Study on the Current Performance of Piping and Structure Coatings in Oil and Gas Field

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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(A.P. Dr. Patthi bin Hussain)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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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.

MOHD RIDZUAN BIN ABDUL RAHIM

ABSTRACT

In oil and gas field, the coating system including blasting and painting process on the piping and structure are very important in order to prevent corrosion happens. Since the life of corrosion protection not successfully exceeded than 50 years requirements, that coating system is known to be failure before reach the expectation life of protection. Therefore, investigations of the failed piping and structure coatings are necessary to be performed by the author in Final Year Project (FYP).

The objective of this project is to investigate the performance of the current piping and structure coatings (outer surface) in oil and gas field. The experimental works including metallography, scanning electron microscopy (SEM), cathodic disbondment test, and pull-off adhesion test described the real performance of the coatings. The results include: (1) Three layers of the coating exist, (2) Good and bad interlocking between coating layers, (3) The coating’s thickness do not comply with the specification standard, (5) Preferable coating’s disbondment, (6) Sacrificial anode by zinc coating exist, and (7) Good adhesion properties of coating’s layers. These results may conclude that the possible reason of current performance coatings failed less than 50 years because of the lack of primer and mid-coat’s thickness and bad interlocking between mid-coat and top-coat layers. This report also will mainly reflect background, problem statement, objectives and scope of study of this project.

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First of all, I would like acknowledge the endless help and support received from my supervisor, A.P. Dr. Patthi bin Hussain. His assistance and guidance have been the main source of motivation to carry out this project. Secondly, my appreciation goes up to my previous internship host company (oil and services company) for assisting me in providing the coating sample in order to work on this project. They also provided me with references for coating system in order for me to study and include the information into literature review part. Also not forget to all UTP's staff and technician whose have been assisting me to finish my project and experimental works.

Last but not least, I would like to thank all my families for providing the support and courage to my success in this education field. Also not forget to fellow colleagues for their assistance and ideas in completion of this project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

In oil and gas industry, the use of engineering coatings to improve the wear life of components is worldwide and the circumstances prevailing at each site that can differ widely play a significant role in choice of coating technique, and also the materials. The factors such as working environment and conditions, availability of specialized subcontract facilities nearby or of on-site skills, materials and equipment are very important, in order to preventative maintenance or reaction to breakdown and causing downtime. Previous experience of site conditions (usually at offshore) is an important factor in deciding the course of action to take and assisting in the decision-making process [1].

Coating provides means for enhancing constructional strength of steels. It makes possible a combined method when one group of dislocation mechanisms is used for bulk hardening (grain refining, creation of stable sub-granular dislocation structures), while the working surface is hardened trough other mechanisms (dislocation density increase, separation of excess phase, etc). Combined hardening provides reduction in metal consumption constructions [11].

Since many years ago, it was compulsory to undergo with coating procedure which including blasting and painting process on the piping and structural at offshore. PETRONAS Carigali Sdn. Bhd. is one of the oil and gas producer company in Malaysia who ensure this procedure must be undertaken well and follows the coating specification. If this procedure does not be conducted well, the serious problem occurs at the work site, i.e. offshore, for example leaking on the pipelines and structures.

In Oxford Dictionary, coating refers to “layer of paint”. The advance meaning tells the coating is a covering that was applied to an object (metal) to improve surface properties of a bulk material usually referred to as a substrate. One can improve among others appearance, adhesion, corrosion resistance, wear resistance, scratch resistance, anything else. For painting, it refers to the practice of applying color to a surface.

For the Final Year Project (FYP), the research and experimental lab have been conducted on the coating system at the OUTER surface of oil and gas piping and structure, and NOT for internal pipe coating.

Figure 1.1: One of the coating procedures - blasting process on the offshore structure

Figure 1.1 shows the example of *abrasive blasting process* that was operated by one of the PETRONAS Carigali’s services contractor. The operation is to remove rust, scale and any other extraneous material from the substrate and also leaves an irregular profile which provides an ideal key for the coating adhesion. Dry abrasive blasting is often the best method of surface preparation for long term protection coating systems. *Abrasive* is the degree of surface roughness and rate of cleaning is partially governed by the characteristics of the abrasive used; these being hardness, size, density and shape [8].

1.2 PROBLEM STATEMENT

The piping and structure coatings in oil and gas field should last in service for more than 50 years [12]. (*See* ***Figure A*** *to* ***D*** *in Appendices for more example of failed coating at offshore platform facilities*)

Hence, the life of corrosion protection should be more than 50 years. However, the current performance of piping and structure coatings show that they failed less than the recommended period. This tells us that the **Life of Corrosion Protection is less than 50 years.** Therefore, investigations of the failed piping and structure coatings are necessary to be performed in order to avoid reversion of the similar problem happens.

1.3 OBJECTIVE AND SCOPE OF STUDY

In general, the objective of this Final Year Project carried out is to investigate the performance of the current piping and structure coatings (external surface) in oil and gas field. The scopes of studies are as follows:

1. To study and research about the coating system on the outer surface of oil and gas piping and structure based on the common specific standard in order to relate with the problem statement that is short life of corrosion protection. This will be described and discussed in the Literature Review part.

2. To conduct some laboratory work and finding the factor of failure on the coated metal (metal of interest: carbon steel) related to why the life of corrosion protection is not be able to exceed than 50 years.

CHAPTER 2

LITERATURE REVIEW

2.1 CORROSION

As we know, the main purpose of the coating is to prevent the corrosion occurs on the surface of the metal. Corrosion is generally an Electro-chemical process, which results from an anodic reaction and at least one cathodic reaction. The corrosion of steel takes place at the anode. The anodic reaction is expressed as follows [1]:

$$M \rightarrow M^{+n} + ne \tag{2.1}$$

where M is the element involved; n is the oxidation state of metal; and e is electrons. Several metals can form more than one positive ion, for instance Fe can readily form Fe^{2+} and Fe^{3+}. Ionic or covalently bonded solids are then formed, which in the case of oxides of metals ranging from an oxidation state of 1 to 4 are M_2O, MO and M_2O_3, MO_2 respectively [1].

By referring to **Figure 2.1 (a)**, metal ions and electrons diffuse faster than oxygen ions. This causes the oxide to grow at the outer surface, and is the mechanism seen in iron, copper, chromium, and cobalt. **Figure 2.1 (b)** shows the oxygen ions and electrons diffuse through the existing oxide layer faster than metal ions. This causes the oxide layer to grow at the metal/oxide interface, a situation seen in titanium and zirconium. Finally, electron conduction maybe rate-determining, and if the oxide is a good insulator the oxide thickness is determined by the distance that electrons can tunnel through it [1].

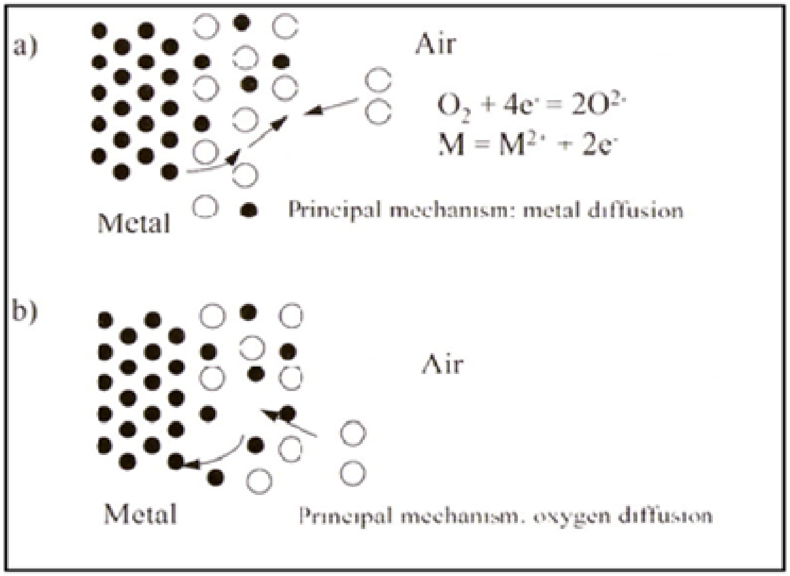


Figure 2.1: Mechanism of oxidation at a surface [1]

For example, **Figure 2.2** shows how the corrosion damage on carbon steel pipe or structure. Note that the pitted area to the right is anodic and gives up the electrons while the cathodic area to the left (where the water and oxygen from the air are present) is where rust appears. The pitted area where the carbon steel is weakened is not where the rust appears [9].

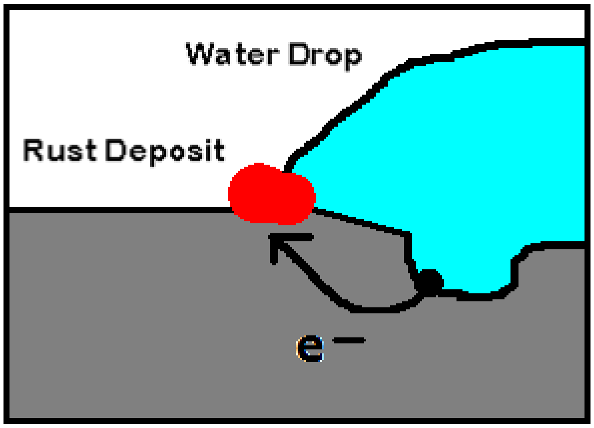


Figure 2.2: Corrosion damage on carbon steel pipe/structure [9]

Corrosion cell is formed on a metal surface when oxygen and water are present. Refer **Figure 2.3**. It shows the electro chemical reaction taking place in the corrosion cell as describe as above anodic reaction plus cathodic reaction as below [2]:

In acidic solution: $2H^+ + 2e \rightarrow H_2$ (2.2)

In neutral and alkaline solution: $O_2 + 2H_2O + 4e \rightarrow 4OH^-$ (2.3)

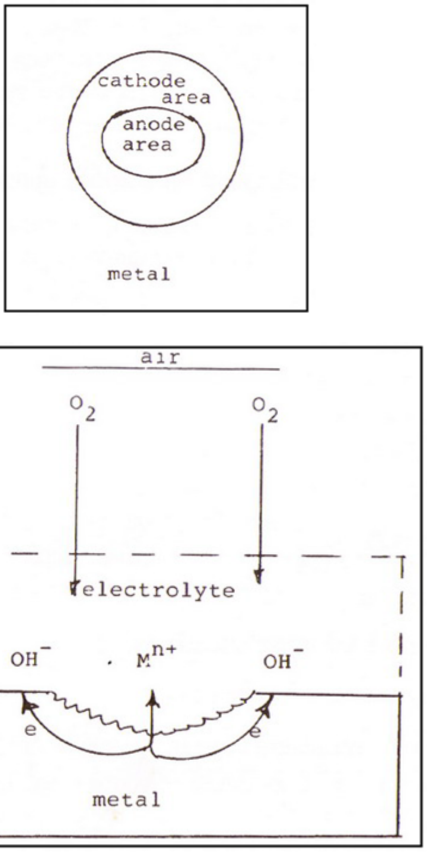


Figure 2.3: Structure of corrosion cell [2]

There are several factors affecting the corrosion happens on the surface of metals. Corrosion reactions can be accelerated by the existence of certain criteria including:

1. Variations in oxygen content on the material surface.
2. The concentration of chemical salts (in this case, it refers to ocean)
3. Other metal compounds of higher nobility (more electro positive) in contact with the steel.
4. High temperature. The higher temperature gives the greater rate of corrosion.
5. Certain types of bacteria near the metal surface.

2.2 INTRODUCTION TO COATING SYSTEMS

The majority of coatings are applied on external surfaces to protect pipe and structure from corrosion, and also atmospheric pollution. For coating to be effective, it must isolate the base metal from the environment. This service life is dependent upon the thickness and the chemical properties of the coating layer. The latter determines the durability of a coating material in specific environment which is the corrosion resistance of a metal coating or the stability of its organic and inorganic compounds. The coating's durability must be greater than that of the based metal or it must be maintained by some means. A coating is often required to protect the base metal with its original pore and crack, which may have resulted from corrosion on the surface of those metals [2].

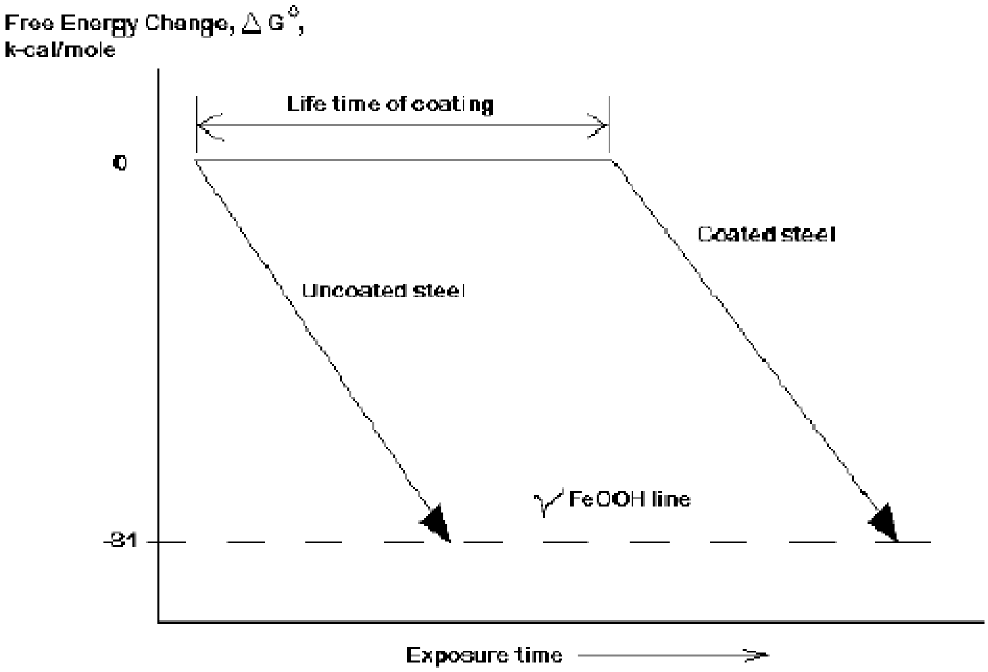


Figure 2.4: Corrosion resistance coating role [2]

The general coating technique that widely used in heavy industrial in the world is classified according to the electrochemical principle upon which they operate to provide protection. These categories are [2]:

1. EMF control
2. Cathodic control protection

3. Anodic control protection
4. Mixed control protection
5. Resistance control protection

The mechanism of the corrosion cell can explain the theories upon which these five categories operate [2].

2.2.1 Surface Preparation for Coating Process

In the early 1970s, the new term "*surface engineering*" was introduced into use in technical terminology, and since then this new field of science and technology has been developed rapidly. Today, the following definition of this engineering discipline is proposed [3, 4, 5].

Surface engineering is a specific discipline, including the following research areas [3]:

1. Manufacturing processes of surface layers; i.e., superficial layers and coatings, performed for both technological and user (service) purpose;
2. Associated physical phenomena;
3. Resulting effects connected with improved performance.

Surface engineering can also be known as an enabling technology, applicable to a wide spectrum of industrial activities (for example in oil and gas industry). This technology covers three major categories of interrelated specification/activities [3, 6]:

1. *Optimizing of surface properties*. This involves the optimizing of the surface (and substrates, i.e., the coating system) in term of corrosion, adhesion, wear, and other material properties.
2. *Coating technology*. This includes the more traditional technologies of painting, electroplating, weld surfacing, plasma and hypervelocity spraying, various thermal

and thermochemical treatments such as nitriding and carburizing, as well as the newer technologies of laser surfacing, physical and chemical vapor deposition, and ion implantation.

3. *Coating characterization.* A principal interest in this case is centered on evaluation of surfaces and interfaces in term of composition, morphology, and structure, and mechanical, tribological, electrical, and optical properties.

Correct surface preparation is a vitally important stage for most coating systems, it is often the process which governs the service life of the coating system. The quality of a surface preparation is governed by the amount of surface contaminate remaining on the substrate after cleaning, although it may also relate to the resultant surface texture, e.g. the surface profile on a substrate after blast cleaning. There are various ways to prepare a surface prior to coating [8]:

1. Abrasive blast cleaning
2. Wire brushing
3. Scraping
4. Grinding
5. Needle gunning
6. Chemical cleaning
7. Water blasting
8. Weathering
9. Flame cleaning
10. Vapour degreasing

Although there are several types of cleaning procedure, but the most interested one in oil and gas industry is *Dry Abrasive Cleaning.* In regulation and protocol of PETRONAS Carigali Sdn. Bhd. company, the items especially metals (piping and structure) must be undergo with this kind of blasting before they will be painted with several coating paints.

2.2.2 Dry Abrasive Cleaning

Dry abrasive cleaning or commonly known as *dry abrasive blasting* is carried out by projecting a highly concentrated stream of small abrasive particles onto the substrate's surface at speeds of approximately 720 km/h (450m.p.h.). The operation removes rust, scale and any other extraneous material from the substrate and also leaves an irregular profile which provides an ideal key for the coating adhesion. Dry abrasive blasting is often the best method of surface preparation for long term protection coating systems. *Abrasive* is the degree of surface roughness and rate of cleaning is partially governed by the characteristics of the abrasive used; these being hardness, size, density and shape [8].

Abrasives are versatility in producing various required degrees of finish, profile, and cleanliness on the metal surface. The degree of surface roughness and the rate of cleaning depend primarily on the characteristic of the abrasive grit used. There are two types of abrasive; Metallic Abrasive and Non-Metallic Abrasive. However, metallic abrasive is primarily used for metal of oil and gas piping and structure.

Figure 2.5: Metallic Abrasive GMA (Garnet Mineral Australia) type – (*These samples were getting from one of the oil and gas services company in Malaysia*)

Figure 2.6: From Left - The Sample of ASTM-A36 Carbon Steel Structural Plate before and after blasting process respectively

The Blasting equipments are [12]:

1. Air Compressor
2. Air Hose
3. Blast Pot/Machine (*See **Figure I** in the appendices*)
4. Blasting Hose
5. Remote/Deadman's Handle
6. Deadman Control System
7. Moisture Separator
8. Blast Nozzle
9. Abrasive
10. Respiration Filter

2.2.2.1 Surface Profile

Surface profile is determined by a range of variables which include the following [12]:

1. The strength and hardness of the surface being cleaned
2. The velocity of the abrasive
3. The hardness and specific gravity of the abrasive
4. The size of the abrasive
5. The angle of abrasive impact
6. The particle shape of the abrasive
7. The time the surface is exposed to blasting

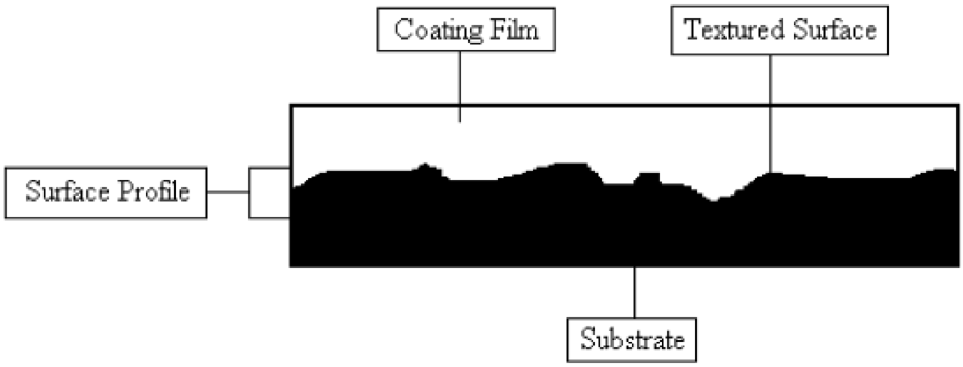


Figure 2.7: Surface profile of the coated metal

2.2.2.2 Surface Preparation Standard for Abrasive Blast Cleaning

There are several standard for abrasive blasting based on the Steel Structures Painting Council (S.S.P.C.).

Table 2.1: Surface Preparation Standard for Abrasive Blast Cleaning [12]

Standard	SSPC	ISO 8501-1	NACE
White Metal Blast Cleaning	SSPC-SP5	SIS Sa3	NACE No.1
Near-White Metal Blast Cleaning	SSPC-SP10	SIS Sa2.5	NACE No.2
Commercial Blast Cleaning	SSPC-SP6	SIS Sa2	NACE No.3
Brush-Off Blast Cleaning	SSPC-SP7	SIS Sa1	NACE No.4

From table above, SSPC-SP5 and SSPC-SP10 are equivalent to standard SIS 05 59 00, Sa 2.5 or Sa 3 respectively. These are usually referred as the common standard of blast cleaning process for Oil and Gas Piping and Structure.

2.2.2.3 Blast Cleaning Method / Preparation

The common methods of blast cleaning that have been applied in Carigali –Triton Operating Company (CTOC) Sdn. Bhd. are shown as below [7].

a) Blast cleaning shall be accordance to SIS 05 59 00, Sa 2.5 or Sa 3 as specified in the coating system (equivalent to SSPC-SP10 and SP5 respectively). Only dry abrasive blast cleaning shall be used.
b) The abrasive shall be free from dust, salts, and other impurities and shall have a mesh size 30 minimum. Recycling of abrasive such as copper slag is not permitted. Garnet abrasives shall be used for Stainless Steel and Duplex Stainless Steel surface.
c) All necessary precautions be taken to ensure that previously painted areas are not damaged or contaminated by blasting operations in particular no contamination of wet coated surfaces by dust and abrasives shall be allowed and where damage or contamination does occur the affected area shall be blast cleaned again and the paint system made good.
d) Where the surface being prepared lies adjacent to a previously coated surface the blast cleaning shall overlap the coated surface by a minimum of 25mm.
e) Blast cleaning shall not be conducted when the surface are less than 3ºC above dew point or when the relative humidity of the air is greater than 80%.
f) All equipment surfaces shall be adequately covered in the vicinity of blasting.
g) No blasting grit shall be allowed to enter equipment and instruments.
h) Blasting pot shall be pressure tested prior to use. All hoses shall be in good condition. Damaged hoses shall be replaced and removed from site.
i) Blasting grit shall be stored in a dry covered area. Wet grit shall be replaced and removed from site.
j) Blasting grit shall be non-radioactivity.
k) Blasting dust shall be properly contained and shall be not allowed to spread to other work areas.

2.2.3 Coating Systems

Paint systems protect the substrate from corrosion by a combination of one or more of the following methods [8]:

1. *The barrier principle*: The substrate is isolated from the environment, which causes corrosion by using a coating, which has a low permeability to moisture and air. This may be achieved by applying a thick coat of paint or applying a paint having low permeability or even better applying a thick, low permeability coating.
2. *Passivation*: Corrosion is arrested by chemical reactions between rust inhibitive pigments in the primer, and the substrate and/or moisture passing through the paint film.
3. *Cathodic protection*: This is achieved by coating the substrate with a paint containing metallic pigments, usually zinc, which is ignoble with respect to the substrate. Cathodic protection may also be achieved by means of metal coatings.

2.2.3.1 Layers of a Paint Film

Paint systems may be single layered coatings or multi layered coatings. In preparation of oil and gas facilities especially piping and structure, a multi layer coating should be used. A multi layered paint system consists of a *Primer*, at least one *Mid-Coat* and a *Finish Coat*. Each coat has its own specification [8].

Carigali Triton Operating Company (CTOC) Sdn. Bhd. has come out with their specification for the painting / coating of offshore facilities. This specification would be the same as the other oil and gas producer such as Petronas Carigali Sdn. Bhd. and Talisman Energy Inc.. **Table 2.2** shows the coating system selection of Carbon Steel piping and structural steel.

Table 2.2: Carbon Steel Piping and Structural Steel with a Design Temperature Equal to or Less Than 120ºC (Ordinary Condition) – S.S.P.C Standard [7]

Coat	Product Code	Description	Minimum Dry Film Thickness (Micron)	Maximum Dry Film Thickness (Micron)
Primer	I	Zinc-Rich Epoxy	75	90
Second	II	High Solid Epoxy	150	200
Final	III	Gloss Two Pack Recoatable Top Coat Acrylic Polyurethane	50	75
Total			275	365

2.2.3.2 Primer Coat

For the *Primer Coat*, its function is to provide maximum and lasting adhesion to the substrate, to provide a key for the next paint layer and, in most cases, to retard corrosion by means of an inhibitive pigment when primer is applied to steel substrates [8].

Figure 2.8: Zinc-Rich Epoxy Primer Coat on the Sample of ASTM-A36 Carbon Steel Structural Plate

2.2.3.3 Mid-Coat

*Mid-Coat*s may be standard undercoats or high build coats, primarily there to serve as a barrier to prevent the passage of water. Primers and finish coats are often thin layered coatings and are quite permeable compared to mid-coats; without a mid-coat the inhibitive pigment in the primer would soon be leached out, which will lead to corrosion.

Mid-coats also build up the film thickness to provide a more even surface by filling slight surface irregularities [8].

Figure 2.9: High-Solid Epoxy Mid-Coat (Second Coat) on the Sample of ASTM-A36 Carbon Steel Structural Plate

2.2.3.4 Finish Coat

The *Finish Coat* (final coat) usually known as *Top-Coat* in a system gives a surface its final appearance; i.e. color and gloss. A final coat must also have solar protective properties and, on most structural work, must have a gloss finish to allow water to flow more readily from a surface and allow the surface to be cleaned easily [8].

Figure 2.10: Top-Coat (Finish/Final Coat) on the Sample of ASTM-A36 Carbon Steel Structural Plate

2.2.3.5 Life of Corrosion Protection

The Life of Corrosion Protection should be **more than 50 years** the Life of *Top-Coat* should be **more than 20 years** in **severe marine environment** [12].

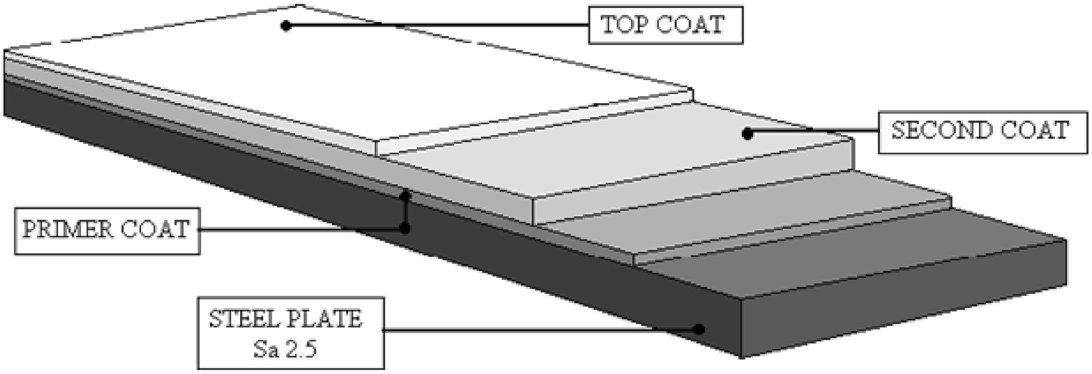


Figure 2.11: The Cross Sectional of Coating System on the Steel Plate

2.2.4 Wet Film Thickness (WFT)

The film thickness of coating layers need to be considered well in order to comply with the Steel Structures Painting Council (S.S.P.C.) standard as shown in **Table 2.2**. There are two types in measuring the film thickness; (1) *Wet Film Thickness* (WFT) and (2) *Dry Film Thickness* (DFT).

The WFT is sometimes recorded as the average between the last touching tooth and the first non-touching tooth. The wet film thickness is taken immediately after coating has been applied so that any deviation from the specified thickness range can be immediately rectified while the paint is still wet, thereby reducing the amount of dried coatings which are outside the specified thickness tolerances. Also any calculations based on volume solids will be meaningless if a lot of solvent has evaporated.

The wet film thickness may be found by using a *Comb Gauge* or an *Eccentric Wheel* [13]. (*See* ***Table A*** *in Appendices part for Wet Film Thickness Requirements*)

Procedure for measuring WFT using a *Comb Gauge* [13]:

1. Immediately after application of the paint, the comb gauge should be placed firmly onto the substrate in such a way that the teeth are normal to the plane of the surface
2. The gauge should then be removed and the teeth examined in order to determine the shortest one to touch the wet paint film. The film thickness should be recorded as lying between the last tooth touching and the first non tooth as shown on the tooth calibrations marked on the gauge.
3. At least two further readings should be taken in different places in order to obtain representative results over the full coated area.

The wet film thickness may be found by calculation [16]:

$$\text{WFT} = \frac{\text{Volume}}{\text{Area}} \qquad (2.4)$$

$$\text{WFT} = \frac{100}{\text{VS}\ \%} \times \text{DFT}$$

:. Where VS % is the percentage of Solids Volume

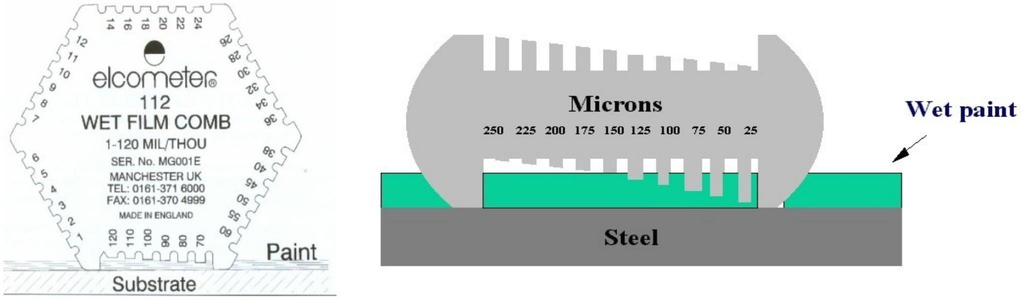


Figure 2.12: Measuring the Wet Film Thickness by using *Comb Gauge* [16]

2.2.5 Dry Film Thickness (DFT)

There are four methods of determining the dry film thickness of paint:

1. Non-destructive test gauges
2. Destructive test gauges
3. Test panels
4. Calculation

2.2.5.1 Non destructive test gauges

Measuring the DFT directly with a non-destructive test gauge is the most widely used method; there are a variety of gauges available with various scale ranges:

1. Magnetic film thickness (*banana*) gauge
2. Pull-off gauge or *Tinsley pencil*
3. Magnetic *horseshoe* gauge
4. Eddy current/electromagnetic gauge

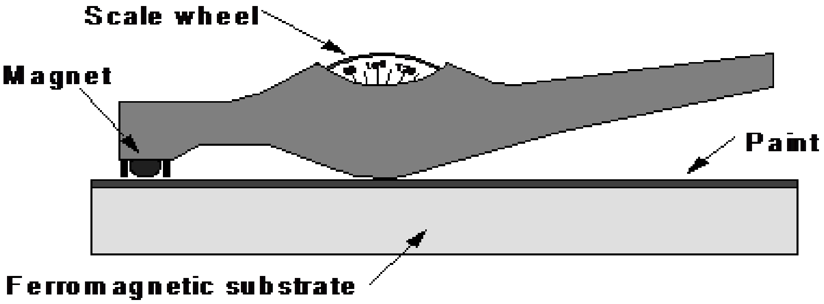


Figure 2.13: Magnetic film (*Banana*) thickness gauge [13]

2.2.5.2 Destructive test gauges

Destructive test gauges cut into the paint film and should therefore only be used where necessary due to the cost of repairing the damaged coating. They are sometimes used on paint films containing M.I.O. pigment; M.I.O. is ferromagnetic and therefore non-destructive test gauges, which rely on a non-magnetic coating, cannot be used. The *paint inspection gauge* (P.I.G) is one such type of destructive test gauge. A small vee shaped channel is cut into the coating at a fixed angle governed by a cutter built into the gauge. The width of the channel is then measured on a graticule scale by means of a microscope which is again built into the instrument.

Other destructive thickness gauges are the *Saberg thickness drill* or *Erichsen thickness drill*s which work on a similar principle to the paint inspection gauge.

2.2.5.3 Test panels

Test panels, for example metal plates of a known thickness, may be used to measure the DFT indirectly, by coating them in the same way as the work being carried out and measuring the DFT with a micrometer.

2.2.5.4 Calculation

The DFT may be assessed indirectly by measuring the WFT of the paint, and providing the volume solids (VS %) content of the paint is known, calculating the DFT with equations below [16] :

$$\mathrm{DFT} = \frac{\mathrm{VS}\ \% \times \mathrm{WFT}}{100} \tag{2.5}$$

∴ Where VS % is the percentage of Solids Volume

2.3 CATHODIC PROTECTION

2.3.1 Basic Principle and Methods

Iron and steel structures that are buried or immersed may be protected against corrosion simply by making electrical connection between the ferrous material and slabs of zinc-zinc anodes. Unlike other methods of protection with zinc this process of *cathodic protection* (C.P.) does not rely on any part of the iron surface being coated. When iron is joined electrically to zinc under immersed conditions, all the iron becomes cathodic and does not corrode, while the zinc becomes anodic and corrodes in preference to the iron to which it is joined, hence "cathodic protection" [15].

The first line of defense against corrosion on a buried or immersed iron or steel structure is usually the coating. If the coating totally isolates the structure from the environment which causes corrosion, the structure will not corrode. However, coatings are not totally impermeable and they are also likely to contain some defects, therefore corrosion would take place unless a secondary system protected these areas [13].

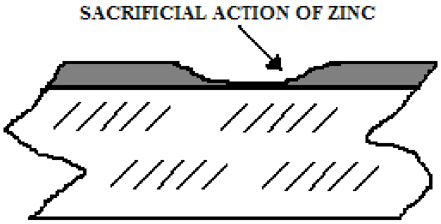


Figure 2.14: Zinc Coating sacrifices itself by Galvanic Action at a coat defect. Sacrificial Action will continue as long as any zinc remains in the area [12]

Figure 2.12 shows the layer of zinc acts as a sacrificial anode which covers the damage metal surface. This will give the maximum protection in order to prevent the corrosion happens at that particular passive area.

Cathodic protection prevents the structure corroding at areas where coating defects exist. The coating defects must be of the type which allows an electrical path to exist from the soil/water to the metal surface. Therefore, cathodic protection is usually back up to the coating for anti-corrosion purposes, although it should be noted that cathodic protection can also be applied to uncoated structures. Both anodic and cathodic areas would be present on the surface of a structure without cathodic protection. Anodic areas on the structure corrode, current flows from anodic areas through the electolyte to cathodic areas. When any exposed metal on the structure's surface receives current, the area becomes cathodic; this prevents corrosion [13].

Cathodic protection is defined in British Standard BS 7361: Part 1: 1991 - Cathodic protection (Code of practice for land and marine applications) as:
'A means of rendering a metal immune from corrosive attack by causing a direct current to flow from its electrolytic environment into the entire metal surface.'

There are two methods of applying cathodic protection:

1. Using sacrificial anodes.
2. Using impressed current.

Both methods achieve cathodic protection by passing small d.c. currents through the electrolyte from anodes which are installed close to the metallic structure. The anodes will corrode and are manufactured in materials which provide a long service life and consistency of corrosion characteristics [13].

2.3.2 Zinc-Rich Coatings

Zinc-Rich coatings, which contain zinc dust and a binding medium, have been widely used since 1930s in purpose of protection of steel structures from corrosion. As coatings, they possess a number of advantages over galvanized coatings and regular organic paints: they are easier to apply, particularly for large or odd-shaped articles, and, they able to provide galvanic protection at edges or the places where the paint coating is defective. In contrast to other types of application of zinc, where the resistance to corrosion is of primary importance, the role of zinc dust in zinc-rich paints is not to resist corrosion but to react with moisture and oxygen, especially in fresh coatings, and in the process to strengthen the paint and to galvanically protect the coated steel [14].

2.3.3 Protection Mechanism

The protection of steel by a zinc-rich coating is mainly via two effects: The barrier effect and galvanic action. While the coating serves as a physical barrier to the environment which the coated steel is used, the zinc particles in the coating provide the galvanic protection. In addition to the galvanic action and the barrier effect of zinc-rich coatings, two other effects that are also beneficial in term of corrosion protection have been identified: (a) the absorption of oxygen by the zinc powder and (b) the inhibition of the oxygen reduction by the zinc corrosion products on the steel surface. The remaining zinc particles, after their insulation from the steel surface, later react with oxygen and thus reduce the amount of oxygen arriving at the steel surface [14].

In order for a galvanic process to occur on steel with a painted zinc-rich coating, three conditions must be satisfied:

1. The zinc particles in the coating must be in electrical contact with each other.
2. The zinc particles must be in electrical contact with the steel.
3. A continues electrolyte must be exist between the zinc particles and steel.

The first two conditions are met by zinc-rich coatings containing sufficiently high zinc content. The third condition is fulfilled when a steel panel bearing a zinc-rich coating is wetted by a film of electrolyte such as salt solution [14].

2.3.4 Cathodic Disbondment Test

Cathodic disbonment test may be performed on a sample cut from coated samples which simulate the coating applied to a structure which is cathodically protected. The test will indicate whether the coating system is susceptible to disbondment if hydrogen gas bubbles are given off from the surface of the substrate. It is likely to be the case in service if the substrate is excessively cathodic, which is excessive amount of cathodic protection to a coated structure can lead to disbondment of the coating [13].

Cathodic disbondment is a significant problem when coating defects are present due to a stripping action caused by the hydrogen bubbles and is especially prominent when the impressed current is way in excess of the corrosion current; this condition is purposely produced for the cathodic disbondment test [13].

The test incorporates a coated test panel (or sample taken from the coated structure) with a hole drilled into the coating; this simulates a paint film defect. Surrounding the hole, a plastic tube is glued down and filled with a specified electrolyte, e.g. a 3% w/v sodium chloride solution. Wires from a battery or transformer are attached to the test panel and to a inert electrode, e.g. platinum rod, set into the lid of the plastic tube and making contact with the electrolyte; a current is then impressed to make the test panel cathodic. The potential required will be specified, -1500 mV is typical [13].

The coating is assessed after a given period of time, e.g. a few weeks, for the amount of stripping which has occurred from the boundary of the hole [13].

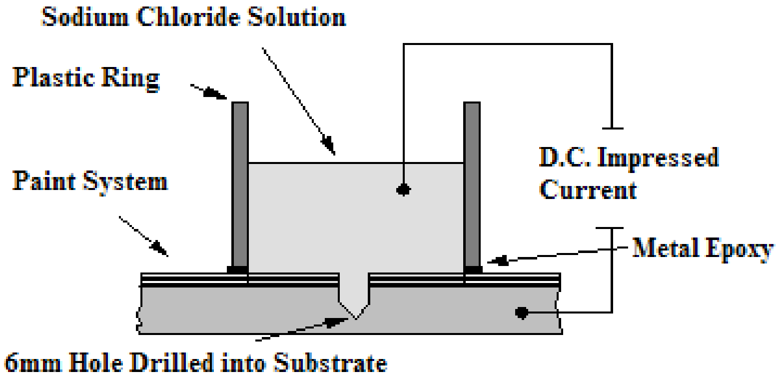


Figure 2.15: Cathodic Disbonment test [13]

2.4 COATING ADHESION

Adhesion failures more often occur between the uncoated substrate and the primer due to inadequate wetting of the substrate which may be as a result of insufficient surface preparation, insufficient dust removal after surface preparation or contamination. All paints within a system should have compatibility between coats and with the substrate. It is advisable to obtain all the components for a paint system from one manufacturer otherwise it may not be possible to guarantee a system; when compatibility is lacking it is often the adhesion which suffers [8].

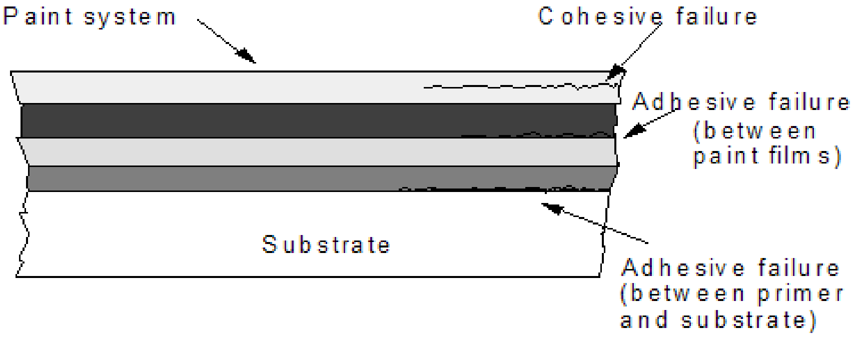


Figure 2.16: Adhesion / Cohesion [8]

There are several test methods contributing in the adhesion method which include *Vee Cut Test, Cross-Cut Test (Cross Hatch Test), X-Cut Tape Test, Hydraulic Adhesion Test,* and *Pull off Adhesion* or *Dolly Test*. For this FYP, the author has used *Pull off Adhesion Test* in order to study the usefulness of this kind of testing.

2.4.1 Pull off Adhesion or Dolly Test

This kind of test may show [8]:

1. Adhesive failure between primer and substrate
2. Adhesive failure between paint films
3. Adhesive failure within a individual paint film

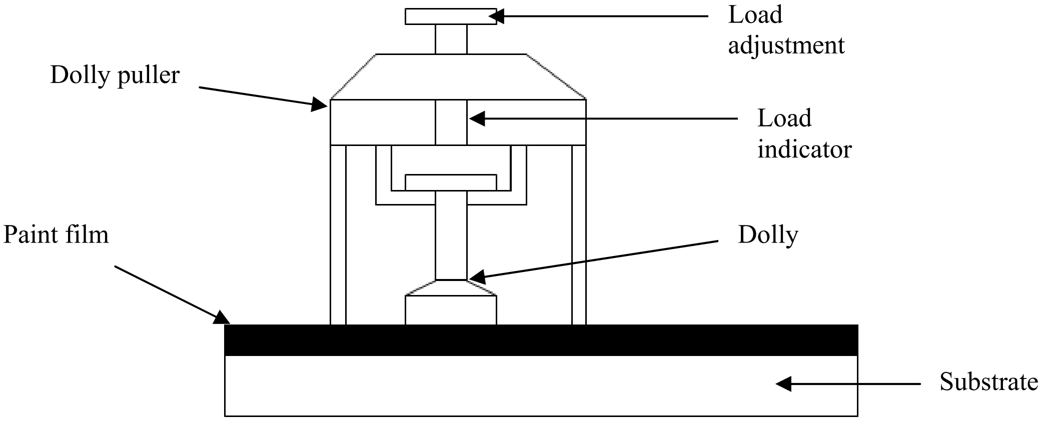


Figure 2.17: Schematic diagram of Pull-Off Dolly test [8]

The procedures of this test as follows:

1. Clean and degrease the surface to be tested and the dolly contact surface.
2. Roughen both surfaces with fine/medium grade emery cloth.
3. Mix regular araldite and stick dolly to the surface, leave for 24 hours at 25°C (see **Figure 3.3**).
4. Cut paint around the dolly down to the substrate using special cutter (see **Figure 3.5**).
5. Attach pull-off instrument and apply pull-off force.
6. Take reading from position of cursor when dolly detaches itself. Values will be typically obtained in either MPa, N/mm^2 or p.s.i..

A minimum pull-off value for the paint type used should ideally be specified in the specification(s) for the work being carried out. For oil and gas coating system, minimum acceptance criteria should be 500 psi (Test Method: ASTM D4541). In the absence of such criteria, a minimum pull-off value should be obtained from the paint manufacturer who should also state categorically whether or not all values less than the minimum pull-off value are deemed a failure [8].

2.5 WEATHER CONDITIONS FOR APPLYING COATINGS

The coating specification should always state the weather conditions in which a coating can or cannot be applied. It is not permissible to apply paints when the following conditions apply [13]:

1. During rain, snow (not applicable in Malaysia), or high winds.
2. When the air or metal temperature is not at least 3°C above the dew point temperature.
3. When the air or metal temperature is below 5°C.
4. When the relative humidity is above 90%.

2.5.1 Relative Humidity (RH%) and Dew Point

Relative humidity is the amount of water vapour in the air expressed as a percentage, compared to the amount of water vapour which could be in the air at the same temperature. The higher the air temperature gives the greater the amount of water vapour which can be held in it.

The dew point is the temperature at which water vapour in the atmosphere would form condensation. Therefore, if the temperature dropped to the dew point temperature the relative humidity would rise to 100% and condensation would be formed on any objects at, or below, that temperature. (*Noted that; the capacity of air to hold water are doubles every 11°C rise in temperature)*

2.5.1.1 Measuring R.H.% and Dew Point

Both relative humidity and dew point are measured using a *hygrometer* of which there are many types:

1. *Aspirated hygrometers*
    a. The screen *hygrometer* and *Masons hygrometer* are static types which rely on a natural airflow over a wet wick.
    b. *Assman* and *psychrodyne* hygrometers are also static types which work by a fan driven air supply over a wet wick.
    c. Whirling hygrometer is a portable and dynamic type which operates by physically moving a wet wick through the air.
2. Dial hygrometers come in two main forms: *hair* and *paper*. Hair hygrometers operate by expansion and contraction of hair, usually human (treated), and are extremely accurate and fast in operation. Paper hygrometers also work on absorption but this time the absorption properties of paper.
3. Digital hygrometers are split into two categories; (1) *RH meters* which give digital readouts of RH and DP only and (2) *thermo-hygrometers* which give a digital readout of RH, DP and ambient dry bulb temperatures.

Figure 2.18: Whirling Hygrometer or Psychrometer [16]

The *whirling hygrometer*, or *psychrometer*, is the most common type used by coating inspectors consisting of two mercury-in-glass thermometers set side by side in a frame which is provided with a handle and spindle so that the frame and thermometers can be rotated quickly about a horizontal axis. The bulb on one of the thermometers, called the wet bulb thermometer, is covered with a closely fitted cylindrical cotton wick, the end of which dips into distilled water or clean rainwater contained in a small cylinder attached to the end of the frame.

The frame is rotated by hand as fast as possible for at least 90 seconds, or as otherwise specified, so that the bulbs pass through the air at least 4 ms^{-1}. This causes the water to evaporate from the wet bulb. The wet bulb cools down to a constant wet bulb temperature due to the evaporation rate of water from the wet wick. The wet bulb temperature must be always read before the dry bulb temperature immediately after rotation. The operation is repeated until consecutive readings of each bulb temperature agree to within 0.2°C.

If it is 100% relative humidity the wet bulb will be the same temperature as the dry bulb, because no evaporation can occur, i.e. the air is saturated. If the wet and dry bulb temperatures are the same, the current temperature is the dew point.

The relative humidity and dew point cannot be read directly from the apparatus, hygrometric tables or special slide rules must be used. Hygrometric tables are more accurate in the 90% RH region and above [13].

2.5.1.2 Metal temperature

The metal temperature is measured with a magnetic temperature gauge, sometimes known as a limpet gauge, or electrical contact thermometer [13].

2.6 HANDLING, TRANSPORT AND STORAGE OF COATED PIPE

Pipes and fittings must be handled, transported and stored in accordance with specified requirements.

2.6.1 Handling

The two main considerations for handling pipe correctly are; (1) personnel safety and (2) prevention of damage to the pipe or coating.

Where practicable, pipes should be lifted using a spreader beam with suitable slings (nylon type), as this is the safest method. Where a spreader beam is not practicable, two leg chain slings (brothers) could be used, these should be fitted with properly designed profiled hooks fitted with guide ropes, and the inner edge of the hooks should be coated in nylon or soft alloy. The use of vacuum lifts and magnetic devices may be permitted.

Chains must not be slung around pipes even if padded. When handling large bends or tees, a nylon sling should be passed through the bore [13].

2.6.2 Transport

When chains or straps, pipe cradles, batten carriers, or stanchions are being used during transport, they must be padded, for example with at least 12 mm of rubber at contact points. Pipes may be stacked in pyramid or parallel fashion when transporting.

Stacking in parallel fashion will require the use of padded pipe cradles or battens between the pipe layers [13].

2.6.3 Stacking at Permanent or Temporary Storage Sites

Pipes are stacked pyramid fashion on either hard standings or soft standings. Hard standings, which may only be used on flat firm ground, consist of bearers (skids or runners), padded with wood wool pads or similar. The number of bearers required for each pipe on the base layer will be governed by the size of the pipe (weight) and the type of coating applied.

Soft standings consist of two parallel sand rows separated by approximately ¾ of the pipe length. Polyethylene sheeting is often required between the sand and the pipes. Stacking should be done in such a way as to avoid accumulation of water inside the pipes; a fall of about 150 mm is desirable. The maximum number of tiers and any requirements for preventing pipe to pipe contact between tiers should be specified [13].

2.7 CODES AND STANDARDS OF OFFSHORE COATING SYSTEM

The applicable Codes, Standards, Specifications and Regulations shall be listed below and shall also include any Codes and Standards etc. referenced by the listed documents below [7].

a) International Standard [7]:

i. ASTM B117: Method of Salt Spray (Fog) Testing

ii. ASTM D570: Test Method for Water Absorption of Plastics

iii. ASTM D2583: Test Method for Indentation Hardness of Rigid Plastics by Means of Barrel Impressor

iv. ASTM G8: Test Method for Cathodic Disbonding of Pipeline Coatings

v. BS 729: Specification for Hot Dip Galvanized Coatings of Iron and Steel Articles

vi. BS 3900: Methods of Test for Paints. Part E6 Cross Cut Test, Part E10 Pull-off Test for Adhesion

vii. BS 4800: Schedule of Paint Colours for Building Purposes

viii. BS 5252: Framework for Colour Coordination for Building Purposes

ix. BS 5493: Code of Practice for Protective Coating of Iron and Steel Structures against Corrosion

x. SIS 05 59 00: Pictorial Surface Preparation Standards for Painting Steel Surfaces

b) Other Specification and Codes / Documents [7]:

i. S.S.P.C. - Steel Structures Painting Council

S.S.P.C. – SP 1	Solvent Cleaning
S.S.P.C. – SP 3	Powertool Cleaning
S.S.P.C. – SP 5	White Metal Blast Cleaning
S.S.P.C. – SP 10	Near White Metal Blast Cleaning

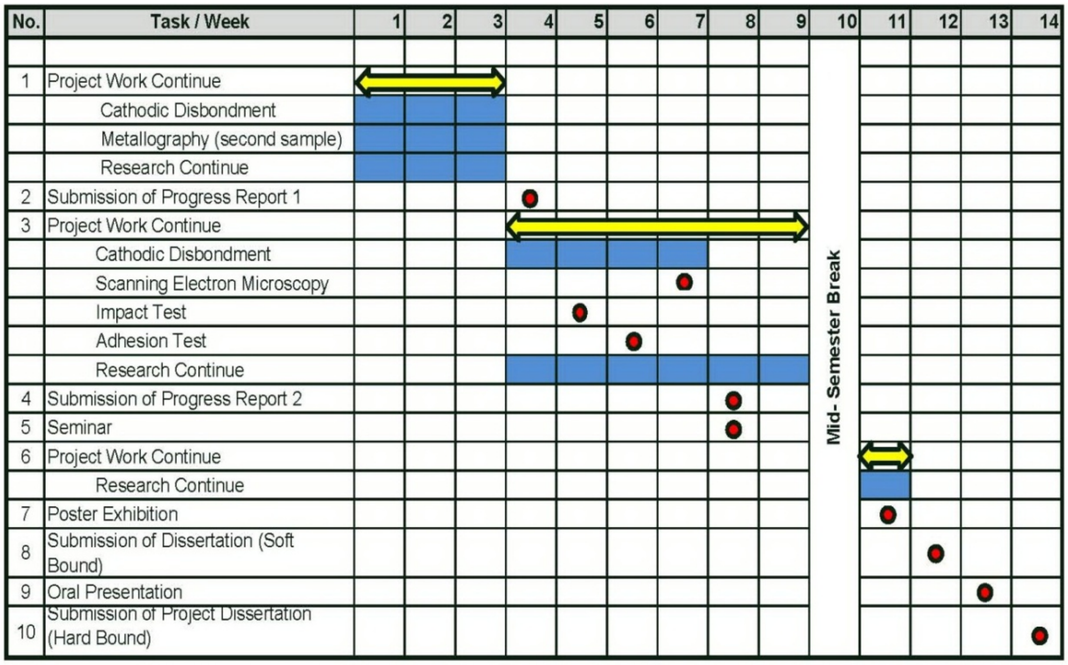
ii. “Personal Protective Advice for the Use of Marine Paints and Compositions” published by the Painmakers Association of Great Britain

CHAPTER 3

METHODOLOGY / PROJECT WORK

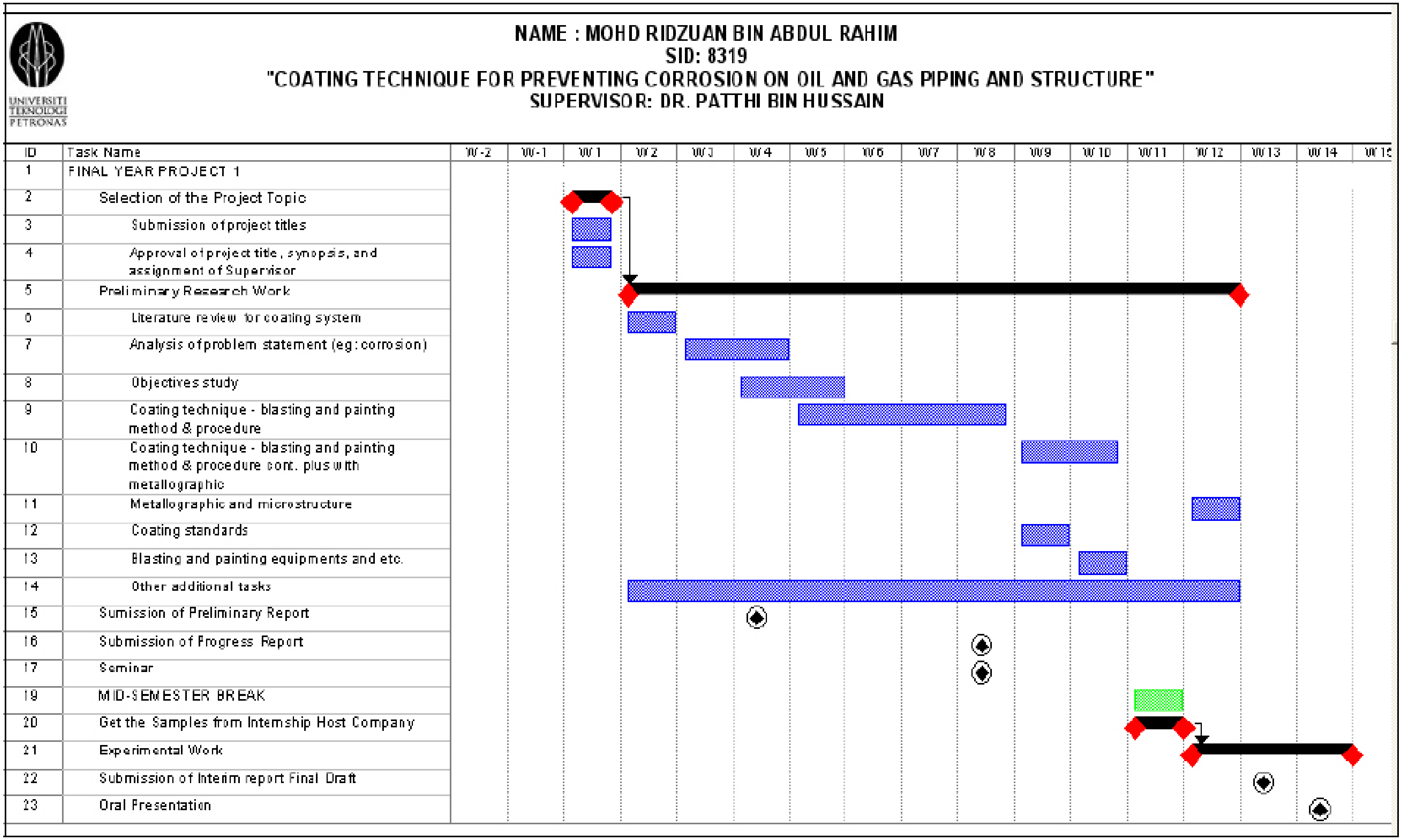
In order to achieve the objective of this project, a proper procedure or steps must be undertaken well. This chapter summarized all the experimental laboratory work that has been done for Final Year Project (FYP). The overall project flow for Final FYP Part I and II are shown on the flow chart and Gantt chart *(See **Figure 3.1**, **3.2**, **3.3**, and **3.4**)*. The laboratory works have been conducted and are given as follows:

1. Metallography on coating samples
2. Scanning Electron Microscopy (SEM)
3. Cathodic Disbondment Test and SEM
4. Pull-Off Adhesion Test



No.	Task / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
											Mid- Semester Break				
1	Project Work Continue	↔	↔	↔											
	Cathodic Disbondment	🟦	🟦	🟦											
	Metallography (second sample)	🟦	🟦	🟦											
	Research Continue	🟦	🟦	🟦											
2	Submission of Progress Report 1				●										
3	Project Work Continue				↔	↔	↔	↔	↔	↔					
	Cathodic Disbondment				🟦	🟦	🟦	🟦							
	Scanning Electron Microscopy							●							
	Impact Test					●									
	Adhesion Test						●								
	Research Continue				🟦	🟦	🟦	🟦	🟦	🟦					
4	Submission of Progress Report 2								●						
5	Seminar								●						
6	Project Work Continue											↔			
	Research Continue											🟦			
7	Poster Exhibition											●			
8	Submission of Dissertation (Soft Bound)												●		
9	Oral Presentation													●	
10	Submission of Project Dissertation (Hard Bound)														●

Figure 3.1: Final Year Project part 2 Gantt chart



NAME : MOHD RIDZUAN BIN ABDUL RAHIM
SID: 8319
"COATING TECHNIQUE FOR PREVENTING CORROSION ON OIL AND GAS PIPING AND STRUCTURE"
SUPERVISOR: DR. PATTHI BIN HUSSAIN

ID	Task Name
1	FINAL YEAR PROJECT 1
2	Selection of the Project Topic
3	Submission of project titles
4	Approval of project title, synopsis, and assignment of Supervisor
5	Preliminary Research Work
6	Literature review for coating system
7	Analysis of problem statement (eg: corrosion)
8	Objectives study
9	Coating technique - blasting and painting method & procedure
10	Coating technique - blasting and painting method & procedure cont. plus with metallographic
11	Metallographic and microstructure
12	Coating standards
13	Blasting and painting equipments and etc.
14	Other additional tasks
15	Sumission of Preliminary Report
16	Submission of Progress Report
17	Seminar
19	MID-SEMESTER BREAK
20	Get the Samples from Internship Host Company
21	Experimental Work
22	Submission of Interim report Final Draft
23	Oral Presentation

Figure 3.2: Final Year Project part 1 Gantt chart

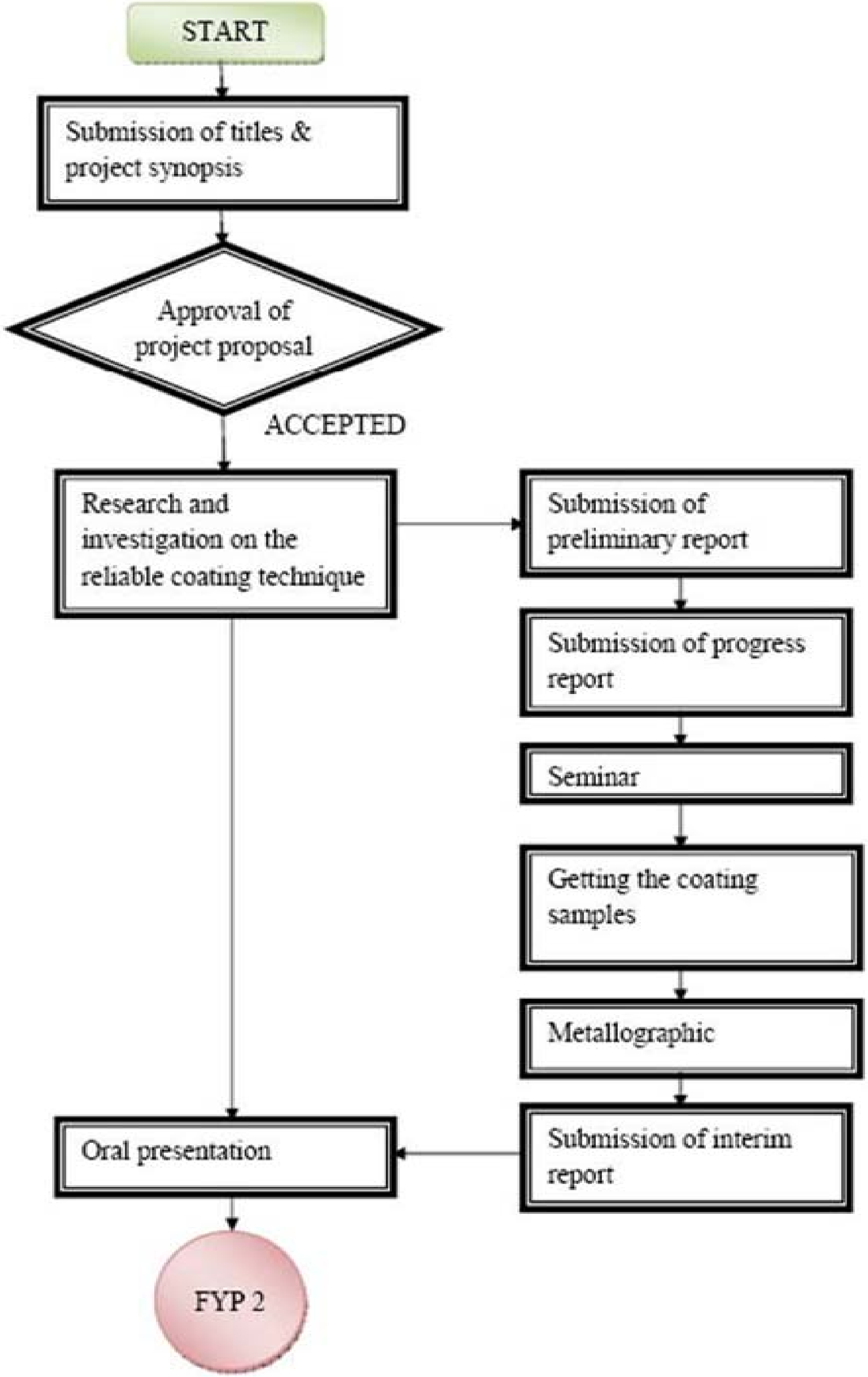


Figure 3.3: Final Year Project part 1 process flow

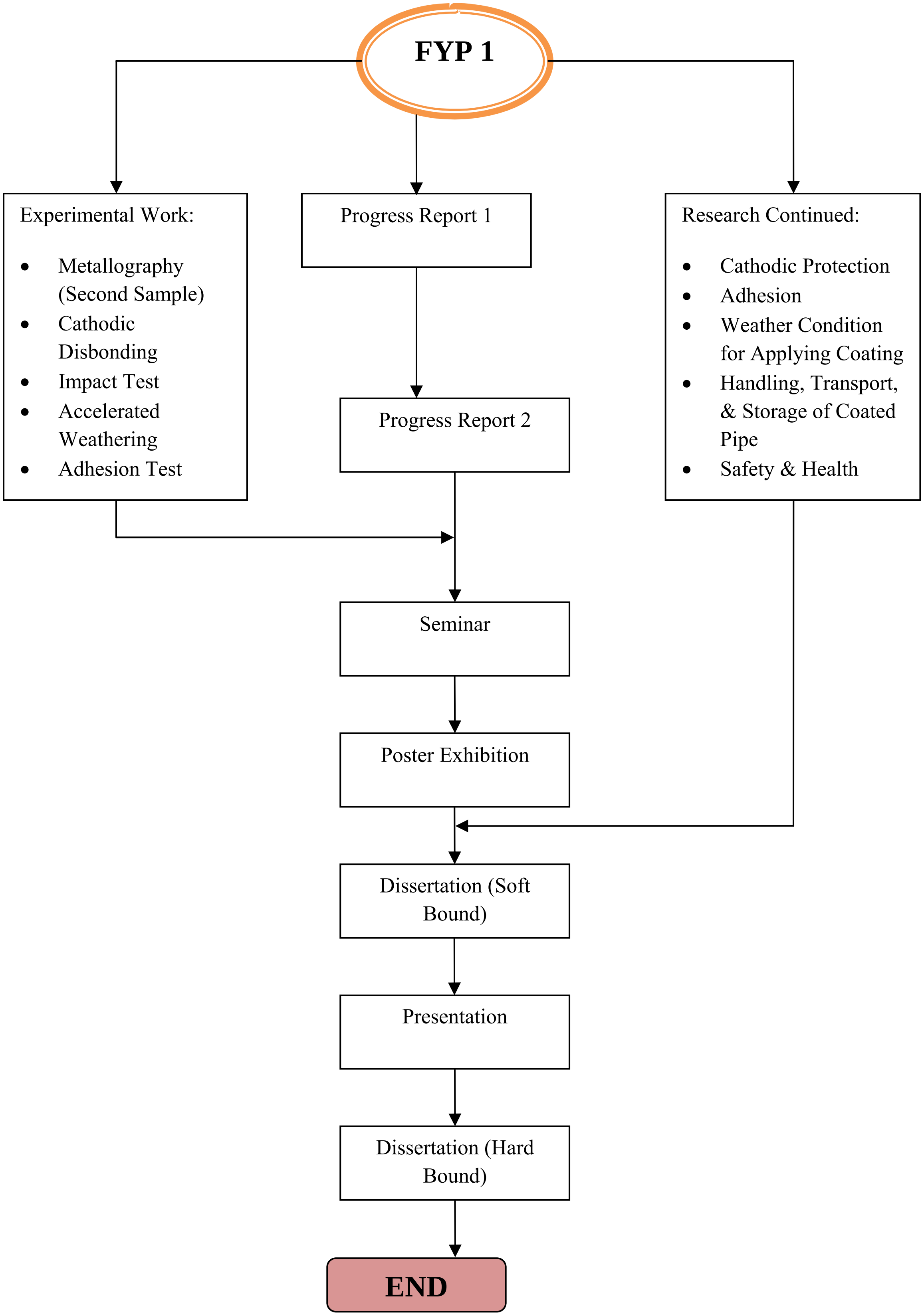


Figure 3.4: Final Year Project part 2 process flow

3.1 METALLOGRAPHY ON COATING SAMPLES

On week eleventh of FYP 1, the author went to one of the oil and gas services company, to collect the coating sample of a carbon steel plate. The author started analyzing the samples by using the technique of Metallography (*Applicable Standard: E7*). The samples already went through blasting process, primer coat, mid-coat, and final coat (*See **Figure 2.6**, **2.8**, **2.9**, and **2.10***).

The purpose of this metallography is to check either there are three layers of coating were applied in the coating process (*Referring standard: S.S.P.C.*). Some basic procedure has been followed as below (*see **Figure 4.1(a)** to **(d)***):

1) Sectioning by using *abrasive cutter* or *band saw* machine (*See **Figure E** and **F** in Appendices*)
2) Mounting of sample (optional in some cases)
3) Grinding
4) Polishing
5) Etching
6) Microscopy and Image recording

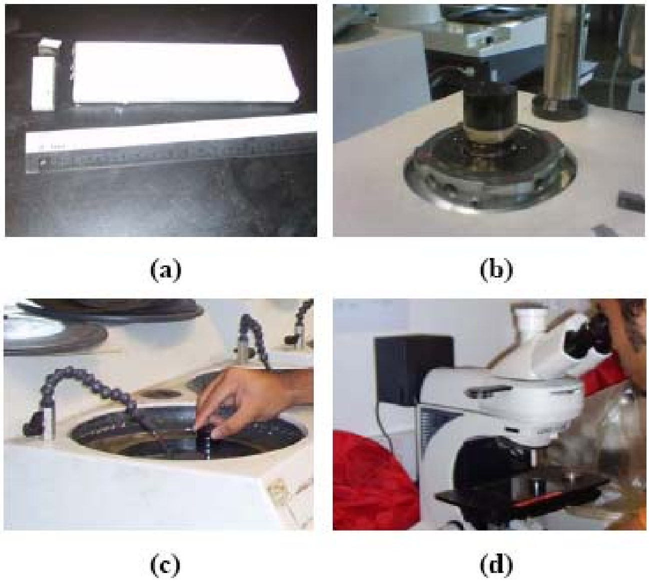


Figure 3.5 (a): Sectioning; **(b)**: Mounting on Sample; **(c)**: Grinding; and **(d)**: Microscopy

3.2 SCANNING ELECTRON MICROSCOPY (SEM)

After performing the metallography process, image was recorded by using optical microscope that available in UTP. The coating sample was analyzed using SEM in order to obtain further details of the microstructure, to measure the coating thickness, and to investigate the interlocking between layers of coatings (*Referring standard: S.S.P.C.*). These procedures were assisted by the UTP technician. (*See **Figure G** in appendices for SEM machine*)

3.3 CATHODIC DISBONDMENT TEST

The author has already worked on the cathodic disbondment testing during FYP part II. This test requires two months to complete. (*Test method for Cathodic Disbondment Test: ASTM G 8*). The detail procedure of the *Cathodic Disbondment Test* has been discussed in literature review part (*see **Page 23**).*

The test will indicate whether the coating system is susceptible to disbondment if hydrogen gas bubbles are given off from the surface of the substrate. It is likely to be the case in service if the substrate is excessively cathodic, which is excessive amount of cathodic protection to a coated structure that lead to disbondment of the coating [13].

Cathodic disbondment is a significant problem when coating defects are present due to a stripping action caused by the hydrogen bubbles and is especially prominent when the impressed current is way in excess of the corrosion current; this condition is purposely produced for the cathodic disbondment test [13]. *(See **Figure 2.15** and **3.2** for the cathodic disbonment testing apparatus)*

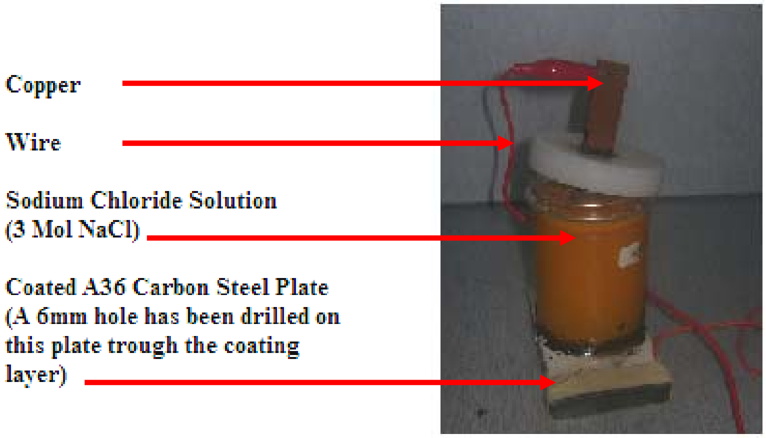


Figure 3.6: Cathodic Disbondment test apparatus

∗ *In order to apply the knowledge in Auto CAD software, the author was prepared a Cathodic Disbondment Testing drawing as shown in* ***Figure H*** *in Appendices.*

3.4 PULL OFF ADHESION OR DOLLY TEST

The procedure of the *Pull off Adhesion* or *Dolly Test* has been discussed in literature review part (*see* ***Page 25****).* (*Test method for Adhesion test: ASTM D4541*)

Before the test was conducted, the dolly must be well cleaned. The entire previous adhesive on the dolly's surface must be cleaned in order to give more adhesion between dolly and coating surface during the test. In order to remove the wasted adhesive on the dolly's surface, the dollies were leaved in the furnace for two days (48 hours) with temperature of 250°C. (*See* ***Figure J*** *in the appendices*)

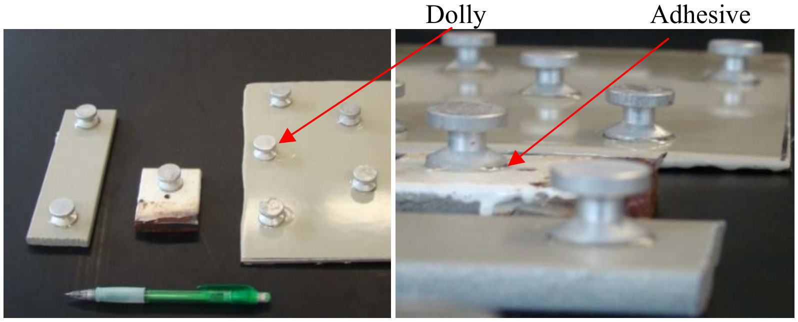


Figure 3.7: Dollies are stick to the coated surface for 24 hours with adhesive

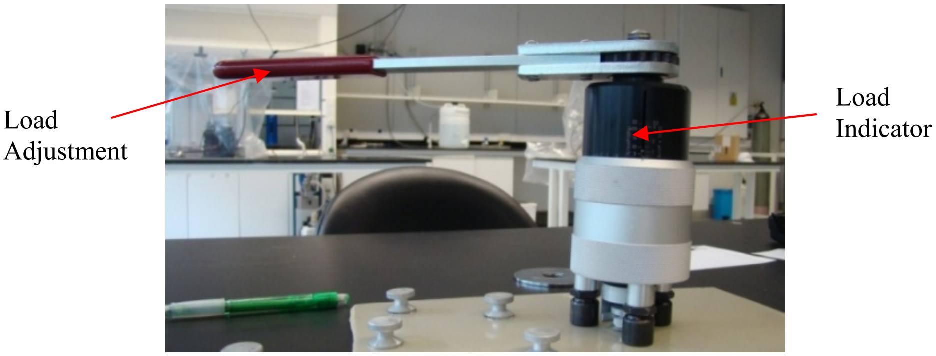


Figure 3.8: Apparatus for Pull off Adhesion or Dolly test

Figure 3.9: Special Coating Cutter to cut around the dolly down to the substrate

Figure 3.7 to **3.9** shows the apparatus that used in this test which is available in UTP. A proper procedure was assisted by the UTP master student, specialized in material engineering.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 MICROSCOPY AND IMAGE RECORDING

4.1.1 Results on Microscopy and Image Recording

The result of the microscopy of the coated sample is shown in **Figure 4.1** below. (*See* ***Figure K*** *in the Appendices for the other coating's microscopy image*)

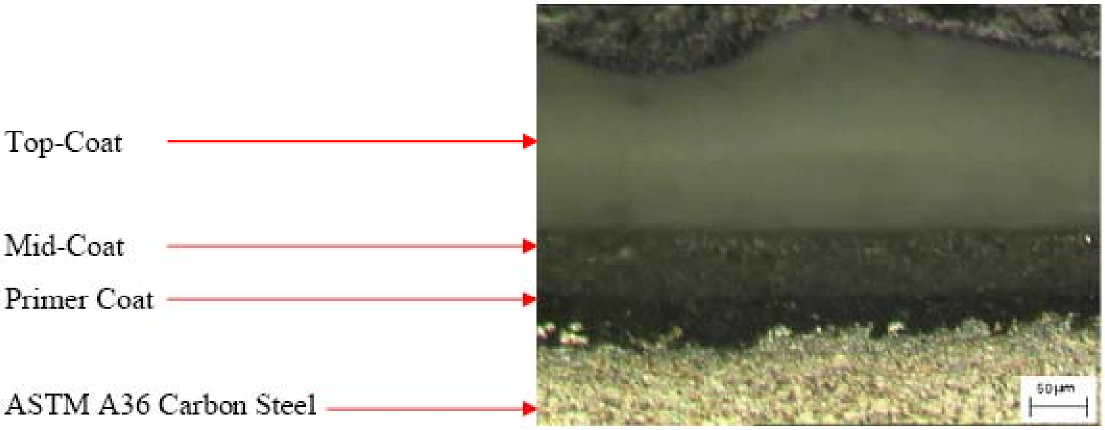


Figure 4.1: Coated Sample's Microscopy Image of 50 Times Magnification

4.1.2 Discussion on Microscopy and Image Recording

There exist three layers of coating system which are Primer Coat, Mid-Coat, and Top-Coat. Based on S.S.P.C. standard, the requirement to have three layers of the coating system is full-filled. However, the coating layers need to be observed more in order to know either the coating system is comply with the standard or not. So, the author continued the experiment with SEM to get more details on the coating's microstructure.

4.2 SCANNING ELECTRON MICROSCOPY (SEM)

4.2.1 Results on Scanning Electron Microscopy (SEM)

The author also investigated the microstructure of coating sample by using *Scanning Electron Microscopy* (SEM) (*See **Figure G** in appendices*). Since coating materials are not electrical conductive, the sample was coated with gold coating before conducting the SEM analysis.

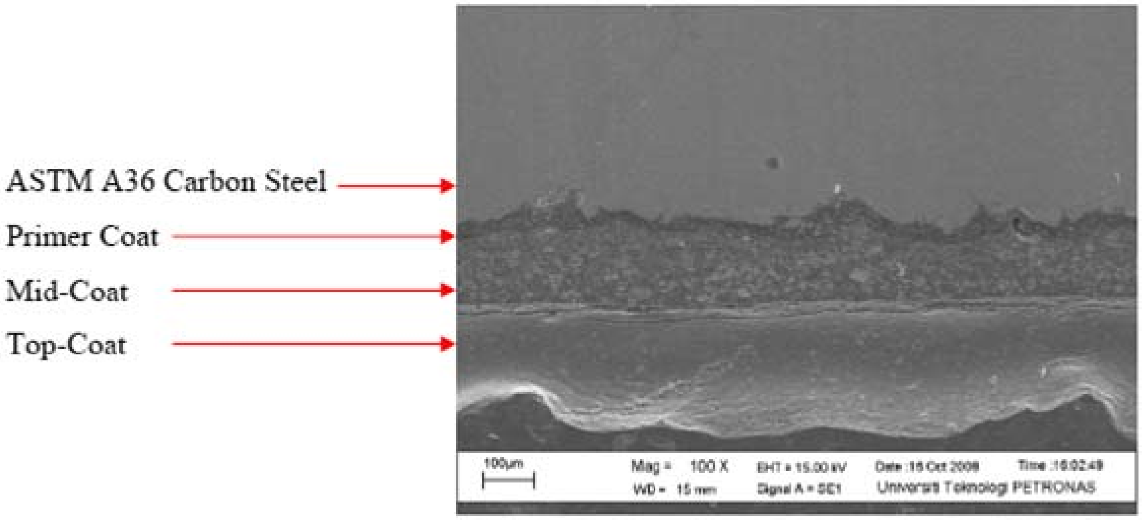


Figure 4.2: Coated sample of SEM image, Magnification 100 X

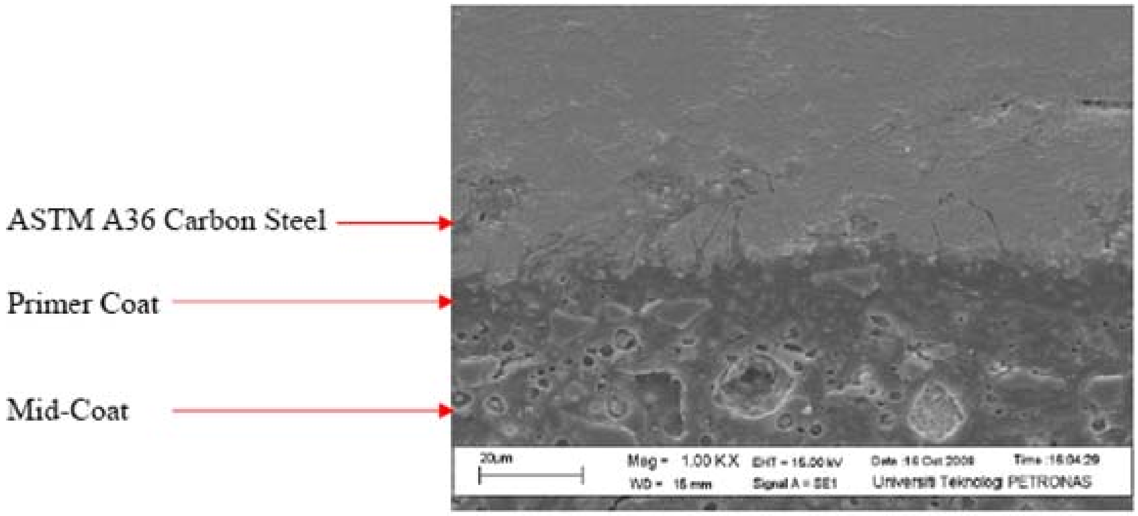


Figure 4.3: Coated sample of SEM image, Magnification 1000 X

4.2.2 Discussion on Scanning Electron Microscopy (SEM)

From **Figure 4.3**, it shows that the interlocking between Carbon Steel and Primer Coat are cohesive. The surface profiles on the carbon steel plate must be irregular in order to get a good interlocking with the primer coat. There are two methods in order to provide a good interlocking between coating paint and steel; *Physical Drying* and *Chemical Curing*. *Physical Drying* happens when the change from liquid (wet) paint to a solid (dry) coating by the PHYSICAL evaporation of solvent. *Chemical Curing* happens when the progressive CHEMICAL change of a paint by reaction with either an internal or external curing agent, or by the introduction of heat [12].

From **Figure 4.4**, there is discontinuity between Mid-Coat and Top Coat. The figure shows there is a bad interlocking or bonding between mid and top coat. This would be one of the reason why coating failed before exceeding 50 years (*refer to Problem Statement*).

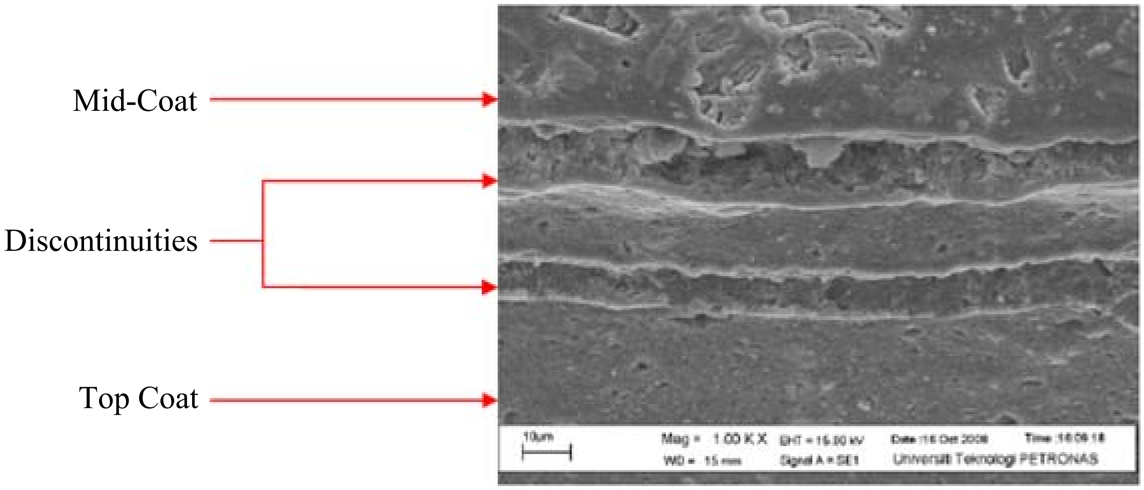


Figure 4.4: Bad interlocking between mid and top coat, Magnification 1000 X

Besides, the failure coating also may be due to lack of coating thickness. The author may check the coating thickness of the samples either it comply with the specification that is shown in **Table 2.2**. Based on **Figure 4.5**, five readings were taken to measure the primer and mid-coat's thickness. The primer thickness (**I**, **II**, **III**, **IV**, and **V**) were measured to be less than 50µm while for mid coat's thickness (**A**, **B**, **C**, **D**, and **E**) were measured to be almost ± 100µm each. They clearly **DOES NOT** comply with the S.S.P.C. standard specification that shows in **Table 2.2** which requires the minimum of primer coat's thickness of 75µm and the maximum is 90µm. The minimum requires of mid-coat's thickness of 150µm and the maximum is 200µm. So, this is another possible factor why the coating failed before exceeding 50 years (*Refer to Problem Statement*). The results of these measurements are tabulated in **Table 4.1**.

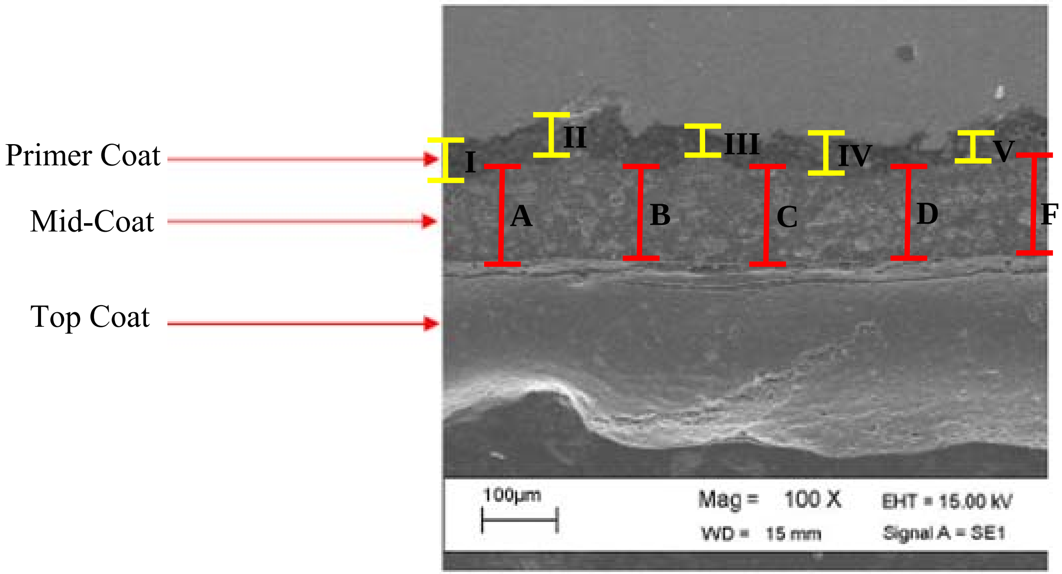


Figure 4.5: Measuring the Thickness of Mid-Coat on the Coated Carbon Steel Sample

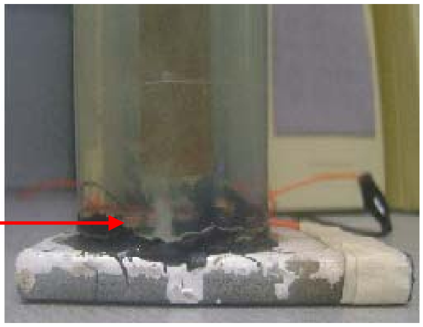
Table 4.1: Comparing results with the S.S.P.C. standard specification

Primer Coat			**Mid-Coat**		
S.S.P.C. Requirements	Measuring Number	Coating Thickness	S.S.P.C. Requirements	Measuring Number	Coating Thickness
75µm to 90µm	I	± 45µm	150µm to 200µm	A	± 100µm
	II	± 45µm		B	± 100µm
	III	± 35µm		C	± 100µm
	IV	± 45µm		D	± 100µm
	V	± 35µm		E	± 100µm

4.3 CATHODIC DISBONDMENT TEST

4.3.1 Results on Cathodic Disbondment Test

Figure 4.6 shows what happened after the circuit was completed. Bubbles were released from the hole that had been drilled on the coating surface.



Bubble of hydrogen gas come out from 6mm hole drilled on the A36 carbon steel plate

Figure 4.6: Bubble of Hydrogen Gas from Drilled Hole

This test was stopped after two months. The result on the drilled coated plate is shown in **Figure 4.7** below.

Figure 4.7: The effect of cathodic disbondment test on the drilled coated plate

After the Cathodic Disbondment testing, the microstructure of coated sample is examined to investigate the sacrificial zinc coating on the defected area (drilled hole into the coated surface). Before that, sectioning of the sample was carried out by using Band Saw Machine (see **Figure 4.8**).

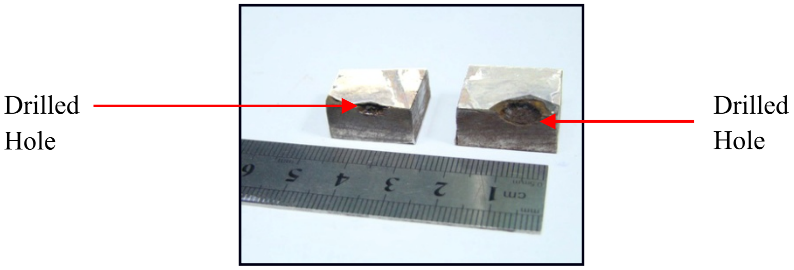


Figure 4.8: Sectioning on the cathodic disbondment sample

Before continuing the analysis with SEM, the samples were coated with gold since coated materials are not electrical conductive. The results of SEM are shown in **Figure 4.9** and **Figure 4.10**.

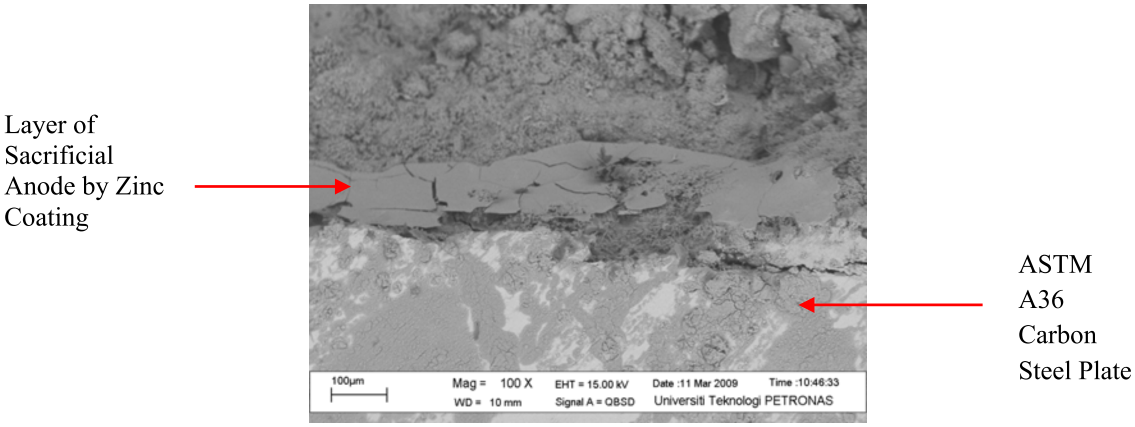


Figure 4.9: Back-scattered SEM image shows the layer of ASTM A36 carbon steel plate and sacrificial anode by zinc coating layer, Magnification 100 X

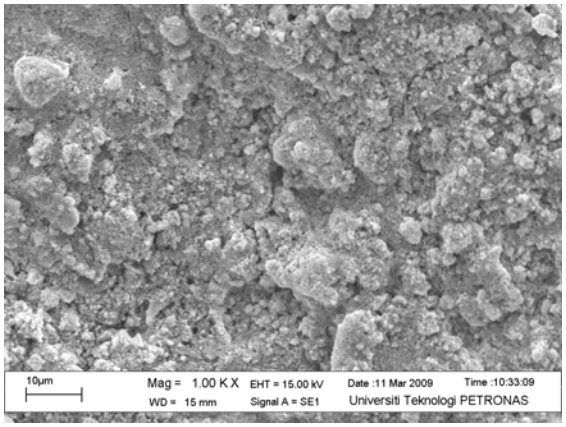


Figure 4.10: The SEM image at on the surface of sacrificial anode by zinc coating layer, Magnification 10 X

4.3.2 Discussion Cathodic Disbondment Test

The acceptance criteria of Cathodic Disbondment test is less than 10mm disbondment (Test Method: ASTM G 8) at room temperature. The result shows that there is less than 10mm disbondment of coating system. This result reveals that the coating system is hard to disbondment when hydrogen bubbles are given off from the surface of the substrate. In order to prove that the coating system is cathodically protected, the reactions in this test should be investigated well. There are two reactions contribute in this testing which are *anodic reaction* and *cathodic reaction*.

4.3.2.1 Anodic Reaction

Anodic Reaction (or Oxidation Reaction) occurs on zinc coating layer. Zinc (Zn) layer (or Zinc Anode) has oxides to become zinc ion (Zn^{2+}). In this case, zinc has sacrificed itself to cover the passive zone (drilled hole) from corrode (see **Figure 4.9**). The equation of the anodic reaction would be [17]:

$$Zn \rightarrow Zn^{2+} + 2e^- \qquad (4.1)$$

Zinc has been dissolved to produce electron (e^-) and cations (positive-charged species). Cations in this case referred to zinc ion (Zn^{2+}). The Scanning Electron Microscopy (SEM) image as shown in **Figure 4.9** may describe as there is a protective from zinc layer on the passive zone. However, the bonding or interlocking between sacrificial zinc and metal (ASTM A36 Carbon Steel) on that zone may not be good enough as shown in that figure. There is a gap between those particular areas. This indicates that the protective by sacrificial zinc anode alone is not for long-term services. A good coating must follow the standard such as S.S.P.C. standard paint 20 for applying Zinc Rich Epoxy in piping and structure coatings system.

The sacrificial zinc anode is very important in order to protect piping and structure in oil and gas facilities. As indicated in Steel Structures Painting Council

(S.S.P.C.) standard, zinc rich epoxy should be in a range of 75 to 90 μm. Other than that, it may cause problems on the sacrificial anode of zinc coating.

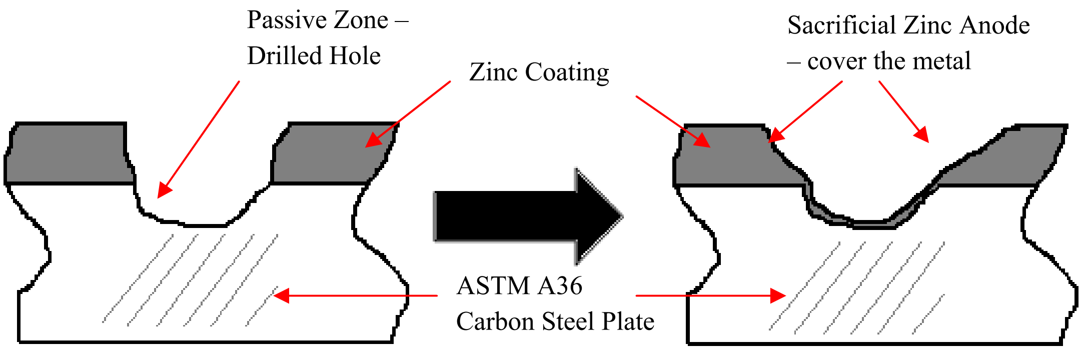


Figure 4.11: Sacrificial Zinc Anode on the Passive Zone

4.2.1.2 Cathodic Reaction

Cathodic Reaction (or Reduction Reaction) happened in aqueous solution to produces hydrogen gas (see **Figure 4.6**). Hydrogen gas (H_2) has been produced by given equation [17]:

$$2H^+ + 2e^- \rightarrow H_2 \qquad (4.2)$$

Hydrogen ion from aqueous solution consumes electrons and produces hydrogen gas.

4.4 PULL-OFF ADHESION TEST

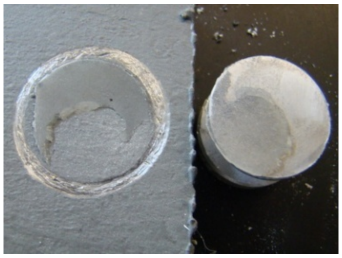
4.4.1 Results on Pull-Off Adhesion Test

The adhesion test was also performed and it is called as *pull-off adhesion* or *dolly test* (accordance with standard of BS 3900: Part E10). The results of this test are tabulated in **Table 4.2**. **Figure 4.12**, **Figure 4.13**, and **Figure 4.14** in **Table 4.2** shows the coating has been failed after certain amount of pull-off load was applied on the coating surface respectively (*see figure L in the appendices for the full kits of pull-off adhesion or dolly test*).

4.4.2 Discussion on Pull-Off Adhesion Test

Based on Test Method ASTM D4541, minimum acceptance criteria for Pull-Off Adhesion test should be 500 psi or lb/in^2. So, the tests show that the adhesion properties for coating system of the experiment's samples are acceptable. All paints within a system should have compatibility between coats and with the substrate. It is advisable to obtain all the components for a paint system from one manufacturer otherwise it may not be possible to guarantee the system; when compatibility is lacking it is often the adhesion which suffers [13].

Table 4.2: Pull of Adhesion Test Result

Layer	Load for coating failed (lb/in^2)		Figure
Primer (Zinc-Rich Epoxy)	**First reading**	600	 **Figure 4.12**
	Second reading	650	
Second (High Solid Epoxy)	**First reading**	600	 **Figure 4.13**
	Second reading	600	
Final (Recoatable Top Coat)	500		 **Figure 4.14**

** Note: The final layer has been tested only at one time due to running out of sample.*

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Based on the results, the performance of the piping and structure coating in oil and gas field has its own positive and negative criteria. The positive criteria are: (1) There are exist three layers of coating system which are include primer coat, mid-coat, and top coat, (2) Interlocking between substrate and primer coat are cohesive, (3) The sacrificial zinc coating exist on defective area on the coating's substrate, and (4) Adhesion properties for coating system are acceptable based on test method. The results also may conclude the protective of zinc layer in coating system is very important in order to protect the defected zone or scratches area on the surface of coated metal.

There are also two possible reasons why the current performance of piping and structure coatings show that they were failed less than 50 years. Those negative criteria are: (1) Lack of primer and mid-coat's thickness and (2) Bad interlocking between mid-coat and top-coat layers.

5.2 DISCUSSION

In order to get the good coating performance on the piping and structure, the platform operator such as Petronas Carigali Sdn. Bhd. must refer the common oil and gas standards and inspect the coatings before let the vendor or services company complete the coating process. The inspection on the piping and structure coatings in oil and gas field must be handled well by painting inspector. For all cases in the piping and structure coatings, the specification standards (ASTM, S.S.P.C., BS, and SIS) must be referred well in order to get the fully protection on the piping and structure by coating system.

Piping and structure coatings must have three layers of protection system which are primer coat, mid-coat, and top coat. Besides, the surface preparation (including dry abrasive blasting) must be well conducted in order to provide an irregular profile on the surface of metal for coating's adhesion properties. All the procedures in coating process must be referred with specification standards in order to get the good performance of piping and structure coating in oil and gas field.

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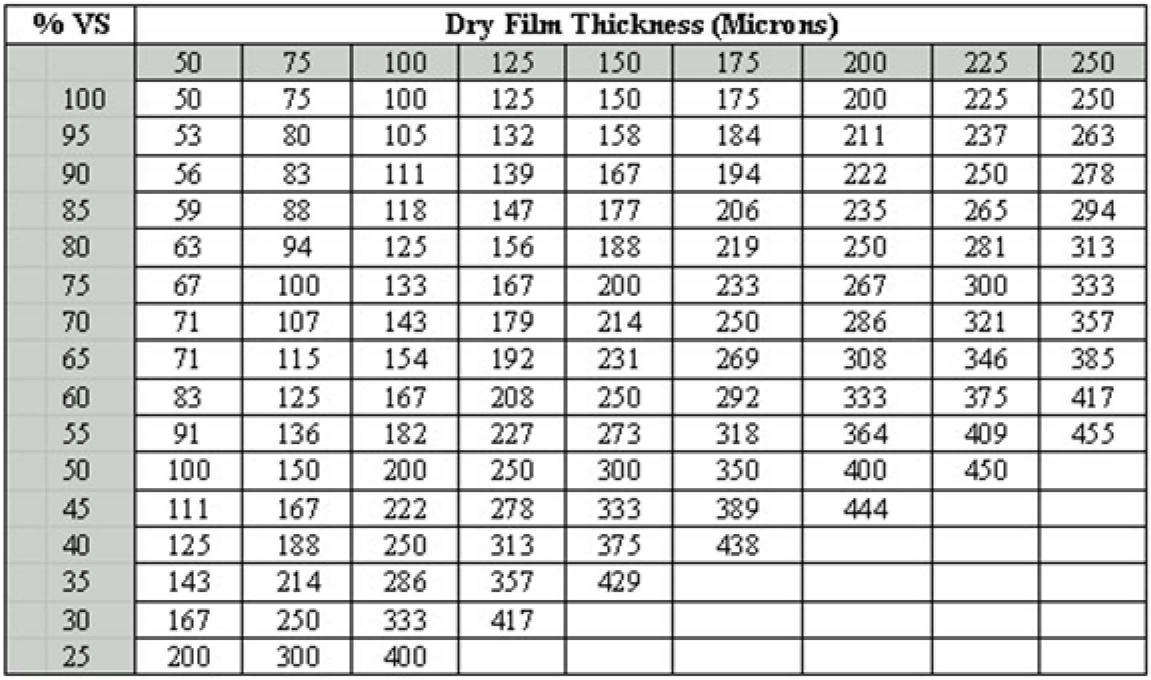
APPENDICES

Figure A: Beam edge failure [10]

Figure B: Tubing on piping [10]

Figure C: Fastener corrosion soon spreads; **D**: More mechanical damage [10]

Table A: Wet Film Thickness Requirements as function of % volume solids (% VS) [16]

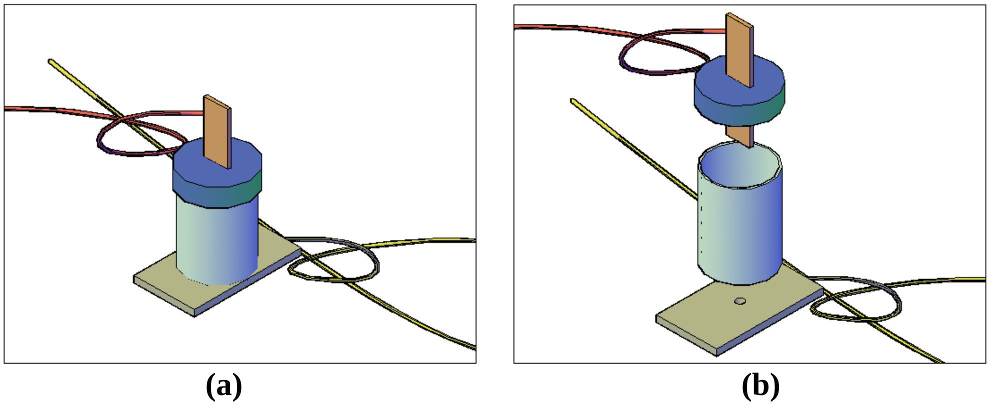


% VS	Dry Film Thickness (Microns)								
	50	75	100	125	150	175	200	225	250
100	50	75	100	125	150	175	200	225	250
95	53	80	105	132	158	184	211	237	263
90	56	83	111	139	167	194	222	250	278
85	59	88	118	147	177	206	235	265	294
80	63	94	125	156	188	219	250	281	313
75	67	100	133	167	200	233	267	300	333
70	71	107	143	179	214	250	286	321	357
65	71	115	154	192	231	269	308	346	385
60	83	125	167	208	250	292	333	375	417
55	91	136	182	227	273	318	364	409	455
50	100	150	200	250	300	350	400	450	
45	111	167	222	278	333	389	444		
40	125	188	250	313	375	438			
35	143	214	286	357	429				
30	167	250	333	417					
25	200	300	400						

Figure E: Abrasive Cutter; provided by Universiti Teknologi Petronas (UTP)

Figure F: Band Saw Machine; provided by UTP

Figure G: Scanning Electron Microscopy (SEM) Machine; provided by UTP



(a) (b)

Figure H: The apparatus of cathodic disbondment test; **(a)**: 3D Auto CAD solid drawing; and **(b)**: 3D Auto CAD assembly drawing – drawn by the author

Figure I: Blasting Pot

Figure J: Dollies were leaved in Furnace for two days before continue with the Pull-Off Adhesion Test

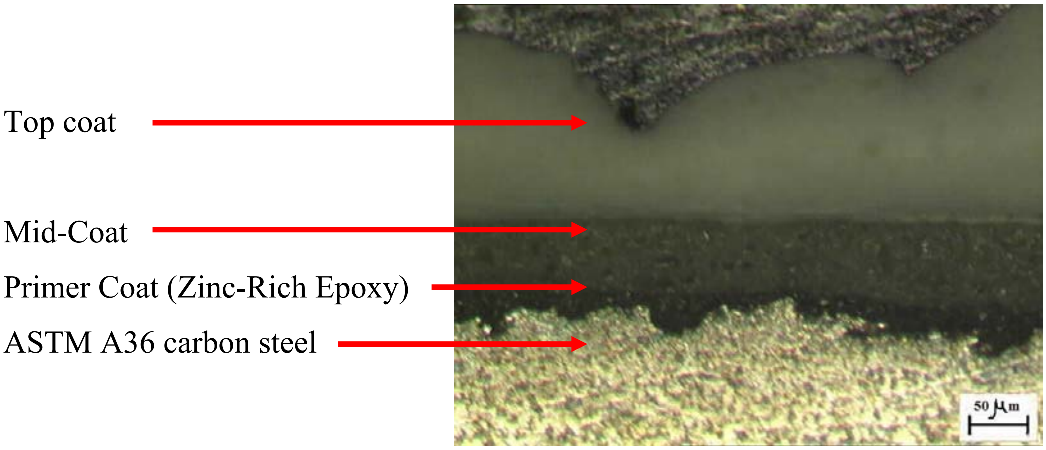


Figure K: Coated Sample’s Microscopy Image of 50 Times Magnification – Exist three layers of coating system

Figure L: The Full Kits of *Pull off Adhesion* or *Dolly Test*