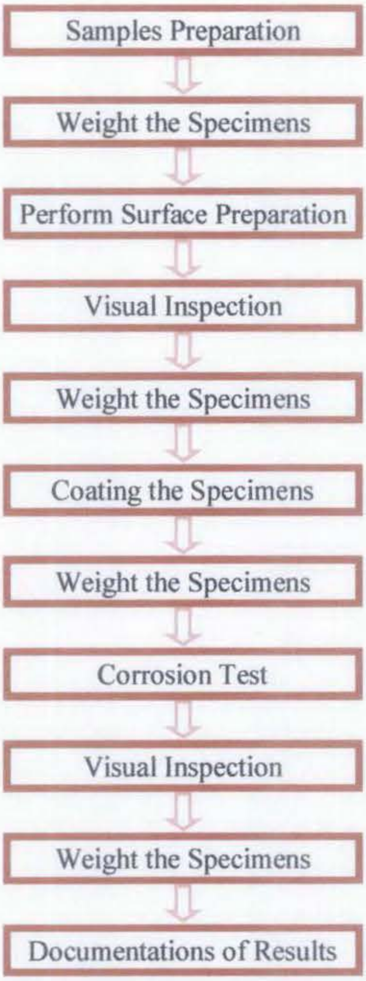


Figure 7: Project flow chart for testing of corrosion properties

As shown by figures above, the performance of coating in terms of adhesion and corrosion properties under the different degrees of surface cleanliness are tested exclusively. Some samples are only tested for the adhesion properties of coating while others are only going tested for its corrosion properties.

Despite the actual situation experienced by oil and gas equipments which include both adhesion and corrosion problems occurring at the same time, it is not practical to perform the adhesion test before or after corrosion test and vice versa.

3.2 ACTIVITIES DESCRIPTION

To elaborate more on the previous section, the project methodology basically involve nine phases (not in actual sequence):

1. Sample preparation.
2. Perform the surface preparation.
3. Coat the specimens.
4. Perform the corrosion test.
5. Perform the visual inspection.
6. Perform the adhesion test.
7. Weight the specimens.
8. Microscopic examination
9. Documentation of results.

3.2.1 Samples Preparation

Metal preparation

There are two sets of plate prepared. The first set consists of four plates and are used for the testing of corrosion properties. The dimensions of the plates (specifically the thickness) are limited to the slots gap in the corrosion chamber. The characteristics of the plates are set to be:

1. Dimension – 150mm (length) x 100mm (width) x 4.5mm (thick).
2. Material – Carbon steel (including mill certificate - see Appendix H).

The second set consists of two plates and are used for the testing of adhesion properties. The dimensions of the plates (specifically the width) are limited to the slots gap in the machine jig. The characteristics of the plates are set to be:

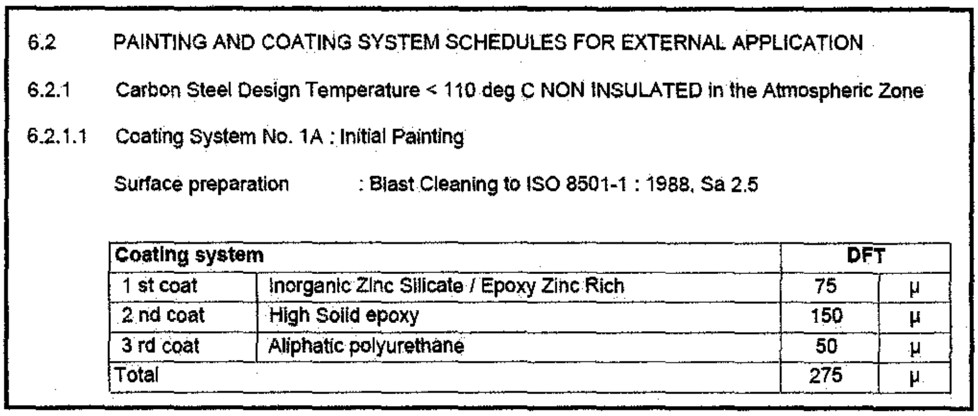
1. Dimension – 70mm (length) x 20mm (width) x 5mm (thick).
2. Material – Carbon steel (including mill certificate - see Appendix H).

All plates are ensured not to have any major surface defects. The mill certificate is basically a birth certificate for steel material. It consists of specific material type, compositions and properties which may be useful for future research and analysis.

See Appendix I for the pictures of the samples for corrosion and adhesion test.

Coating Preparation

For this project, the three coatings as shown in the coating system below are purchased. The product data sheets of the coatings are included in Appendix Z as it contains technical information for the preparation and application method of the coating.



6.2 PAINTING AND COATING SYSTEM SCHEDULES FOR EXTERNAL APPLICATION

6.2.1 Carbon Steel Design Temperature < 110 deg C NON INSULATED in the Atmospheric Zone

6.2.1.1 Coating System No. 1A : Initial Painting

Surface preparation : Blast Cleaning to ISO 8501-1 : 1988, Sa 2.5

Coating system		**DFT**	
1 st coat	Inorganic Zinc Silicate / Epoxy Zinc Rich	75	µ
2 nd coat	High Solid epoxy	150	µ
3 rd coat	Aliphatic polyurethane	50	µ
Total		275	µ

Figure 8: Coating system No. 1A based on PTS [5]

3.2.2 Surface Preparation

Two samples from the first set of plate and one sample from the second set of plate are blast-cleaned to the standard of Sa 2. The other two samples from the first set of plate and one sample from the second set of plate are blast-cleaned to the standard of Sa 2.5. Every surface of the plate will be involved with the surface preparation.

Table 4: The summary of samples division under the different surface preparation standards and tests

Test	Standards	
	Blast cleaning to Sa 2	Blast cleaning to Sa 2.5
	Plates	
Corrosion Test	A, B	C, D
Adhesion Test	E	F

In this project, all surfaces on the plate are blast-cleaned to the standard mentioned above. However, only one surface of the plate is involved in the analysis, visual inspection as well as the testing of adhesion.

3.2.3 Coating the Specimens

Based on the coating system no. 1A in the previous page, Inorganic Zinc Silicate, High Solid Epoxy and Aliphatic Polyurethane are applied as the base coat, 2nd coat and topcoat respectively. The applications of coating involve all surfaces on the plate.

Instrument used to apply the coating is the Air Spray [5]. The coating applications are based on the recommendation from the manufacturer which can be referred in the coating product data sheet in Appendix Z. The activities of coating preparation and application for this project are shown in Appendix J.

The coating thickness in every application is measured using DFT (Dry-Film Thickness) gauge. The application of DFT give us the value of the coating thickness in which it will guide us in determining whether or not the coating thickness for the first coat for example, has adhere to the thickness of the first coating in the no. 1A coating system. Thus, the thickness of coating for each application is recorded in the table below.

Table 5: Table used to record the coating thickness readings

Procedure	Measuring DFT					
Standards	Blast cleaning to Sa 2			Blast cleaning to Sa 2.5		
Plates	A	B	E	C	D	F
1st coat (μm)						
2nd coat (μm)						
3rd coat (μm)						

3.2.4 Perform Corrosion Test

One of the tests required for the coating systems testing (see Appendix K) chosen for this project is the corrosion test. The corrosion test is conducted based on ASTM B117 (Salt Spray Test) [10] and in conjunction with ISO 9227:2006 [11].

It is a widely used method of testing that introduces a spray in a closed chamber where some specimens are exposed at specific locations and angles [14]. This method is considered because it has the ability to duplicate the real situation experienced by the operating equipments in the real service. The samples arrangement in the salt-spray corrosion chamber is shown in Appendix L while the process parameters are shown in Appendix M.

The test duration for the corrosion test is 336 hours which is approximately 14 days. While the specification of the corrosion chamber of the university facilities had already followed the standard which is ASTM B117, the salt solution needs to be prepared to meet the required volume of 5% of the total volume of water involved.

Appendix N shows the measurement of salt quantity activity conducted in UTP laboratory facility. The calculation in determining the weight of the salt required to be used is as shown below.

Volume of water required for 14 days of exposure,

$$V_{water} = 70L$$

While $1m^3 = 1000L$,

$$V_{water} = 70L \times 1m^3 / 1000L = 0.070m^3$$

Since density of water,

$$\rho_{water} = 1000kg/m^3$$

Mass of water,

$$m_{water} = 1000kg/m^3 \times 0.070m^3 = 70kg$$

According to ASTM B117, the amount of salt required should be 5% from the total amount of water used. As much as 0.3% of impurities are allowed in the calculation.

Therefore, mass of salt,

$$m_{salt} = 5.3\% \times 70kg = 3.71kg$$

3.2.5 Calculation of Corrosion Rate

The formula for the calculation on corrosion rate for ASTM B117-90 test samples are based on the mass loss method and are as shown below:

Corrosion Rate (millimeter per year) =

$$\frac{K \times W}{D \times A \times T}$$

where,

K = Constant (87.6 for millimeter per year, 534 for mils per year)
W = Weight loss (mg)
D = Density (g/cm^3)
A = Area (in^2 or cm^2)
T = Time (hr)

3.2.6 Perform Visual Inspection

It is necessary to perform visual inspection after two methods throughout this project which are after performing the surface preparation and after conducting corrosion test. Inspection needs to be done visually based on ISO 8501-1 [9] to determine whether the surface on each plate has been blast clean to their respective standards.

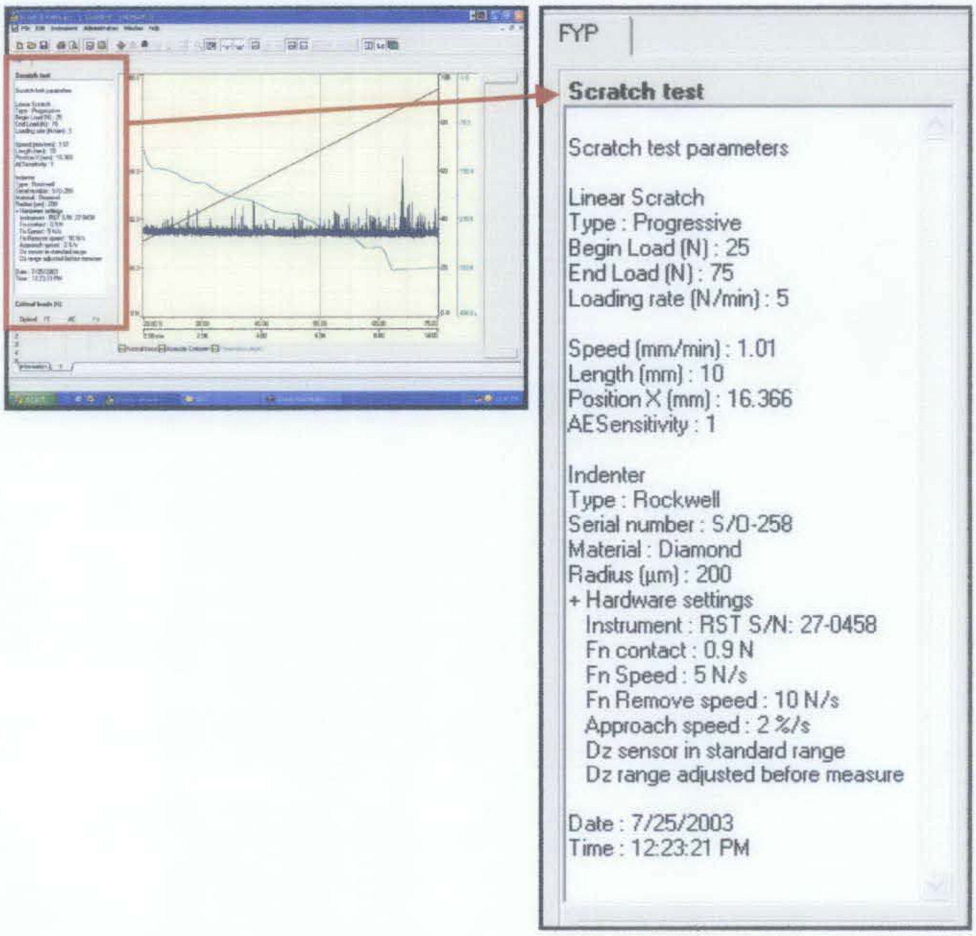
As previously mentioned, the corrosion test will be conducted for 336 hours. The visual appearance of the samples after the test will be evaluated and recorded. Throughout the test, the cabinet or corrosion chamber will be open at only short duration for conducting visual inspection and calculating mass loss to ensure minimal disturbance. The time elapsed prior to the appearance of the first signs of corrosion, if any will be recorded.

The visual examination is conducted to evaluate the degree of rusting of the specimens. The method of visual examination will be based on ASTM D610 [13] and ISO 4628-3:2003 [15]. The table for recording the visual inspection data is shown in Appendix O.

3.2.7 Perform Adhesion Test

Apart from the corrosion test, adhesion test are also conducted to evaluate the performance of the coating. Scratch Test [12] is used to detect the failure in coating and thus evaluating the coating performance. Scratch test has been conducted (see Appendix P) on a sample for each blast-cleaning process (Plate E and F). The summarized process parameters are as shown below:

Linear Scratch	Load Type: Progressive
Initial Load: 25N	Final Load: 75N
Loading Rate: 5N/min	Scratch Length: 10mm
Speed: 1.01mm/min	Acoustic Emission Sensitivity: 1



Scratch test

Scratch test parameters

Linear Scratch
Type : Progressive
Begin Load (N) : 25
End Load (N) : 75
Loading rate (N/min) : 5

Speed (mm/min) : 1.01
Length (mm) : 10
Position X (mm) : 16.366
AESensitivity : 1

Indenter
Type : Rockwell
Serial number : S/D-258
Material : Diamond
Radius (µm) : 200
+ Hardware settings
  Instrument : RST S/N: 27-0458
  Fn contact : 0.9 N
  Fn Speed : 5 N/s
  Fn Remove speed : 10 N/s
  Approach speed : 2 %/s
  Dz sensor in standard range
  Dz range adjusted before measure

Date : 7/25/2003
Time : 12:23:21 PM

Figure 9: Scratch Test Parameters

3.2.8 Weight the Specimens

Throughout this project, the weight of each sample is recorded four times for the samples that will undergo corrosion test while two times for those which will undergo adhesion test.

The first and the second weight recording session will be done before and after the surface preparation. The calculation of mass loss during the blast cleaning procedure may not be as essential as the final mass measurement. However, it may be useful for future references and analyses.

Table 6: 1st and 2nd mass measuring and recording

Procedure	Blast Cleaning					
Standards	Blast cleaning to Sa 2			Blast cleaning to Sa 2.5		
Plates	A	B	E	C	D	F
Initial mass (mg)						
Final mass (mg)						
Mass loss (mg)						

The third and fourth session will be done before and after the corrosion test is conducted. This is to study the mass loss during the corrosion test and the effect of corrosion onto the plate. All samples are then thoroughly clean and let to dry before the mass is measured.

Table 7: 3rd and 4th mass measuring and recording

Procedure	Corrosion Test			
Standards	Blast cleaning to Sa 2		Blast cleaning to Sa 2.5	
Plates	A	B	C	D
Initial mass (mg)				
Final mass (mg)				
Mass loss (mg)				

For both situations in which during the surface preparation and the corrosion test, the mass loss per square meter will be calculated [11]. These calculations are important in analyzing the corrosion rate of the samples tested and will be a good addition of data to the visual inspection method.

3.2.9 3D Non-Contact Measurement

The 3D non-contact measuring machine is used as the alternative to using optical microscope for depicting the location of coating failure. As shown in the figure below, a test sample (after undergone scratch test) is placed on the platform for further processing by the QVPAK software in the computer.

Figure 10: 3D non-contact measurement facility in UTP

The procedure to perform the measurement on the sample (see Appendix Q):

1. Ensuring the scratch length of 10mm.
   - Coordinate A are taken from the sample's top edge location. Coordinate D are taken from a point estimated to be the location where the scratch starts. Coordinate B are taken from a point estimated to be the location where the scratch ends.
   - The location of x-coordinate for all three points are assumed align around 28mm from the sample's left edge.
   - Thus, we get the y-coordinate for all point A, D and B to be 0.0376mm, 17.8596mm and 7.2752mm respectively.
   - Scratch length, $L_s = Y_D - Y_A - Y_B$

     $= 17.8596\text{mm} - 0.0376\text{mm} - 7.2752\text{mm}$

     $= 10.5468\text{mm}$
   - Therefore, the value calculated is close with the actual scratch length of 10mm.

2. Estimating the location of coating failure.
    - Coordinate D are taken from a point estimated to be the location where the scratch starts. Coordinate C are taken from a point estimated to be the location where coating failure occurs.
    - The location of x-coordinate for all points are assumed align around 28mm from the sample's left edge.
    - Thus, we get the y-coordinate for all point D and C to be 17.8596mm and 9.2596mm respectively.
    - Location of failure, $L_f = Y_D - Y_C$

      $= 17.8596\text{mm} - 9.2596\text{mm}$

      $= 8.6\text{mm}$
    - Therefore, it is estimated that the coating failure occurs at 8.6mm from the start point of the scratch.

The coating failure location will be used to confirm the failure location from the scratch profile graph such as Figure 14.

3.2.10 Documentation of Results

All findings, observation and results of testing throughout this project are documented. Analyses are made based on those findings to determine the performance of coating under different surface preparation standards.

3.3 PROJECT GANTT CHART

The Gantt chart for Final Year Project I and Final Year Project II are shown in Appendix R.

3.4 TEST MATRIX

The project work summary is established in the form of test matrix. The test matrix is provided in the tables below. The previous sections have explained the details regarding the materials and test procedures used in the investigation.

Table 8: Test Matrix for corrosion test

Parameters	Value	
Material	Carbon Steel	
Cleanliness Standard	Sa 2	Sa 2.5
Quantity of Sample	2	2
No. of Coating	1st - Inorganic Zinc Silicate	
	2nd - High Solid Epoxy	
	3rd - Aliphatic Polyurethane	
Testing Method	ASTM B117	
Measurement Techniques	Corrosion Rate – Mass Loss ASTM D610	
No. of Surface to be Tested	1 surface per sample	

Table 9: Test Matrix for adhesion test

Parameters	Value	
Material	Carbon Steel	
Cleanliness Standard	Sa 2	Sa 2.5
Quantity of Sample	1	1
No. of Coating	1st - Inorganic Zinc Silicate	
	2nd - High Solid Epoxy	
	3rd - Aliphatic Polyurethane	
Testing and Measurement Methods	Scratch Test 3D Non-Contact Measurement	
No. of Surface to be Tested	1 surface per sample	

CHAPTER 4

RESULTS AND DISCUSSION

4.1. PROJECT RESULTS AND ANALYSIS

4.1.1 Weight Measurement

The table below shows the weight measurement of all plates before and after the blast-cleaning process. The initial mass of the plates indicates the mass before blast-cleaning while the final mass of the plates indicates their mass after undergo the blast-cleaning process.

Table 10: Weight of the plates before and after blast-cleaning process, and mass loss

Procedure	Blast Cleaning					
Standards	Blast cleaning to Sa 2			Blast cleaning to Sa 2.5		
Plates	A	B	E	C	D	F
Initial mass (g)	532.96	535.64	55.75	541.37	540.09	56.05
Final mass (g)	523.44	526.17	46.91	531.44	530.51	46.80
Mass loss (g)	9.52	9.47	8.84	9.93	9.58	9.25

The table below shows the weight measurement after the plates had undergoes coating process. The initial mass indicates the weight of the plates after undergo blast-cleaning process / before coating while the final mass indicates the weight of the plates after undergo coating process.

Table 11: Weight of the plates before and after coating process

Procedure	Coating					
Standards	Blast cleaning to Sa 2			Blast cleaning to Sa 2.5		
Plates	A	B	E	C	D	F
Initial mass (g)	523.44	526.17	46.91	531.44	530.51	46.80
Final mass (g)	556.57	558.33	78.64	566.45	564.81	77.97
Mass of coating (g)	33.13	32.16	31.73	35.01	34.30	31.17

4.1.2 Coating Thickness Measurement

The table below shows the coating thickness measurement for all plates by using the Dry-Film Thickness (DFT) gauge. The total coating thickness for all plates should be above and around to 275μm. Table 12 shows the coating thickness after 1st coating.

Table 12: DFT measurement of all plates after 1st coating

Procedure	Measuring DFT					
Standards	Blast cleaning to Sa 2			Blast cleaning to Sa 2.5		
Plates	A	B	E	C	D	F
1st coat (μm)	111	95	123	104	99	95

Figure 11 and 12 below show the color and texture of the sample after undergone the 1st coating process respectively. The color scheme for the 1st coat can be referred in Appendix Z.

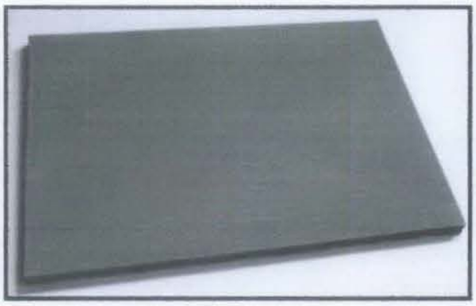


Figure 11: Sample of plate coated with 1st coat (primer)

Figure 12: Close-up view on the texture of the plate coated with 1st coat (primer)

Table 13 shows the coating thickness after 2nd coating. Figure 13 and 14 show the color and texture of the sample after undergone the 2nd coating process respectively. The color scheme for the 2nd coat can be referred in Appendix Z.

Table 13: DFT measurement of all plates after 2nd coating

Procedure	Measuring DFT					
Standards	Blast cleaning to Sa 2			Blast cleaning to Sa 2.5		
Plates	A	B	E	C	D	F
2nd coat (μm)	243	238	266	237	250	240

Figure 13: Sample of plate coated with 2^{nd} coat

Figure 14: Close-up view on the texture of the plate coated with 2^{nd} coat

Table 14 shows the coating thickness after 3^{rd} coating. Figure 15 and 16 below show the color and texture of the sample after undergone the 3^{rd} coating process respectively. The color scheme for the 3^{rd} coat can be referred in Appendix Z.

Table 14: DFT measurement of all plates after 3^{rd} coating

Procedure	Measuring DFT					
Standards	Blast cleaning to Sa 2			Blast cleaning to Sa 2.5		
Plates	A	B	E	C	D	F
3^{rd} coat (μm)	281	289	288	284	287	290

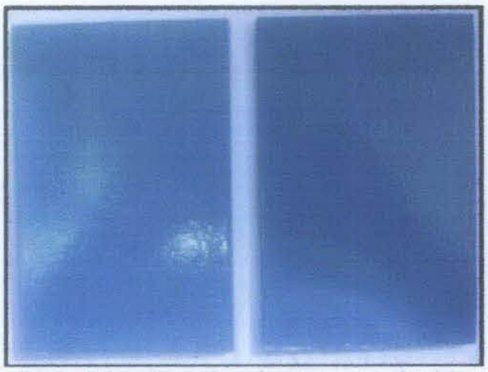


Figure 15: Sample of plate coated with 3^{rd} coat

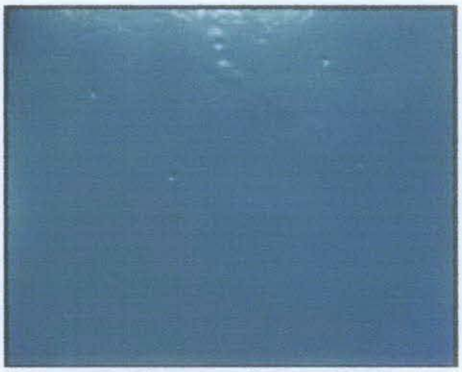
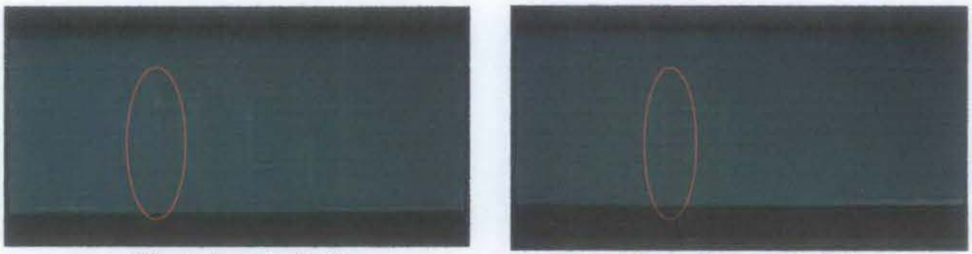


Figure 16: Close-up view on the texture of the plate coated with 3^{rd} coat

4.1.3 Scratch Test

Scratch test has been conducted and manages to produce two scratch profile or results. The computer software that functions together with the scratch test machine has produced the critical load for each sample. Below are the samples showing scratches after the test is conducted.



Blast-clean to Sa 2 Blast-clean to Sa 2.5

Figure 17: Plates that are used for scratch test (size: 70mm x 20mm x 4.5mm)

The red circled scratches as shown in Figure 17 above corresponds with the scratch profile results as shown in Figure 18 and Figure 19 respectively. For this project, the critical load was observed to be at the point where the penetration depth profile begins to decrease its value.

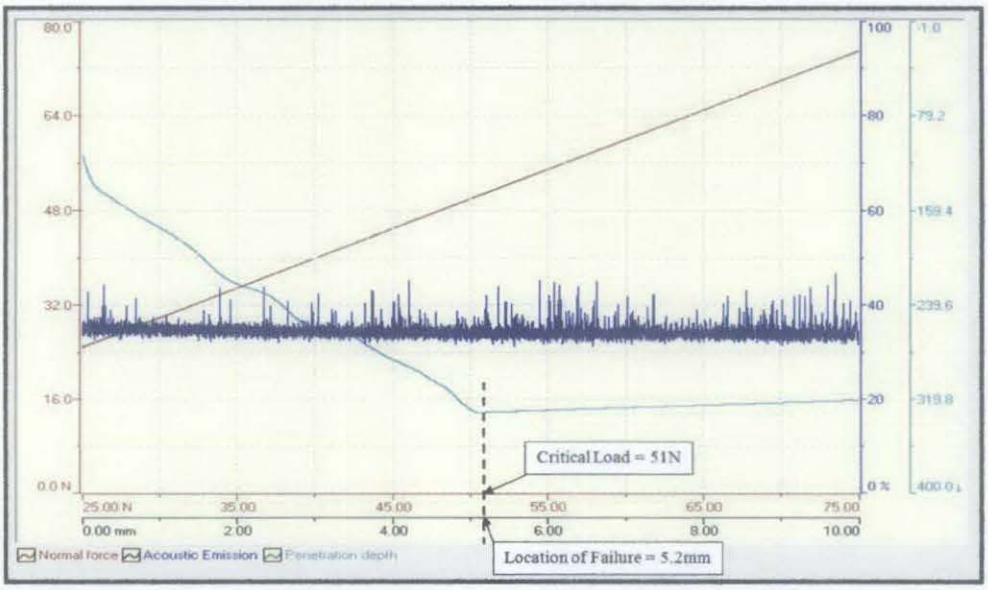


Figure 18: Scratch test profile on sample E (Blast-cleaned to Sa 2)

As shown in Figure 18, the penetration depth (green color) profile was increasing its value from around 110µm until around 328µm. The profile then suddenly begins to decrease its value until around 320µm. The sudden change of the penetration depth value possibly depicts the starting of collision or friction between the diamond stylus and the bare metal substrates.

The critical load at that point is estimated to be 51N and the first location of the failure is estimated to be 5.3mm.

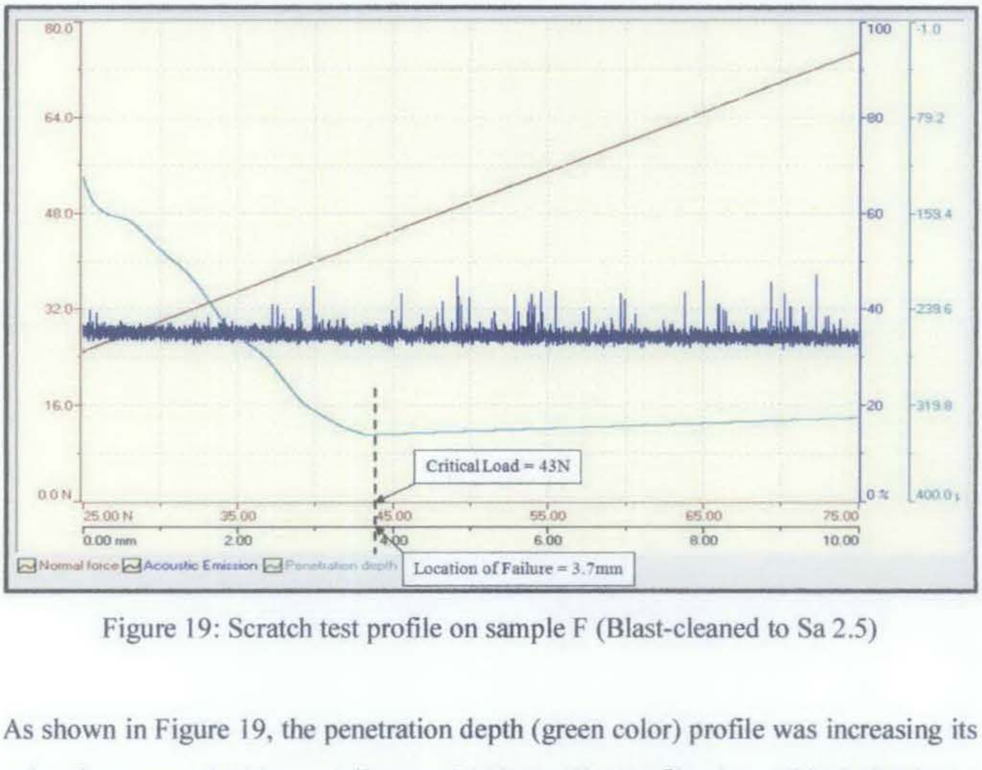


Figure 19: Scratch test profile on sample F (Blast-cleaned to Sa 2.5)

As shown in Figure 19, the penetration depth (green color) profile was increasing its value from around 130µm until around 342µm. The profile also suddenly begins to decrease until around 320µm. The critical load at the point is estimated to be 43N and the first location of the failure is estimated to be 3.7mm.

4.1.4 3D Non-Contact Measurement

Sa 2 sample (see Appendix S for the coordinates figure)

The scratch length, L_s

$= Y_F - Y_B - Y_A$

$= 17.8839 - 7.1276 - 0.0135$

$= 10.7479\text{mm}$

Percentage deviation from actual length, P

$= (10.7479 - 10) / 10 \times 100\%$

$= 7.479\%$

Location of first failure, L_{f1}

$= Y_F - Y_E$

$= 17.8839 - 12.7843$

$= 5.0996\text{mm}$

The location of first failure occurs at 5.0996mm from the starting point of the scratch. This value, when compared to the value extracted from the scratch profile graph (Figure 18) which is 5.2mm shown a really close value. Thus, the location of first failure shown in Coordinate E figure confirms the critical load.

Below is the calculation for the location where other coating failures for the same Sa 2 samples are indentified.

Location of second failure, L_{f2}

$= Y_F - Y_D$

$= 17.8839 - 10.0830$

$= 7.8009\text{mm}$

Location of third failure, L_{f3}

$= Y_F - Y_C$

$= 17.8839 - 9.2844$

$= 8.5995\text{mm}$

Sa 2.5 sample (see Appendix T for the coordinates figure)

The scratch length, L_s

$= Y_F - Y_B - Y_A$

$= 18.6956 - 8.3587 - (-0.0089)$

$= 10.3458\text{mm}$

Percentage deviation from actual length, P

$= (10.3458 - 10) / 10 \times 100\%$

$= 3.458\%$

Location of first failure, L_{f1}

$= Y_F - Y_E$

$= 18.6956 - 15.0955$

$= 3.6001\text{mm}$

The location of first failure occurs at 3.6001mm from the starting point of the scratch. This value, when compared to the value extracted from the scratch profile graph (Figure 19) which is 3.7mm shown a really close value. Thus, the location of first failure shown in Coordinate E figure confirms the critical load.

Below is the calculation for the location where other coating failures for the same Sa 2.5 sample are indentified.

Location of second failure, L_{f2}

$= Y_F - Y_D$

$= 18.6956 - 11.9959$

$= 6.6997\text{mm}$

Location of third failure, L_{f3}

$= Y_F - Y_C$

$= 18.6956 - 9.5952$

$= 9.1004\text{mm}$

4.1.5 Acoustic Emission Vs. Microscopic Examination

This section will involve comparing the acoustic emission profile (dark blue color) from Figure 18 and Figure 19 with the pictures produced from 3D non-contact measurement.

As shown in Figure 20 in the next page, the coordinate E location indicates the beginning of the coating failure. From Coordinate E to Coordinate D section, we can see the acoustic emission profile becomes noisier compared to the section before Coordinate E. The acoustic emission increases its intensity in this region. We can see a lot of "value jumps" in the profile.

As from Coordinate D and further, the value jumps continue to occur. This indicates that the coating continues to fail and may gather along the diamond stylus path thus increasing the intensity of the acoustic emission profile.

The intensifying occurrence of "value jumps" in Figure 20 also consistent with the pictures shown in Coordinate E, D and C. It appears that the coating failure starts with the large micro cracks (Coordinate E) and propagate further along the scratch path until the coating experience flaking thus exposing its bare metal substrates (Coordinate D and C).

As shown in Figure 21, the coordinate E location also indicates the beginning of the coating failure. From Coordinate E to Coordinate D section, we can see the acoustic emission profile becomes noisier compared to the section before Coordinate E. The same phenomena occur here where we can see a lot of "value jumps" in the profile even though in comparison to Figure 21, the intensity or noise is lower.

As from Coordinate D and further, the value jumps continue to occur as an indication of the coating continues to fail. It appears that the coating failure starts with a smaller and finer micro cracks (Coordinate E) and propagates further as the density of the cracks increase (Coordinate D). However, the failure in Coordinate C is much less severe than in Figure 20. In addition to no occurrence of flaking, the coating seems to be compressed downwards possibly by the effect of friction with the diamond stylus.

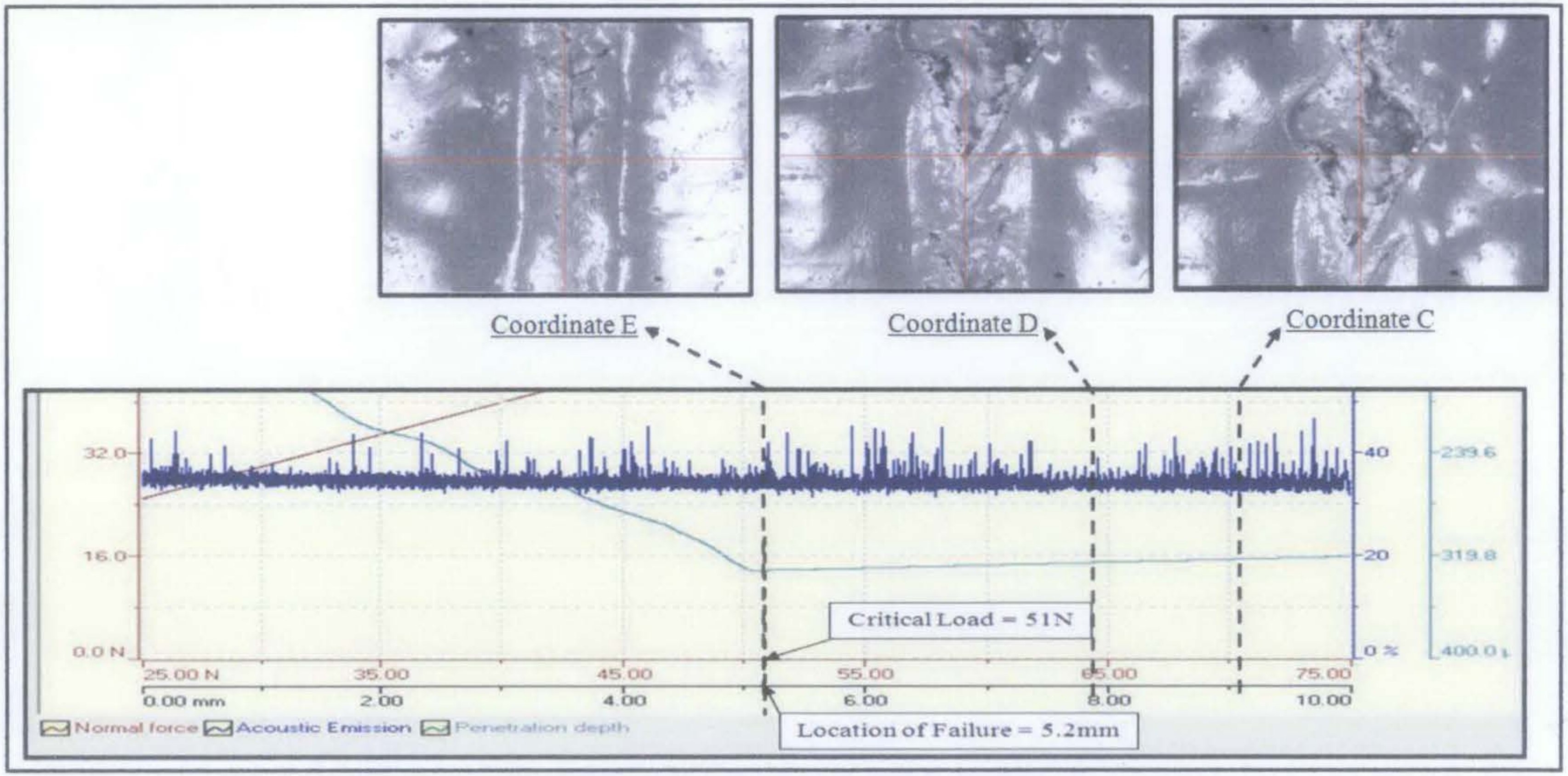


Figure 20: Corresponding failure with acoustic emission profile for Sa 2 sample

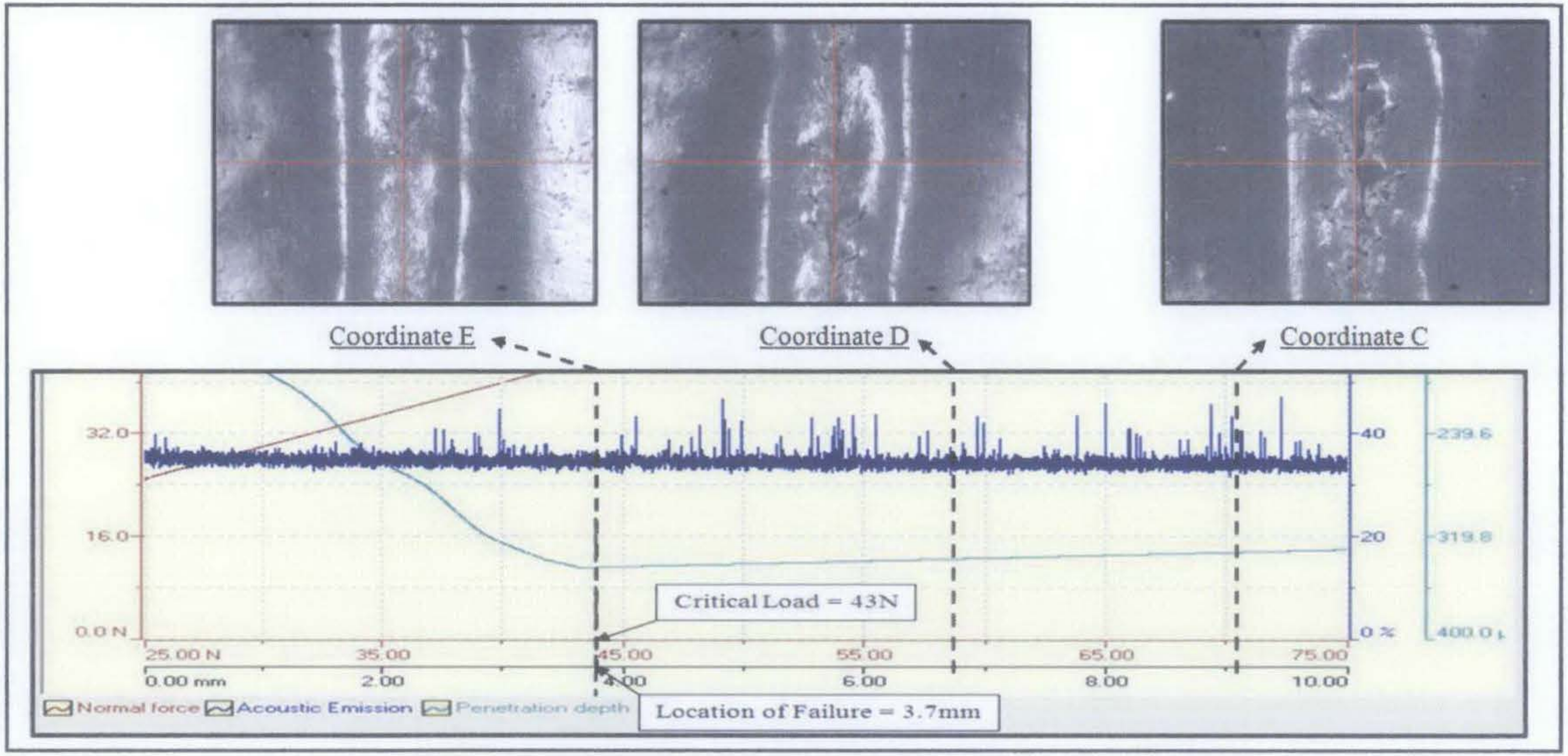


Figure 21: Corresponding failure with acoustic emission profile for Sa 2.5 sample

4.1.6 Corrosion Test

The corrosion test is conducted with the duration of 336hours (14 days). The corrosion chamber setting is prepared as per ASTM B117-90. The table below shows the result from Sa 2 samples exposed to corrosive environment.

Table 15: Corrosion rate on Sa 2 samples based on mass loss method for ASTM B 117-90 test

Blast-Clean to Sa 2					
Mass (g)		Day	Hours of Exposure (hrs)	Mass Loss (g)	Corrosion Rate (mm per year)
Sample A	Sample B				
556.57	558.33	0	0	-	-
556.57	558.33	1	24	0	0
556.57	558.33	2	48	0	0
556.57	558.33	3	72	0	0
556.57	558.33	4	96	0	0
556.57	558.33	5	120	0	0
556.57	558.33	6	144	0	0
556.57	558.33	7	168	0	0
556.57	558.33	8	192	0	0
556.57	558.33	9	216	0	0
556.57	558.33	10	240	0	0
556.57	558.33	11	264	0	0
556.57	558.33	12	288	0	0
556.57	558.33	13	312	0	0
556.57	558.33	14	336	0	0

Calculation on corrosion rate based on the mass loss method is as shown below.

Corrosion Rate (millimeter per year), CR =

$$\frac{K \times W}{D \times A \times T}$$

where,

$K = 87.6$ $T = 24\text{hrs}$

$D = 7850\text{kg/m}^3 = 7.85\text{g/cm}^3$ $A = 10\text{cm} \times 15\text{cm} = 150\text{cm}^2$

W (weight loss) equals to 0 grams throughout the test, the nominator in the equation above also become 0. Thus, since the mass of both sample A and B remain constant throughout the test or 14 days, their corrosion rate is 0 millimeter per year.

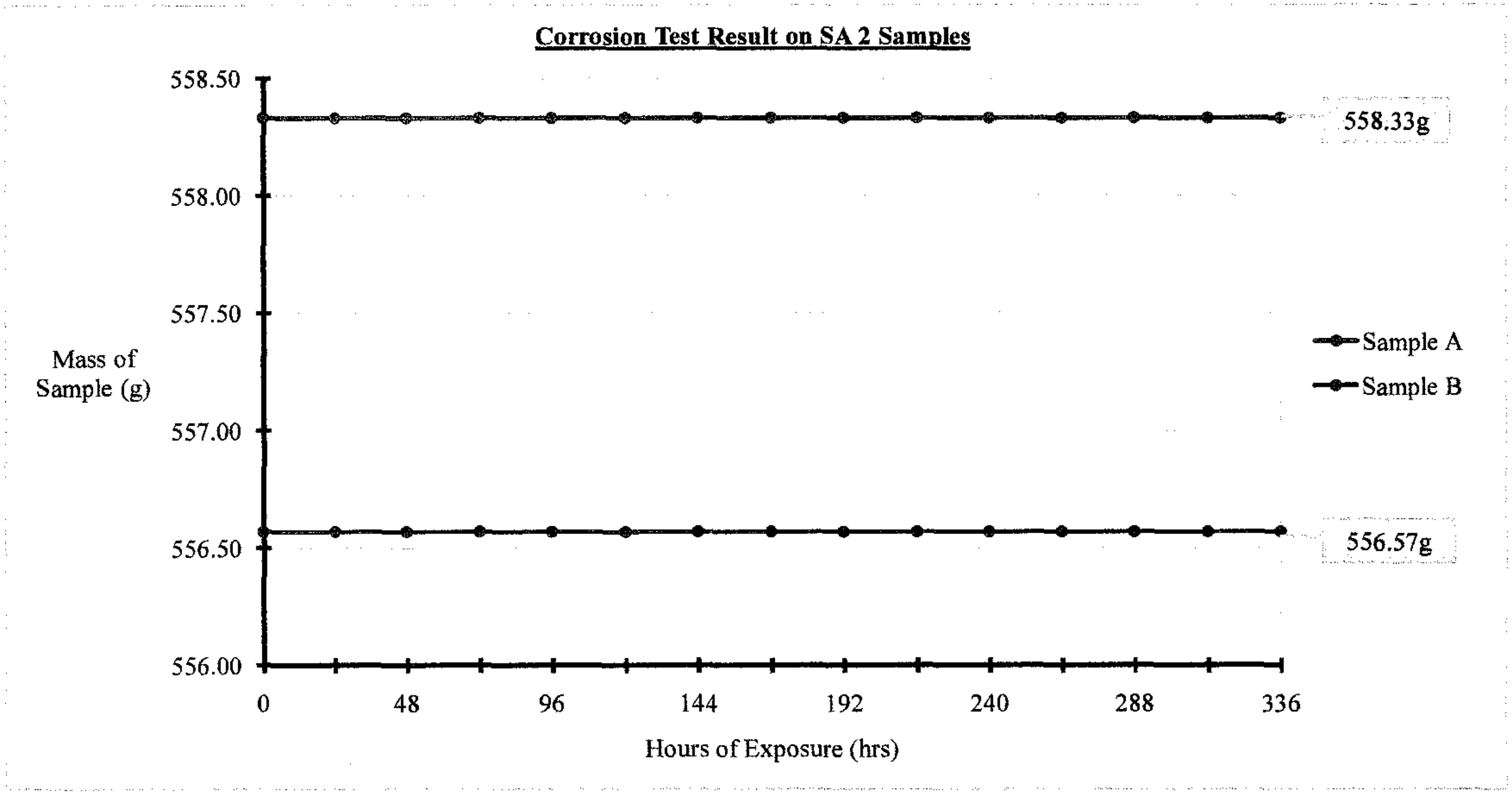


Figure 22: Mass of Sample vs. Hours of Exposure (Sa 2 Samples)

The table below shows the result from Sa 2 samples exposed to corrosive environment.

Table 16: Corrosion rate on Sa 2.5 samples based on mass loss method for ASTM B 117-90 test

Blast-Clean to Sa 2.5					
Mass (g)		Day	Hours of Exposure (hrs)	Mass Loss (g)	Corrosion Rate (mm per year)
Sample C	Sample D				
566.45	564.81	0	0	-	-
566.45	564.81	1	24	0	0
566.45	564.81	2	48	0	0
566.45	564.81	3	72	0	0
566.45	564.81	4	96	0	0
566.45	564.81	5	120	0	0
566.45	564.81	6	144	0	0
566.45	564.81	7	168	0	0
566.45	564.81	8	192	0	0
566.45	564.81	9	216	0	0
566.45	564.81	10	240	0	0
566.45	564.81	11	264	0	0
566.45	564.81	12	288	0	0
566.45	564.81	13	312	0	0
566.45	564.81	14	336	0	0

Calculation on corrosion rate based on the mass loss method is as shown below.

Corrosion Rate (millimeter per year) =

$$\frac{K \times W}{D \times A \times T}$$

where,

$K = 87.6$

$D = 7850\text{kg/m}^3 = 7.85\text{g/cm}^3$

$T = 24\text{hrs}$

$A = 10\text{cm} \times 15\text{cm} = 150\text{cm}^2$

W (weight loss) equals to 0 grams throughout the test, the nominator in the equation above also become 0. Thus, since the mass of both sample C and D remain constant throughout the test or 14 days, their corrosion rate is 0 millimeter per year.

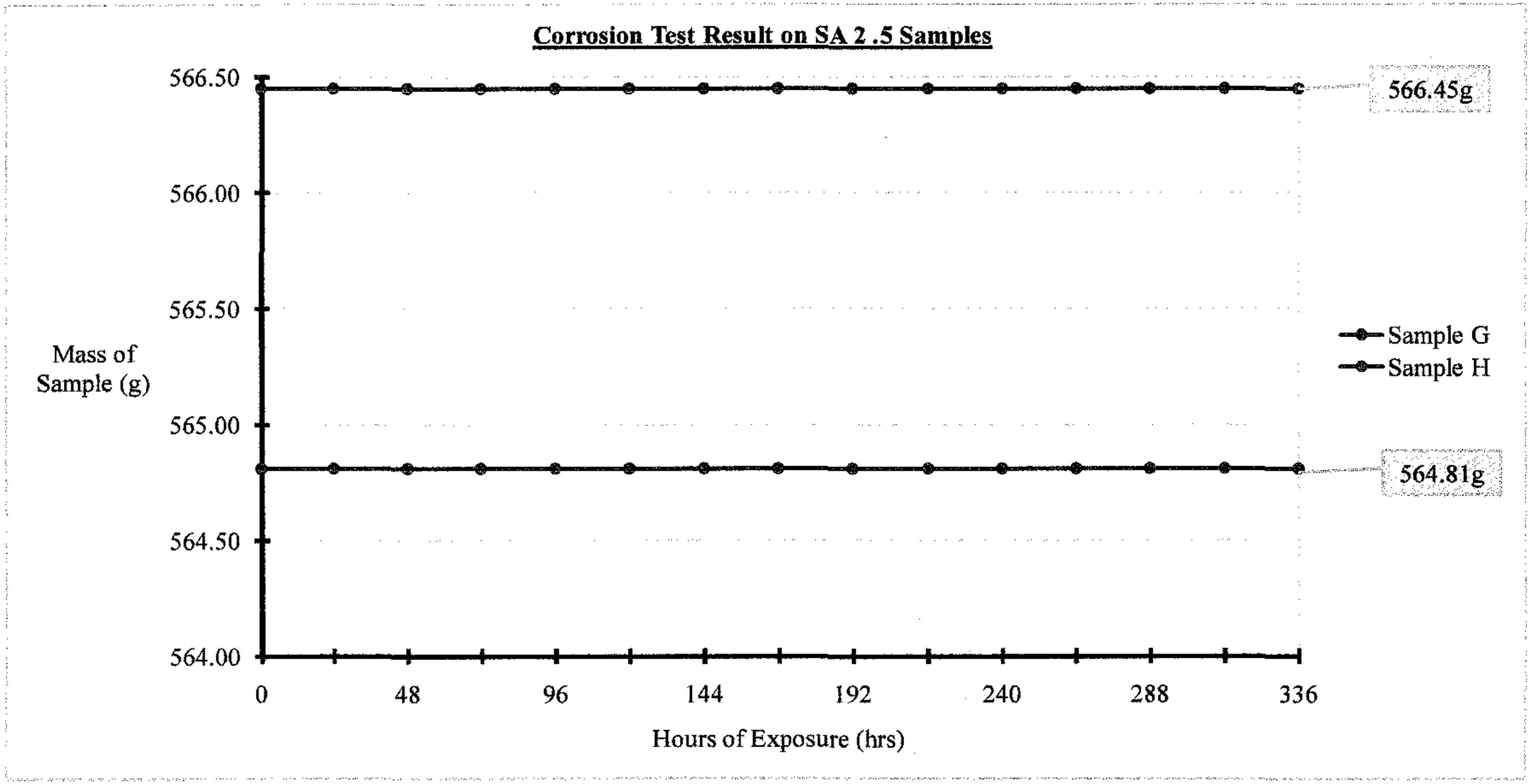


Figure 23: Mass of Sample vs. Hours of Exposure (Sa 2.5 Samples)

4.1.7 Visual Examination

The visual examination is conducted to evaluate the degree of rusting of the specimens. As mention in methodology section, the method of visual examination will be based on ASTM D610 [13] and ISO 4628-3:2003 [15].

Identical area is set for examination for all four samples (see Appendix U). Based on ASTM D610, the outcome of the visual examination is depicted through the existence of Spots, General or/and Pinpoint rusting.

However, all plates did not show any sign of corrosion within the surface inspected. Therefore, all plates are graded with Rust Grade 10 for having less than or equal to 0.01 percent of rusted surface. We can see clearly in all the figures in Appendix U that there are no spots or areas that are different in color compared to the green color of the coating.

The table below shows the evaluation results on all corrosion test samples.

Table 17: Evaluation and degree of rusting for ASTM B 117-90 test result

Blast-Cleaning Standard	Samples	Area Percentage (%)	Rust Grade
Sa 2	A	0	10
	B	0	10
Sa 2.5	C	0	10
	D	0	10

4.2 DATA GATHERING AND DISCUSSION

This section will discuss the real life situation involving costs allocated for the application of blast cleaning standards of Sa 2 and Sa 2.5. The cost evaluation is done based on two projects managed by a certain company, manufacturer and sub-contractor. The details:

1. Company – Owner of the equipments (i.e. pressure vessel or heat exchanger)
2. Manufacturer – Company responsible for the manufacturing process of the equipments.
3. Sub-contractor – Company responsible for the application of blasting and painting of the equipments.

To ease the understanding of the next section, Project A is managed by PCSB (PETRONAS Carigali Sdn. Bhd.) while Project B is managed by PGB (PETRONAS Gas Berhad). The manufacturer and sub-contractor are not named to avoid the violation of confidentiality.

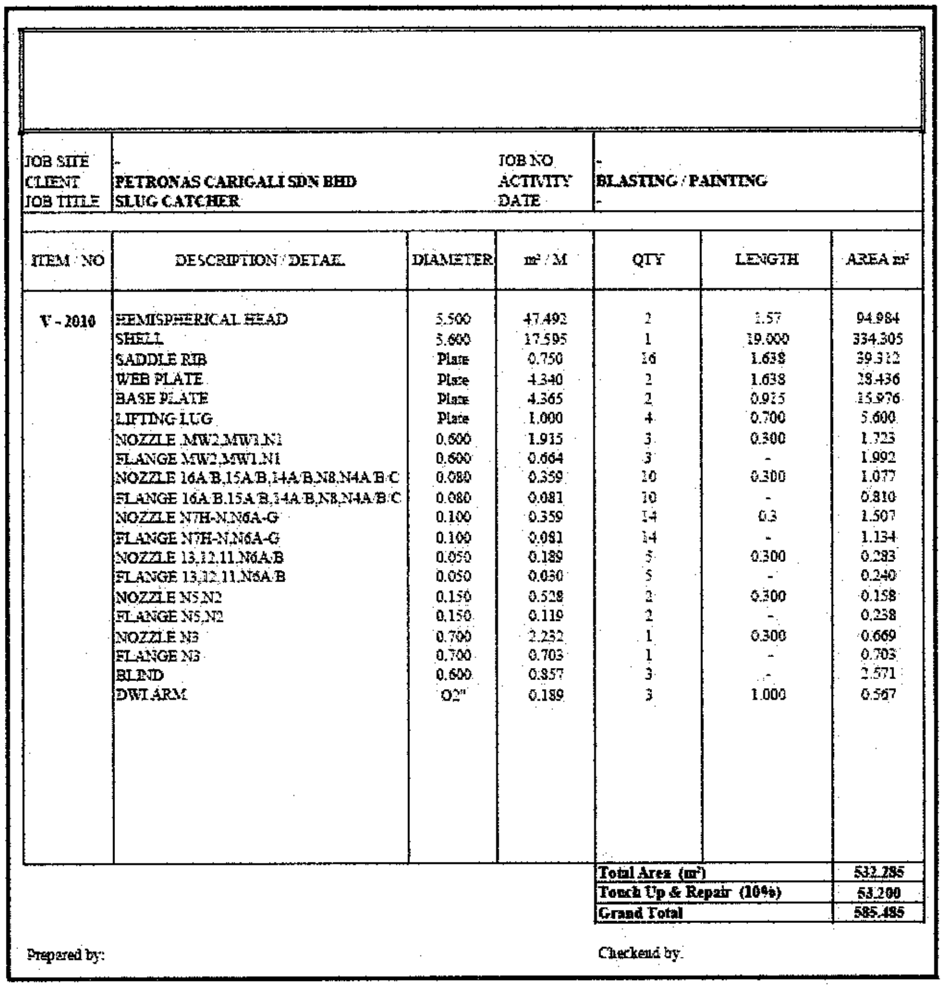
4.2.1 Previous PETRONAS Projects

Project A

1. Activity Report

The activity report as shown in Figure 24 is published by the sub-contractor. It will indicate that they have done the calculations on the total area required for blasting and painting. Upon having this information, they will establish a quotation for the service cost for blasting and painting work.

Job Site indicates the location where the blasting and painting work is done which in this case, in the manufacturing company's blasting and painting yard. *Client* indicates the owner of the equipments (PCSB - PETRONAS Carigali Sdn. Bhd.) and *Job Title* shows the name of the equipment to be manufactured. *V-2010* is the equipments number while *V* is the abbreviation for Pressure Vessel.



JOB SITE	-	JOB NO	-
CLIENT	PETRONAS CARIGALI SDN BHD	ACTIVITY	BLASTING / PAINTING
JOB TITLE	SLUG CATCHER	DATE	-

ITEM / NO	DESCRIPTION / DETAIL	DIAMETER	m² / M	QTY	LENGTH	AREA m²
V - 2010	HEMISPHERICAL HEAD	5.500	47.492	2	1.57	94.984
	SHELL	5.600	17.595	1	19.000	334.305
	SADDLE RIB	Plate	0.750	16	1.638	39.312
	WEB PLATE	Plate	4.340	2	1.638	28.436
	BASE PLATE	Plate	4.365	2	0.915	15.976
	LIFTING LUG	Plate	1.000	4	0.700	5.600
	NOZZLE MW2,MW1,N1	0.600	1.915	3	0.300	1.723
	FLANGE MW2,MW1,N1	0.600	0.664	3	-	1.992
	NOZZLE 16A/B,15A/B,14A/B,N8,N4A/B/C	0.080	0.359	10	0.300	1.077
	FLANGE 16A/B,15A/B,14A/B,N8,N4A/B/C	0.080	0.081	10	-	0.810
	NOZZLE N7H-N,N6A-G	0.100	0.359	14	0.3	1.507
	FLANGE N7H-N,N6A-G	0.100	0.081	14	-	1.134
	NOZZLE 13,12,11,N6A/B	0.050	0.189	5	0.300	0.283
	FLANGE 13,12,11,N6A/B	0.050	0.030	5	-	0.240
	NOZZLE N5,N2	0.150	0.528	2	0.300	0.158
	FLANGE N5,N2	0.150	0.119	2	-	0.238
	NOZZLE N3	0.700	2.232	1	0.300	0.669
	FLANGE N3	0.700	0.703	1	-	0.703
	BLIND	0.600	0.857	3	-	2.571
	DWI ARM	O2"	0.189	3	1.000	0.567

Total Area (m²)	**532.285**
Touch Up & Repair (10%)	**53.200**
Grand Total	**585.485**

Prepared by:

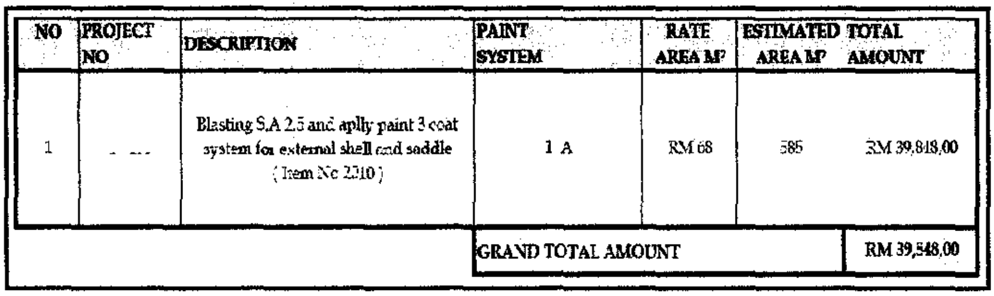
Checkend by:

Figure 24: Activity Report for Project A

From the above figure, we now know the total area of the Slug Catcher that needs blasting service which is 532.285m^2. The sub-contractor has allocated 10 percent of the total area for touch up and repair services. Thus, the final total area that needs to be blasted is 585.485 m^2.

2. Quotation

As shown in Figure 9 below, the same item V-2010 (Slug Catcher) is considered. For the application of blast cleaning to Sa 2.5 standard and coating system No. 1A, the sub-contractor has charged a rate of RM 68 per meter square. Thus, with the total area of 585 m^2, the PCSB has to pay a staggering amount of RM39,848 just for the process. Be reminded that this amount does not yet include other manufacturing cost for the equipments.



NO	PROJECT NO	DESCRIPTION	PAINT SYSTEM	RATE AREA M^2	ESTIMATED AREA M^2	TOTAL AMOUNT
1	- ---	Blasting S.A 2.5 and aplly paint 3 coat system for external shell and saddle (Item No 2010)	1 A	RM 68	585	RM 39,848,00
			GRAND TOTAL AMOUNT			RM 39,548,00

Figure 25: Quotation for Blasting and Painting Service

For both figures including those in the appendices, columns which are blank contain the confidential information and cannot be shown.

Project B

Basically, Project B also involved situation similar to Project A. The figure for Activity Report and Quotation are shown in Appendix V and W respectively. While Project A involves only the manufacturing of single equipment, Project B involves six equipments. The owner of those equipments is PETRONAS Gas Berhad (PGB). For the process of blasting and painting, this project cost RM31,280 in which it is less than project A.

4.2.2 Cost Comparisons between Sa 2.5 and Sa 2.

Let's take Project A for example. An estimated area of 585m^2 will undergo blasting and painting job. The rate charged by the sub-contractor for the coating system no. 1A with surface preparation to the standard of Sa 2.5 is RM68 per m^2. Thus, PETRONAS will have to pay the total amount of:

$$585.485 \text{ m}^2 \text{ x RM68} = \text{RM39, 848}$$

Then again, the typical rate charged by the sub-contractor for the coating system no. 1A with surface preparation to the standard of Sa 2 is RM28 per m^2. Thus, if we calculate using this rate for the same coating system and same area required for blasting, PETRONAS will just have to pay the amount of:

$$585.485 \text{ m}^2 \text{ x RM28} = \text{RM16,390}$$

We can see between results of calculations, (1) and (2), the amount needs to be allocated with the application of Sa 2 standard is less than half the amount when Sa 2.5 standard is applied. However, if saving the amount of RM 23,458 is not significant enough for a big company like PETRONAS, let's assume the next scenario would happen:

"In a year, PETRONAS have 5 projects; each of the projects involves the manufacturing of 5 equipments; each of the equipments has a total estimated area of 250m^2; in ten years time, PETRONAS will do a similar project each year".

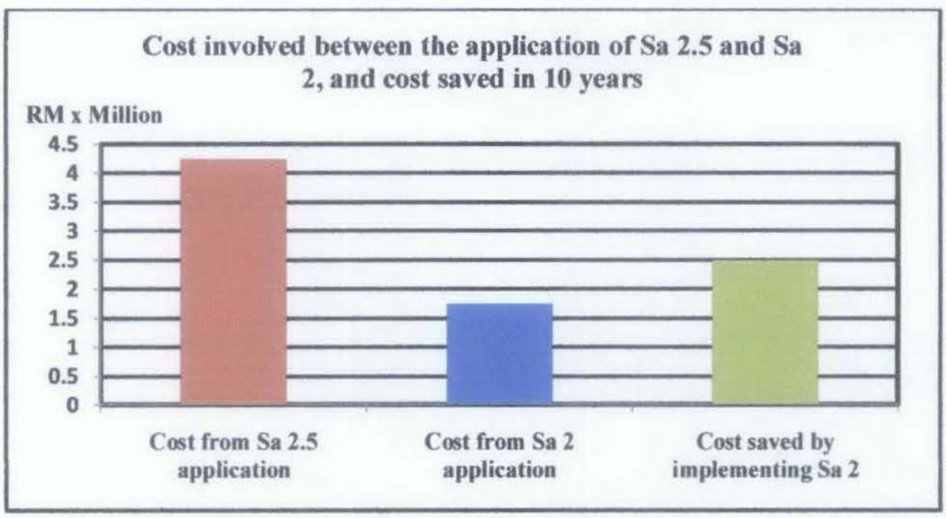


Figure 26: Cost comparisons between Sa 2 and Sa 2.5 application as well as cost saved by implementing Sa 2

Thus, the above figure shows the comparisons of the costs for the application of coating system no. 1A and the blast cleaning standard between Sa 2 and Sa 2.5, as well as the cost saved by implementing Sa 2. By considering the scenario given, if implemented, the application of Sa 2 will save PETRONAS up to RM2.5 million in 10 years time.

4.2.3 Summary

Based on the project work that has been completed, the findings can be summarized as shown below.

Table 18: Comparison of the between Sa 2 and Sa 2.5 sample under different factor

Sample	Tests						Cost (per m^2)
	Corrosion Test		Adhesion Test				
	Corrosion Rate (mm/yr)	*Rust Grade	Critical Load (N)	AE intensity	Location of failure (mm)	**Severity of failure	
Sa 2	0	10	51	High	5.2	5	RM 28
Sa 2.5	0	10	43	Medium	3.7	2	RM 68

* based on ASTM D610

** 1 to 5 scale (with 1 being lowest and 5 being highest in terms of severity level)

From the perspective of protection against corrosion, the performance of samples prepared under the standards of Sa 2 is at par with the samples prepared under Sa 2.5 standards. The entire sample acquires the highest rust grade and 0mm of corrosion rate per year.

From the perspective of adhesion properties, Sa 2 sample performed well in sustaining a higher critical load compared to Sa 2.5 sample. Having a higher value in location of failure indicates that it takes Sa 2 sample a longer time to expose its bare metal substrates to the environment than the Sa 2.5 sample.

However, the acoustic emission indicates a higher intensity produced from Sa 2 sample. This is due to the collection of coating residue along the diamond stylus path. The intensity level is consistent with the severity of the coating failure examined from Sa 2 sample. This means that compared to Sa 2.5 sample, Sa 2 sample has a larger exposed area of bare metal.

On the other hand, economical analysis regarding the cost allocated for the service of blasting and painting had been done based on PETRONAS previous projects. Findings made were, with the implementation of the blast-cleaning surface preparation to the standard of Sa 2 will definitely be cost-effective.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Thus, we can conclude that compared to Sa 2.5, Sa 2 has better overall performances which are:

- Corrosion Rate of 0mm/yr
- Rust Grade of 0
- Higher critical load – 51N
- Location of failure is farther from the start of scratch – 5.2mm
- Cost – RM 28/m^2

If Sa 2 system is to be implemented with the current coating system No. 1A, aside from being cost-effective, the equipments involves or prepared under Sa 2 standards requires special attention and coating defects by human error should be avoided at any cost. Risk-based inspection should be implemented together with this new system so that we can prevent coating failure on the operating equipments.

5.2 RECOMMENDATION

For future work and research, it is recommended to prolong the hours of exposure of the test samples to the corrosive environment inside the corrosion chamber. This is due to the fact that with the non-defect fully coated samples being tested, the indication of rusting or corrosion is very hard to occur within short duration of exposure. The proposed hours of exposure for all samples should be 6 months or more [23].

One surface of the coating on the metal sample should be scribed prior to the salt spray exposure [23]. The result from this action will allow us to study the type of corrosion that will form along the scribed mark / area. Furthermore, we can calculate the corrosion rate more accurately.

As for the weight measurement, it is recommended to use more precise measuring equipment which can measure up to the accuracy of 0.0001gram. This is necessary to get more accurate corrosion rate result from the calculation of mass loss.

Aside from scratch test as the only adhesion test, it is recommended to add another test which is Pull-off test (ASTM D4541) so that we can get more accurate quantitative results and data thus learn deeper about the relation of surface preparation in terms of blast-cleanliness standards with the adhesion properties of coating.

ASTM D4541 test method covers a procedure for evaluating the pull-off strength (commonly referred to as adhesion) of a coating system from metal substrates. The test determines either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force (pass/fail) [26].

Failure will occur along the weakest plane within the system comprised of the test fixture, adhesive, coating system, and substrate, and will be exposed by the fracture surface [26].

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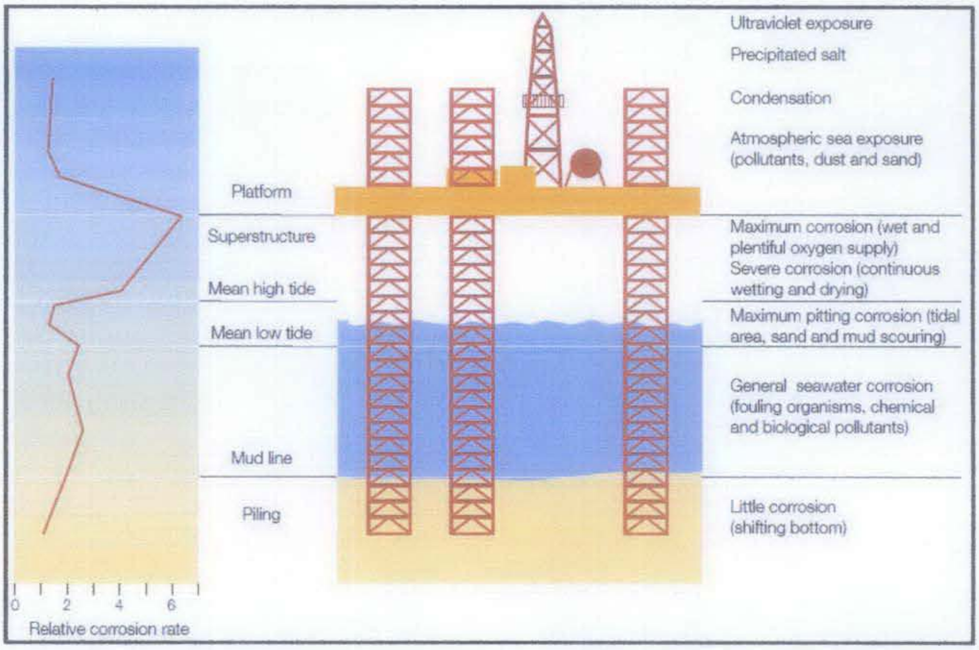
APPENDICES

Appendix A – Diverse corrosive environments attacking a typical offshore rig



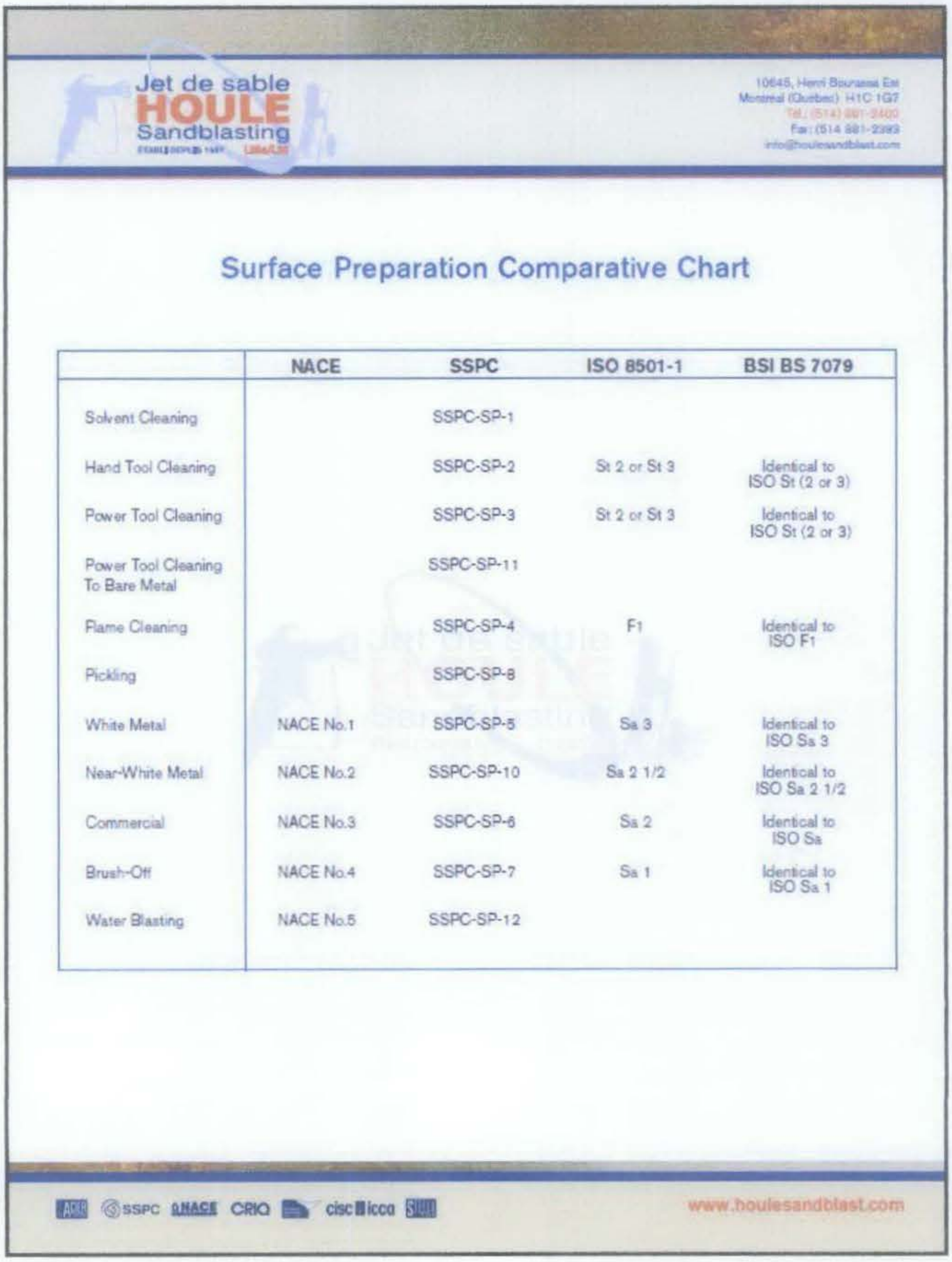
Appendix B – Coating system No. 1A based on PTS

Coating System No. 1A : Initial Painting

Surface preparation : Blast Cleaning to ISO 8501-1 : 1988, Sa 2.5

Coating system		DFT	
1 st coat	Inorganic Zinc Silicate / Epoxy Zinc Rich	75	μ
2 nd coat	High Solid epoxy	150	μ
3 rd coat	Aliphatic polyurethane	50	μ
Total		275	μ

Appendix C – Comparisons between the nomenclatures for different surface preparation standards.



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Surface Preparation Comparative Chart

	NACE	SSPC	ISO 8501-1	BSI BS 7079
Solvent Cleaning		SSPC-SP-1		
Hand Tool Cleaning		SSPC-SP-2	St 2 or St 3	Identical to ISO St (2 or 3)
Power Tool Cleaning		SSPC-SP-3	St 2 or St 3	Identical to ISO St (2 or 3)
Power Tool Cleaning To Bare Metal		SSPC-SP-11		
Flame Cleaning		SSPC-SP-4	F1	Identical to ISO F1
Pickling		SSPC-SP-8		
White Metal	NACE No.1	SSPC-SP-5	Sa 3	Identical to ISO Sa 3
Near-White Metal	NACE No.2	SSPC-SP-10	Sa 2 1/2	Identical to ISO Sa 2 1/2
Commercial	NACE No.3	SSPC-SP-6	Sa 2	Identical to ISO Sa
Brush-Off	NACE No.4	SSPC-SP-7	Sa 1	Identical to ISO Sa 1
Water Blasting	NACE No.5	SSPC-SP-12		

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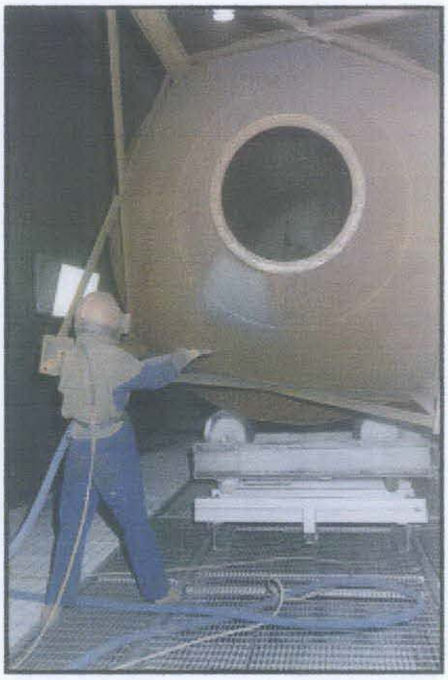
Appendix D – Typical blast-cleaning activities



Appendix E - Degrees of cleanliness of blast-cleaned surfaces

Key: Steel where mill scale has started to flake and light rusting occurs.

Key: Steel where all mill scale has flaked off and complete rusting has occured.

Key: Steel where pitting and complete rusting has taken place.

Brush-Off *Brush-Off* *Brush-Off*

Commercial *Commercial* *Commercial*

Near-White Metal *Near-White Metal* *Near-White Metal*

White Metal *White Metal* *White Metal*

Degrees of Cleanliness of Blast-Cleaned Surfaces*

*Images shown are previously uncoated surfaces, viewed without magnification

Brush-Off
Tightly adherent mill scale and rust may remain on the surface. Mill scale and rust are considered adherent if they cannot be removed with a dull putty knife.

SSPC-SP7
NACE No 4
SA-1

Commercial
Evenly dispersed very light shadows, streaks and discolorations caused by stains of rust and mill scale may remain on no more than 33% of the surface.

SSPC-SP 6
NACE No. 3
SA-2

Near-white Metal
Evenly dispersed very light shadows, streaks and discolorations caused by stains of rust and mill scale may remain on 5% of the surface.

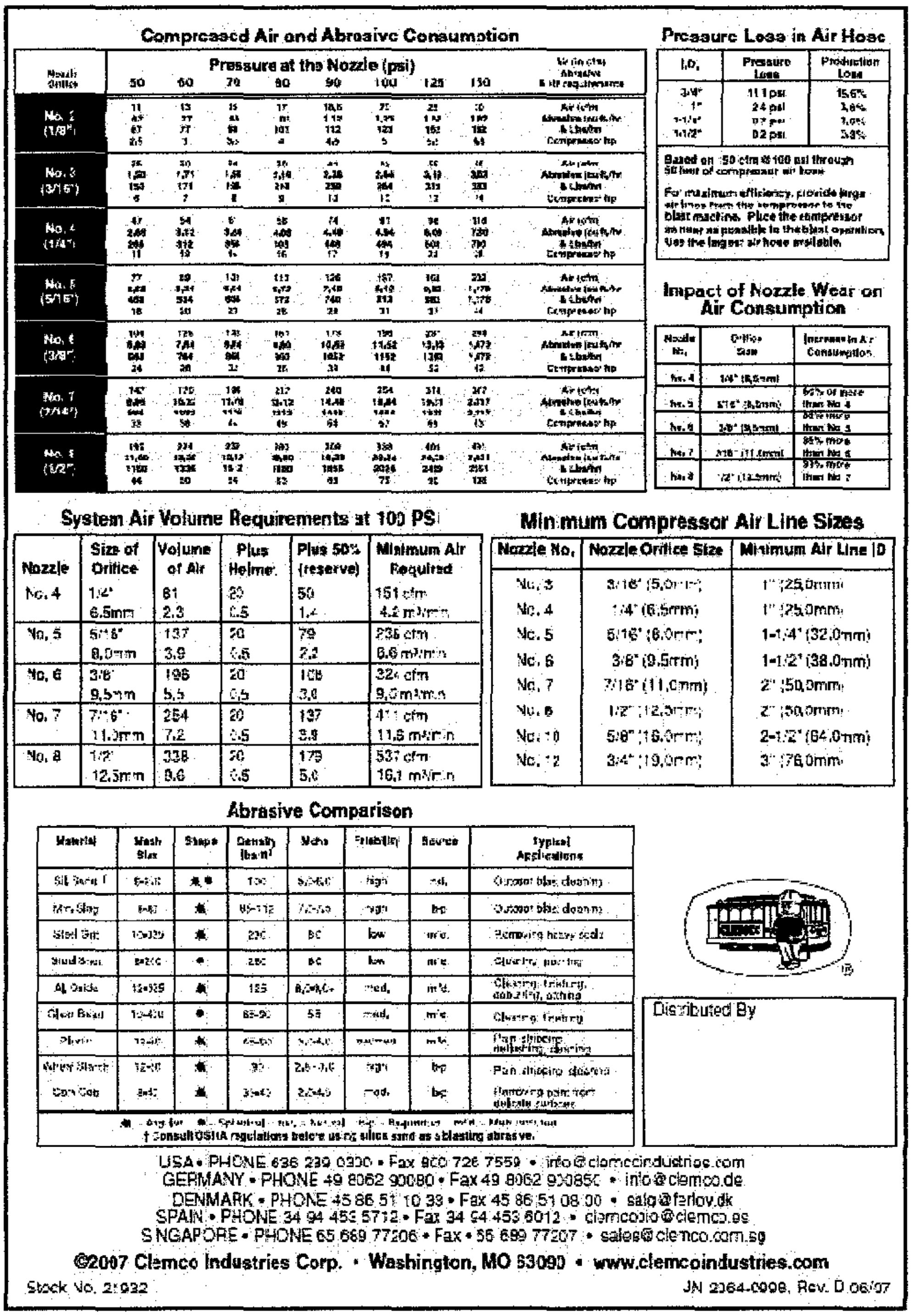
SSPC-SP 10
NACE No. 2
SA-2 1/2

White Metal
Free of all visible oil, grease, dirt, dust, mill scale and rust.

SSPC-SP 5
NACE No. 1
SA-3

For the complete official guide to surface cleanliness, refer to SSPC-Vis 1: Guide and Reference Photographs for Dry Abrasive Blast Cleaning; SSPC Publication 02-12 www.sspc.org

Appendix F – Typical equipments parameters and functions



Compressed Air and Abrasive Consumption

Nozzle Orifice	50	60	70	80	90	100	125	150	Air (in cfm) Abrasive & HP requirements
No. 2 (1/8")	11	13	15	17	18.5	20	25	30	Air (cfm)
	.67	.77	.88	1.01	1.12	1.23	1.52	1.82	Abrasive (cu.ft/hr
	67	77	88	101	112	123	152	182	& Lbs/hr)
	2.5	3	3.5	4	4.5	5	5.5	6.5	Compressor hp
No. 3 (3/16")	26	30	33	38	41	45	55	66	Air (cfm)
	1.50	1.71	1.96	2.16	2.38	2.64	3.19	3.83	Abrasive (cu.ft/hr
	150	171	196	216	238	264	319	383	& Lbs/hr)
	6	7	8	9	10	11	13	14	Compressor hp
No. 4 (1/4")	47	54	61	68	74	81	98	118	Air (cfm)
	2.68	3.12	3.54	4.08	4.48	4.94	6.08	7.30	Abrasive (cu.ft/hr
	268	312	354	408	448	494	608	730	& Lbs/hr)
	11	12	14	16	17	19	23	28	Compressor hp
No. 5 (5/16")	77	89	101	113	126	137	168	202	Air (cfm)
	4.68	5.34	6.04	6.72	7.40	8.12	9.82	11.78	Abrasive (cu.ft/hr
	468	534	604	672	740	812	982	1,178	& Lbs/hr)
	18	20	23	26	28	31	37	44	Compressor hp
No. 6 (3/8")	108	126	143	161	173	196	237	284	Air (cfm)
	6.88	7.84	8.84	9.60	10.52	11.52	13.92	16.72	Abrasive (cu.ft/hr
	688	784	884	960	1052	1152	1392	1672	& Lbs/hr)
	24	28	32	35	39	44	52	62	Compressor hp
No. 7 (7/16")	147	170	194	217	240	254	314	377	Air (cfm)
	8.96	10.32	11.60	13.12	14.48	15.84	19.36	23.20	Abrasive (cu.ft/hr
	896	1032	1160	1312	1448	1584	1936	2320	& Lbs/hr)
	33	38	44	49	54	57	69	83	Compressor hp
No. 8 (1/2")	195	224	252	280	309	338	409	491	Air (cfm)
	11.60	13.36	15.12	16.80	18.56	20.24	24.80	29.36	Abrasive (cu.ft/hr
	1160	1336	1512	1680	1856	2024	2480	2936	& Lbs/hr)
	44	50	56	63	69	75	90	110	Compressor hp

Pressure Loss in Air Hose

I.D.	Pressure Loss	Production Loss
3/4"	11.1 psi	15.6%
1"	2.4 psi	3.4%
1-1/4"	0.7 psi	1.0%
1-1/2"	0.2 psi	0.3%

Based on 150 cfm @ 100 psi through 50 feet of compressor air hose.

For maximum efficiency, provide large air lines from the compressor to the blast machine. Place the compressor as near as possible to the blast operation. Use the largest air hose available.

Impact of Nozzle Wear on Air Consumption

Nozzle No.	Orifice Size	Increase in Air Consumption
No. 4	1/4" (6.5mm)	
No. 5	5/16" (8.0mm)	57% more than No. 4
No. 6	3/8" (9.5mm)	44% more than No. 5
No. 7	7/16" (11.0mm)	35% more than No. 6
No. 8	1/2" (12.5mm)	31% more than No. 7

System Air Volume Requirements at 100 PSI

Nozzle	Size of Orifice	Volume of Air	Plus Helmet	Plus 50% (reserve)	Minimum Air Required
No. 4	1/4" 6.5mm	81 2.3	20 0.5	50 1.4	151 cfm 4.2 m^3/min
No. 5	5/16" 8.0mm	137 3.9	20 0.5	79 2.2	236 cfm 6.6 m^3/min
No. 6	3/8" 9.5mm	196 5.5	20 0.5	108 3.0	324 cfm 9.0 m^3/min
No. 7	7/16" 11.0mm	254 7.2	20 0.5	137 3.9	411 cfm 11.6 m^3/min
No. 8	1/2" 12.5mm	338 9.6	20 0.5	179 5.0	537 cfm 16.1 m^3/min

Minimum Compressor Air Line Sizes

Nozzle No.	Nozzle Orifice Size	Minimum Air Line ID
No. 3	3/16" (5.0mm)	1" (25.0mm)
No. 4	1/4" (6.5mm)	1" (25.0mm)
No. 5	5/16" (8.0mm)	1-1/4" (32.0mm)
No. 6	3/8" (9.5mm)	1-1/2" (38.0mm)
No. 7	7/16" (11.0mm)	2" (50.0mm)
No. 8	1/2" (12.5mm)	2" (50.0mm)
No. 10	5/8" (16.0mm)	2-1/2" (64.0mm)
No. 12	3/4" (19.0mm)	3" (76.0mm)

Abrasive Comparison

Material	Mesh Size	Shape	Density lbs/ft^3	Mohs	Friability	Source	Typical Applications
Silica Sand†	6-270	▲●	100	5.0-6.0	high	nat.	Outdoor blast cleaning
Min. Slag	8-80	▲	85-112	7.0-7.5	high	bp	Outdoor blast cleaning
Steel Grit	10-325	▲	230	8.0	low	m'fd.	Removing heavy scale
Steel Shot	8-200	●	280	8.0	low	m'fd.	Cleaning, peening
Al. Oxide	12-325	▲	125	8.0-9.0+	med.	m'fd.	Cleaning, finishing, deburring, etching
Glass Bead	10-400	●	85-90	5.5	med.	m'fd.	Cleaning, finishing
Plastic	12-80	▲	45-60	3.0-4.0	[illegible]	m'fd.	Paint stripping, deflashing, cleaning
Wheat Starch	12-50	▲	90	2.8-3.0	high	bp	Paint stripping, cleaning
Corn Cob	8-40	▲	35-45	2.0-4.5	med.	bp	Removing paint from delicate surfaces

▲ – Angular ● – Spherical nat. – Natural bp – By-product m'fd. – Manufactured

† Consult OSHA regulations before using silica sand as a blasting abrasive.

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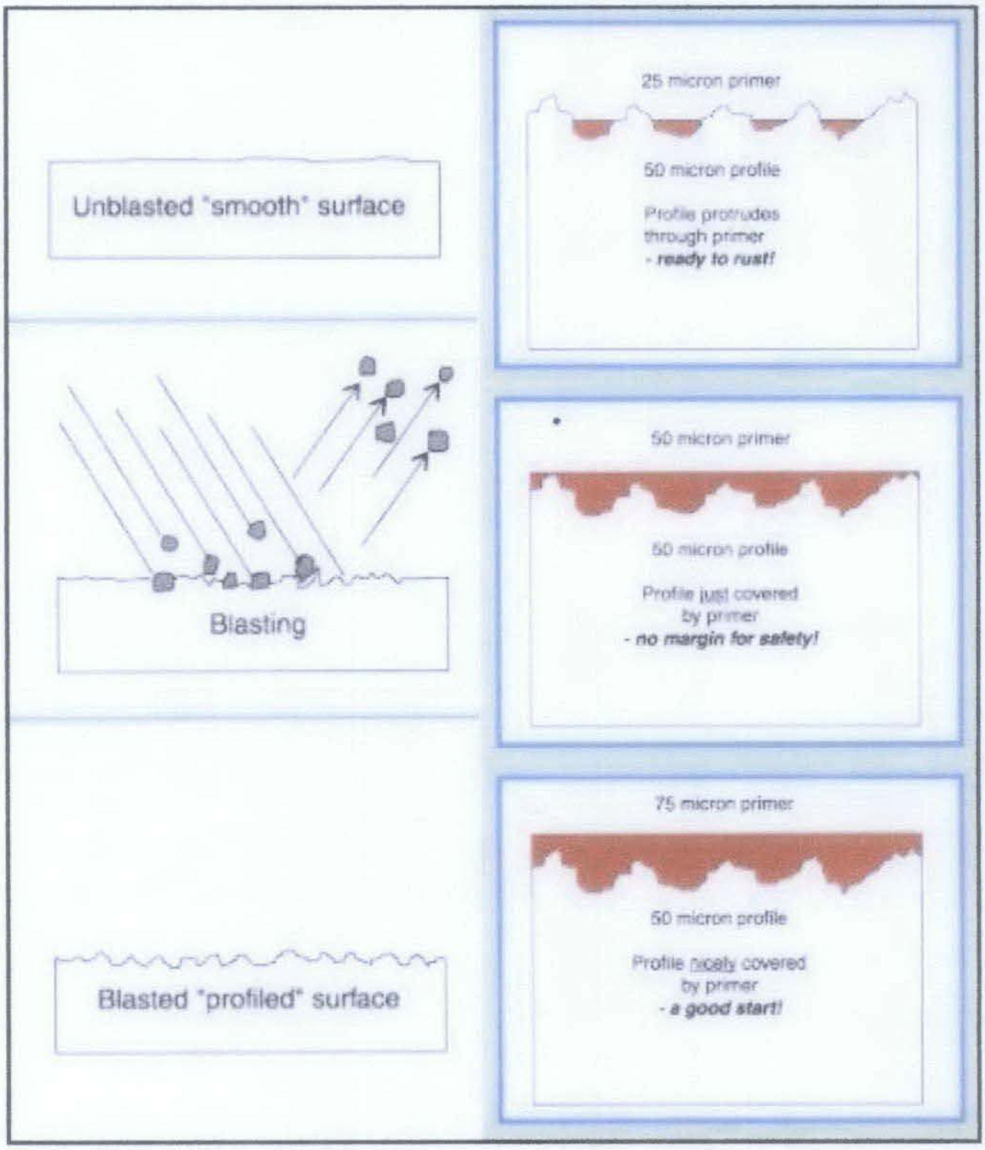
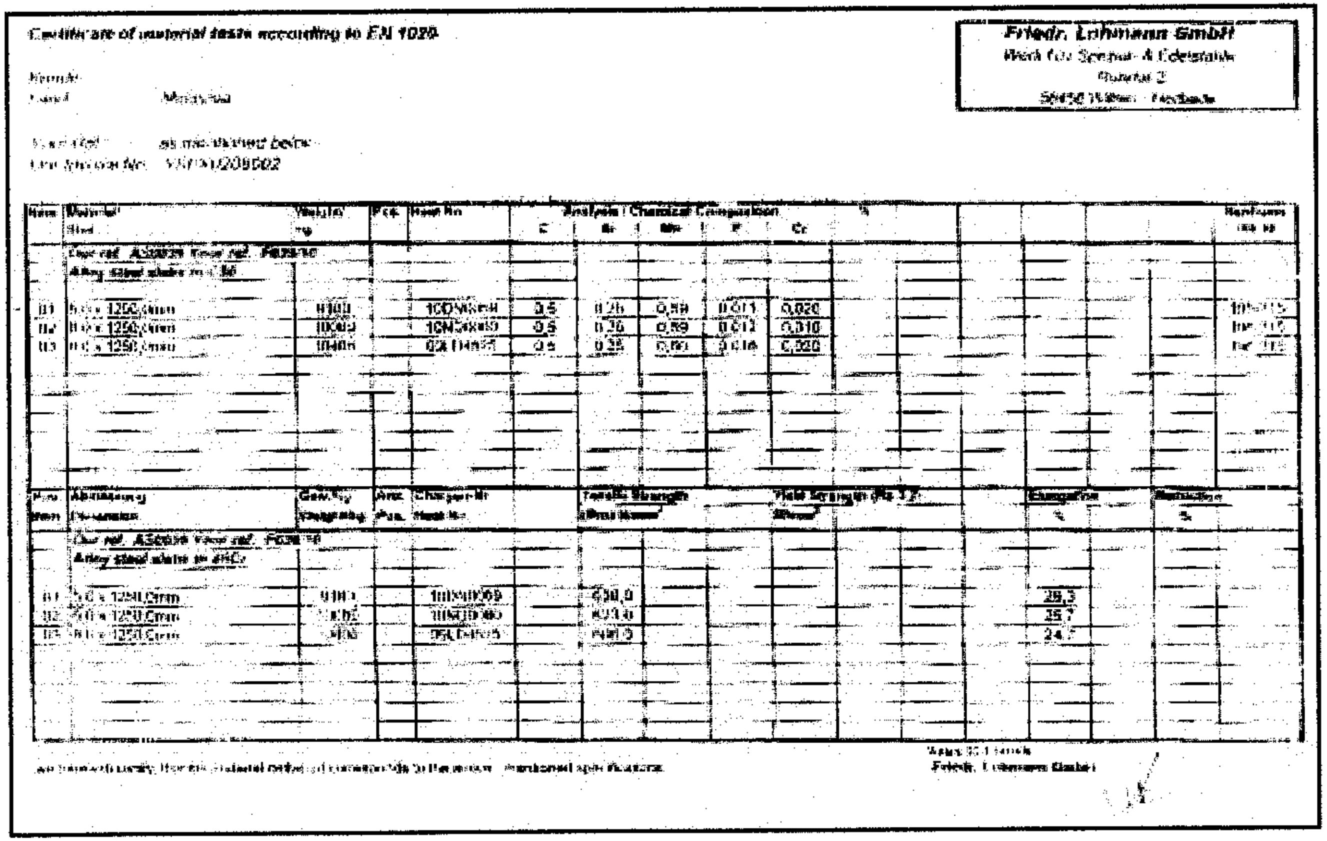
JN 2064-0998, Rev. D 06/07

Appendix G – The critical elements of surface preparation before coating



Appendix H – Mill certificate for the carbon steel specimens



Certificate of material tests according to EN 1020

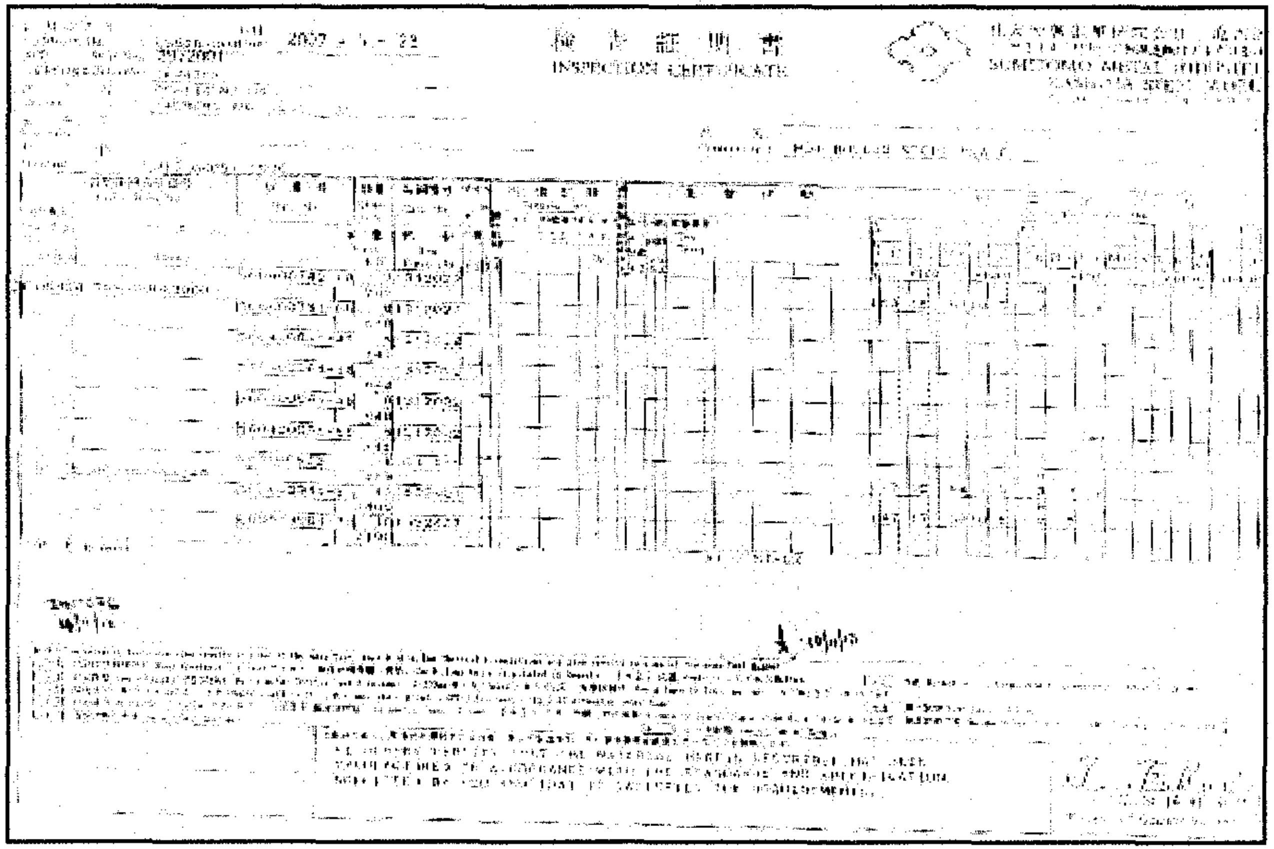
Friedr. Lohmann GmbH

Item	Material / Size	Weight kg	Pcs	Heat No	C	Si	Mn	P	Cr
01	[illegible] x 1250,0mm	[illegible]		[illegible]	0,5	0,26	0,59	0,011	0,020
02	[illegible] x 1250,0mm	[illegible]		[illegible]	0,5	0,26	0,59	0,012	0,010
03	[illegible] x 1250,0mm	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0,020

Pos.	Dimension	Weight kg	Pcs.	Heat No	Tensile Strength	Yield Strength	Elongation %
01	[illegible] x 1250,0mm	[illegible]		[illegible]	630,0		28,3
02	[illegible] x 1250,0mm	[illegible]		[illegible]	[illegible]		25,7
03	[illegible] x 1250,0mm	[illegible]		[illegible]	[illegible]		24,7

Friedr. Lohmann GmbH

Appendix H Cont'd (2) – Mill certificate for the carbon steel specimens



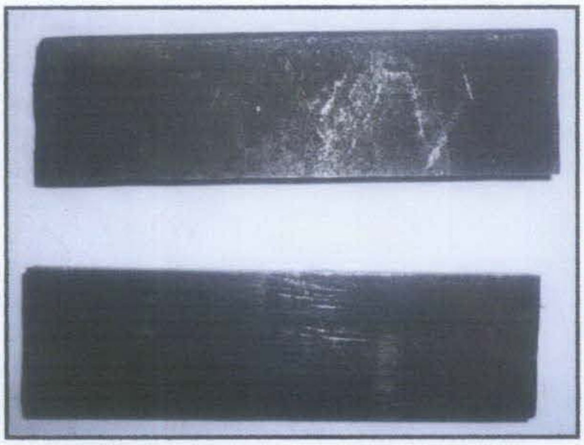
検 査 証 明 書
INSPECTION CERTIFICATE

SUMITOMO METAL

HOT ROLLED STEEL PLATE

Appendix I – The samples involved for each testing

Sample for corrosion test - 150mm (length) x 100mm (width) x 4.5mm (thick)



Sample for adhesion test - 70mm (length) x 20mm (width) x 5mm (thick)

Appendix J – Coating preparation and application activities

Coating preparation process – mixing and stirring

Applying coating onto the samples

Appendix K - Coating system testing requirements based on PTS

Coating System No	Salt Spray	Cyclic Salt Fog/UV Exposure	Adhesion	Impact	Abrasion	Water Immersion	Cathodic Disbonding	Accelerated Weathering	Heat Resistance
External Coating Systems									
1A									
1B 1C									
2A									
2B									
2C									
3A									
3B									
4A 4B									
5A(1) 5A(2)									
5B(1)									
5B(2)									
6A									
7A(1)									
7A(2)									
7A(3) 8B									
11									

Note :

Cyclic Salt Fog/UV Exposure test may be carried out in addition to the Salt Spray and Accelerated Weathering tests whenever considered necessary.

Adhesion test shall be carried out using the hydraulic adhesion/tensile tester.

Abrasion test is mandatory for coating systems which will be exposed to abrasion, wear and tear.

Appendix L – Samples arrangement inside the corrosion chamber

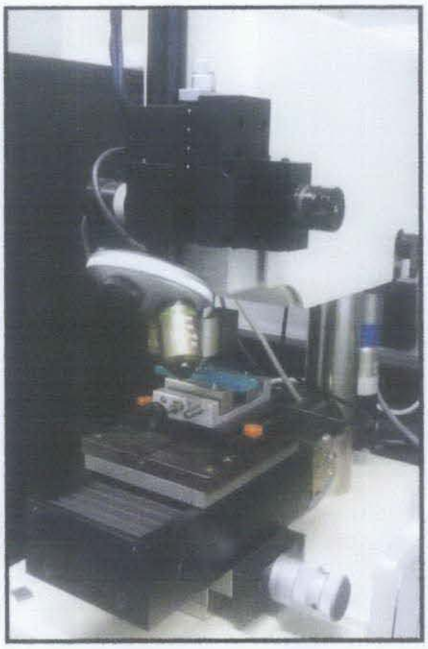
Appendix M – Parameters and ASTM standard shown on the machine's user-interface

Appendix N – Precise measurement of salt weight

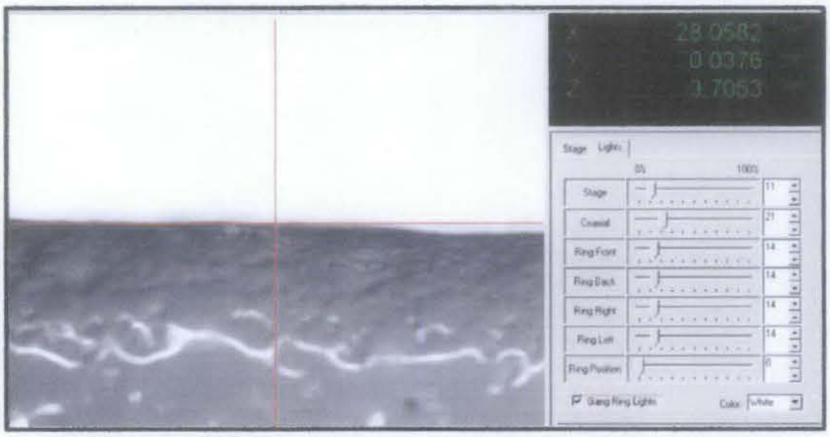
Appendix O - Table for recording the degree of rusting for each sample

Blast-Cleaning Standard	Samples	Area Percentage (%)	Rust Grade
Sa 2	A		
	B		
Sa 2.5	G		
	H		

Appendix P – Sample being tested by the scratch test machine



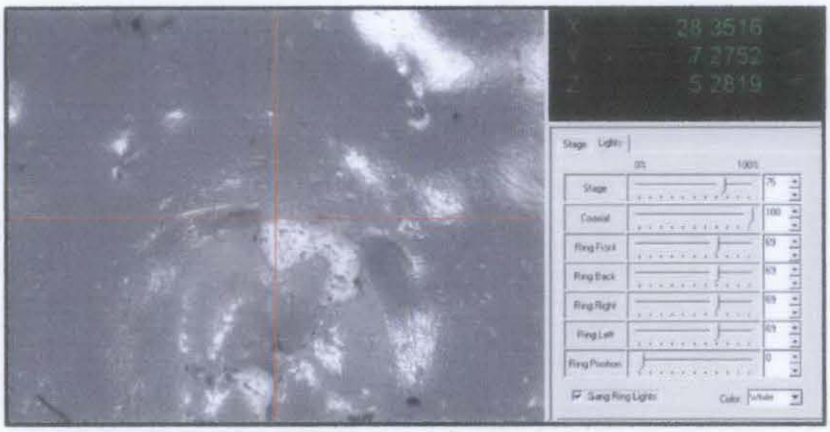
Appendix Q – Coordinate used for estimating scratch length and coating failure location



X 28.0582
Y 0.0376
Z 3.7053

Stage 11
Coaxial 21
Ring Front 14
Ring Back 14
Ring Right 14
Ring Left 14
Ring Position 0
☑ Gang Ring Lights
Color: White

Coordinate A, (X_A, Y_A) for top edge location which is (28.0582, 0.0376)

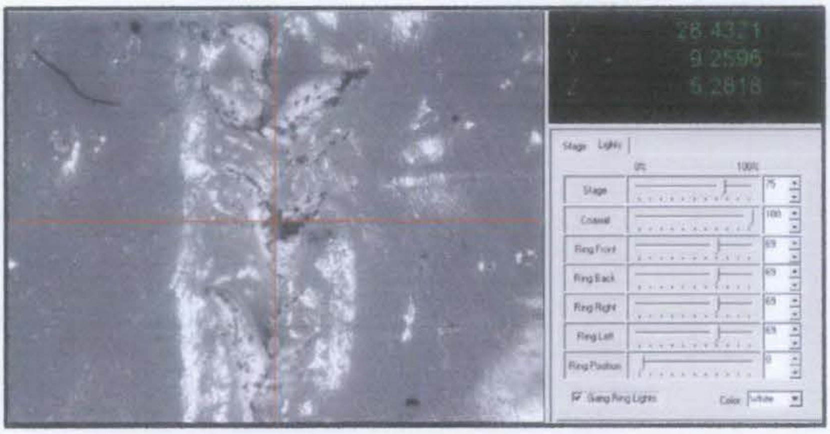


X 28.3516
Y 7.2752
Z 5.2819

Stage 75
Coaxial 100
Ring Front 69
Ring Back 69
Ring Right 69
Ring Left 69
Ring Position 0
☑ Gang Ring Lights
Color: White

Coordinate B, (X_B, Y_B) for end of scratch location which is (28.3516, 7.2752)

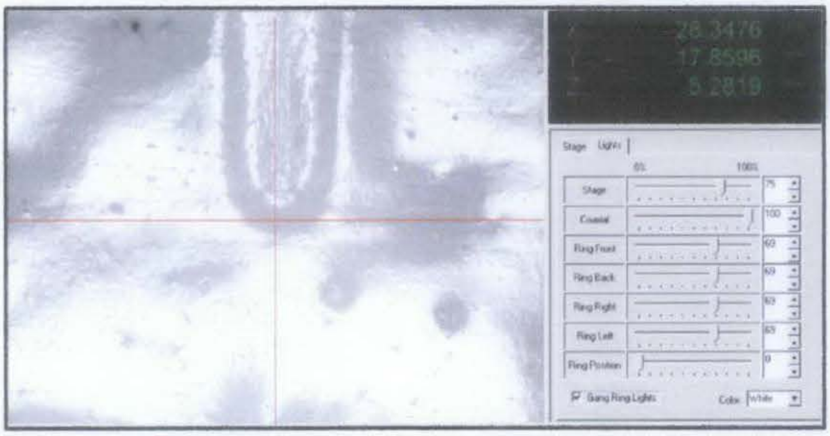
Appendix Q Cont'd (2) – Coordinate used for estimating scratch length and coating failure location



X 28.4321
Y 9.2596
Z 6.2818

Stage 75
Coaxial 100
Ring Front 69
Ring Back 69
Ring Right 69
Ring Left 69
Ring Position 0
☑ Gang Ring Lights
Color White

Coordinate C, (X_C, Y_C) for coating failure location which is (28.4321, 9.2596)



X 28.3476
Y 17.8596
Z 6.2819

Stage 75
Coaxial 100
Ring Front 69
Ring Back 69
Ring Right 69
Ring Left 69
Ring Position 0
☑ Gang Ring Lights
Color White

Coordinate D, (X_D, Y_D) for start of scratch location which is (28.3476, 17.8596)

Appendix R – Project Gantt chart

No.	Details	1	2	3	4	5	6		7	8	9	10	11	12	13	14	15	16
1	Selection of FYP topic title	🟦	🟦					MID SEMESTER BREAK										
2	Preliminary Research Work		🟦	🟦	🟦													
3	Submission of Preliminary Report				🟥													
4	Study on the Corrosion Working Principles				🟦	🟦	🟦											
5	Study on the Coating Working Principles				🟦	🟦	🟦											
6	Study on the Methods of Surface Preparation					🟦	🟦		🟦									
7	Study on the Methods of Coating Techniques					🟦	🟦		🟦									
8	Submission of Progress Report									🟥								
9	Seminar									🟥								
10	Selection of Surface Preparation Method									🟦	🟦							
11	Selection of Coating Technique									🟦	🟦							
12	Study on the Adhesion Measurement Methods and Procedures										🟦	🟦						
13	Study on the Corrosion Measurement Methods and Procedures										🟦	🟦						
14	Selection of Adhesion Measurement Method												🟦	🟦				
15	Selection of Corrosion Measurement Method												🟦	🟦				
16	Preparation For Interim Report													🟦	🟦	🟦		
17	Submission of Interim Report Final Draft															🟥		
18	Oral Presentation																🟥	🟥

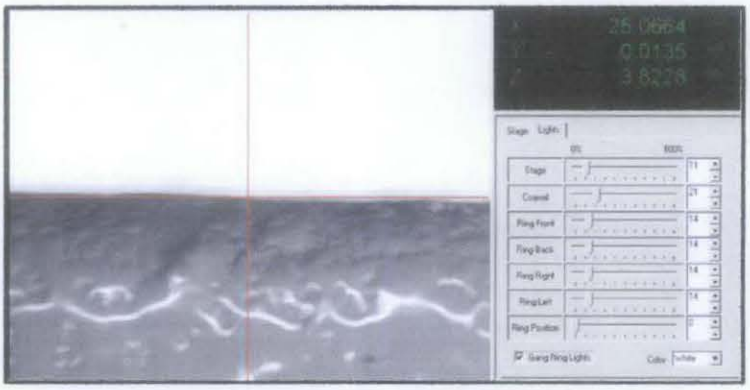
Final Year Project I

Appendix R Cont'd (2) – Project Gantt chart

No.	**Details**	**1**	**2**	**3**	**4**	**5**	**6**		**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Conducting Surface Preparation	🟦	🟦					**MID SEMESTER BREAK**									
2	Performing Coating		🟦	🟦	🟦	🟦											
3	Preparing for Corrosion Test						🟦		🟦								
4	Conducting Corrosion Test								🟦	🟦	🟦	🟦					
5	Preparing for Adhesion Test (Scratch Test)						🟦		🟦								
6	Conducting the Adhesion Test (Scratch Test)								🟦	🟦							
7	Submission of Progress Report										🟥						
8	Preparing for Adhesion Test (Pull-Off Test)									🟦	🟦						
9	Conducting the Adhesion Test (Pull-Off Test)										🟦	🟦					
10	Pre-EDX												🟥				
11	Submission of Draft Report													🟥			
12	Preparation of Project Dissertation											🟦	🟦	🟦	🟦	🟦	
13	Submission of Dissertation (soft bound)														🟥		
14	Preparation of Technical Paper													🟦	🟥		
15	Submission of Technical Paper														🟥		
16	Oral Presentation															🟥	
17	Submission of Project Dissertation (hard bound)																🟥

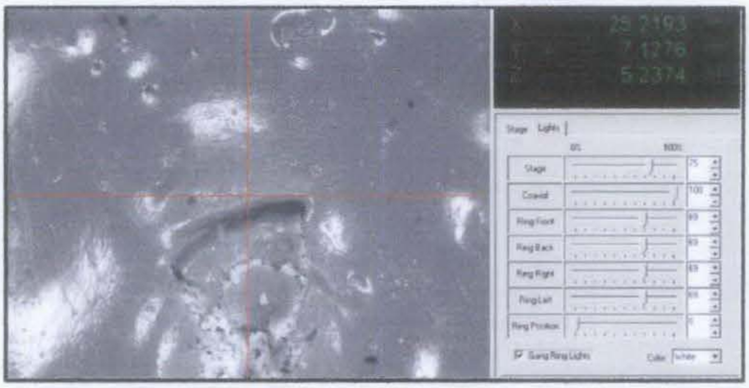
Final Year Project II

Appendix S – Coordinates for 3D non-contact measurement for Sa 2 sample



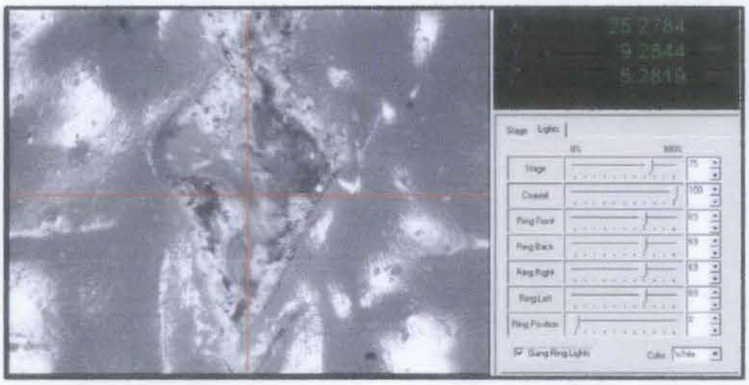
X 25.0664
Y 0.0135
Z 3.8228

Coordinate A, (X_A, Y_A) for top edge location which is (25.0664, 0.0135)



X 25.2193
Y 7.1276
Z 5.2374

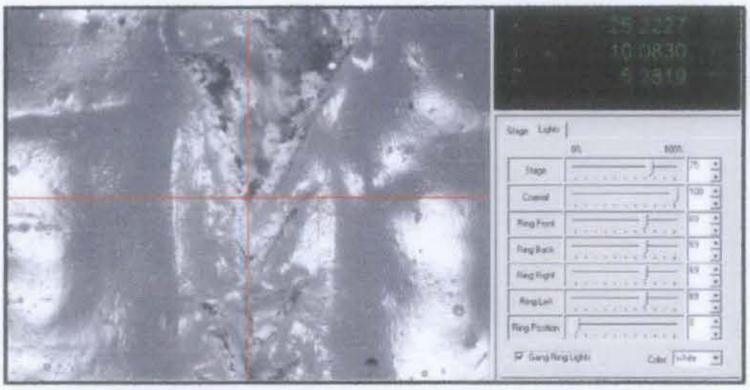
Coordinate B, (X_B, Y_B) for end of scratch location which is (25.2193, 7.1276)



X 25.2784
Y 9.2844
Z 5.2819

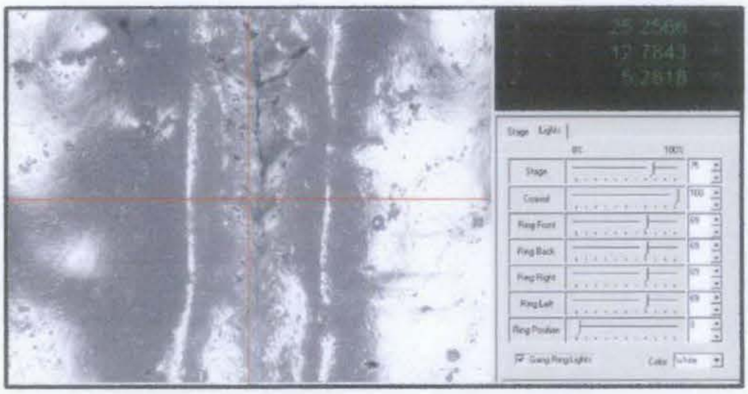
Coordinate C, (X_C, Y_C) for coating failure location which is (25.2784, 9.2844)

Appendix S (Cont'd) – Coordinates for 3D non-contact measurement for Sa 2 sample



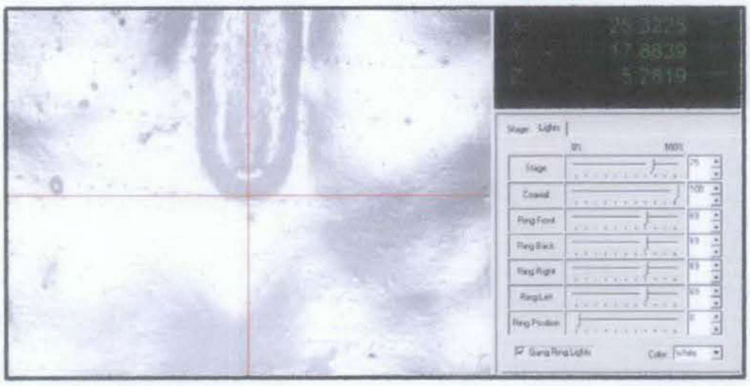
25.2227
10.0830
5.2819

Coordinate D, (X_D, Y_D) for coating failure location which is (25.2227, 10.0830)



25.2566
12.7843
5.2818

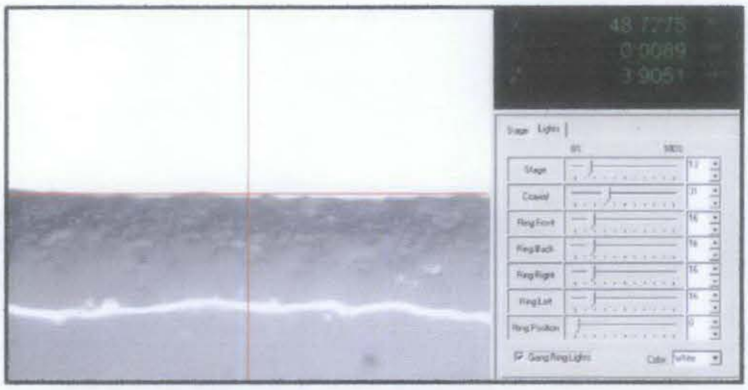
Coordinate E, (X_E, Y_E) for coating failure location which is (25.2566, 12.7843)



25.3225
17.8839
5.2819

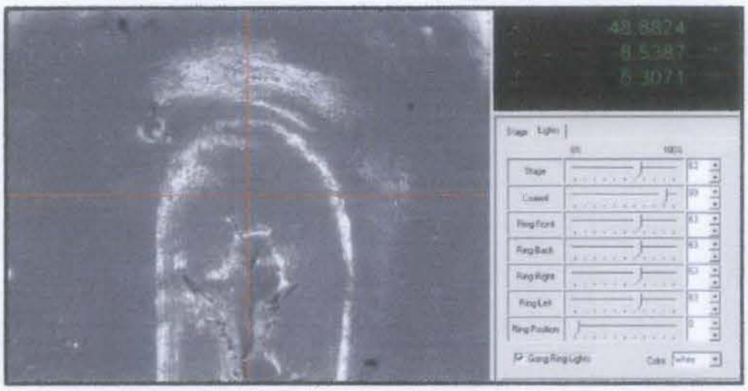
Coordinate F, (X_F, Y_F) for start of scratch location which is (25.3225, 17.8839)

Appendix T – Coordinates for 3D non-contact measurement for Sa 2.5 sample



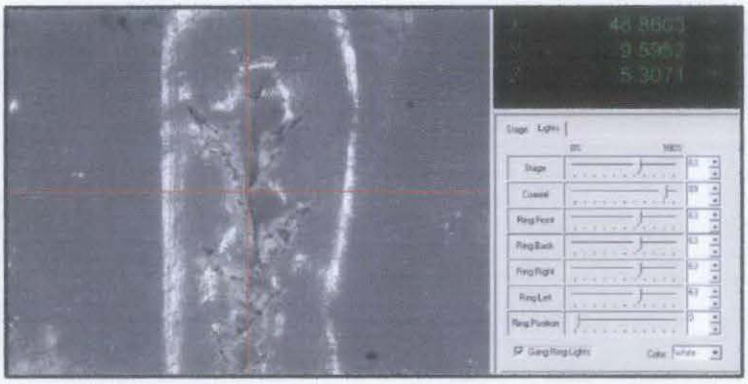
48.7275
0.0089
3.9051

Coordinate A, (X_A, Y_A) for top edge location which is (48.7275, 0.0089)



48.8824
8.5387
8.3071

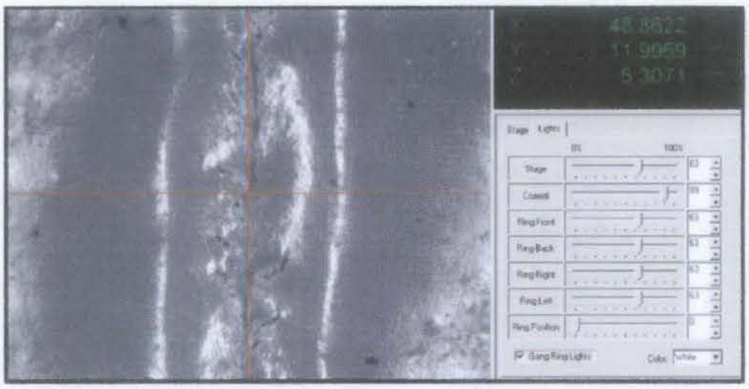
Coordinate B, (X_B, Y_B) for end of scratch location which is (48.8824, 8.5387)



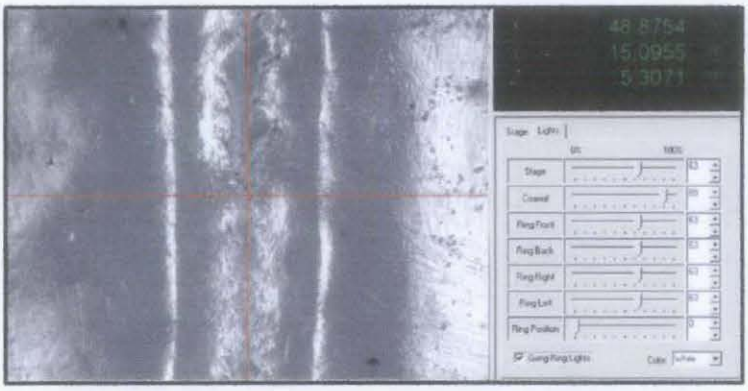
48.8603
9.5952
5.3071

Coordinate C, (X_C, Y_C) for coating failure location which is (48.8603, 9.5952)

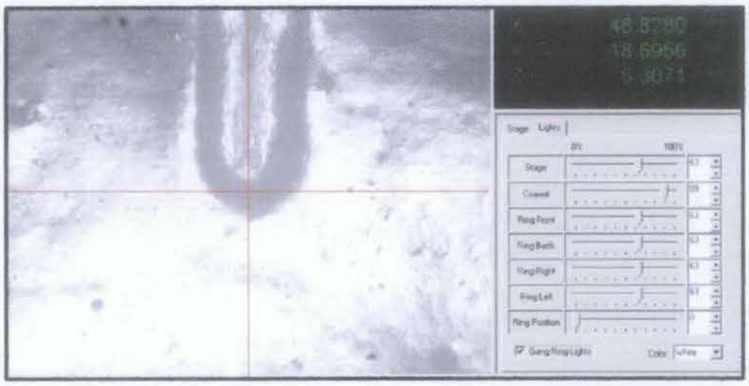
Appendix T (Cont'd) – Coordinates for 3D non-contact measurement for Sa 2.5 sample


X 48.8622
Y 11.9959
Z 5.3071

Coordinate D, (X_D, Y_D) for coating failure location which is (48.8622, 11.9959)

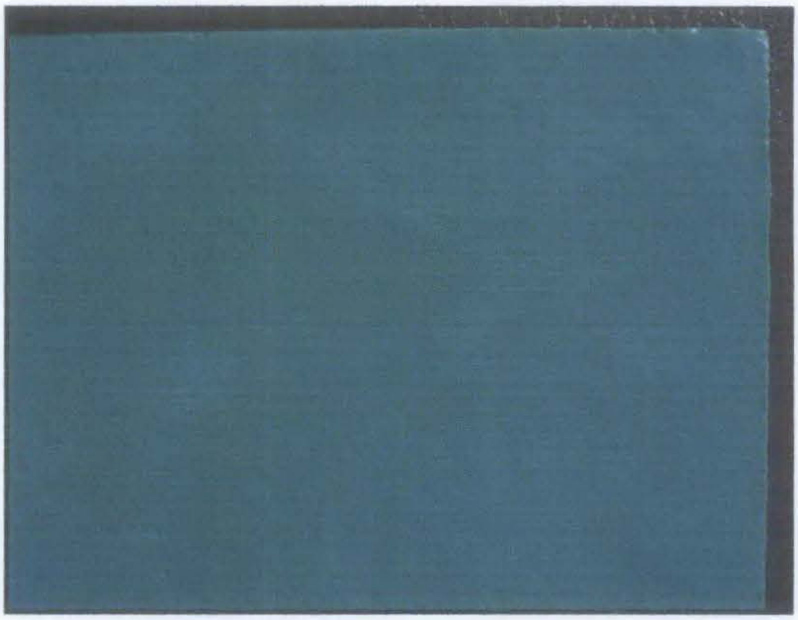

X 48.8754
Y 15.0955
Z 5.3071

Coordinate E, (X_E, Y_E) for coating failure location which is (48.8754, 15.0955)

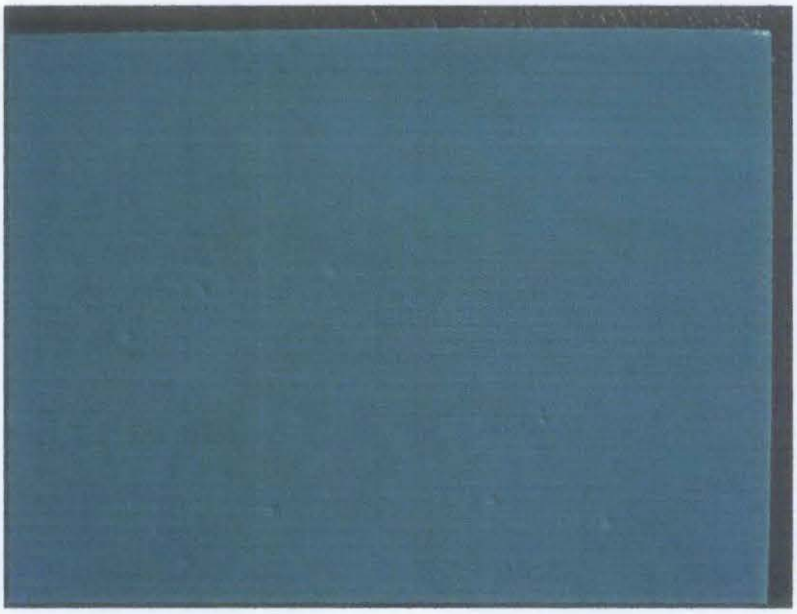

X 48.8280
Y 18.6956
Z 5.3071

Coordinate F, (X_F, Y_F) for start of scratch location which is (48.8280, 18.6956)

Appendix U – Figures showing the area in which visual examination is conducted

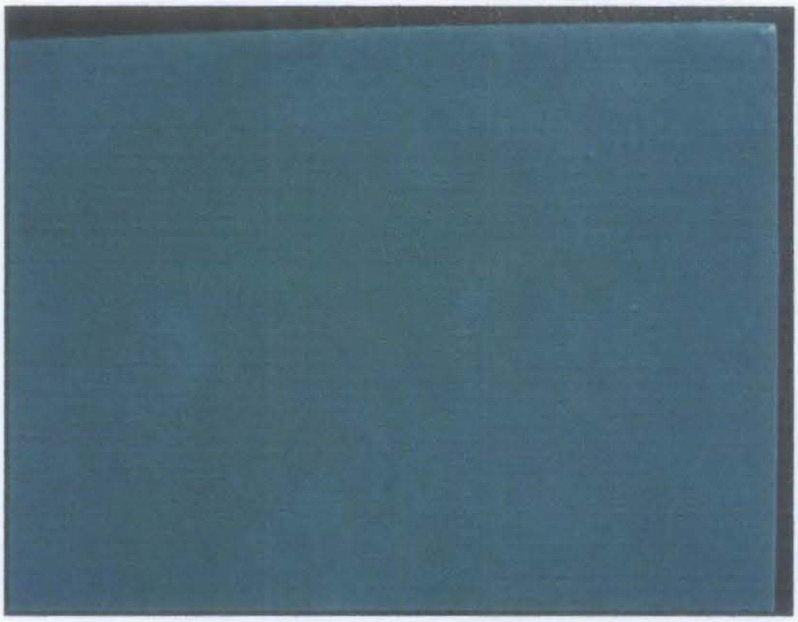


Sample A

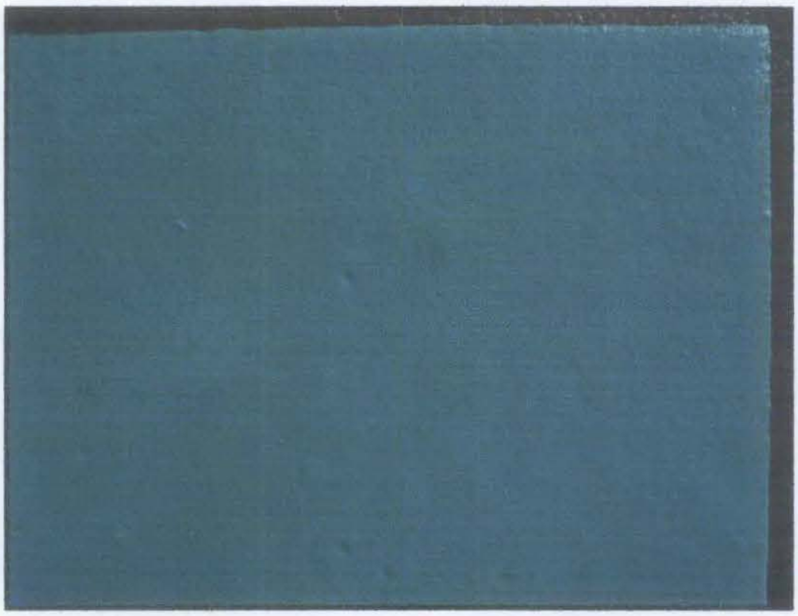


Sample B

Appendix U (Cont'd) – Figures showing the area in which visual examination is conducted

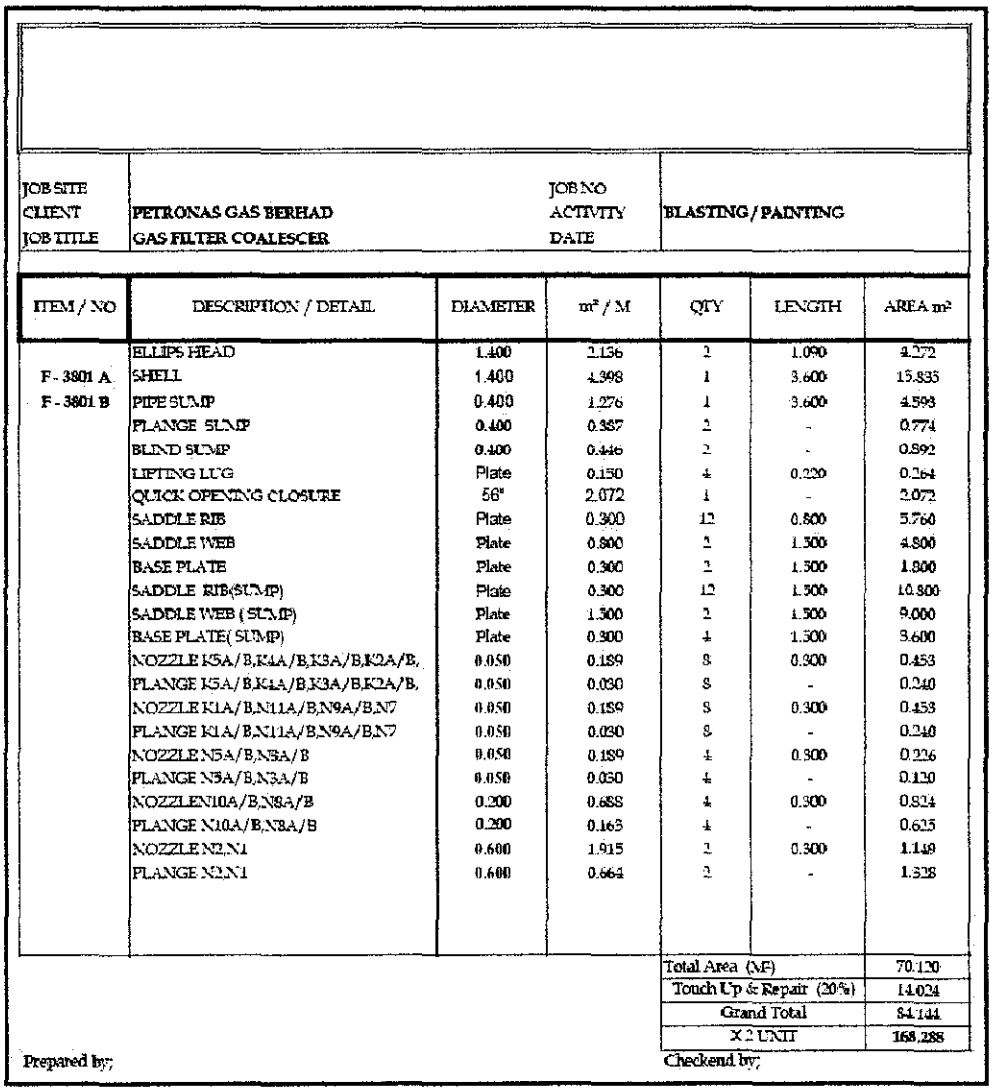


Sample C



Sample D

Appendix V – Activity report for Project B



JOB SITE		JOB NO	
CLIENT	PETRONAS GAS BERHAD	ACTIVITY	BLASTING / PAINTING
JOB TITLE	GAS FILTER COALESCER	DATE	

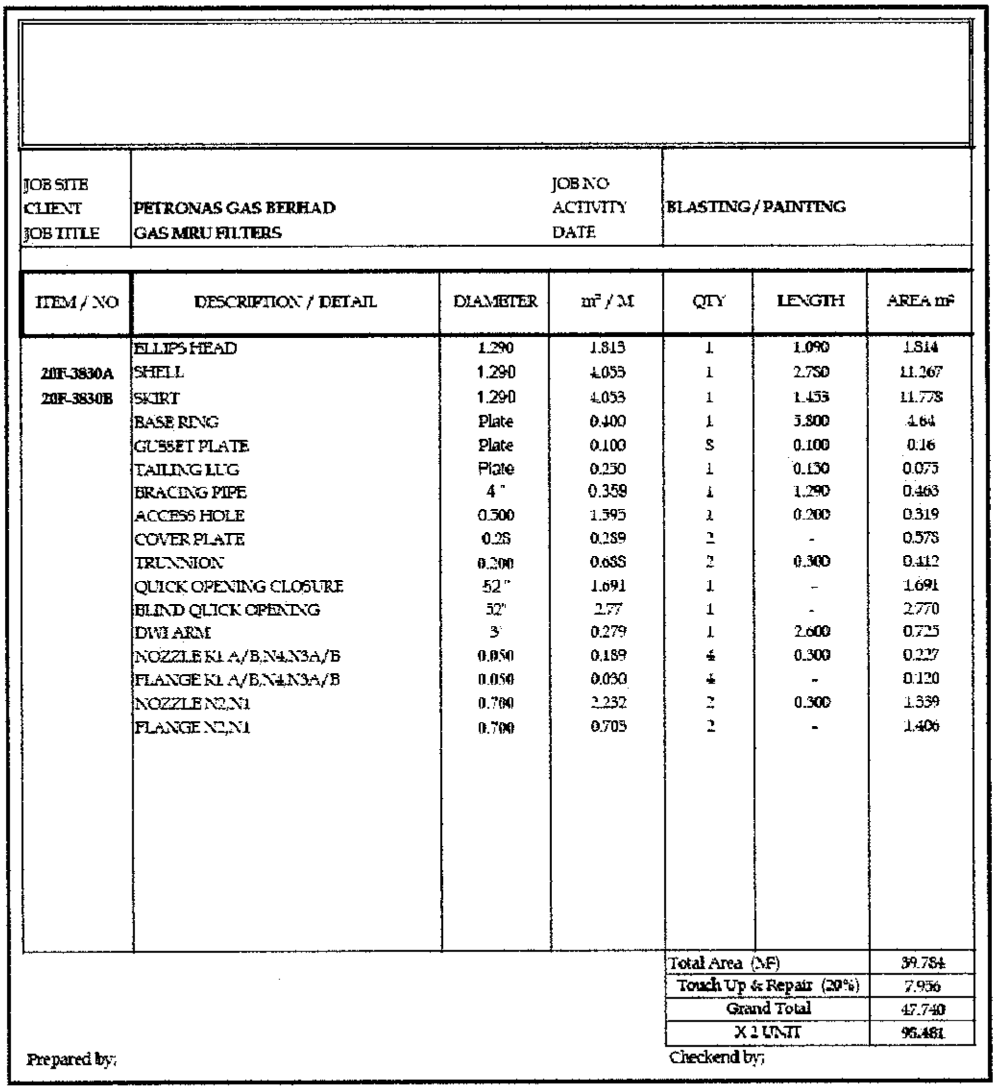
ITEM / NO	DESCRIPTION / DETAIL	DIAMETER	m^2 / M	QTY	LENGTH	AREA m^2
	ELLIPS HEAD	1.400	2.136	2	1.090	4.272
F - 3801 A	SHELL	1.400	4.398	1	3.600	15.835
F - 3801 B	PIPE SUMP	0.400	1.276	1	3.600	4.593
	FLANGE SUMP	0.400	0.387	2	-	0.774
	BLIND SUMP	0.400	0.446	2	-	0.892
	LIFTING LUG	Plate	0.150	4	0.220	0.264
	QUICK OPENING CLOSURE	56"	2.072	1	-	2.072
	SADDLE RIB	Plate	0.300	12	0.800	5.760
	SADDLE WEB	Plate	0.800	2	1.500	4.800
	BASE PLATE	Plate	0.300	2	1.500	1.800
	SADDLE RIB(SUMP)	Plate	0.300	12	1.500	10.800
	SADDLE WEB (SUMP)	Plate	1.500	2	1.500	9.000
	BASE PLATE(SUMP)	Plate	0.300	4	1.500	3.600
	NOZZLE K5A/B,K4A/B,K3A/B,K2A/B,	0.050	0.189	8	0.300	0.453
	FLANGE K5A/B,K4A/B,K3A/B,K2A/B,	0.050	0.030	8	-	0.240
	NOZZLE K1A/B,N11A/B,N9A/B,N7	0.050	0.189	8	0.300	0.453
	FLANGE K1A/B,N11A/B,N9A/B,N7	0.050	0.030	8	-	0.240
	NOZZLE N5A/B,N3A/B	0.050	0.189	4	0.300	0.226
	FLANGE N5A/B,N3A/B	0.050	0.030	4	-	0.120
	NOZZLEN10A/B,N8A/B	0.200	0.688	4	0.300	0.824
	FLANGE N10A/B,N8A/B	0.200	0.163	4	-	0.625
	NOZZLE N2,N1	0.600	1.915	2	0.300	1.149
	FLANGE N2,N1	0.600	0.664	2	-	1.328

Total Area (M^2)	70.120
Touch Up & Repair (20%)	14.024
Grand Total	84.144
X 2 UNIT	168.288

Prepared by;

Checkend by;

Appendix V Cont'd (2) – Activity report for Project B



JOB SITE		JOB NO	
CLIENT	**PETRONAS GAS BERHAD**	ACTIVITY	**BLASTING / PAINTING**
JOB TITLE	**GAS MRU FILTERS**	DATE	

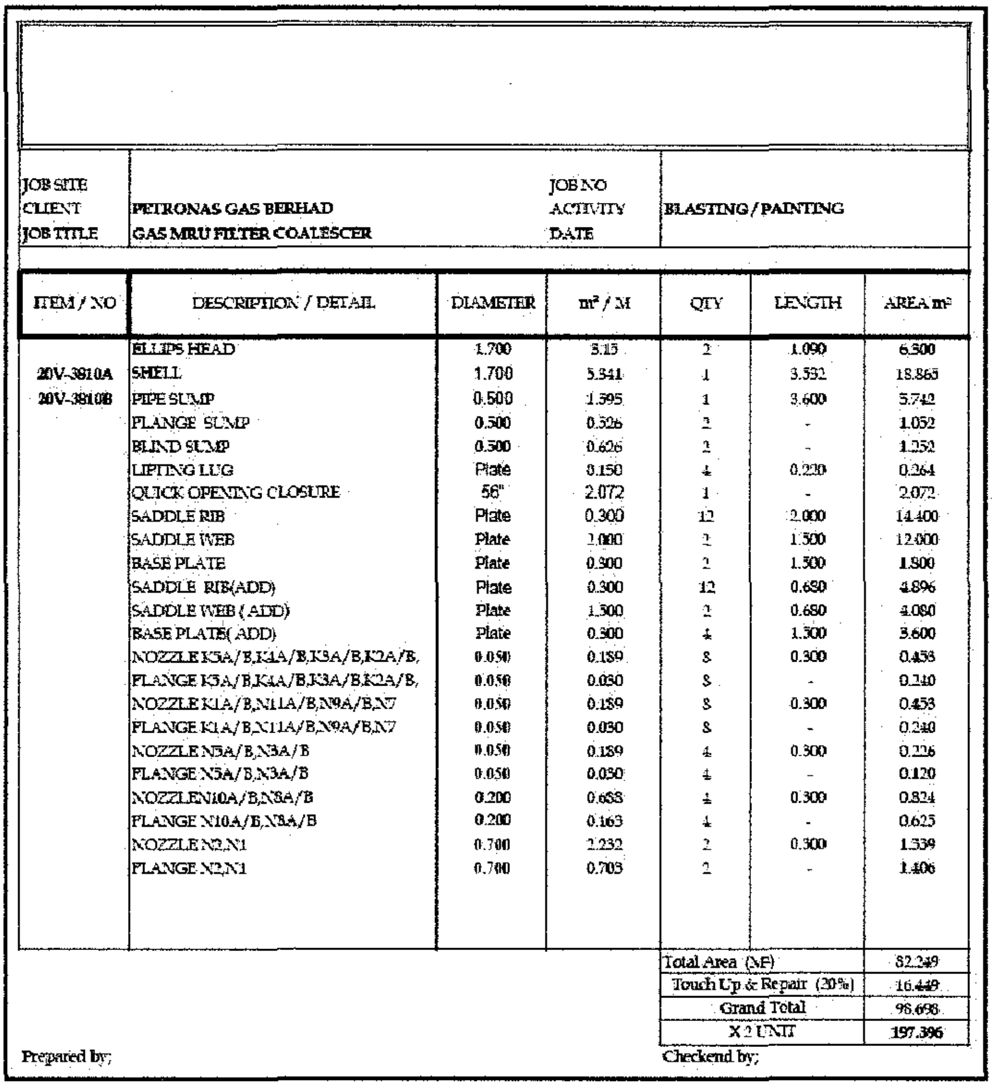
ITEM / NO	DESCRIPTION / DETAIL	DIAMETER	m^2 / M	QTY	LENGTH	AREA m^2
	ELLIPS HEAD	1.290	1.813	1	1.090	1.814
20F-3830A	SHELL	1.290	4.053	1	2.780	11.267
20F-3830B	SKIRT	1.290	4.053	1	1.453	11.778
	BASE RING	Plate	0.400	1	5.800	4.64
	GUSSET PLATE	Plate	0.100	8	0.100	0.16
	TAILING LUG	Plate	0.250	1	0.150	0.075
	BRACING PIPE	4 "	0.359	1	1.290	0.463
	ACCESS HOLE	0.500	1.595	1	0.200	0.319
	COVER PLATE	0.28	0.289	2	-	0.578
	TRUNNION	0.200	0.688	2	0.300	0.412
	QUICK OPENING CLOSURE	52 "	1.691	1	-	1.691
	BLIND QUICK OPENING	52"	2.77	1	-	2.770
	DWI ARM	3"	0.279	1	2.600	0.725
	NOZZLE K1 A/B,N4,N3A/B	0.050	0.189	4	0.300	0.227
	FLANGE K1 A/B,N4,N3A/B	0.050	0.030	4	-	0.120
	NOZZLE N2,N1	0.700	2.232	2	0.300	1.339
	FLANGE N2,N1	0.700	0.703	2	-	1.406

Total Area (MF)	39.784
Touch Up & Repair (20%)	7.956
Grand Total	47.740
X 2 UNIT	95.481

Prepared by;

Checkend by;

Appendix V Cont'd (3) – Activity report for Project B



JOB SITE		JOB NO	
CLIENT	PETRONAS GAS BERHAD	ACTIVITY	BLASTING / PAINTING
JOB TITLE	GAS MRU FILTER COALESCER	DATE	

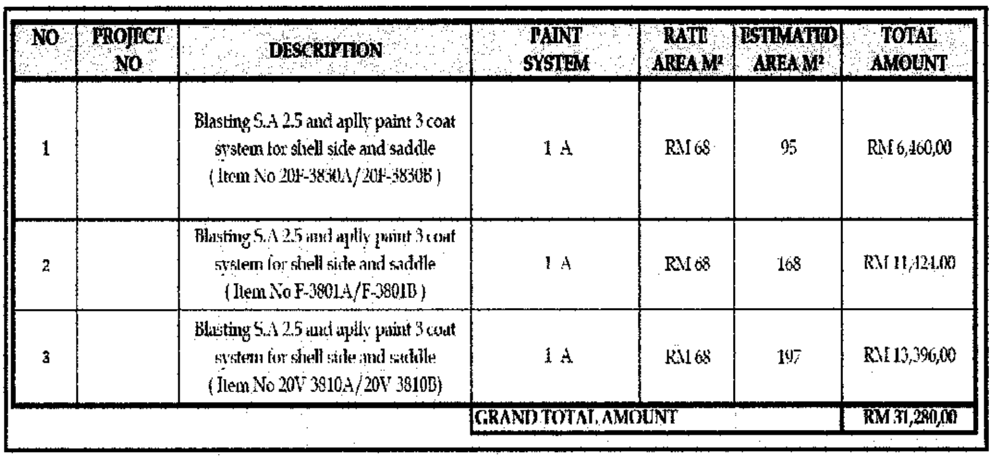
ITEM / NO	DESCRIPTION / DETAIL	DIAMETER	m² / M	QTY	LENGTH	AREA m²
	ELLIPS HEAD	1.700	3.15	2	1.090	6.300
20V-3810A	SHELL	1.700	5.341	1	3.532	18.865
20V-3810B	PIPE SUMP	0.500	1.595	1	3.600	5.742
	FLANGE SUMP	0.500	0.526	2	-	1.052
	BLIND SUMP	0.500	0.626	2	-	1.252
	LIFTING LUG	Plate	0.150	4	0.220	0.264
	QUICK OPENING CLOSURE	56"	2.072	1	-	2.072
	SADDLE RIB	Plate	0.300	12	2.000	14.400
	SADDLE WEB	Plate	2.000	2	1.500	12.000
	BASE PLATE	Plate	0.300	2	1.500	1.800
	SADDLE RIB(ADD)	Plate	0.300	12	0.680	4.896
	SADDLE WEB (ADD)	Plate	1.500	2	0.680	4.080
	BASE PLATE(ADD)	Plate	0.300	4	1.300	3.600
	NOZZLE K5A/B,K4A/B,K3A/B,K2A/B,	0.050	0.189	8	0.300	0.453
	FLANGE K5A/B,K4A/B,K3A/B,K2A/B,	0.050	0.030	8	-	0.240
	NOZZLE K1A/B,N11A/B,N9A/B,N7	0.050	0.189	8	0.300	0.453
	FLANGE K1A/B,N11A/B,N9A/B,N7	0.050	0.030	8	-	0.240
	NOZZLE N5A/B,N3A/B	0.050	0.189	4	0.300	0.226
	FLANGE N5A/B,N3A/B	0.050	0.030	4	-	0.120
	NOZZLEN10A/B,N8A/B	0.200	0.688	4	0.300	0.824
	FLANGE N10A/B,N8A/B	0.200	0.163	4	-	0.625
	NOZZLE N2,N1	0.700	2.232	2	0.300	1.339
	FLANGE N2,N1	0.700	0.703	2	-	1.406

Total Area (M²)	82.249
Touch Up & Repair (20%)	16.449
Grand Total	98.698
X 2 UNIT	197.396

Prepared by;

Checkend by;

Appendix W – Blasting and painting quotation for Project B



NO	PROJECT NO	DESCRIPTION	PAINT SYSTEM	RATE AREA M²	ESTIMATED AREA M²	TOTAL AMOUNT
1		Blasting S.A 2.5 and aplly paint 3 coat system for shell side and saddle (Item No 20F-3830A/20F-3830B)	1 A	RM 68	95	RM 6,460,00
2		Blasting S.A 2.5 and aplly paint 3 coat system for shell side and saddle (Item No F-3801A/F-3801B)	1 A	RM 68	168	RM 11,424.00
3		Blasting S.A 2.5 and aplly paint 3 coat system for shell side and saddle (Item No 20V 3810A/20V 3810B)	1 A	RM 68	197	RM 13,396,00
			GRAND TOTAL AMOUNT			RM 31,280,00

Appendix X – Surface preparation specification

NEAREST EQUIVALENT OF THE MAIN SURFACE PREPARATION SPECIFICATIONS.			
Abrasive Blast Cleaning	**SSPC**	**ISO 8501-1**	**NACE**
Extremely Thorough, White Metal Blast	SP 5	SA 3	No. 1
Very Thorough, Near White Metal Blast	SP 10	Sa 2.5	No. 2
Thorough, Commercial Blast	SP 6	Sa 2	No. 3
Light Brush-Off Blast	SP 7	SA 1	No.4
Tool Cleaning	**SSPC**	**ISO 8501-1**	**NACE**
Extremely Thorough, Power Tool Cleaning	SP 11	-	-
Very Thorough, Power Tool Cleaning	SP 3	St 3	-
Thorough, Hand Tool Cleaning	SP 2	St 2	-
Solvent Cleaning	**SSPC**	**ISO**	**NACE**
Solvent Cleaning	SP 1	-	-

Appendix Y – ASTM Standards

Designation: B 117 – 03

Standard Practice for Operating Salt Spray (Fog) Apparatus[1]

This standard is issued under the fixed designation B 117; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

e

'his practice covers the apparatus, procedure, and ns required to create and maintain the salt spray (fog) ironment. Suitable apparatus which may be used is d in Appendix X1.

'his practice does not prescribe the type of test speci- exposure periods to be used for a specific product, nor pretation to be given to the results.

'he values stated in SI units are to be regarded as l. The inch-pound units in parentheses are provided for tion and may be approximate.

'his standard does not purport to address all of the 'oncerns, if any, associated with its use. It is the bility of the user of this standard to establish appro- ıfety and health practices and determine the applica- regulatory limitations prior to use.

renced Documents

STM Standards:

Method for Copper-Accelerated Acetic Acid-Salt ıy (Fog) Testing (CASS Test)[2]

Practice for Preparation of Cold-Rolled Steel Panels Testing Paint, Varnish, Conversion Coatings, and ıted Coating Products[3]

'3 Specification for Reagent Water[4]

ı4 Test Method for Evaluation of Painted or Coated cimens Subjected to Corrosive Environments[3]

Test Method for pH of Aqueous Solutions with the ːs Electrode[5]

Practice for Conducting an Interlaboratory Study to ːrmine the Precision of a Test Method[6]

G 85 Practice for Modified Salt Spray (Fog) Testing[7]

3. Significance and Use

3.1 This practice provides a controlled corrosive environment which has been utilized to produce relative corrosion resistance information for specimens of metals and coated metals exposed in a given test chamber.

3.2 Prediction of performance in natural environments has seldom been correlated with salt spray results when used as stand alone data.

3.2.1 Correlation and extrapolation of corrosion performance based on exposure to the test environment provided by this practice are not always predictable.

3.2.2 Correlation and extrapolation should be considered only in cases where appropriate corroborating long-term atmospheric exposures have been conducted.

3.3 The reproducibility of results in the salt spray exposure is highly dependent on the type of specimens tested and the evaluation criteria selected, as well as the control of the operating variables. In any testing program, sufficient replicates should be included to establish the variability of the results. Variability has been observed when similar specimens are tested in different fog chambers even though the testing conditions are nominally similar and within the ranges specified in this practice.

4. Apparatus

4.1 The apparatus required for salt spray (fog) exposure consists of a fog chamber, a salt solution reservoir, a supply of suitably conditioned compressed air, one or more atomizing nozzles, specimen supports, provision for heating the chamber, and necessary means of control. The size and detailed construction of the apparatus are optional, provided the conditions obtained meet the requirements of this practice.

4.2 Drops of solution which accumulate on the ceiling or cover of the chamber shall not be permitted to fall on the specimens being exposed.

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ractice is under the jurisdiction of ASTM Committee G01 on Corrosion ınd is the direct responsibility of Subcommittee G01.05 on Laboratory Tests.

edition approved October 1, 2003. Published October 2003. Originally ı 1939. Last previous edition approved in 2002 as B 117 – 02.

l Book of ASTM Standards, Vol 02.05.

l Book of ASTM Standards, Vol 06.01.

l Book of ASTM Standards, Vol 11.01.

l Book of ASTM Standards, Vol 15.05.

l Book of ASTM Standards, Vol 14.02.

[7] *Annual Book of ASTM Standards*, Vol 03.02.

›s of solution which fall from the specimens shall rned to the solution reservoir for respraying.

:rial of construction shall be such that it will not orrosiveness of the fog.

vater used for this practice shall conform to Type IV pecification D 1193 (except that for this practice hlorides and sodium may be ignored). This does not nning tap water. All other water will be referred to grade.

ecimens

type and number of test specimens to be used, as criteria for the evaluation of the test results, shall be the specifications covering the material or product sed or shall be mutually agreed upon between the .nd the seller.

ιtion of Test Specimens

imens shall be suitably cleaned. The cleaning ll be optional depending on the nature of the surface ıtaminants. Care shall be taken that specimens are ıminated after cleaning by excessive or careless

imens for the evaluation of paints and other organic ıall be prepared in accordance with applicable n(s) for the material(s) being exposed, or as agreed :en the purchaser and the supplier. Otherwise, the ens shall consist of steel meeting the requirements D 609 and shall be cleaned and prepared for coating ce with the applicable procedure of Practice D 609. imens coated with paints or nonmetallic coatings : cleaned or handled excessively prior to test. never it is desired to determine the development of om an abraded area in the paint or organic coating, scribed line shall be made through the coating with rument so as to expose the underlying metal before : conditions of making the scratch shall be as 'est Method D 1654, unless otherwise agreed upon : purchaser and the seller. ss otherwise specified, the cut edges of plated, uplex materials and areas containing identification n contact with the racks or supports shall be ith a suitable coating stable under the conditions of

hould it be desirable to cut test specimens from parts or from nted, or otherwise coated steel sheet, the cut edges shall be :oating them with paint, wax, tape, or other effective media velopment of a galvanic effect between such edges and the d or otherwise coated metal surfaces, is prevented.

of Specimens During Exposure

›osition of the specimens in the salt spray chamber est shall be such that the following conditions are

ess otherwise specified, the specimens shall be r suspended between 15 and 30° from the vertical ›ly parallel to the principal direction of flow of fog chamber, based upon the dominant surface being

7.1.2 The specimens shall not contact each other or any metallic material or any material capable of acting as a wick.

7.1.3 Each specimen shall be placed to permit unencumbered exposure to the fog.

7.1.4 Salt solution from one specimen shall not drip on any other specimen.

NOTE 2—Suitable materials for the construction or coating of racks and supports are glass, rubber, plastic, or suitably coated wood. Bare metal shall not be used. Specimens shall preferably be supported from the bottom or the side. Slotted wooden strips are suitable for the support of flat panels. Suspension from glass hooks or waxed string may be used as long as the specified position of the specimens is obtained, if necessary by means of secondary support at the bottom of the specimens.

8. Salt Solution

8.1 The salt solution shall be prepared by dissolving 5 ± 1 parts by mass of sodium chloride in 95 parts of water conforming to Type IV water in Specification D 1193 (except that for this practice limits for chlorides and sodium may be ignored). Careful attention should be given to the chemical content of the salt. The salt used shall be sodium chloride with not more than 0.3 % by mass of total impurities. Halides (Bromide, Fluoride, and Iodide) other than Chloride shall constitute less than 0.1 % by mass of the salt content. Copper content shall be less than 0.3 ppm by mass. Sodium chloride containing anti-caking agents shall not be used because such agents may act as corrosion inhibitors. See Table 1 for a listing of these impurity restrictions. Upon agreement between the purchaser and the seller, analysis may be required and limits established for elements or compounds not specified in the chemical composition given above.

TABLE 1 Maximum Allowable Limits for Impurity Levels in Sodium Chloride[A,B]

Impurity Description	Allowable Amount
Total Impurities	≤ 0.3 %
Halides (Bromide, Fluoride and Iodide) excluding Chloride	≤ 0.1 %
Copper	< 0.3 ppm
Anti-caking Agents	0.0 %

[A] A common formula used to calculate the amount of salt required by mass to achieve a 5 % salt solution of a known mass of water is:

.053 *X Mass of Water = Mass of NaCl required*

The mass of water is 1 g per 1 mL. To calculate the mass of salt required in grams to mix 1 L of a 5 % salt solution, multiply .053 by 1000 g (35.27 oz., the mass of 1 L of water). This formula yields a result of 53 g (1.87 oz.) of NaCl required for each liter of water to achieve a 5 % salt solution by mass.

The 0.053 multiplier for the sodium chloride used above is derived by the following:

1000 g (mass of a full L of water) divided by 0.95

(water is only 95 % of the total mixture by mass) yields 1053 g

This 1053 g is the total mass of the mixture of one L of water with a 5% sodium chloride concentration. 1053 g minus the original weight of the L of water, 1000 g, yields 53 g for the weight of the sodium chloride. 53 g of total sodium chloride divided by the original 1000 g of water yields a 0.053 multiplier for the sodium chloride.

As an example: to mix the equivalent of 200 L (52.83 gal) of 5 % sodium chloride solution, mix 10.6 kg (23.37 lb) of sodium chloride into 200 L (52.83 gal) of water. 200 L of water weighs 200,000 g. 200,000 g of water x .053 (sodium chloride multiplier) = 10,600 g of sodium chloride, or 10.6 kg.

[B] In order to ensure that the proper salt concentration was achieved when mixing the solution, it is recommended that the solution be checked with either a salimeter hydrometer or specific gravity hydrometer. When using a salimeter hydrometer, the measurement should be between 4 and 6 % at 25°C (77°F). When using a specific gravity hydrometer, the measurement should be between 1.0255 and 1.0400 at 25°C (77°F).

he pH of the salt solution shall be such that when
d at 35°C (95°F) the collected solution will be in the
ge from 6.5 to 7.2 (Note 3). Before the solution is
d it shall be free of suspended solids (Note 4). The pH
ment shall be made at 25°C (77°F) using a suitable
I-sensing electrode, reference electrode, and pH meter
in accordance with Test Method E 70.

—Temperature affects the pH of a salt solution prepared from
urated with carbon dioxide at room temperature and pH adjust-
y be made by the following three methods:
hen the pH of a salt solution is adjusted at room temperature, and
at 35°C (95°F), the pH of the collected solution will be higher
original solution due to the loss of carbon dioxide at the higher
re. When the pH of the salt solution is adjusted at room
re, it is therefore necessary to adjust it below 6.5 so the collected
fter atomizing at 35°C (95°F) will meet the pH limits of 6.5 to
about a 50-mL sample of the salt solution as prepared at room
re, boil gently for 30 s, cool, and determine the pH. When the
salt solution is adjusted to 6.5 to 7.2 by this procedure, the pH
mized and collected solution at 35°C (95°F) will come within

ating the salt solution to boiling and cooling to 35°C (95°F) and
ng it at 35°C (95°F) for approximately 48 h before adjusting the
ces a solution the pH of which does not materially change when
at 35°C (95°F).
ating the water from which the salt solution is prepared to 35°C
above, to expel carbon dioxide, and adjusting the pH of the salt
vithin the limits of 6.5 to 7.2 produces a solution the pH of which
materially change when atomized at 35°C (95°F).
—The freshly prepared salt solution may be filtered or decanted
is placed in the reservoir, or the end of the tube leading from the
o the atomizer may be covered with a double layer of cheesecloth
t plugging of the nozzle.
—The pH can be adjusted by additions of dilute ACS reagent
rochloric acid or sodium hydroxide solutions.

Supply

he compressed air supply to the Air Saturator Tower
free of grease, oil, and dirt before use by passing
well-maintained filters. (Note 6) This air should be
ed at a sufficient pressure at the base of the Air
r Tower to meet the suggested pressures of Table 2 at
of the Air Saturator Tower.

—The air supply may be freed from oil and dirt by passing it
suitable oil/water extractor (that is commercially available) to
oil from reaching the Air Saturator Tower. Many oil/water
have an expiration indicator, proper preventive maintenance
should take these into account.

he compressed air supply to the atomizer nozzle or
shall be conditioned by introducing it into the bottom
er fillwed with water. A common method of introduc-
air is through an air dispersion device (X1.4.1). The
the water must be maintained automatically to ensure
humidification. It is common practice to maintain the
ture in this tower between 46 and 49°C (114–121°F) to
e cooling effect of expansion to atmospheric pressure
he atomization process. Table 2 in 9.3 of this practice
he temperature, at different pressures, that are com-
used to offset the cooling effect of expansion to
eric pressure.
areful attention should be given to the relationship of
mperature to pressure since this relationship can have
a direct impact to maintaining proper collection rates (Note 7). It is preferable to saturate the air at temperatures well above the chamber temperature as insurance of a wet fog as listed in Table 2.

TABLE 2 Suggested Temperature and Pressure guideline for the top of the Air Saturator Tower for the operation of a test at 35°C (95°F)

Air Pressure, kPa	Temperature, °C	Air Pressure, PSI	Temperature, °F
83	46	12	114
96	47	14	117
110	48	16	119
124	49	18	121

NOTE 7—If the tower is run outside of these suggested temperature and pressure ranges to acheive proper collection rates as described in 10.2 of this practice, other means of verifying the proper corrosion rate in the chamber should be investigated, such as the use of control specimens (panels of known performance in the test conducted). It is preferred that control panels be provided that bracket the expected test specimen performance. The controls allow for the normalization of test conditions during repeated running of the test and will also allow comparisons of test results from different repeats of the same test. (Refer to Appendix X3, Evaluation of Corrosive Conditions, for mass loss procedures).

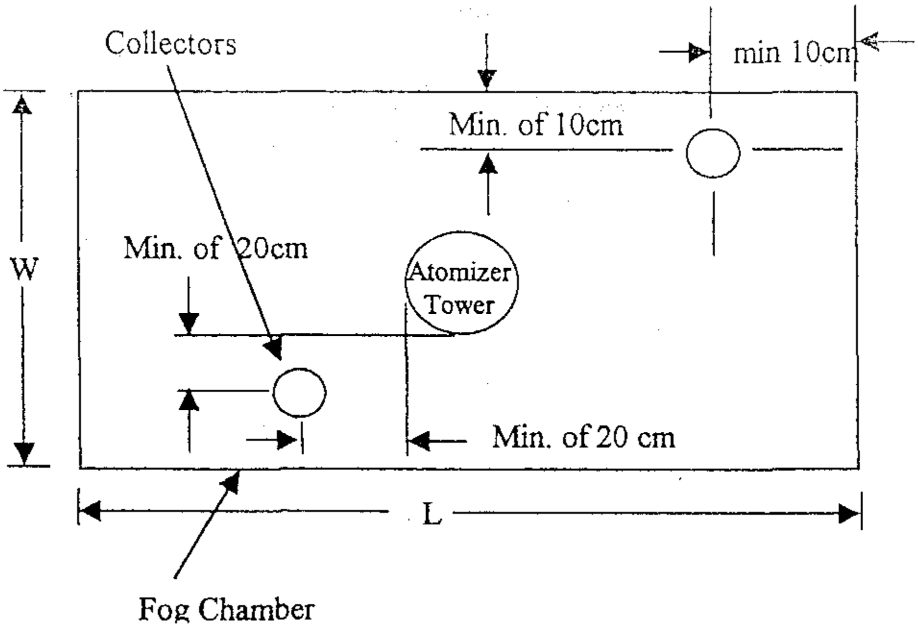
10. Conditions in the Salt Spray Chamber

10.1 *Temperature*—The exposure zone of the salt spray chamber shall be maintained at 35 + 1.1 – 1.7°C (95 + 2 – 3°F). Each set point and its tolerance represents an operational control point for equilibrium conditions at a single location in the cabinet which may not necessarily represent the uniformity of conditions throughout the cabinet. The temperature within the exposure zone of the closed cabinet shall be recorded (Note 8) at least twice a day at least 7 h apart (except on Saturdays, Sundays, and holidays when the salt spray test is not interrupted for exposing, rearranging, or removing test specimens or to check and replenish the solution in the reservoir)

NOTE 8—A suitable method to record the temperature is by a continuous recording device or by a thermometer which can be read from outside the closed cabinet. The recorded temperature must be obtained with the salt spray chamber closed to avoid a false low reading because of wet-bulb effect when the chamber is open.

10.2 *Atomization and Quantity of Fog*—Place at least two clean fog collectors per atomizer tower within the exposure zone so that no drops of solution will be collected from the test specimens or any other source. Position the collectors in the proximity of the test specimens, one nearest to any nozzle and the other farthest from all nozzles. A typical arrangement is shown in Fig. 1. The fog shall be such that for each 80 cm^2 (12.4 in.^{2}) of horizontal collecting area, there will be collected from 1.0 to 2.0 mL of solution per hour based on an average run of at least 16 h (Note 9). The sodium chloride concentration of the collected solution shall be 5 ± 1 mass % (Notes 9-11). The pH of the collected solution shall be 6.5 to 7.2. The pH measurement shall be made as described in 8.2 (Note 3).

NOTE 9—Suitable collecting devices are glass or plastic funnels with



is figure shows a typical fog collector arrangement for a single atomizer tower cabinet. The same fog collector arrangement is also applicable atomizer tower and horizontal ("T" type) atomizer tower cabinet constructions as well.

FIG. 1 Arrangement of Fog Collectors

serted through stoppers into graduated cylinders, or crystal-s. Funnels and dishes with a diameter of 10 cm (3.94 in.) have bout 80 cm^2 (12.4 in.^{2}).

—A solution having a specific gravity of 1.0255 to 1.0400 at) will meet the concentration requirement. The sodium ncentration may also be determined using a suitable salinity xample, utilizing a sodium ion-selective glass electrode) or ally as follows. Dilute 5 mL of the collected solution to 100 tilled water and mix thoroughly; pipet a 10-mL aliquot into an dish or casserole; add 40 mL of distilled water and 1 mL of um chromate solution (chloride-free) and titrate with 0.1 *N* solution to the first appearance of a permanent red coloration. that requires between 3.4 and 5.1 mL of 0.1 *N* silver nitrate l meet the concentration requirements.

—Salt solutions from 2 to 6 % will give the same results, niformity the limits are set at 4 to 6 %.

e nozzle or nozzles shall be so directed or baffled of the spray can impinge directly on the test .

nuity of Exposure

nless otherwise specified in the specifications cover-aterial or product being tested, the test shall be s for the duration of the entire test period. Continu-ion implies that the chamber be closed and the spray continuously except for the short daily interruptions to inspect, rearrange, or remove test specimens, to replenish the solution in the reservoir, and to make recordings as described in Section 10. Operations o scheduled that these interruptions are held to a

d of Exposure

e period of exposure shall be as designated by the ons covering the material or product being tested or y agreed upon between the purchaser and the seller.

NOTE 12—Recommended exposure periods are to be as agreed upon between the purchaser and the seller, but exposure periods of multiples of 24 h are suggested.

13. Cleaning of Tested Specimens

13.1 Unless otherwise specified in the specifications covering the material or product being tested, specimens shall be treated as follows at the end of the test:

13.1.1 The specimens shall be carefully removed.

13.2 Specimens may be gently washed or dipped in clean running water not warmer than 38°C (100°F) to remove salt deposits from their surface, and then immediately dried.

14. Evaluation of Results

14.1 A careful and immediate examination shall be made as required by the specifications covering the material or product being tested or by agreement between the purchaser and the seller.

15. Records and Reports

15.1 The following information shall be recorded, unless otherwise prescribed in the specifications covering the material or product being tested:

15.1.1 Type of salt and water used in preparing the salt solution,

15.1.2 All readings of temperature within the exposure zone of the chamber,

15.1.3 Daily records of data obtained from each fog-collecting device including the following:

15.1.3.1 Volume of salt solution collected in millilitres per hour per 80 cm^2 (12.4 in.^{2}),

15.1.3.2 Concentration or specific gravity at 35°C (95°F) of solution collected, and

15.1.3.3 pH of collected solution.

.2 Type of specimen and its dimensions, or number or iption of part,

3 Method of cleaning specimens before and after testing,

4 Method of supporting or suspending article in the salt chamber,

5 Description of protection used as required in 6.5,

6 Exposure period,

7 Interruptions in exposure, cause, and length of time,

15.8 Results of all inspections.

Note 13—If any of the atomized salt solution which has not contacted the test specimens is returned to the reservoir, it is advisable to record the concentration or specific gravity of this solution also.

16. Keywords

16.1 controlled corrosive environment; corrosive conditions; determining mass loss; salt spray (fog) exposure

APPENDIXES

(Nonmandatory Information)

X1. CONSTRUCTION OF APPARATUS

Cabinets

1.1 Standard salt spray cabinets are available from .l suppliers, but certain pertinent accessories are required : they will function according to this practice and provide tent control for duplication of results.

1.2 The salt spray cabinet consists of the basic chamber, '-saturator tower, a salt solution reservoir, atomizing s, specimen supports, provisions for heating the chamıd suitable controls for maintaining the desired tempera-

1.3 Accessories such as a suitable adjustable baffle or fog tower, automatic level control for the salt reservoir, ıtomatic level control for the air-saturator tower are :nt parts of the apparatus.

1.4 The size and shape of the cabinet shall be such that mization and quantity of collected solution is within the of this practice.

.5 The chamber shall be made of suitably inert mate-.ch as plastic, glass, or stone, or constructed of metal and /ith impervious plastics, rubber, or epoxy-type materials .valent.

.6 All piping that contacts the salt solution or spray be of inert materials such as plastic. Vent piping should ufficient size so that a minimum of back pressure exists ould be installed so that no solution is trapped. The d end of the vent pipe should be shielded from extreme ents that may cause fluctuation of pressure or vacuum in inet.

'emperature Control

.1 The maintenance of temperature within the salt :r can be accomplished by several methods. It is ly desirable to control the temperature of the surround- the salt spray chamber and to maintain it as stable as :. This may be accomplished by placing the apparatus ıstant-temperature room, but may also be achieved by ding the basic chamber of a jacket containing water or controlled temperature.

2 The use of immersion heaters in an internal salt : reservoir or within the chamber is detrimental where heat losses are appreciable because of solution evaporation and radiant heat on the specimens.

X1.3 Spray Nozzles

X1.3.1 Satisfactory nozzles may be made of hard rubber, plastic, or other inert materials. The most commonly used type is made of plastic. Nozzles calibrated for air consumption and solution-atomized are available. The operating characteristics of a typical nozzle are given in Table X1.1.

X1.3.2 It can readily be seen that air consumption is relatively stable at the pressures normally used, but a marked reduction in solution sprayed occurs if the level of the solution is allowed to drop appreciably during the test. Thus, the level of the solution in the salt reservoir must be maintained automatically to ensure uniform fog delivery during the test.[8]

X1.3.3 If the nozzle selected does not atomize the salt solution into uniform droplets, it will be necessary to direct the spray at a baffle or wall to pick up the larger drops and prevent them from impinging on the test specimens. Pending a complete understanding of air-pressure effects, and so forth, it is important that the nozzle selected shall produce the desired

TABLE X1.1 Operating Characteristics of Typical Spray Nozzle

Siphon Height, cm	Air Flow, dm^3/min				Solution Consumption, cm^3/h			
	Air Pressure, kPa				Air Pressure, kPa			
	34	69	103	138	34	69	103	138
10	19	26.5	31.5	36	2100	3840	4584	5256
20	19	26.5	31.5	36	636	2760	3720	4320
30	19	26.5	31.5	36	0	1380	3000	3710
40	19	26.6	31.5	36	0	780	2124	2904

Siphon Height, in.	Air Flow, L/min				Solution Consumption, mL/h			
	Air Pressure, psi				Air Pressure, psi			
	5	10	15	20	5	10	15	20
4	19	26.5	31.5	36	2100	3840	4584	5256
8	19	26.5	31.5	36	636	2760	3720	4320
12	19	26.5	31.5	36	0	1380	3000	3710
16	19	26.6	31.5	36	0	780	2124	2904

---

[8] A suitable device for maintaining the level of liquid in either the saturator tower or reservoir of test solution may be designed by a local engineering group, or may be purchased from manufacturers of test cabinets as an accessory.

when operated at the air pressure selected. Nozzles
:essarily located at one end, but may be placed in the
can also be directed vertically up through a suitable

for Atomization

The air used for atomization must be free of grease,
irt before use by passing through well-maintained
om air may be compressed, heated, humidified, and
a water-sealed rotary pump if the temperature of the
uitably controlled. Otherwise cleaned air may be
into the bottom of a tower filled with water through
tone or multiple nozzles. The level of the water must
ned automatically to ensure adequate humidification.
r operated in accordance with this method and
X1 will have a relative humidity between 95 and
e salt solutions from 2 to 6 % will give the same
ugh for uniformity the limits are set at 4 to 6 %), it
le to saturate the air at temperatures well above the
emperature as insurance of a wet fog. Table X1.2
temperatures, at different pressures, that are required
the cooling effect of expansion to atmospheric

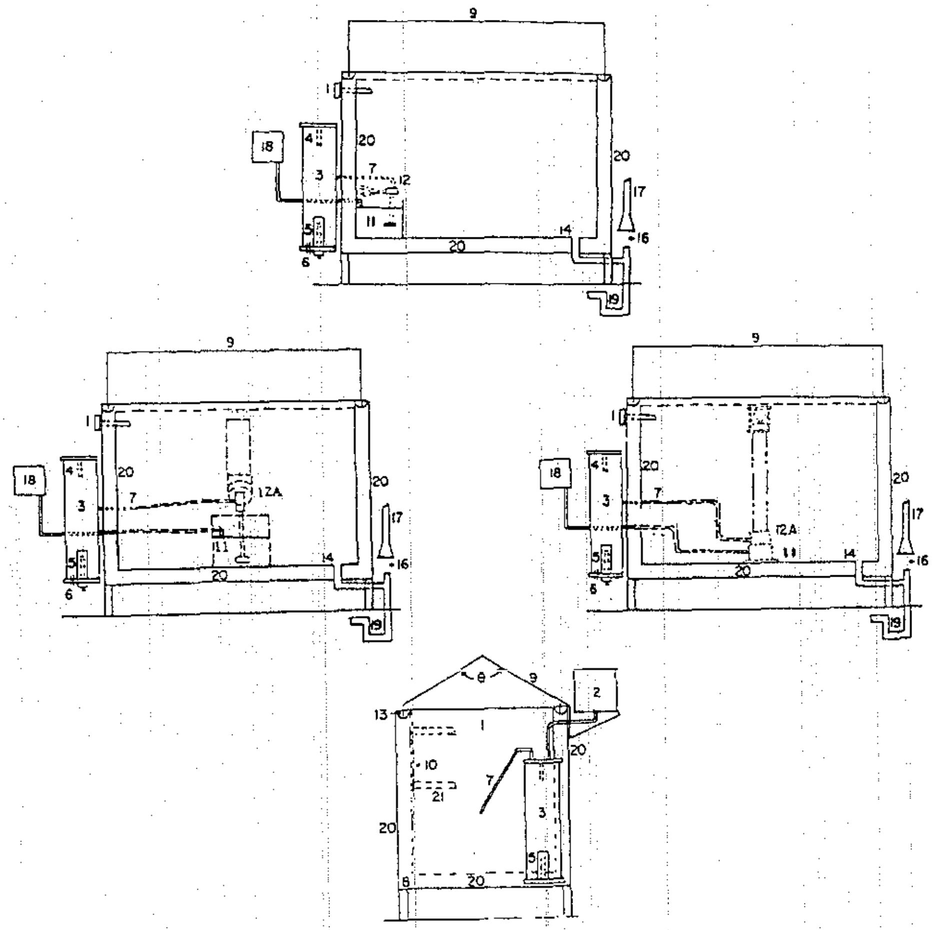
TABLE X1.2 Temperature and Pressure Requirements for Operation of Test at 95°F

	Air Pressure, kPa			
	83	96	110	124
Temperature, °C	46	47	48	49
	Air Pressure, psi			
	12	14	16	18
Temperature, °F	114	117	119	121

X1.4.2 Experience has shown that most uniform spray chamber atmospheres are obtained by increasing the atomizing air temperature sufficiently to offset heat losses, except those that can be replaced otherwise at very low-temperature gradients.

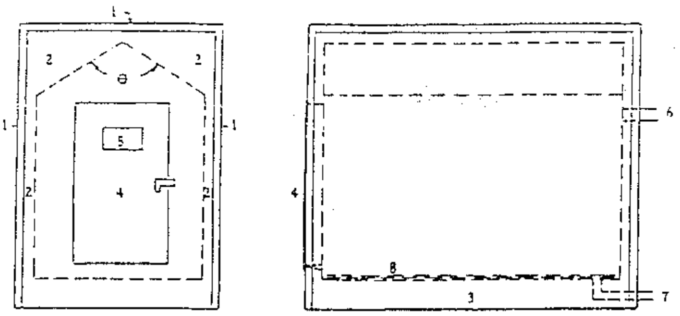
X1.5 Types of Construction

X1.5.1 A modern laboratory cabinet is shown in Fig. X1.1. Walk-in chambers are usually constructed with a sloping ceiling. Suitably located and directed spray nozzles avoid ceiling accumulation and drip. Nozzles may be located at the ceiling, or 0.91 m (3 ft) from the floor directed upward at 30 to 60° over a passageway. The number of nozzles depends on type and capacity and is related to the area of the test space. An 11 to 19 L (3 to 5-gal) reservoir is required within the chamber, with the level controlled. The major features of a walk-in type cabinet, which differs significantly from the laboratory type, are illustrated in Fig. X1.2. Construction of a plastic nozzle, such as is furnished by several suppliers, is shown in Fig. X1.3.



—θ—Angle of lid, 90 to 125°
iermometer and thermostat for controlling heater (Item No. 8) in base
ıtomatic water leveling device
ımidifying tower
ıtomatic temperature regulator for controlling heater (Item No. 5)
ımersion heater, nonrusting
r inlet, multiple openings
r tube to spray nozzle
eater in base
nged top, hydraulically operated, or counterbalanced
ackets for rods supporting specimens, or test table
ernal reservoir
ray nozzle above reservoir, suitably designed, located, and baffled
spray nozzle housed in dispersion tower located preferably in center of cabinet (typical examples)
iter seal
mbination drain and exhaust. Exhaust at opposite side of test space from spray nozzle (Item 12), but preferably in combination with drain, waste
p, and forced draft waste pipe (Items 16, 17, and 19).
mplete separation between forced draft waste pipe (Item 17) and combination drain and exhaust (Items 14 and 19) to avoid undesirable suction
back pressure.
rced draft waste pipe
tomatic leveling device for reservoir
iste trap
space or water jacket
t table or rack, well below roof area
—This figure shows the various components including alternate arrangements of the spray nozzles and solution reservoir.

FIG. X1.1 Typical Salt Spray Cabinet



he controls are the same, in general as for the smaller laboratory type cabinet (Fig. X1.1), but are sized to care for the larger cube. The chamber
owing features:
e of ceiling, 90 to 125°
y insulated outer panels
pace
watt density heaters, or steam coils
e- or double-, full-opening door (refrigeration type), with
d sloping door sill
ing window/s
chamber vent
chamber drain
boards on floor

FIG. X1.2 Walk-in Chamber, 1.5 by 2.4 m (5 by 8 ft) and Upward in Overall Size

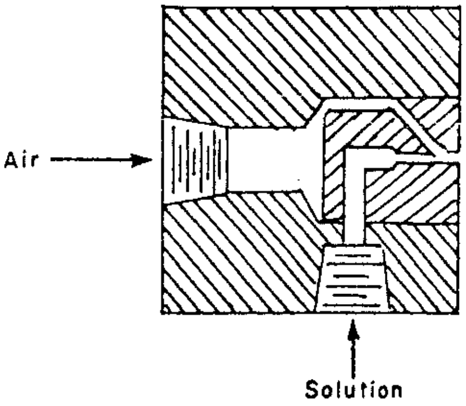
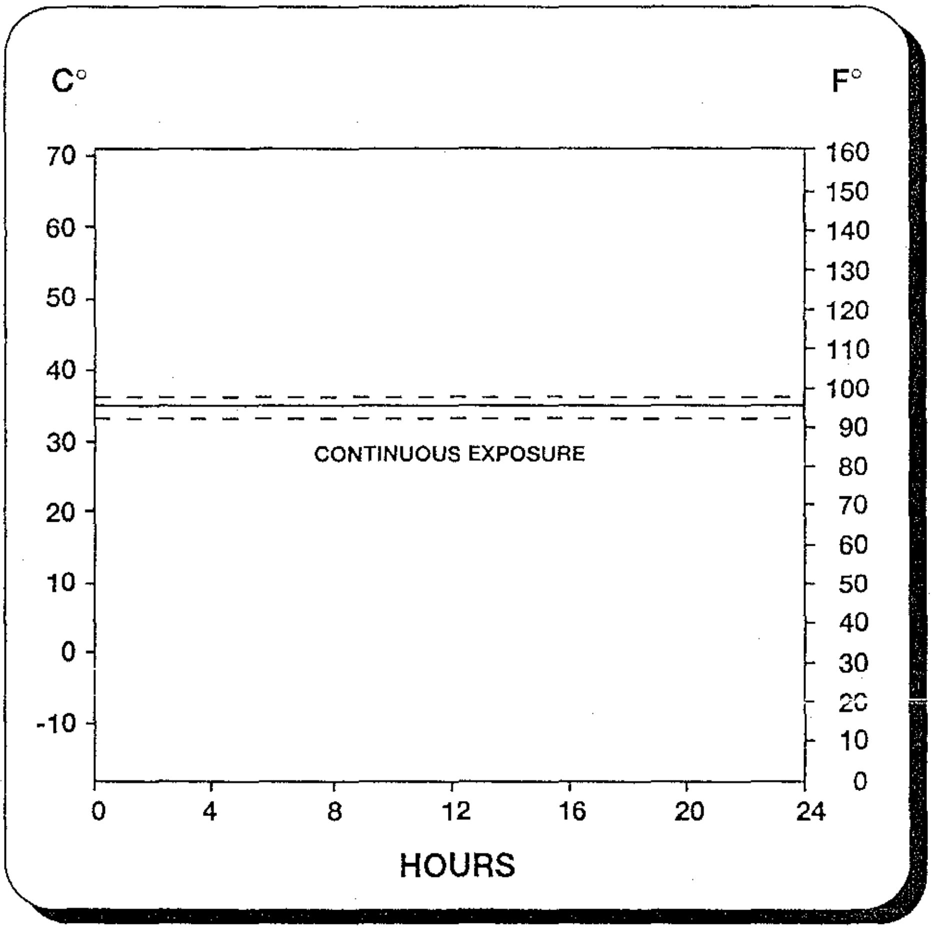


FIG. X1.3 Typical Spray Nozzle

X2. USE OF THE SALT SPRAY (FOG) TEST IN RESEARCH

This practice is primarily used for process qualifica-
uality acceptance. Regarding any new applications, it
al to correlate the results of this practice with actual
sure results. (See Fig. X2.1.)

The salt spray has been used to a considerable extent
rpose of comparing different materials or finishes. It
noted there is usually not a direct relation between
(fog) resistance and resistance to corrosion in other
cause the chemistry of the reactions, including the
of films and their protective value, frequently varies
ith the precise conditions encountered. Informed
are aware of the erratic composition of basic alloys,
bility of wide variations in quality and thickness of
ns produced on the same racks at the same time, and
quent need for a mathematical determination of the
number of specimens required to constitute an adequate sample for test purposes. In this connection it is well to point out that Practice B 117 is not applicable to the study or testing of decorative chromium plate (nickel-chromium) on steel or on zinc-base die castings or of cadmium plate on steel. For this purpose Method B 368 and Practice G 85 are available, which are also considered by some to be superior for comparison of chemically treated aluminum (chromated, phosphated, or anodized), although final conclusions regarding the validity of test results related to service experience have not been reached. Practice B 117 and Practice G 85 are considered to be most useful in estimating the relative behavior of closely related materials in marine atmospheres, since it simulates the basic conditions with some acceleration due to either wetness or temperature, or both.



ution: 5 ± 1 parts by mass of sodium chloride (NaCl) in 95 parts by mass of Specification D 1193 Type IV water.
o 7.2 of collected solution.
osure zone of the salt spray chamber shall be maintained at 35 + 1.1 - 1.7°C (95 + 2 - 3°F). Each set point and its tolerance represents an operational control
uilibrium conditions at a single location in the cabinet which may not necessarily represent the uniformity of conditions throughout the cabinet.
rate of 1.0 to 2.0 mL/hr per 80 cm^2 of horizontal collection area.

ed chart lines indicate temperature tolerance limits.
nted with permission.

FIG. X2.1 Standard Practice for Operating Salt Spray (Fog) Apparatus

X3. EVALUATION OF CORROSIVE CONDITIONS

General—This appendix covers test panels and pro-
or evaluating the corrosive conditions within a salt
inet. The procedure involves the exposure of steel test
d the determination of their mass losses in a specified
time. This may be done monthly or more frequently
consistent operation over time. It is also useful for
g the corrosive conditions among different cabinets.

Test Panels—The required test panels, 76 by 127 by
3.0 by 5.0 by .0315 in.), are made from SAE 1008
ial-grade cold-rolled carbon steel (UNS G10080).

Preparation of Panels Before Testing—Clean panels
sting by degreasing only, so that the surfaces are free
l. or other foreign matter that could influence the test
fter cleaning, weigh each panel on an analytical
the nearest 1.0 mg and record the mass.

X3.4 *Positioning of Test Panels*—Place a minimum of two weighed panels in the cabinet, with the 127-mm (5.0 in.) length supported 30° from vertical. Place the panels in the proximity of the condensate collectors. (See Section 6.)

X3.5 *Duration of Test*—Expose panels to the salt fog for 48 to 168 h.

X3.6 *Cleaning of Test Panels After Exposure*—After removal of the panels from the cabinet, rinse each panel immediately with running tap water to remove salt, and rinse in reagent grade water (see Specification D 1193, Type IV). Chemically clean each panel for 10 min at 20 to 25°C in a fresh solution prepared as follows:

> Mix 1000 mL of hydrochloric acid (sp gr 1.19) with 1000 mL reagent grade water (D 1193, Type IV) and add 10 g of hexamethylene tetramine. After cleaning, rinse each panel with reagent grade water (Type IV) and dry (see 13.2).

Determining Mass Loss—Immediately after drying, the mass loss by reweighing and subtracting panel exposure from its original mass.

TABLE X3.1 Repeatability Statistics

ased on two replicates in every test run. No. = number of t spray cabinets in test program; r = 95 % repeatability limits, vg, coefficient of variation, %; and S_r = repeatability standard g.

Test Duration, h	Average Mass Loss, g	S_r, g	Cv, %	r, g	No.
48	0.8170	0.0588	7.20	0.1646	12
96	1.5347	0.1048	7.28	0.2934	12
168	2.5996	0.2498	9.61	0.6994	12
48	0.7787	0.0403	5.17	0.1128	10
96	1.4094	0.0923	6.55	0.2584	10
168	2.4309	0.1594	6.56	0.4463	10
48	0.8566	0.0686	8.01	0.1921	5
96	1.5720	0.0976	6.21	0.2733	5
168	2.7600	0.2588	9.38	0.7246	5

TABLE X3.2 Reproducibility Statistics

o. = number of different salt spray cabinets in test program; producibility limits, g; $Cv = S_R$/avg, coefficient of variation, = reproducibility standard deviation, g.

Test Duration, h	Average Mass Loss, g	S_R, g	Cv, %	R, g	No.
48	0.8170	0.0947	11.58	0.2652	12
96	1.5347	0.2019	14.02	0.5653	12
168	2.5996	0.3255	12.52	0.9114	12
48	0.7787	0.0805	10.33	0.2254	10
96	1.4094	0.1626	11.54	0.4553	10
168	2.4309	0.3402	14.00	0.9526	10
48	0.8566	0.1529	17.85	0.4281	5
96	1.5720	0.1319	8.39	0.3693	5
168	2.7600	0.3873	14.03	1.0844	5

Data generated in the interlaboratory study using d are available from ASTM as a Research Report.[9]

X3.8 *Precision and Bias—Steel Panel Test:*

X3.8.1 An interlaboratory test program using three different sets of UNS G10080 steel panels, 76 by 127 by 0.8 mm (3.0 by 5.0 by .0315 in.) has shown that the repeatability of the mass loss of the steel panels, that is, the consistency in mass loss results that may be expected when replicate panels are run simultaneously in a salt spray cabinet, is dependent upon exposure time and the panel lot or source. The interlaboratory program yielded repeatability standard deviations, S_r, from which 95 % repeatability limits, r, were calculated as follows (see Practice E 691):

$$r = 2.8\,S_r \qquad \text{(X3.1)}$$

The values of S_r and r are reported in Table X3.1. Note that the corrosion rate of steel in this environment is approximately constant over the exposure interval and that the ratio of the standard deviation to the average mass loss, the coefficient of variation, *Cv*, varies between 5 and 10 % with a weighted average of 7.4 % and an r of ±21 % of the average mass loss.

X3.8.2 This interlaboratory program also produced results on the reproducibility of results, that is, the consistency of mass loss results in tests in different laboratories or in different cabinets in the same facility. This program yielded reproducibility standard deviations, S_R ,from which 95 % reproducibility limits, R, were calculated as follows (See Practice E 691):

$$R = 2.8\,S_R \qquad \text{(X3.2)}$$

The values of S_R and R are reported in Table X3.2. Note that the ratio of standard deviation to the average mass loss, the coefficient of variation, *Cv*, varies between 8 to 18 % with a weighted average of 12.7 % and an R of ±36 % of the average mass loss.

X3.8.3 The mass loss of steel in this salt spray practice is dependent upon the area of steel exposed, the temperature, time of exposure, salt solution make up and purity, pH, spray conditions, and the metallurgy of the steel. The procedure in Appendix X3 for measuring the corrosivity of neutral salt spray cabinets with steel panels has no bias because the value of corrosivity of the salt spray is defined only in terms of this practice.

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from ASTM Headquarters. Request RR No. G1-1003.

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Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces[1]

This standard is issued under the fixed designation D 610; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

est method covers the evaluation of the degree of ainted steel surfaces. The visual examples which ːrcentage of rusting given in the written specifica- art of the standard. In the event of a dispute, the ition prevails. These visual examples were devel- peration with SSPC: The Society for Protective further standardization of methods.

ıtandard does not purport to address all of the ːrns, if any, associated with its use. It is the v of the user of this standard to establish appro- and health practices and determine the applica- ılatory limitations prior to use.

ed Documents

4 Adjunct/SSPC: The Society for Protective Coat-

2/ASTM D 610 Standard Method of Evaluating of Rusting on Painted Steel Surfaces[2]

ıce and Use

nount of rusting beneath or through a paint film is factor in determining whether a coating system ːpaired or replaced. This test method provides a means for quantifying the amount and distribution rface rust.

egree of rusting is evaluated using a zero to ten ɔn the percentage of visible surface rust.

istribution of the rust is classified as spot rust, pinpoint rust or hybrid rust.

4. Interferences

4.1 The visual examples that are part of this test method and the associated rust-grade scale cover only rusting evidenced by visible surface rust.

4.2 The use of the visual examples requires the following cautions:

4.2.1 Some finishes are stained by rust. This staining must not be confused with the actual rusting involved.

4.2.2 Accumulated dirt or other material may make accurate determination of the degree of rusting difficult.

4.2.3 Certain types of deposited dirt that contain iron or iron compounds may cause surface discoloration that should not be mistaken for corrosion.

4.2.4 Failure may vary over a given area. Discretion must therefore be used when selecting a single rust grade or rust distribution that is to be representative of a large area or structure, or in subdividing a structure for evaluation.

4.2.5 The color of the finish coating should be taken into account in evaluating surfaces as failures will be more apparent on a finish that shows color contrast with rust, such as used in these reference standards, than on a similar color, such as an iron oxide finish.

5. Procedure

5.1 Select an area to be evaluated.

5.2 Determine the type of rust distribution using definitions in Table 1 and visual examples in Fig. 1, Fig. 2, and Fig. 3.

5.3 Estimate percentage of surface area rusted using the visual examples in Fig. 1, Fig. 2, and Fig. 3 or SSPC-VIS 2, or both, by electronic scanning techniques or other method agreed upon by contracting parties.

NOTE 1—The numerical rust grade scale is an exponential function of the area of rust. The rust grade versus area of rust is a straight line plot on semilogarithmic coordinate from rust grade 10 to rust grade 4. The slope of the curve was changed at 10 % of the area rusted to 100 % rusted to permit inclusion of complete rusting on the 0 to 10 rust scale.

5.4 Use percentage of surface area rusted to identify rust grade (see Table 1). Assign rust rating using rust grade of 0-10 followed by the type of rust distribution identified by *S* for spot, *G* for general, *P* for pinpoint or *H* for Hybrid.

5.5 The visual examples are not required for use of the rust-grade scale since the scale is based upon the percent of the

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thod is under the jurisdiction of ASTM Committee D01 on Paint ings, Materials, and Applications and is the direct responsibility of ɔ1.46 on Industrial Protective Coatings.

od has been jointly approved by ASTM and SSPC: The Society for gs.

ɔn approved May 10, 2001. Published July 2001. Originally 10 – 41. Last previous edition D 610 – 95.

ıal examples are available at a nominal cost from ASTM Head- Adjunct ADJD0610a), SSPC Publication No. 00-08 from SSPC: Protective Coatings, 40 24th Street, Sixth Floor, Pittsburgh, PA ː.org.

***A Summary of Changes section appears at the end of this standard.**

100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, United States.

TABLE 1 Scale and Description of Rust Ratings

		Visual Examples		
·ade	Percent of Surface Rusted	Spot(s)	General (G)	Pinpoint (P)
	Less than or equal to 0.01 percent		None	
	Greater than 0.01 percent and up to 0.03 percent	9–S	9–G	9–P
	Greater than 0.03 percent and up to 0.1 percent	8–S	8–G	8–P
	Greater than 0.1 percent and up to 0.3 percent	7–S	7–G	7–P
	Greater than 0.3 percent and up to 1.0 percent	6–S	6–G	6–P
	Greater than 1.0 percent and up to 3.0 percent	5–S	5–G	5–P
	Greater than 3.0 percent and up to 10.0 percent	4–S	4–G	4–P
	Greater than 10.0 percent and up to 16.0 percent	3–S	3–G	3–P
	Greater than 16.0 percent and up to 33.0 percent	2–S	2–G	2–P
	Greater than 33.0 percent and up to 50.0 percent	1–S	1–G	1–P
	Greater than 50 percent		None	

on Types:
ıg—Spot rusting occurs when the bulk of the rusting is concentrated in a few localized areas of the painted surface. The visual examples depicting this re labeled 9-S thru 1-S (See Fig. 1, Fig. 2, and Fig. 3).
ısting—General rusting occurs when various size rust spots are randomly distributed across the surface. The visual examples depicting this type of rusting thru 1-G. (See Fig. 1, Fig. 2, and Fig. 3).
ısting—Pinpoint rusting occurs when the rust is distributed across the surface as very small individual specks of rust. The visual examples depicting this re labeled 9-P through 1-P. (See Fig. 1, Fig. 2, and Fig. 3).
ting—An actual rusting surface may be a hybrid of the types of rust distribution depicted in the visual examples. In this case, report the total percent of ıe surface. 9-H through 1-H.

nd any method of assessing area rust may be used the rust grade.

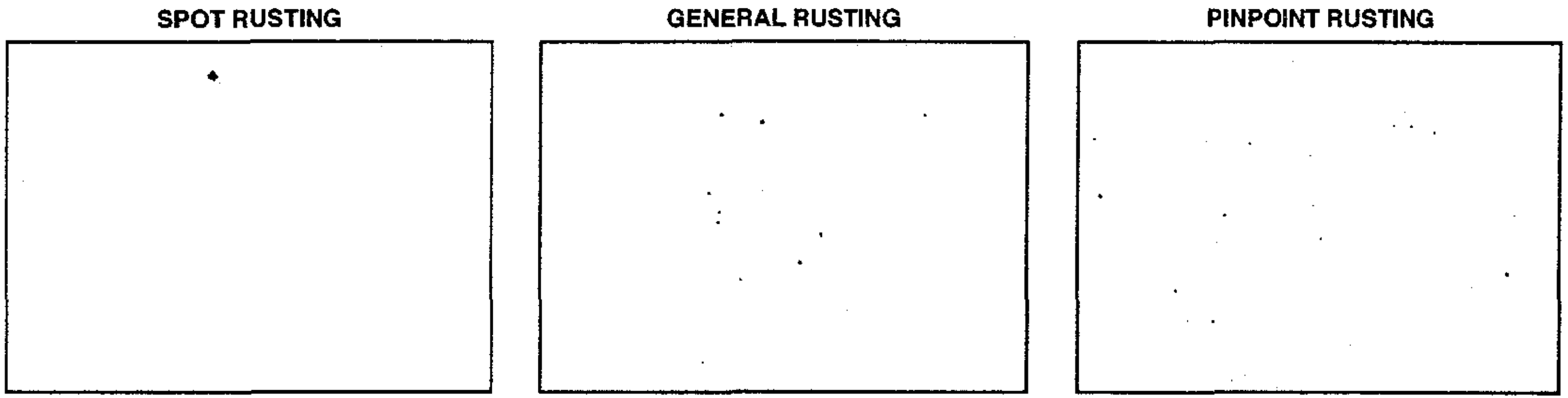
fy sample or area evaluated.
t rust grade using rating of 0-10.
t rust distribution using *S* for Spot, *G* for General, nt and *H* for Hybrid.

7. Precision and Bias

7.1 No precision or bias statement can be made for this test method.

8. Keywords

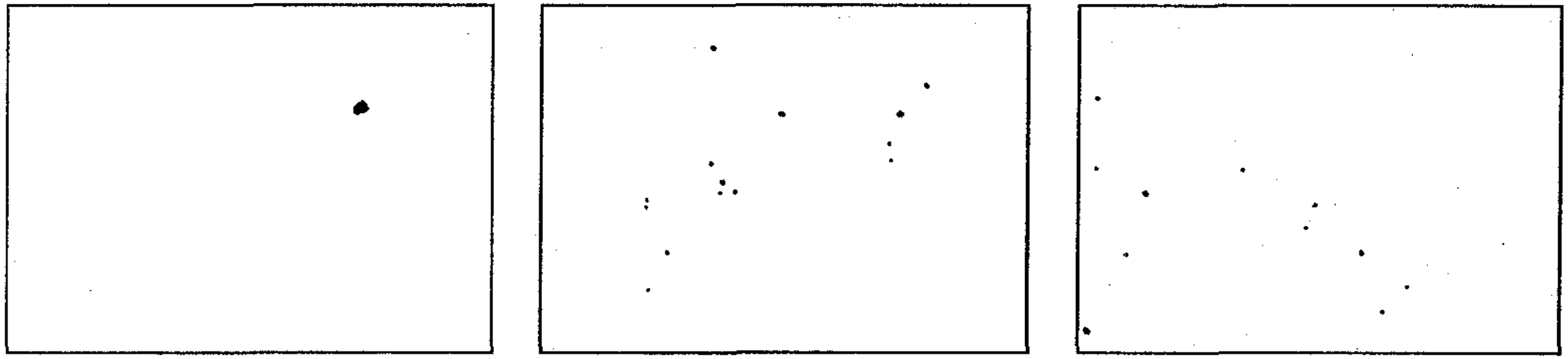
8.1 corrosion; rusting



Rust Grade 9-S, 0.03% Rusted

Rust Grade 9-G, 0.03% Rusted

Rust Grade 9-P, 0.03% Rusted



Rust Grade 8-S, 0.1% Rusted

Rust Grade 8-G, 0.1% Rusted

Rust Grade 8-P, 0.1% Rusted

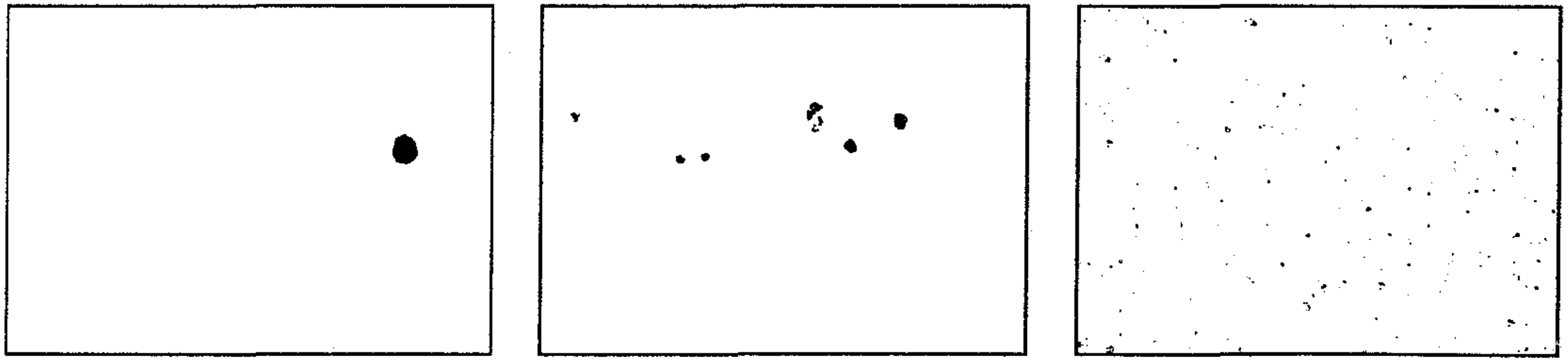
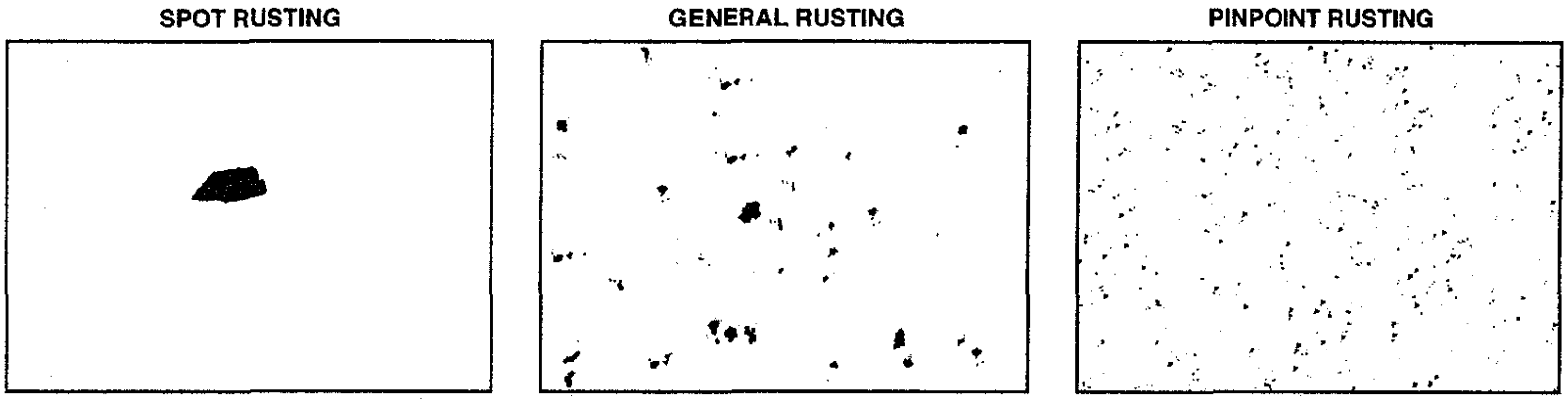


FIG. 1 Examples of Area Percentages



Rust Grade 6-S, 1% Rusted　Rust Grade 6-G, 1% Rusted　Rust Grade 6-P, 1% Rusted

Rust Grade 5-S, 3% Rusted　Rust Grade 5-G, 3% Rusted　Rust Grade 5-P, 3% Rusted

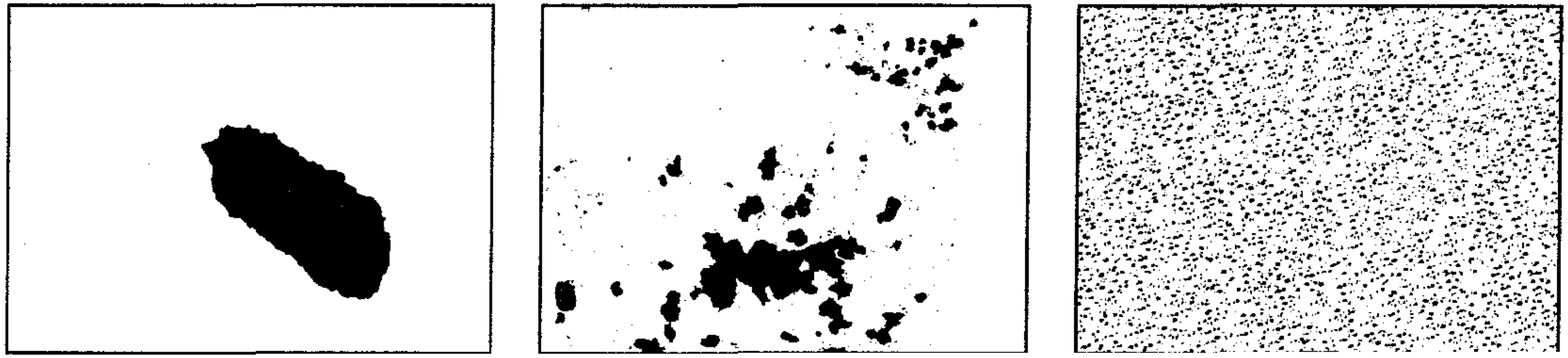


FIG. 2 Examples of Area Percentages

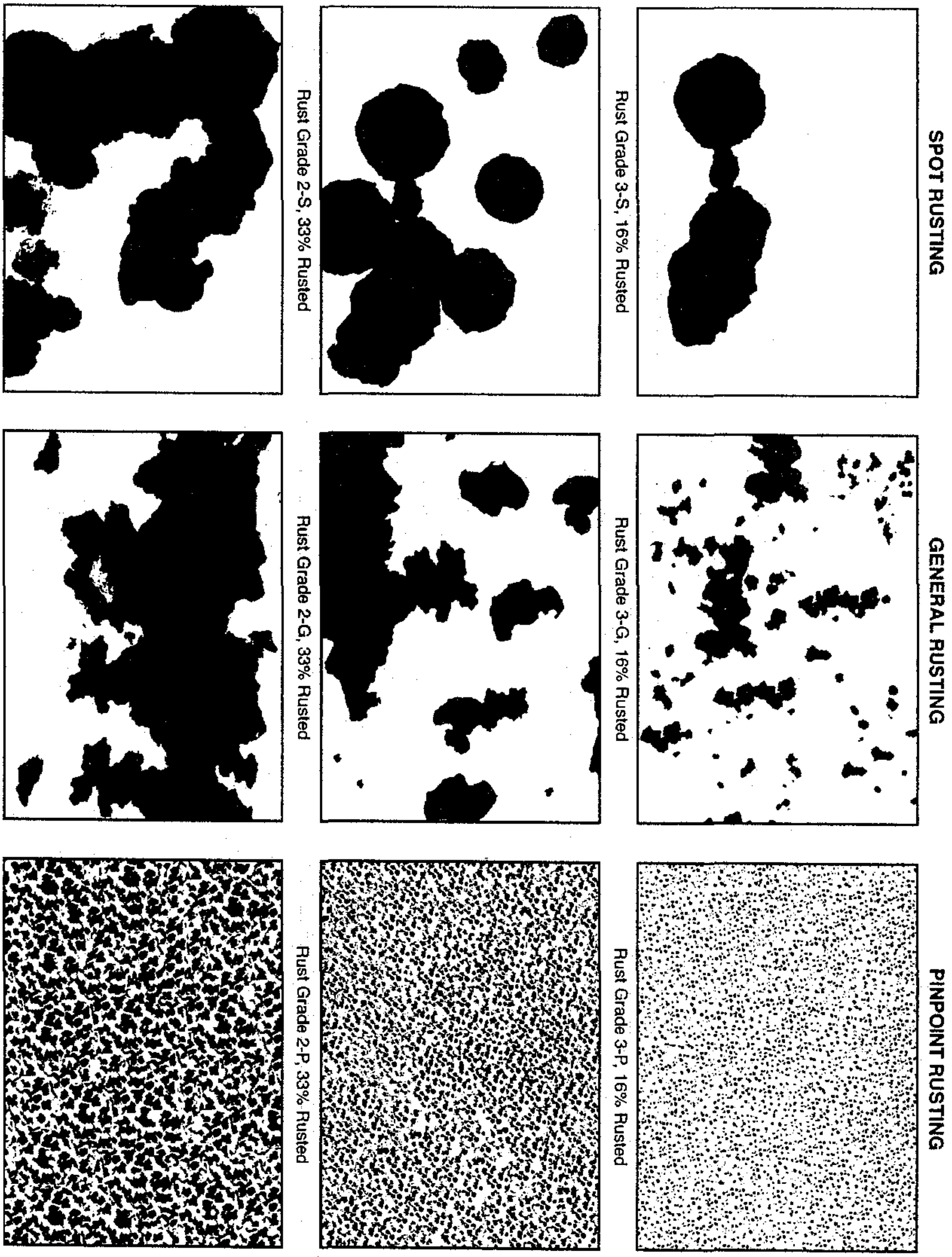


FIG. 3 Examples of Area Percentages

SUMMARY OF CHANGES

ommittee D01 has identified the location of selected changes to this standard since the last date of issue that impact the use of this standard.

Designation: D 4541 – 02

Standard Test Method for
Pull-Off Strength of Coatings Using Portable Adhesion Testers[1]

This standard is issued under the fixed designation D 4541; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

test method covers a procedure for evaluating the
:ength (commonly referred to as adhesion) of a
rigid substrates such as metal, concrete or wood.
:termines either the greatest perpendicular force (in
at a surface area can bear before a plug of material
1, or whether the surface remains intact at a pre-
ce (pass/fail). Failure will occur along the weakest
n the system comprised of the test fixture, adhesive,
stem, and substrate, and will be exposed by the
rface. This test method maximizes tensile stress as
:o the shear stress applied by other methods, such as
knife adhesion, and results may not be comparable.
-off strength measurements depend upon both ma-
instrumental parameters. Results obtained by each
d may give different results. Results should only be
or each test method and not be compared with other
s. There are five instrument types, identified as Test
-E. It is imperative to identify the test method used
rting results.

; test method uses a class of apparatus known as
ıll-off adhesion testers.[2] They are capable of apply-
entric load and counter load to a single surface so
ıgs can be tested even though only one side is
Measurements are limited by the strength of adhe-
s between the loading fixture and the specimen
the cohesive strengths of the adhesive, coating
l substrate.

; test can be destructive and spot repairs may be

values stated in MPa (inch-pound) units are to be
s the standard. The values given in parentheses are
ation only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding[3]

D 3933 Guide for Preparation of Aluminum Surfaces for Structural Adhesives Bonding (Phosphoric Acid Anodizing)[3]

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials[4]

2.2 *ANSI Standard:*

N512 Protective Coatings (Paints) for the Nuclear Industry[5]

2.3 *ISO Standard:*

4624 Paints and Varnish—Pull-Off Test for Adhesion[5]

3. Summary of Test Method

3.1 The general pull-off test is performed by securing a loading fixture (dolly, stud) normal (perpendicular) to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then gradually increased and monitored until either a plug of material is detached, or a specified value is reached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved. The pull-off strength is computed based on the maximum indicated load, the instrument calibration data, and the original surface area stressed. Pull-off strength results obtained using different

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method is under the jurisdiction of ASTM Committee D01 on Paint
oatings, Materials, and Applications and is the direct responsibility of
: D01.46 on Industrial Protective Coatings.
lition approved Feb. 10, 2002. Published April 2002. Originally
) 4541 – 93. Last previous edition D 4541 – $95^{\epsilon 1}$.
adhesion tester may be somewhat of a misnomer, but its adoption by
urers and at least two patents indicates continued usage.

[3] *Annual Book of ASTM Standards*, Vol 15.06.

[4] *Annual Book of ASTM Standards*, Vol 06.01.

[5] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

ay be different because the results depend on al parameters (see Appendix X1).

ance and Use

pull-off strength of a coating is an important e property that has been used in specifications. This d serves as a means for uniformly preparing and ated surfaces, and evaluating and reporting the s test method is applicable to any portable apparatus e basic requirements for determining the pull-off a coating.

ations in results obtained using different devices or ibstrates with the same coating are possible (see X1). Therefore, it is recommended that the type of nd the substrate be mutually agreed upon between ed parties.

purchaser or specifier shall designate a specific test t is, A, B, C, D or E, when calling out this standard.

tus

sion Tester, commercially available, or comparable pecific examples of which are listed in Annex A5.

ading Fixtures, having a flat surface on one end that red to the coating and a means of attachment to the other end.

aching Assembly (adhesion tester), having a cen- engaging the fixture.

e, on the detaching assembly, or an annular bearing ded for uniformly pressing against the coating nd the fixture either directly, or by way of an bearing ring. A means of aligning the base is at the resultant force is normal to the surface.

ans of moving the grip away from the base in as continuous a manner as possible so that a torsion l (opposing pull of the grip and push of the base me axis) force results between them.

er, or means of limiting the rate of stress to less (150 psi/s) so that the maximum stress is obtained about 100 s. A timer is the minimum equipment y the operator along with the force indicator in

taining the maximum stress in 100 s or less by keeping the of shear to less than 1 MPa/s (150 psi/s) is valid for the ff strength measured with these types of apparatuses.

e Indicator and Calibration Information, for the actual force delivered to the loading fixture.

t, or other means for cleaning the loading fixture ger prints, moisture, and oxides tend to be the aminants.

andpaper, or other means of cleaning the coating alter its integrity by chemical or solvent attack. If ding is anticipated, choose only a very fine grade grit or finer) that will not introduce flaws or leave

5.4 *Adhesive*, for securing the fixture to the coating that does not affect the coating properties. Two component epoxies[6] and acrylics[7] have been found to be the most versatile.

5.5 *Magnetic or Mechanical Clamps*, if needed, for holding the fixture in place while the adhesive cures.

5.6 *Cotton Swabs*, or other means for removing excess adhesive and defining the adhered area. Any method for removing excess adhesive that damages the surface, such as scoring (see 6.7), must generally be avoided since induced surface flaws may cause premature failure of the coating.

5.7 *Circular Hole Cutter* (optional), to score through to the substrate around the loading fixture.

6. Test Preparation

6.1 The method for selecting the coating sites to be prepared for testing depends upon the objectives of the test and agreements between the contracting parties. There are, however, a few physical restrictions imposed by the general method and apparatus. The following requirements apply to all sites:

6.1.1 The selected test area must be a flat surface large enough to accommodate the specified number of replicate tests. The surface may have any orientation with reference to gravitational pull. Each test site must be separated by at least the distance needed to accommodate the detaching apparatus. The size of a test site is essentially that of the secured loading fixture. At least three replications are usually required in order to statistically characterize the test area.

6.1.2 The selected test areas must also have enough perpendicular and radial clearance to accommodate the apparatus, be flat enough to permit alignment, and be rigid enough to support the counter force. It should be noted that measurements close to an edge may not be representative of the coating as a whole.

6.2 Since the rigidity of the substrate affects pull-off strength results and is not a controllable test variable in field measurements, some knowledge of the substrate thickness and composition should be reported for subsequent analysis or laboratory comparisons. For example, steel substrate of less than 3.2 mm (⅛-in.) thickness usually reduce pull-off strength results compared to 6.4 mm (¼-in.) thick steel substrates.

6.3 Subject to the requirements of 6.1, select representative test areas and clean the surfaces in a manner that will not affect integrity of the coating or leave a residue. Surface abrasion may introduce flaws and should generally be avoided. A fine abrasive (see 5.3) should only be used if needed to remove loose or weakly adhered surface contaminants.

6.4 Clean the loading fixture surface as indicated by the apparatus manufacturer. Failures at the fixture-adhesive interface can often be avoided by treating the fixture surfaces in accordance with an appropriate ASTM standard practice for preparing metal surfaces for adhesive bonding.

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[6] Araldite Adhesive, available from Ciba-Geigy Plastics, Duxford, Cambridge, CB2 4QA, England, Hysol Epoxy Patch Kit 907, available from Hysol Div., The Dexter Corp., Willow Pass Rd., Pittsburg, CA 94565, and Scotch Weld Adhesive 1838B/A, available from 3M, Adhesives, Coatings and Sealers Div., 3M Center, St. Paul, MN 55144, have been found satisfactory for this purpose.

[7] Versiloc 201 and 204 with accelerator, available from Lord Corp., Industrial Adhesive Div., 2000 W. Grandview Blvd., P.O. Box 10038, Erie, PA 16514, have been found satisfactory for this purpose.

ıides D 2651 and D 3933 are typical of well-proven meth-
ring adhesive bond strengths to metal surfaces.

re the adhesive in accordance with the adhesive
r's recommendations. Apply the adhesive to the
ıe surface to be tested, or both, using a method
ed by the adhesive manufacturer. Be certain to
hesive across the entire surface. Position fixture on
o be tested. Carefully remove the excess adhesive
d the fixture. (**Warning**—Movement, especially
ı cause tiny bubbles to coalesce into large holidays
te stress discontinuities during testing.)

dding about 1 percent of #5 glass beads to the adhesive
alignment of the test fixture to the surface.

l on the adhesive manufacturer's recommendations
icipated environmental conditions, allow enough
adhesive to set up and reach the recommended
; the adhesive set and early cure stage, a constant
sure should be maintained on the fixture. Magnetic
cal clamping systems work well, but systems
ck, such as masking tape, should be used with care
at they do not relax with time and allow air to
een the fixture and the test area.
ng around the fixture violates the fundamental
criterion that an unaltered coating be tested. If
ınd the test surface is employed, extreme care is
prevent micro-cracking in the coating, since such
cause reduced adhesion values. Scored samples
different test, and this procedure should be clearly
h the results.

is common to score around the test fixture when performing
titious substrates where the tensile strength of the substrate
lower than either the pull-off or cohesive strength of the
ı.

the approximate temperature and relative humidity
me of test.

cedure

Methods:

Method A — Fixed Alignment Adhesion Tester

Operate the instrument in accordance with Annex

Method B — Fixed Alignment Adhesion Tester

perate the instrument in accordance with Annex

Method C — Self-Alignment Adhesion Tester Type

perate the instrument in accordance with Annex

Method D — Self-Alignment Adhesion Tester Type

perate the instrument in accordance with Annex

Method E — Self-Alignment Adhesion Tester Type

perate the instrument in accordance with Annex

7.2 Select an adhesion-tester with a detaching assembly having a force calibration spanning the range of expected values along with its compatible loading fixture. Mid-range measurements are usually the best, but read the manufacturer's operating instructions before proceeding.

7.3 If a bearing ring or comparable device (5.1.3) is to be used, place it concentrically around the loading fixture on the coating surface. If shims are required when a bearing ring is employed, place them between the tester base and bearing ring rather than on the coating surface.

7.4 Carefully connect the central grip of the detaching assembly to the loading fixture without bumping, bending, or otherwise prestressing the sample and connect the detaching assembly to its control mechanism, if necessary. For nonhorizontal surfaces, support the detaching assembly so that its weight does not contribute to the force exerted in the test.

7.5 Align the device according to the manufacturer's instructions and set the force indicator to zero.

NOTE 5—Proper alignment is critical, see Appendix X2. If alignment is required, use the procedure recommended by the manufacturer of the adhesion tester and report the procedure used.

7.6 Increase the load to the fixture in as smooth and continuous a manner as possible, at a rate of less than 1 MPa/s (150 psi/s) so that failure occurs or the maximum stress is reached in about 100 s or less (see Note 1).

7.7 Record the force attained at failure or the maximum force applied.

7.8 If a plug of material is detached, label and store the fixture for qualification of the failed surface in accordance with 8.3.

7.9 Report any departures from the procedure such as possible misalignment, hesitations in the force application, etc.

8. Calculation and Interpretation of Results

8.1 If instructed by the manufacturer, use the instrument calibration factors to convert the indicated force for each test into the actual force applied.

8.2 Either use the calibration chart supplied by the manufacturer or compute the relative stress applied to each coating sample as follows:

$$X = 4F/\pi d^2 \tag{1}$$

where:

X = greatest mean pull-off stress applied during a pass/fail test, or the pull-off strength achieved at failure. Both have units of MPa (psi).

F = actual force applied to the test surface as determined in 8.1, and

d = equivalent diameter of the original surface area stressed having units of inches (or millimetres). This is usually equal to the diameter of the loading fixture.

8.3 For all tests to failure, estimate the percent of adhesive and cohesive failures in accordance to their respective areas and location within the test system comprised of coating and adhesive layers. A convenient scheme that describes the total test system is outlined in 8.3.1 through 8.3.3. (See ISO 4624.)

-A laboratory tensile testing machine is used in ISO 4624.
escribe the specimen as substrate *A*, upon which
: coating layers *B*, *C*, *D*, etc., have been applied,
the adhesive, *Y*, that secures the fixture, *Z*, to the top

esignate cohesive failures by the layers within which
· as *A*, *B*, *C*, etc., and the percent of each.
esignate adhesive failures by the interfaces at which
as *A/B*, *B/C*, *C/D*, etc., and the percent of each.
esult that is very different from most of the results
used by a mistake in recording or calculating. If
ese is not the cause, then examine the experimental
ces surrounding this run. If an irregular result can be
o an experimental cause, drop this result from the
owever, do not discard a result unless there are valid
al reasons for doing so or unless the result is a
outlier. Valid nonstatistical reasons for dropping
ude alignment of the apparatus that is not normal to
, poor definition of the area stressed due to improper
of the adhesive, poorly defined glue lines and
, holidays in the adhesive caused by voids or
improperly prepared surfaces, and sliding or twist-
ture during the initial cure. Scratched or scored
ay contain stress concentrations leading to prema-
es. Dixon's test, as described in Practice D 3980,
d to detect outliers.
egard any test where glue failure represents more
of the area. If a pass/fail criterium is being used and
re occurs at a pull-off strength greater than the
eport the result as "pass with a pull-off strength
ained}..."
er information relative to the interpretation of the
is given in Appendix X2.

rt the following information:
ef description of the general nature of the test, such
aboratory testing, generic type of coating, etc.
nperature and relative humidity and any other
vironmental conditions during the test period.
cription of the apparatus used, including: appara-
turer and model number, loading fixture type and
and bearing ring type and dimensions.

| Precision of Adhesion Pull-Off Measurements

	Coefficient of Variation, v, %	Degrees of Freedom	Maximum Acceptable Difference, %
nstrument:			
	8.5	48	29.0
	12.2	129	41.0
		177	
nstrument:			
	8.7	20	25.5
	20.6	58	58.7
		78	

9.1.4 Description of the test system, if possible, by the indexing scheme outlined in 8.3 including: product identity and generic type for each coat and any other information supplied, the substrate identity (thickness, type, orientation, etc.), and the adhesive used.

9.1.5 Test results.

9.1.5.1 Date, test location, testing agent.

9.1.5.2 For pass/fail tests, stress applied along with the result, for example, pass or fail and note the plane of any failure (see 8.3 and ANSI N512).

9.1.5.3 For tests to failure, report all values computed in 8.2 along with the nature and location of the failures as specified in 8.3, or, if only the average strength is required, report the average strength along with the statistics.

9.1.5.4 If corrections of the results have been made, or if certain values have been omitted such as the lowest or highest values or others, reasons for the adjustments and criteria used.

9.1.5.5 For any test where scoring was employed, indicate it by placing a footnote superscript beside each data point affected and a footnote to that effect at the bottom of each page on which such data appears. Note any other deviations from the procedure.

10. Precision and Bias [8]

10.1 *Precision*—In an interlaboratory study of Test Methods A-D, operators made measurements, generally in triplicate but in a few cases in duplicate, on coated panels covering a moderate range at the intermediate adhesion level using four different types of instruments (see Annex A1-Annex A5 and Appendix X1). The number of participating laboratories varied with each instrument and in the case of one instrument with the material. Only two laboratories had access to Type I instruments but two operators in each made the triplicate tests. During the statistical analysis of the results three individual results and one set of triplicates obtained with Type II instruments were rejected as outliers; one single test with Type III instruments and three single results with Type I instruments were rejected. The pooled intra- and inter-laboratory coefficients of variation were found to be those shown in Table 1. Based on these coefficients the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

10.1.1 *Replicate Repeatability*—Triplicate results obtained by the same operator using instruments from the same category should be considered suspect if they differ in percent relative by more than the values given in Table 1.

NOTE 7—Difference in percent relative to two results, x_1 and x_2, is the absolute value of

$$\frac{(x_1 - x_2)}{(x_1 + x_2)/2} \times 100. \qquad (2)$$

10.1.2 *Reproducibility*—Two results, each the mean of triplicates, obtained by operators in different laboratories using

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[8] Supporting data are available from ASTM International Headquarters. Request RR: D01-1094

of the same category should be considered suspect
r in percent relative by more than the values given

—This test method has no bias statement since
ıcceptable reference material suitable for determin-
of this test method.

11. Keywords

11.1 adhesion; coatings; field; paint; portable; pull-off strength; tensile test

ANNEXES

(Mandatory Information)

A1. FIXED-ALIGNMENT ADHESION TESTER, TYPE I

paratus:

. fixed-alignment portable tester as shown in Fig.

—Precision data for Type I instruments described in Table 1
l using the devices illustrated in Fig. A1.1.

'he tester is comprised of detachable aluminum
ures, 50 mm (1.97 in.) in diameter, screws with
ads that are screwed into the center of a fixture, a
e testing assembly that holds the head of the screw,
ge, dynamometer, wheel and crank.

'he testers are available in four models, with maxi-
forces of 5, 15, 25, and 50 kN (1125, 3375, 5625,
lb) respectively. For a fixture having a 50 mm (1.97
r, a 5 kN device corresponds to a range of 2.5 MPa
si).

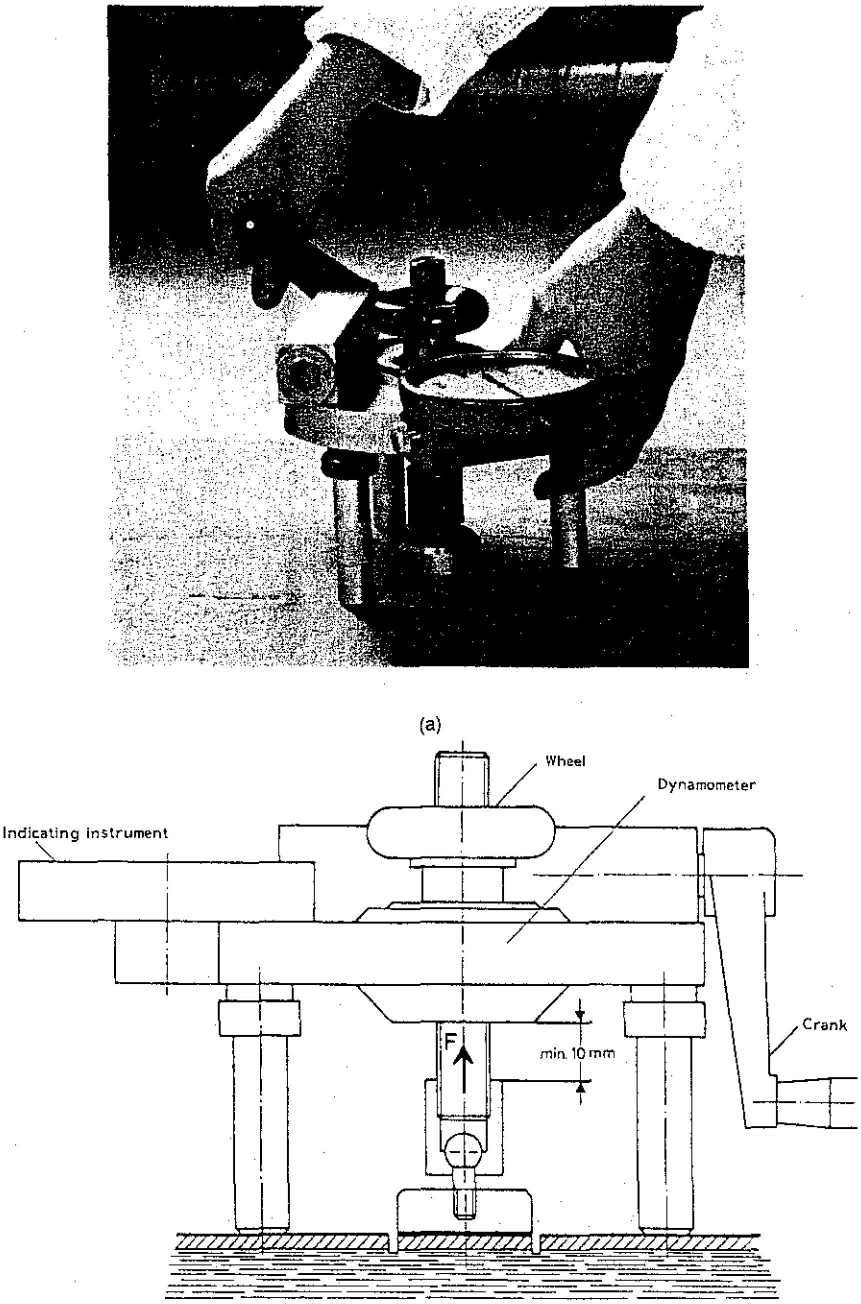
A1.2 *Procedure:*

A1.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to this instrument are described in this section.

A1.2.2 Set the pointer on the zero mark by first pressing the push-button located on the left of the indicator. While holding the push-button, turn the little knob located on the upper part of the indicator to set the pointer at zero. Set the zero after testing by pressing the push-button.

A1.2.3 After fixing a loading fixture to a substrate, insert a screw with a spherical head into the center of the fixture. Position the testing equipment on the metal disc. Then by means of the notched wheel, fix the head of the spherical screw into the socket at the base of the equipment. For the first mechanical approach, stop screwing down the wheel when the pointer on the indicator shifts from the ZERO mark. Tests are done by turning the crank. After each test, turn the crank in the opposite direction until it stops.

Z5 tester is available from PROCEQ SA, Riesbachstrasse 57,
ch, Switzerland.



(a)

(b)

FIG. A1.1 Photograph (a) and sketch (b) of Type I instruments

A2. FIXED-ALIGNMENT ADHESION TESTER TYPE II

paratus:

his is a fixed-alignment portable tester, as shown in

—Precision data for Table 1 were obtained using the devices Fig. A2.1.

A2.1.2 The tester is comprised of detachable aluminum loading fixtures having a flat conic base that is 20 mm (0.8 in.) in diameter on one end for securing to the coating, and a circular *T*-bolt head on the other end, a central grip for engaging the loading fixture that is forced away from a tripod base by the interaction of a handwheel (or nut), and a coaxial bolt connected through a series of belleville washers, or springs in later models, that acts as both a torsion relief and a spring that displaces a dragging indicator with respect to a scale.

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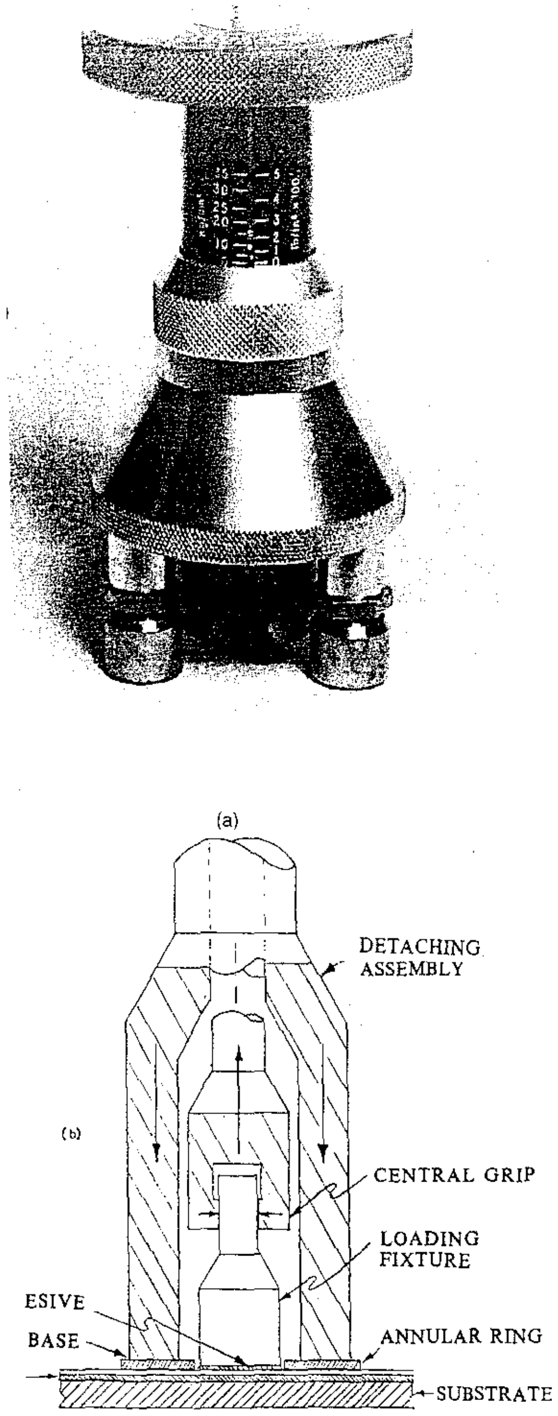
meter. Model 106, adhesion tester is available from Elcometer d., Edge Lane, Droylston, Manchester M35 6UB, United Kingdom.



Photograph (a) and schematic (b) of Type II, Fixed Alignment Pull-Off Tester

A2.1.3 The force is indicated by measuring the maximum spring displacement when loaded. Care should be taken to see that substrate bending does not influence its final position or the actual force delivered by the spring arrangement.

A2.1.4 The devices are available in four ranges: From 3.5, 7.0, 14, and 28 MPa (0 to 500, 0 to 1000, 0 to 2000, and 0 to 4000 psi).

A2.2 *Procedure:*

A2.2.1 Center the bearing ring on the coating surface concentric with the loading fixture. Turn the hand wheel or nut of the tester counter-clockwise, lowering the grip so that it slips under the head of the loading fixture.

A2.2.2 Align or shim the three instrument swivel pads of the tripod base so that the instrument will pull perpendicularly to the surface at the bearing ring. The annular ring can be used on flexible substrates.

A2.2.3 Take up the slack between the various members and slide the dragging (force) indicator located on the tester to zero.

A2.2.4 Firmly hold the instrument with one hand. Do not allow the base to move or slide during the test. With the other hand, turn the handwheel clockwise using as smooth and constant motion as possible. Do not jerk or exceed a stress rate of 150 psi/s (1 MPa/s) that is attained by allowing in excess of 7 s/7 MPa (7 s/1000 psi), stress. If the 14 or 28 MPa (2000 or 4000 psi) models are used, the handwheel is replaced with a nut requiring a wrench for tightening. The wrench must be used in a plane parallel to the substrate so that the loading fixture will not be removed by a shearing force or misalignment, thus negating the results. The maximum stress must be reached within about 100 s.

A2.2.5 The pulling force applied to the loading fixture is increased to a maximum or until the system fails at its weakest locus. Upon failure, the scale will rise slightly, while the dragging indicator retains the apparent load. The apparatus scale indicates an approximate stress directly in pounds per square inch, but may be compared to a calibration curve.

A2.2.6 Record the highest value attained by reading along the bottom of the dragging indicator.

A3. SELF-ALIGNING ADHESION TESTER TYPE III

pparatus:

his is a self-aligning tester, as shown in Fig. A3.1.[11]

—Precision data for Type II instruments shown in Table 1
d using the devices described in Fig. A3.1.

oad is applied through the center of the dolly by a
iston and pin. The diameter of the piston bore is
t the area of the bore is equal to the net area of the
efore, the pressure reacted by the dolly is the same
sure in the bore and is transmitted directly to a
ge.

he apparatus is comprised of: a dolly, 19 mm (0.75
diameter, 3 mm (0.125 in.) inside diameter,
iston and pin by which load is applied to the dolly,
re gage, threaded plunger and handle.

he force is indicated by the maximum hydraulic
displayed on the gage, since the effective areas of
ore and the dolly are the same.

A3.1.5 The testers are available in three standard working ranges: 0 to 10 MPa (0 to 1500 psi), 0 to 15 MPa (0 to 2250 psi), 0 to 20 MPa (0 to 3000 psi). Special dollies shaped to test tubular sections are available.

A3.2 *Procedure:*

A3.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to this instrument are described in this section.

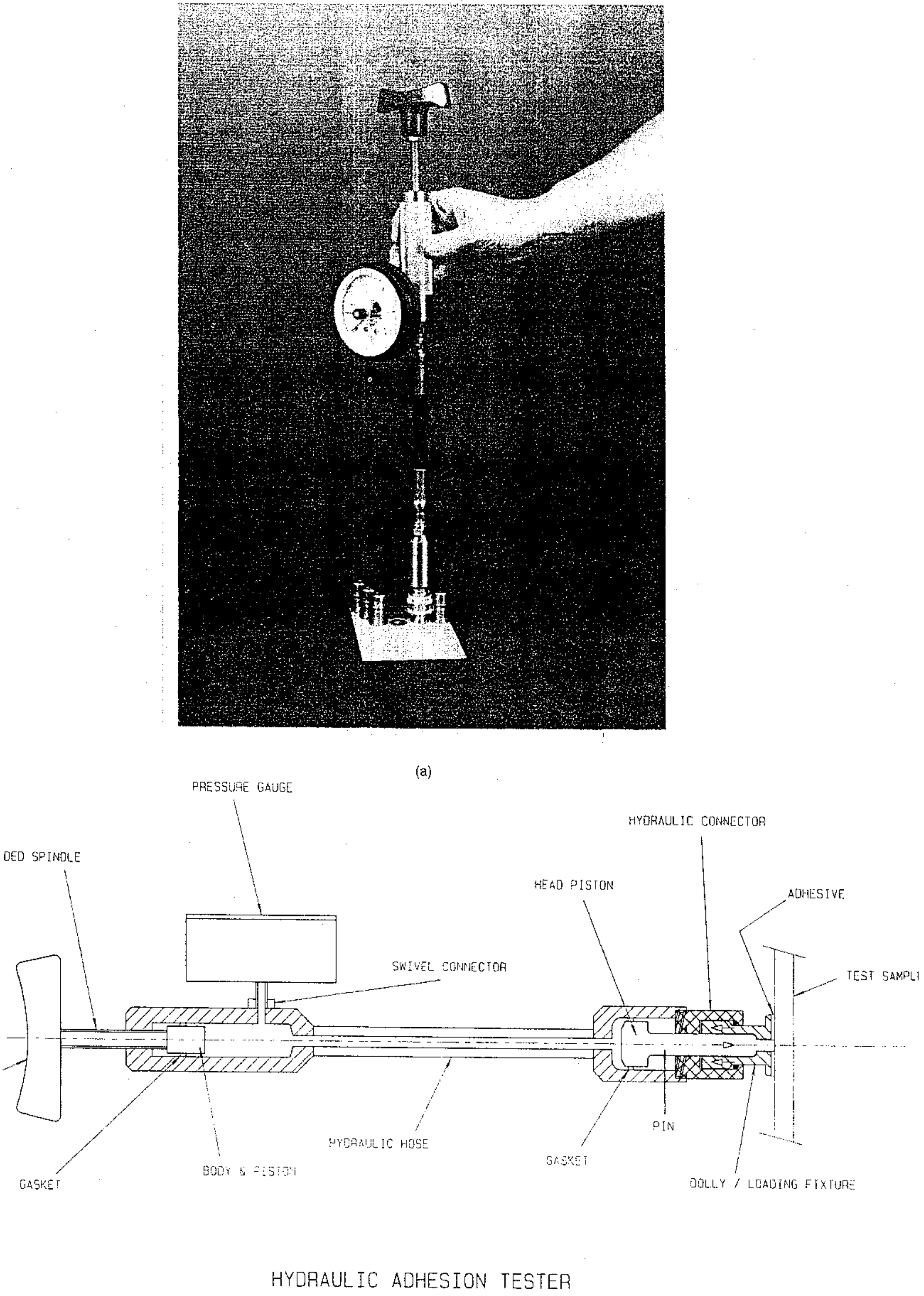
A3.2.2 Insert a decreased TFE-fluorocarbon plug into the dolly until the tip protrudes from the surface of the dolly. When applying adhesive to the dolly, avoid getting adhesive on the plug. Remove plug after holding the dolly in place for 10 s.

A3.2.3 Ensure that the black needle of the tester is reading zero. Connect a test dolly to the head and increase the pressure by turning the handle clockwise until the pin protrudes from the dolly. Decrease pressure to zero and remove the test dolly.

A3.2.4 Connect the head to the dolly to be tested, by pulling back the snap-on ring, pushing the head and releasing the snap-on ring. Ensure the tester is held normal to the surface to be tested and that the hose is straight.

A3.2.5 Increase the pressure slowly by turning the handle clockwise until either the maximum stress or failure is reached.

Mark VII adhesion tester is available from Hydraulic Adhesion Test
l., 629 Inlet Rd., North Palm Beach, FL 33408.



(a)

(b)

FIG. A3.1 Photograph (a) and schematic (b) of Type III, Self-Alignment Tester

A4. SELF-ALIGNMENT ADHESION TESTER TYPE IV

pparatus:

This is a self-aligning tester, which may have a ned pressure source and has a measuring system that choice of different load range detaching assemblies. ı in Fig. A4.1.[12]

]—Precision data for Type IV instruments shown in Table 1 :d using the devices illustrated in Fig. A4.1.

The apparatus is comprised of: (*1*) a loading fixture lat cylindrical base that is 12.5 mm (0.5 in.) in n one end for attachment to the test coating and a ; used with the fixture to reproducibly define the area e. The other end of the fixture has 3/8-16 UNC) a central threaded grip for engaging the loading ›ugh the center of the detaching assembly that is y by the interaction of a self-aligning seal; and (*3*) ed gas that enters the detaching assembly through a se connected to a pressurization rate controller and gage (or electronic sensor).

he force is indicated by the maximum gas pressure ıctive area of the detaching assembly and can be ibrated.

he detaching assemblies are available in six stan- in multiples of two from 3.5 MPa (0 to 500 psi) to) 000 psi). Special ranges are available.

hree models of control modules that control all etaching assemblies are available.

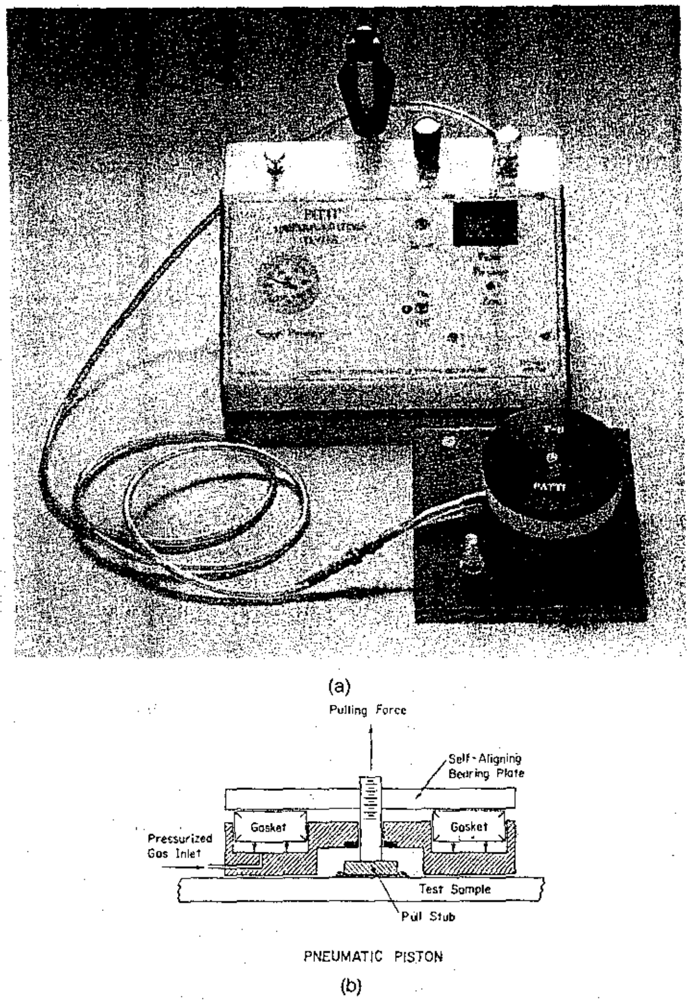
ocedure:

ollow the general procedures described in Sections ›cedures specific to Type IV testers are described in ıg section.

osition the annular detaching assembly over the hed to the coating to be tested, and loosely engage ia the central threaded grip. Leave at least 1.6-mm learance between the detaching assembly and the the threaded grip so that the seal can protrude lign itself when pressurized.

Iake the appropriate pneumatic connections and e valve 1/4 turn.

ero the pressure measuring system.


(a)

(b)

FIG. A4.1 Photograph (a) and schematic of piston (b) of Type IV Self-Alignment Adhesion Tester

A4.2.5 Press the run button to control the gas flow to the detaching assembly and make final adjustment of rate valve so that rate of stress does not exceed 1 MPa/s (150 psi/s) yet reaches its maximum within 100 s.

A4.2.6 Record both the maximum pressure attained and the specific detaching assembly. Conversion to coating stress for ½-in. (12-mm) stud is found in a table supplied for each detaching assembly.

I self-alignment adhesion tester is available from SEMicro Corp., ranch Way, Rockville, MD 20855.

A5. SELF-ALIGNING ADHESION TESTER TYPE V

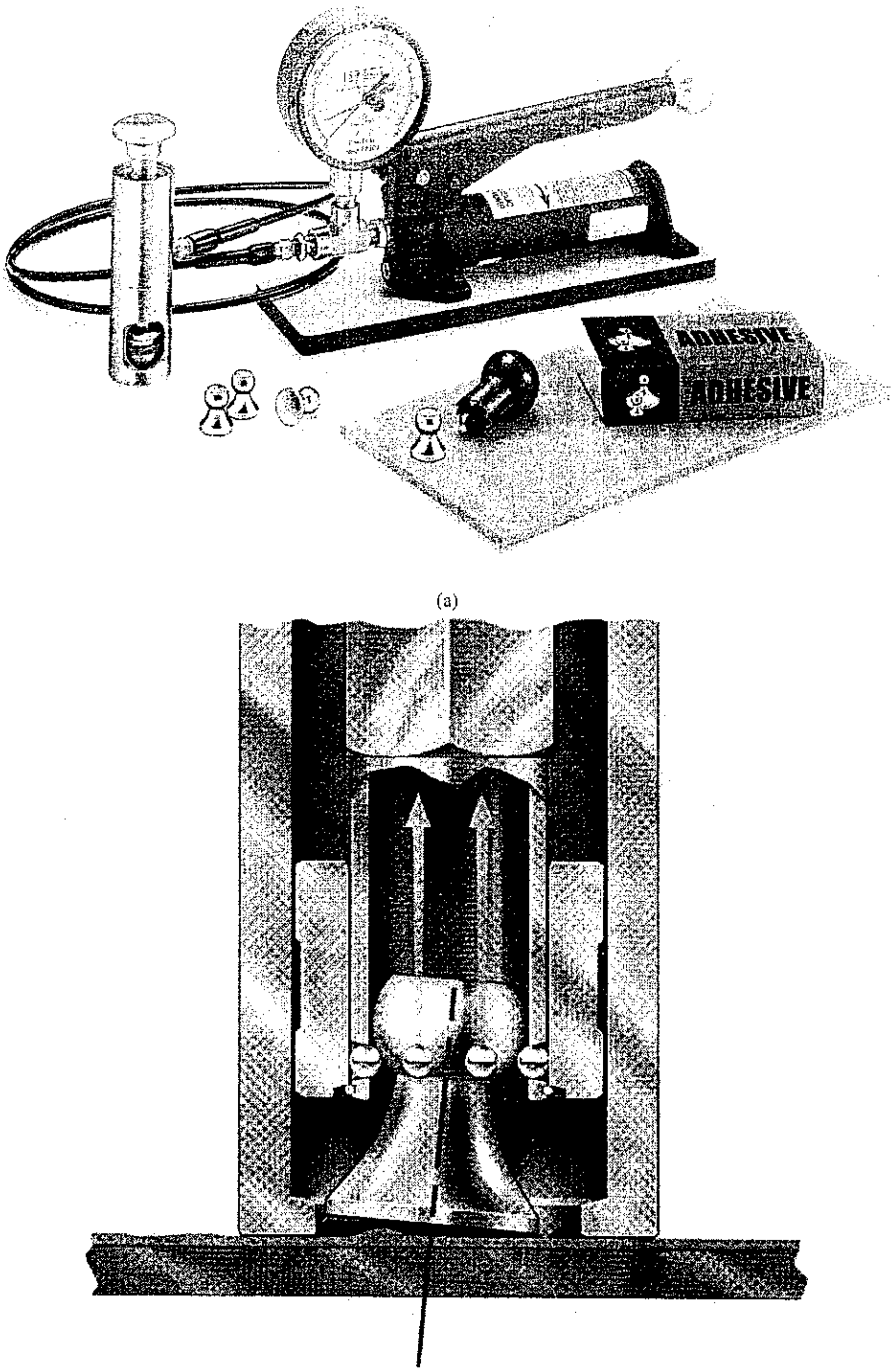
paratus:

ıis is a self-aligning tester, as shown in Fig. A5.1[13].

A5.1.2 Self-aligning spherical dolly head. Load evenly distributes pulling force over the surface being tested, ensuring a perpendicular, balanced pull-off. The diameter of the standard dolly 20 mm (0.78 in.) is equal to the area of the position bore in the actuator. Therefore, the pressure reacted by the dolly is

---

:st Pull-Off Tester is available from DeFelsko Corporation, 802 Ogdensburg, NY 13669 USA.



(a)

(b)

FIG. A5.1 Drawing (a) and schematic (b) of Type V, Self-Aligning Tester

s the pressure in the actuator and is transmitted
he pressure gauge. Conversion charts and calcula-
vided for the 50 mm (1.97 in.) dollies and common
s 10 and 14 mm (0.39 in. and 0.55 in. respectively).

he apparatus is comprised of: a dolly, 20 to 50 mm
1 1.97 in. respectively) diameter, hydraulic actuator
e load is applied to the dolly, pressure gauge, and
ımp.

he drag pointer on the pressure gauge indicates the
orce.

A5.1.5 The testers are available in two standard ranges 0 to 7 MPa (0 to 1000 psi) with 20 mm (0.78 in.) dollies and accessories for finishes on plastics, metals, and wood: 0 to 21 MPa (0 to 3 100 psi) with 20 or 50 mm, or both, (0.78 in. or 1.97 in., or both) dollies and accessories for coatings on metals or concrete, or both. Special dollies, typically 10 mm (0.39 in.) and 14 mm (0.55 in.), are available for use on curved surfaces and when higher pull-off pressures are required.

A5.2 *Procedure:*

Follow the general procedures described in Sections rocedures specific to Type V Testers are described in n.

Ensure the pressure relief valve on the pump is y open. Turn the "drag" indicator on the pressure ero. Push the actuator handle completely down into r assembly.

Place the actuator assembly over the dolly head and quick coupling to the dolly. Close the pressure relief he pump.

Ensure the pump is on a well-supported horizontal it is necessary to place the pump on a vertical surface, position the unit so the pump hose outlet is in the down position to prevent air from being pumped into the actuator. Begin pumping the pump handle until the indicator on the pressure gauge starts to move. Continue pumping at a uniform rate of no more than 1 MPa/s (150 psi/s) until the actuator pulls the dolly from the coating.

A5.2.5 Immediately following the pull, open the pressure relief valve on the pump to release the pressure. The "drag" indicator on the pressure gauge will maintain the maximum pressure reading. Record the pull off pressure and mark the dolly for future qualitative analysis.

APPENDIXES

(Nonmandatory Information)

X1. INTERLABORATORY PULL-OFF DATA

able X1.1 is a summary of the interlaboratory n data. It is included in this appendix to illustrate the e of a pull-off result upon the type of testing device.

TABLE X1.1 Summary of Round-robin Data

Instrument	Type I	Type II	Type III	Type IV
Paint Sample	Mean of Three Results, psi (outliers discarded)			
A	201	586	1185	1160
B	185	674	1157	1099
C	190	827	1245	1333
D	297	888	1686	1678
	Range of Mean Results, psi			
	112	302	529	579

X2. STRESS CALCULATION

he stress computed in 8.2 is equal to the uniform ength of the analogous rigid coating system if the ce is distributed uniformly over the critical locus at of failure. For any given continuous stress distribu- the peak-to-mean stress ratio is known, the uniform ngth may be approximated as:

$$U = XR_o \tag{X2.1}$$

iform pull-off strength, representing the greatest rce that could be applied to the given surface area, i (MPa),

easured in-situ pull-off strength calculated in 8.2, i (MPa) and

ak-to-mean stress ratio for an aligned system.

rtant to note that a difference between these pull-off oes not necessarily constitute an error; rather the surement simply reflects the actual character of the ing system with respect to the analogous ideal rigid

X2.2 An error is introduced if the alignment of the apparatus is not normal to the surface. An approximate correction by the peak-to-mean stress ratio is:

$$R = R_o(1 + 0.14\,az/d), \tag{X2.2}$$

where:

z = distance from the surface to the first gimbal or the point at which the force and counter force are generated by the action of the driving mechanism, in. (mm),

d = diameter of the loading fixture, in. (mm),

a = angle of misalignment, degrees (less than 5), and

R = maximum peak-to-mean stress ratio for the misaligned rigid system.

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Appendix Z – Product data sheet for coating

International®

Interzinc® 22

Inorganic Zinc Rich Silicate

RODUCT ESCRIPTION

A two component solvent based inorganic zinc rich ethyl silicate primer, containing 85% zinc by weight, in the dry film. Complies with the composition and performance requirements of SSPC Paint 20.

Available in ASTM D520, Type II zinc dust version.

ITENDED USES

A metallic zinc primer suitable for use with a wide range of high performance systems and topcoats in both maintenance and new construction of bridges, tanks, pipework, offshore structures and structural steelwork.
Provides excellent corrosion protection for correctly prepared steel substrates, up to temperatures of 540°C (1004°F) when suitably topcoated.
Fast drying primer capable of application in a wide range of climatic conditions.

RACTICAL IFORMATION FOR ITERZINC 22

Colour	Greenish Grey
Gloss Level	Matt
Volume Solids	63%
Typical Thickness	50-80 microns (2-3.2 mils) dry equivalent to 79-127 microns (3.2-5.1 mils) wet
Theoretical Coverage	8.40 m²/litre at 75 microns d.f.t and stated volume solids 337 sq.ft/US gallon at 3 mils d.f.t and stated volume solids
Practical Coverage	Allow appropriate loss factors
Method of Application	Airless Spray, Air Spray

Drying Time

			Overcoating Interval with recommended topcoats	
Temperature	**Touch Dry**	**Hard Dry**	*Minimum*	*Maximum*
5°C (41°F) [1]	30 minutes	3 hours	36 hours	Extended[2]
15°C (59°F) [1]	20 minutes	90 minutes	24 hours	Extended[2]
25°C (77°F) [1]	10 minutes	1 hour	16 hours	Extended[2]
40°C (104°F) [1]	5 minutes	30 minutes	8 hours	Extended[2]

[1] Drying and overcoating times are dependent upon ambient conditions. The figures quoted above have been determined at the quoted temperature and 65% relative humidity. See Product Characteristics for further advice.
[2] Maximum overcoating intervals are shorter when using polysiloxane topcoats. Consult International Protective Coatings for further details.

EGULATORY DATA

Flash Point	Part A 14°C (57°F); Part B Not applicable; Mixed 15°C (59°F)	
Product Weight	2.50 kg/l (20.9 lb/gal)	
VOC	4.08 lb/gal (490 g/lt) 222 g/kg	EPA Method 24 EU Solvent Emissions Directive (Council Directive 1999/13/EC)

See Product Characteristics section for further details

**JRFACE
REPARATION**

All surfaces to be coated should be clean, dry and free from contamination. Prior to paint application all surfaces should be assessed and treated in accordance with ISO 8504:2000.

Oil or grease should be removed in accordance with SSPC-SP1 solvent cleaning.

Abrasive Blast Cleaning

Abrasive blast clean to Sa2½ (ISO 8501-1:2007) or SSPC-SP6 (or SSPC-SP10 for optimum performance). If oxidation has occurred between blasting and application of Interzinc 22, the surface should be reblasted to the specified visual standard.

Surface defects revealed by the blast cleaning process should be ground, filled, or treated in the appropriate manner.

A surface profile of 40-75 microns (1.5-3.0 mils) is recommended.

Shop Primed Steelwork

Interzinc 22 is suitable for application to unweathered steelwork freshly coated with zinc silicate shop primers.

If the zinc shop primer shows extensive or widely scattered breakdown, or excessive zinc corrosion products, overall sweep blasting will be necessary. Other types of shop primer are not suitable for overcoating and will require complete removal by abrasive blast cleaning.

Weld seams and damaged areas should be blast cleaned to Sa2½ (ISO 8501-1:2007) or SSPC-SP6.

Damaged / Repair Areas

All damaged areas should ideally be blast cleaned to Sa2½ (ISO 8501-1:2007) or SSPC-SP6. However, it is acceptable that small areas can be power tool cleaned to Pt3 (JSRA SPSS:1984) or SSPC-SP11, provided the area is not polished. Repair of the damaged area can then be carried out using a recommended zinc epoxy primer - consult International Protective Coatings for specific advice.

PPLICATION

Mixing	Interzinc 22 is supplied in 2 parts, a liquid Binder base component (Part A) and a Powder component (Part B). The Powder (Part B) should be slowly added to the liquid Binder (Part A) whilst stirring with a mechanical agitator. DO NOT ADD LIQUID TO POWDER. Material should be filtered prior to application and should be constantly agitated in the pot during spraying. Once the unit has been mixed it should be used within the working pot life specified.
Mix Ratio	3.17 part(s) : 1.00 part(s) by volume

Working Pot Life	5°C (41°F)	15°C (59°F)	25°C (77°F)	40°C (104°F)
	12 hours	8 hours	4 hours	2 hours

Airless Spray	Recommended	Tip Range 0.38-0.53 mm (15-21 thou) Total output fluid pressure at spray tip not less than 112 kg/cm² (1593 p.s.i.)
Air Spray (Pressure Pot)	Recommended	Gun DeVilbiss MBC or JGA Air Cap 704 or 765 Fluid Tip E
Brush	Suitable - small areas only	Typically 25-50 microns (1.0-2.0 mils) can be achieved
Roller	Not recommended	
Thinner	International GTA803 (International GTA415)	Do not thin more than allowed by local environmental legislation
Cleaner	International GTA803 or International GTA415	
Work Stoppages	Do not allow material to remain in hoses, gun or spray equipment. Thoroughly flush all equipment with International GTA803. Once units of paint have been mixed they should not be resealed and it is advised that after prolonged stoppages work recommences with freshly mixed units.	
Clean Up	Clean all equipment immediately after use with International GTA803. It is good working practice to periodically flush out spray equipment during the course of the working day. Frequency of cleaning will depend upon amount sprayed, temperature and elapsed time, including any delays. All surplus materials and empty containers should be disposed of in accordance with appropriate regional regulations/legislation.	

RODUCT HARACTERISTICS

Interzinc 22 is available in various low lead zinc dust versions dependent upon local legislation/project specification. When utilising the ASTM D520 Type II specification, the appropriate zinc dust grade must be used. Contact International Protective Coatings for further details.

Prior to overcoating, Interzinc 22 must be clean, dry and free from both soluble salts and excessive zinc corrosion products.

Surface temperature must always be a minimum of 3°C above dew point.

When applying Interzinc 22 in confined spaces ensure adequate ventilation.

The minimum overcoating interval is dependent upon the relative humidity during cure. Below 65% relative humidity the minimum recoat period will normally be at least 24 hours, but will be dependent upon the ambient temperature and relative humidity during the application and curing period.

If thinning is required to assist spray application in warmer climates, (typically >28°C (82°F)), it is recommended that International GTA803 thinners are used.

It is recommended that prior to overcoating a solvent rub test to ASTM D4752 should be undertaken. A value of 4 indicates a satisfactory degree of cure for overcoating purposes.

At relative humidities below 50%, curing will be severely retarded and humidity may need to be increased by steam or water spraying. Alternatively, the use of Interzinc accelerator solution may be necessary. Please consult International Protective Coatings for further details in this situation.

Excessive film thickness and/or over-application of Interzinc 22 can lead to mudcracking, which will require complete removal of the affected areas by abrasive blasting and re-application in accordance with the original specification.

Care should be exercised to avoid application of dry film thickness in excess of 125 microns (5 mils).

For high temperature systems the thickness of Interzinc 22 should be restricted to 50 microns (2 mils) d.f.t. Continuous dry temperature resistance of Interzinc 22 is 400°C (752°F) if left untopcoated, however, if this product is used as a primer for Intertherm 50, the dry temperature resistance will be 540°C (1004° F).

Untopcoated Interzinc 22 is not suitable for exposure in acid or alkaline conditions or continuous water immersion.

This product has the following specification approvals:
- SSPC Paint Specification No. 20 Type 1C
- BS5493 (1977) : EP2A
- Shell Specification 40.48.00.30 V1(g)
- ASTM A490 Class B Slip Coefficient
- BS4604 Friction Grip

Note: VOC values are typical and are provided for guidance purpose only. These may be subject to variation depending on factors such as differences in colour and normal manufacturing tolerances.

Low molecular weight reactive additives, which will form part of the film during normal ambient cure conditions, will also affect VOC values determined using EPA Method 24.

YSTEMS OMPATIBILITY

When it is necessary for Interzinc 22 to be overcoated by itself due to low dry film thickness, the coating surface must be fresh and unweathered. A minimum of 50 microns (2 mils) d.f.t of any subsequent coat of Interzinc 22 is needed to ensure good film formation.

Before overcoating with recommended topcoats ensure the Interzinc 22 is fully cured (see above) and if weathering has occurred all zinc salts should be removed from the surface by fresh water washing, and if necessary scrubbing with bristle brushes.

Typical topcoats and intermediates are:

Intercryl 530
Intercure 200
Intercure 420
Intergard 251
Intergard 269
Intergard 475HS
Interseal 670HS
Interfine 979
Intertherm 50
Intertherm 715

In some cases it may be necessary to apply a mist coat of suitable viscosity to minimise bubbling. This will depend upon the age of the Interzinc 22, surface roughness and ambient conditions during curing and application. Alternatively, an epoxy sealer coat, such as Intergard 269, can be used to reduce bubbling problems.

For other suitable topcoats/intermediates, consult International Protective Coatings.

DDITIONAL IFORMATION

Further information regarding industry standards, terms and abbreviations used in this data sheet can be found in the following documents available at www.international-pc.com:

- Definitions & Abbreviations
- Surface Preparation
- Paint Application
- Theoretical & Practical Coverage

Individual copies of these information sections are available upon request.

AFETY RECAUTIONS

This product is intended for use only by professional applicators in industrial situations in accordance with the advice given on this sheet, the Material Safety Data Sheet and the container(s), and should not be used without reference to the Material Safety Data Sheet (MSDS) which International Protective Coatings has provided to its customers.

All work involving the application and use of this product should be performed in compliance with all relevant national, Health, Safety & Environmental standards and regulations.

In the event welding or flame cutting is performed on metal coated with this product, dust and fumes will be emitted which will require the use of appropriate personal protective equipment and adequate local exhaust ventilation.

If in doubt regarding the suitability of use of this product, consult International Protective Coatings for further advice.

PACK SIZE

Unit Size	Part A		Part B	
	Vol	Pack	Vol	Pack
14 litre	10.64 litre	15 litre	3.36 litre	20 litre
5 US gal	3.8 US gal	5 US gal	1.2 US gal	5 US gal

For availability of other pack sizes, contact International Protective Coatings.

SHIPPING WEIGHT

Unit Size	Part A	Part B
14 litre	11.7 kg	25.8 kg
5 US gal	37.5 lb	66.1 lb

STORAGE

Shelf Life	Part A: 6 months minimum at 25°C. Part B: 12 months minimum at 25°C (77°F). Subject to re-inspection thereafter. Store in dry, shaded conditions away from sources of heat and ignition.

portant Note

e information in this data sheet is not intended to be exhaustive; any person using the product for any purpose other than that specifically recommended in this data sheet without first taining written confirmation from us as to the suitability of the product for the intended purpose does so at their own risk. All advice given or statements made about the product hether in this data sheet or otherwise) is correct to the best of our knowledge but we have no control over the quality or the condition of the substrate or the many factors affecting the e and application of the product. Therefore, unless we specifically agree in writing to do so, we do not accept any liability at all for the performance of the product or for (subject to the ximum extent permitted by law) any loss or damage arising out of the use of the product. We hereby disclaim any warranties or representations, express or implied, by operation of or otherwise, including, without limitation, any implied warranty of merchantability or fitness for a particular purpose. All products supplied and technical advice given are subject to Conditions of Sale. You should request a copy of this document and review it carefully. The information contained in this data sheet is liable to modification from time to time in the t of experience and our policy of continuous development. It is the user's responsibility to check with their local International Paint representative that this data sheet is current prior to ng the product.

ue date: 07/07/2009

Intergard® 475HS

Epoxy

RODUCT ESCRIPTION

A low VOC, high solids, high build, two component epoxy coating. Available with conventional pigmentation, or alternatively can be pigmented with micaceous iron oxide to provide enhanced overcoating properties.

ITENDED USES

For use as a high build epoxy coating to improve barrier protection for a range of anti-corrosive coating systems in a wide range of environments including offshore structures, petrochemical plants, pulp and paper mills and bridges.
Suitable for use in both maintenance and new construction situations as part of an anti-corrosive coating system.
The micaceous iron oxide variant improves long term overcoating properties, better facilitating application in the fabrication shop, prior to shipping, with final overcoating on site.

RACTICAL IFORMATION FOR ITERGARD 475HS

Colour	Light Grey MIO and a selected range of colours
Gloss Level	Matt
Volume Solids	80%
Typical Thickness	100-200 microns (4-8 mils) dry equivalent to 125-250 microns (5-10 mils) wet
Theoretical Coverage	6.40 m²/litre at 125 microns d.f.t and stated volume solids 257 sq.ft/US gallon at 5 mils d.f.t and stated volume solids
Practical Coverage	Allow appropriate loss factors
Method of Application	Airless Spray, Air Spray, Brush, Roller

Drying Time

			Overcoating Interval with recommended topcoats	
Temperature	**Touch Dry**	**Hard Dry**	*Minimum*	*Maximum*
-5°C (23°F)	150 minutes	48 hours	48 hours	Extended[1]
5°C (41°F)	90 minutes	16 hours	16 hours	Extended[1]
15°C (59°F)	75 minutes	10 hours	10 hours	Extended[1]
25°C (77°F)	60 minutes	5 hours	5 hours	Extended[1]

[1] See International Protective Coatings Definitions and Abbreviations
Maximum overcoating intervals are shorter when using polysiloxane topcoats. Consult International Protective Coatings for further details.

EGULATORY DATA

Flash Point	Part A 34°C (93°F); Part B 31°C (88°F); Mixed 33°C (91°F)	
Product Weight	2.10 kg/l (17.5 lb/gal)	
VOC	1.72 lb/gal (207 g/lt)	EPA Method 24
	92 g/kg	EU Solvent Emissions Directive (Council Directive 1999/13/EC)

See Product Characteristics section for further details

Ecotech is an initiative by International Protective Coatings a world leader in coating technology to promote the use of environmentally sensitive products across the globe.

URFACE REPARATION

All surfaces to be coated should be clean, dry and free from contamination. Prior to paint application all surfaces should be assessed and treated in accordance with ISO 8504:2000.

Primed Surfaces

Intergard 475HS should always be applied over a recommended anti-corrosive coating scheme. The primer surface should be dry and free from all contamination and Intergard 475HS must be applied within the overcoating intervals specified (consult the relevant product data sheet).

Areas of breakdown, damage etc., should be prepared to the specified standard (e.g. Sa2½ (ISO 8501-1:2007) or SSPC-SP6, Abrasive Blasting, or SSPC-SP11, Power Tool Cleaning) and patch primed prior to the application of Intergard 475HS.

Zinc Primed Surfaces

Ensure that the surface of the primer is clean, dry and free from contamination and zinc salts before application of Intergard 475HS. Ensure zinc primers are fully cured before overcoating.

PPLICATION

Mixing	Material is supplied in two containers as a unit. Always mix a complete unit in the proportions supplied. Once the unit has been mixed it must be used within the working pot life specified. (1) Agitate Base (Part A) with a power agitator. (2) Combine entire contents of Curing Agent (Part B) with Base (Part A) and mix thoroughly with power agitator.	
Mix Ratio	3 part(s) : 1 part(s) by volume	

Working Pot Life

-5°C (23°F)	5°C (41°F)	15°C (59°F)	25°C (77°F)
60 minutes	60 minutes	60 minutes	60 minutes

Airless Spray	Recommended	Tip Range 0.53-0.63 mm (21-25 thou) Total output fluid pressure at spray tip not less than 190 kg/cm² (2702 p.s.i.)
Air Spray (Pressure Pot)	Recommended	Gun: DeVilbiss MBC or JGA Air Cap: 704 or 765 Fluid Tip: E
Brush	Suitable	Typically 75 microns (3.0 mils) can be achieved
Roller	Suitable	Typically 75 microns (3.0 mils) can be achieved
Thinner	International GTA007	Do not thin more than allowed by local environmental legislation
Cleaner	International GTA822 (or International GTA415)	
Work Stoppages	Do not allow material to remain in hoses, gun or spray equipment. Thoroughly flush all equipment with International GTA822. Once units of paint have been mixed they should not be resealed and it is advised that after prolonged stoppages work recommences with freshly mixed units.	
Clean Up	Clean all equipment immediately after use with International GTA822. It is good working practice to periodically flush out spray equipment during the course of the working day. Frequency of cleaning will depend upon amount sprayed, temperature and elapsed time, including any delays. All surplus materials and empty containers should be disposed of in accordance with appropriate regional regulations/legislation.	

RODUCT HARACTERISTICS

Intergard 475HS is primarily designed for use as a high build barrier coat to impart barrier protection to a coating system. It is recommended that it should be overcoated with a durable finish from the Interfine or Interthane range when appearance is important.

Maximum film build in one coat is best attained by airless spray. When applying by methods other than airless spray, the required film build is unlikely to be achieved. Application by air spray may require a multiple cross spray pattern to attain maximum film build. Low or high temperatures may require specific application techniques to achieve maximum film build.

When applying Intergard 475HS by brush or roller, it may be necessary to apply multiple coats to achieve the total specified system dry film thickness.

Surface temperature must always be a minimum of 3°C above dew point.

When applying Intergard 475HS in confined spaces ensure adequate ventilation.

Exposure to unacceptably low temperatures and/or high humidities during or immediately after application may result in incomplete cure and surface contamination that could jeopardise subsequent intercoat adhesion.

For further details regarding cure times and overcoatability, please contact International Protective Coatings.

Interchanging standard and elevated temperature curing agents during application to a specific structure will give rise to an observable colour change due to the difference in the yellowing/discolouration process common to all epoxies on exposure to UV light.

In common with all epoxies Intergard 475HS will chalk and discolour on exterior exposure. However, these phenomena are not detrimental to anti-corrosive performance.

Intergard 475HS is not designed for continuous water immersion.

The micaceous iron oxide variant of this product is frequently used as a 'travel coat' prior to final overcoating on site. To ensure best extended overcoating properties ensure over-application does not occur and that the surface is fully cleaned of any contamination which may be present in the surface texture due to the coarse nature of the micaceous iron oxide pigmentation.

When applying Intergard 475HS at temperatures less than 15°C (59°F) or wet film thicknesses of 150 microns (6 mils) or less, addition of around 5% International GTA007 thinners will improve film appearance, sprayability and aid film thickness control.

Note: VOC values are typical and are provided for guidance purpose only. These may be subject to variation depending on factors such as differences in colour and normal manufacturing tolerances.

Low molecular weight reactive additives, which will form part of the film during normal ambient cure conditions, will also affect VOC values determined using EPA Method 24.

YSTEMS OMPATIBILITY

Intergard 475HS is designed for use over correctly primed steel. Suitable primers are:

Intercure 200
Intergard 251
Intergard 269
Interzinc 22 (mist coat or tie coat may be required)*
Interzinc 315
Interzinc 52

Suitable topcoats are:

Intergard 740
Interthane 990
Interfine 629HS
Intergard 475HS

For alternative primers and finishes, consult International Protective Coatings.

*See relevant product data sheet for details.

DDITIONAL FORMATION

Further information regarding industry standards, terms and abbreviations used in this data sheet can be found in the following documents available at www.international-pc.com:

- Definitions & Abbreviations
- Surface Preparation
- Paint Application
- Theoretical & Practical Coverage

Individual copies of these information sections are available upon request.

AFETY RECAUTIONS

This product is intended for use only by professional applicators in industrial situations in accordance with the advice given on this sheet, the Material Safety Data Sheet and the container(s), and should not be used without reference to the Material Safety Data Sheet (MSDS) which International Protective Coatings has provided to its customers.

All work involving the application and use of this product should be performed in compliance with all relevant national, Health, Safety & Environmental standards and regulations.

In the event welding or flame cutting is performed on metal coated with this product, dust and fumes will be emitted which will require the use of appropriate personal protective equipment and adequate local exhaust ventilation.

If in doubt regarding the suitability of use of this product, consult International Protective Coatings for further advice.

PACK SIZE

Unit Size	Part A		Part B	
	Vol	Pack	Vol	Pack
20 litre	15 litre	20 litre	5 litre	5 litre
5 US gal	3 US gal	5 US gal	1 US gal	1 US gal

For availability of other pack sizes, contact International Protective Coatings.

SHIPPING WEIGHT

Unit Size	Part A	Part B
20 litre	35.4 kg	9.3 kg
5 US gal	57.1 lb	8.4 lb

STORAGE

Shelf Life	12 months minimum at 25°C (77°F). Subject to re-inspection thereafter. Store in dry, shaded conditions away from sources of heat and ignition.

nportant Note

e information in this data sheet is not intended to be exhaustive; any person using the product for any purpose other than that specifically recommended in this data sheet without first taining written confirmation from us as to the suitability of the product for the intended purpose does so at their own risk. All advice given or statements made about the product hether in this data sheet or otherwise) is correct to the best of our knowledge but we have no control over the quality or the condition of the substrate or the many factors affecting the e and application of the product. Therefore, unless we specifically agree in writing to do so, we do not accept any liability at all for the performance of the product or for (subject to the aximum extent permitted by law) any loss or damage arising out of the use of the product. We hereby disclaim any warranties or representations, express or implied, by operation of w or otherwise, including, without limitation, any implied warranty of merchantability or fitness for a particular purpose. All products supplied and technical advice given are subject to r Conditions of Sale. You should request a copy of this document and review it carefully. The information contained in this data sheet is liable to modification from time to time in the ht of experience and our policy of continuous development. It is the user's responsibility to check with their local International Paint representative that this data sheet is current prior to ing the product.

sue date: 07/07/2009

ww.international-pc.com

Interthane® 990

Polyurethane

RODUCT ESCRIPTION

A two component acrylic polyurethane finish giving excellent durability and long term recoatability.

ITENDED USES

Suitable for use in both new construction and as a maintenance finish which can be used in a wide variety of environments including offshore structures, chemical and petrochemical plants, bridges, pulp and paper mills, and in the power industry.

RACTICAL IFORMATION FOR ITERTHANE 990

Colour	Wide range via the Chromascan system
Gloss Level	High Gloss
Volume Solids	57% ± 3% (depends on colour)
Typical Thickness	50-75 microns (2-3 mils) dry equivalent to 88-132 microns (3.5-5.3 mils) wet
Theoretical Coverage	11.40 m^2/litre at 50 microns d.f.t and stated volume solids 457 sq.ft/US gallon at 2 mils d.f.t and stated volume solids
Practical Coverage	Allow appropriate loss factors
Method of Application	Airless Spray, Air Spray, Brush, Roller

Drying Time

			Overcoating Interval with recommended topcoats	
Temperature	**Touch Dry**	**Hard Dry**	*Minimum*	*Maximum*
5°C (41°F)	5 hours	24 hours	24 hours	Extended[1]
15°C (59°F)	2.5 hours	10 hours	10 hours	Extended[1]
25°C (77°F)	1.5 hours	6 hours	6 hours	Extended[1]
40°C (104°F)	1 hour	3 hours	3 hours	Extended[1]

[1] See International Protective Coatings Definitions and Abbreviations

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EGULATORY DATA

Flash Point	Part A 34°C (93°F); Part B 49°C (120°F); Mixed 35°C (95°F)	
Product Weight	1.21 kg/l (10.1 lb/gal)	
VOC	3.50 lb/gal (420 g/lt) 341 g/kg	EPA Method 24 EU Solvent Emissions Directive (Council Directive 1999/13/EC)

See Product Characteristics section for further details

URFACE REPARATION

All surfaces to be coated should be clean, dry and free from contamination. Prior to paint application all surfaces should be assessed and treated in accordance with ISO 8504:2000.

Primed Surfaces

Interthane 990 should always be applied over a recommended anti-corrosive coating scheme. The primer surface should be dry and free from all contamination and Interthane 990 must be applied within the overcoating intervals specified (consult the relevant product data sheet).

Areas of breakdown, damage etc., should be prepared to the specified standard (e.g. Sa2½ (ISO 8501-1:2007) or SSPC-SP6, Abrasive Blasting, or SSPC-SP11, Power Tool Cleaning) and patch primed prior to the application of Interthane 990.

PPLICATION

Mixing	Material is supplied in two containers as a unit. Always mix a complete unit in the proportions supplied. Once the unit has been mixed it must be used within the working pot life specified. (1) Agitate Base (Part A) with a power agitator. (2) Combine entire contents of Curing Agent (Part B) with Base (Part A) and mix thoroughly with power agitator.	
Mix Ratio	6 part(s): 1part(s) by volume	

Working Pot Life

5°C (41°F)	15°C (59°F)	25°C (77°F)	40°C (104°F)
12 hours	4 hours	2 hours	45 minutes

Airless Spray	Recommended	Tip Range 0.33-0.45 mm (13-18 thou) Total output fluid pressure at spray tip not less than 155 kg/cm² (2204 p.s.i.)
Air Spray (Pressure Pot)	Recommended	Gun DeVilbiss MBC or JGA Air Cap 704 or 765 Fluid Tip E
Air Spray (Conventional)	Suitable	Use suitable proprietary equipment
Brush	Suitable	Typically 40-50 microns (1.6-2.0 mils) can be achieved
Roller	Suitable	Typically 40-50 microns (1.6-2.0 mils) can be achieved
Thinner	International GTA713 or International GTA733 (or International GTA056)	Do not thin more than allowed by local environmental legislation
Cleaner	International GTA713 or International GTA733	
Work Stoppages	Do not allow material to remain in hoses, gun or spray equipment. Thoroughly flush all equipment with International GTA713. Once units of paint have been mixed they should not be resealed and it is advised that after prolonged stoppages work recommences with freshly mixed units.	
Clean Up	Clean all equipment immediately after use with International GTA713. It is good working practice to periodically flush out spray equipment during the course of the working day. Frequency of cleaning will depend upon amount sprayed, temperature and elapsed time, including any delays. All surplus materials and empty containers should be disposed of in accordance with appropriate regional regulations/legislation.	

RODUCT HARACTERISTICS

Interthane 990 is available in a range of metallic finishes - please consult the separate Interthane 990 Metallic Working Procedures document for further information.

Level of sheen and surface finish are dependent on application method. Avoid using a mixture of application methods whenever possible.

Best results in terms of gloss and appearance will always be obtained by conventional air spray application.

For brush and roller application, and in some colours, two or more coats of Interthane 990 may be required to give uniform coverage, especially when applying Interthane 990 over dark undercoats, and when using certain lead free bright colours such as yellows and oranges. Best practice is to use a colour compatible intermediate or anticorrosive coating under the Interthane 990.

When overcoating after weathering or ageing, ensure the coating is fully cleaned to remove all surface contamination such as oil, grease, salt crystals and traffic fumes, before application of a further coat of Interthane 990.

Absolute measured adhesion of topcoats to aged Interthane 990 is less than that to fresh material, however, it is adequate for the specified end use.

This product must only be thinned using the recommended International thinners. The use of alternative thinners, particularly those containing alcohols, can severely inhibit the curing mechanism of the coating.

Surface temperature must always be a minimum of 3°C (5°F) above dew point.

When applying Interthane 990 in confined spaces ensure adequate ventilation.

Condensation occurring during or immediately after application may result in a matt finish and an inferior film.

Premature exposure to ponding water will cause colour change, especially in dark colours and at low temperatures.

This product is not recommended for use in immersion conditions. When severe chemical or solvent splashing is likely to occur contact International Protective Coatings for information regarding suitability.

A modified version of Interthane 990 is available for use within the Korean marketplace in order to provide improved workability.

Note: VOC values quoted are based on maximum possible for the product taking into account variations due to colour differences and normal manufacturing tolerances.

Low molecular weight reactive additives, which will form part of the film during normal ambient cure conditions, will also affect VOC values determined using EPA Method 24.

YSTEMS OMPATIBILITY

The following primers/intermediates are recommended for Interthane 990:

Intercure 200
Intercure 200HS
Intercure 420
Intergard 251
Intergard 269
Intergard 345
Intergard 475HS
Interseal 670HS
Interzinc 315
Interzinc 52
Interzinc 52HS
Interzone 505
Interzone 954
Interzone 1000

Interthane 990 is designed only to be topcoated with itself.

For other suitable primers/intermediates consult International Protective Coatings.

DDITIONAL FORMATION

Further information regarding industry standards, terms and abbreviations used in this data sheet can be found in the following documents available at www.international-pc.com:

- Definitions & Abbreviations
- Surface Preparation
- Paint Application
- Theoretical & Practical Coverage
- Interthane 990 Metallic Finish Working Procedures

Individual copies of these information sections are available upon request.

AFETY RECAUTIONS

This product is intended for use only by professional applicators in industrial situations in accordance with the advice given on this sheet, the Material Safety Data Sheet and the container(s), and should not be used without reference to the Material Safety Data Sheet (MSDS) which International Protective Coatings has provided to its customers.

All work involving the application and use of this product should be performed in compliance with all relevant national, Health, Safety & Environmental standards and regulations.

In the event welding or flame cutting is performed on metal coated with this product, dust and fumes will be emitted which will require the use of appropriate personal protective equipment and adequate local exhaust ventilation.

If in doubt regarding the suitability of use of this product, consult International Protective Coatings for further advice.

Warning: Contains isocyanate. Wear air-fed hood for spray application.

PACK SIZE

Unit Size	Part A		Part B	
	Vol	Pack	Vol	Pack
20 litre	17.14 litre	20 litre	2.86 litre	3.7 litre
5 US gal	4.29 US gal	5 US gal	0.71 US gal	1 US gal

For availability of other pack sizes, contact International Protective Coatings.

SHIPPING WEIGHT

Unit Size	Part A	Part B
20 litre	23.1 kg	3.5 kg
5 US gal	47.6 lb	7.1 lb

STORAGE

Shelf Life	24 months (Part A) & 12 months (Part B) minimum at 25°C (77°F) Subject to re-inspection thereafter. Store in dry, shaded conditions away from sources of heat and ignition.

nportant Note

he information in this data sheet is not intended to be exhaustive; any person using the product for any purpose other than that specifically recommended in this data sheet without first btaining written confirmation from us as to the suitability of the product for the intended purpose does so at their own risk. All advice given or statements made about the product vhether in this data sheet or otherwise) is correct to the best of our knowledge but we have no control over the quality or the condition of the substrate or the many factors affecting the se and application of the product. Therefore, unless we specifically agree in writing to do so, we do not accept any liability at all for the performance of the product or for (subject to the aximum extent permitted by law) any loss or damage arising out of the use of the product. We hereby disclaim any warranties or representations, express or implied, by operation of w or otherwise, including, without limitation, any implied warranty of merchantability or fitness for a particular purpose. All products supplied and technical advice given are subject to ur Conditions of Sale. You should request a copy of this document and review it carefully. The information contained in this data sheet is liable to modification from time to time in the ght of experience and our policy of continuous development. It is the user's responsibility to check with their local International Paint representative that this data sheet is current prior to sing the product.

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