Effects of Surface Roughness on the Adhesion and Corrosion Properties of Organic Coating Applied on One Surface of One Sample Set of Mild Steel

by

Ahmad Helmi Mohd Amin (8125)

Final Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

_____
(Assoc. Prof. Dr. Mustafar Bin Sudin)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

July 2010

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.

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AHMAD HELMI MOHD AMIN

ABSTRACT

This report basically discusses the research done and basic understanding of the chosen topic, which is the **Effects of Surface Roughness on the Adhesion and Corrosion Properties of Organic Coating Applied on One Surface of One Sample Set of Mild Steel.** One of the effected areas after performing surface preparation on any metal surface is the surface roughness. The samples for this study are mild steel. Three samples with different surface roughness were prepared. ASTM B 117-90 Salt Spray (Fog) test is carried out in order to study the corrosion behavior and performance in accelerated environment. The adhesion behavior was determined by performing scratch test on the coated surface after underwent the accelerated corrosive environment while the corrosion performance was determined by visual inspection. In this study, oil modified alkyd-based enamel coating is selected as the test sample.

ACKNOWLEDGEMENTS

The author wishes to take the opportunity to express his utmost gratitude The Almighty upon the completion of this Final Year Project. Without His Love and Mercy it is impossible to do anything related to this project and anything else.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

An organic coating composition is described, which can be used to enrich the surface region of a metal-based substrate. Many paints, coatings and high performance organic coatings have been developed as a need to protect equipment from environmental damage. Of prime importance in the development of protective coatings was the industry that produced most of the basic ingredients from which most synthetic resins were developed.

Surface roughness is the measure if the finer surface irregularities in the surface texture. These are result of the manufacturing process employed to create the surface. Surface roughness, Ra is rated as the arithmetic average deviation of the surface valleys and peaks expressed in micro inches or micro meters. ISO standards use the term CLA (Centre Line Average). Both are interpreted identical.

The ability of a manufacturing operation to produce a specific surface roughness depends on many factors. For example, in end mill cutting, the final surface depends on the rotational speed of the end mill cutter, the velocity of transverse, the rate of feed, the amount and type of lubrication at the point of cutting, and the mechanical properties of pieces being machined. A small change in any of the above factors can have a significant effect on the surface produce. [1]

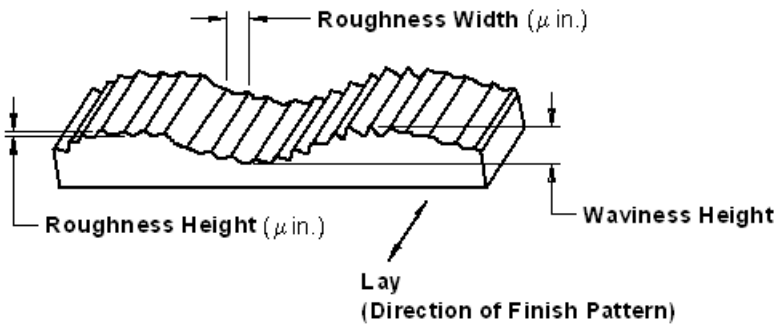


Figure 1: Surface Roughness

1.2 Problem Statement

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**. [2]

Although roughness is usually undesirable, it is difficult and expensive to control in manufacturing. Decreasing the roughness of a surface will usually increase exponentially its manufacturing costs. This often results in a trade-off between the manufacturing cost of a component and its performance in application.

1.3 Objective and Scope of Study

The main objectives of this study are:

1. Obtain the clear correlation between the effect of various surface roughness towards the adhesion and corrosion properties of organic coating applied on the metal surface.
2. Record and analyze the physical condition of the coating after undergone the accelerated corrosive environment.

Scope of work of this project is to experiment and compare the effect of surface roughness measured on different metal surface to the adhesion and corrosion properties of the applied oil modified alkyd-based enamel coating on the surface. The metal plate used is mild steel contains 0.16–0.29% [3] carbon sized 20 x 70 x 4.5 mm. All the experiment will be carried out in the laboratory. The real-environment conditions will be replaced by the use of the Salt-Spray Corrosion Chamber for an accelerated corrosive environment.

CHAPTER 2

LITERATURE REVIEW

2. INTRODUCTION

This study is concerning some major field that very important to be understood in order to complete the research. Some of the main areas in this study are Surface Roughness, Profilometer, Coating Material, as well as Salt Fog Test.

2.1 Surface Roughness

Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface.

Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

Roughness may be measured using contact or non-contact methods. Contact methods involve dragging a measurement stylus across the surface; these instruments include profilometer. [4]

Specifying surface profile is critical. A surface roughness that is too shallow can result in adhesion difficulties, and surface roughness (and insufficient coating thickness) that is too deep can result in pinpoint rusting because unprotected peaks of the profile protrude above the surface of the coating. As a general rule, the surface profile should be a nominal 15 to 20 percent of the total coating system thickness (up to 0.38 mm [15 mils]). [5]

2.2 Profilometer

Profilometer is a measuring instrument used to measure a surface's profile, in order to quantify its roughness. Vertical resolution is usually in the nanometer level, though lateral resolution is usually poorer.

Contact Profilometer is a diamond stylus is moved vertically in contact with a sample and then moved laterally across the sample for a specified distance and specified contact force. A profilometer can measure small surface variations in vertical stylus displacement as a function of position. A typical profilometer can measure small vertical features ranging in height from 10 nanometers to 1 millimeter. The height position of the diamond stylus generates an analog signal which is converted into a digital signal stored, analyzed and displayed. The radius of diamond stylus ranges from 20 nanometers to 25 μm, and the horizontal resolution is controlled by the scan speed and data signal sampling rate. The stylus tracking force can range from less than 1 to 50 milligrams. [6]

2.2.1 Advantages of contact profilometer:

- Acceptance: Most of the world's surface finish standards are written for contact profilometer.
- Surface Independence: Contacting the surface is often an advantage in dirty environments where non-contact methods can end up measuring surface contaminants instead of the surface itself. However, because the stylus is in contact with the surface, this method is not sensitive to surface reflectance or color.
- Resolution: The stylus tip radius can be as small as 20 nanometers, significantly better than white-light optical profiling.
- Direct Technique: No modeling required. [6]

2.3 Coating Material

Coating materials are applied in a thin film to provide protection or decoration to a surface. Most films are thin in comparison to the work piece. In order to achieve the desired characteristics from the thin film, the coating material formulation must be carefully considered in relation to the part characteristics, surface preparation, and application technique and curing method. The correct combination of components and process steps can lead to a film that provides long-lasting beauty and defense against the elements.

2.4 Salt Fog Testing

Salt Fog Testing is typically performed on coated or painted samples for marine, automotive, and military equipment. Salt Fog Testing is also an excellent way to test the permeability of coatings and seals. Salt spray test is an accelerated corrosion test that produces a corrosive attack to the coated samples in order to predict its suitability in use as a protective finish. The apparatus for testing consists of a closed testing chamber, where a salted solution is sprayed by means of a nozzle. This produces a corroding environment in the chamber and thus, parts in it are attacked under this severe corroding atmosphere. Chamber construction, testing procedure and testing parameters are standardized under national and international standards, such as ASTM B 117 and ISO 9227. These standards describe the necessary information to carry out this test; testing parameters such as temperature, air pressure of the sprayed solution, preparation of the spraying solution, concentration, pH, etc. The method of coating application on the surface will be varies.

The apparatus for testing consists of a closed testing chamber, where a salted solution is sprayed by means of a nozzle. This produces a corroding environment in the chamber and thus, parts in it are attacked under this severe corroding atmosphere. Typical volumes of these chambers are of 15 cubic feet because for historical reasons that was the smallest volume accepted by ASTM-B-117, since the 90's there is no request about volume in ASTM, ISO recommends that the chamber shouldn't be smaller than

200 liters in order to receive an acceptable amount of test samples, chambers are available from sizes as small as 9.3 cu ft (260 L) up to 2,058 cubic feet (58,300 L), most common machines range from 15 to 160 cubic feet (420–4,500 L). Tests performed with a solution of NaCl. [7]

2.5 Scratch Test

Scratch Test is a new method in determining the adhesion strength of a coating. During the scratch, the stage moves in the X-direction and a probe remains stationary while applying a controlled load on the specimen. The load is applied by a cantilever system. The three load modes include constant, incremental, and progressive loads. In a progressive load mode, the load of failure or adhesion strength is at the load where the probe first eliminates the coating.

The specimen must be flat with a length and width preferably between 0.5 inch and 1.25 inches. On the other hand the coating must have a roughness <5 µm. Differences preparation in the surface of the substrate and application procedure of the coating will alter results.

However, there are some challenges for using scratch test for testing such as there are no ASTM standards on how fast, load rate and length to scratch the surface of the coated specimen. Then, the determination of adhesion strength of the coatings is difficult for a scratch test because the failure point of each coating has different characteristics of failure during a progressive load scratch. [8]

Scratch tests were performed using a CSM Instruments with a spherical micro-contact indenter used in progressive mode. For spherical contact geometry, the imposed effective strain depends on the depth of penetration and is linearly proportional to the ratio of the radius of efficient contact, r, to the radius of the spherical geometry, R.[9]

CHAPTER 3

METHODOLOGY

3.1 GHANTT CHART

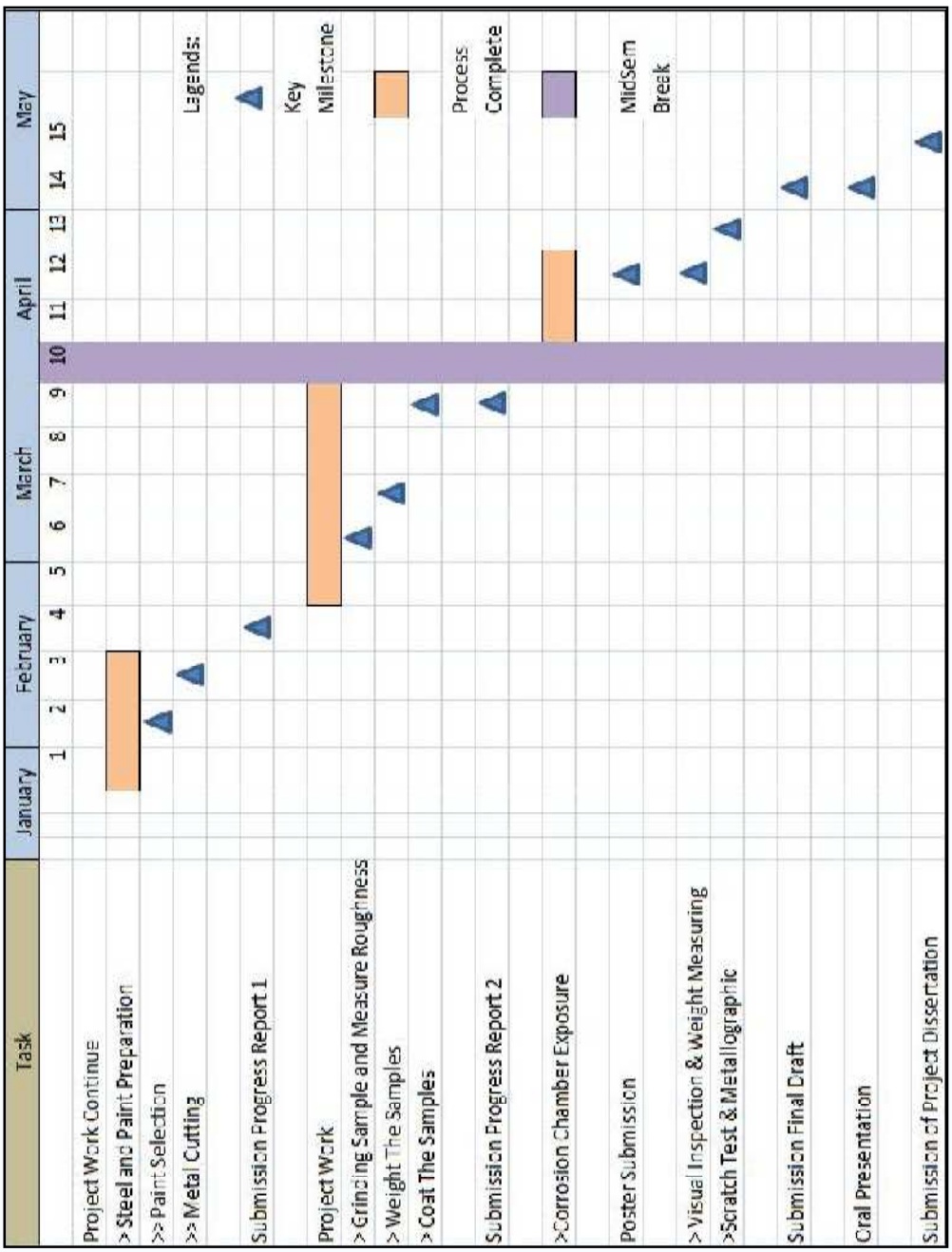


Chart 1: Project Ghannt Chart

3.2 PROJECT ACTIVITIES

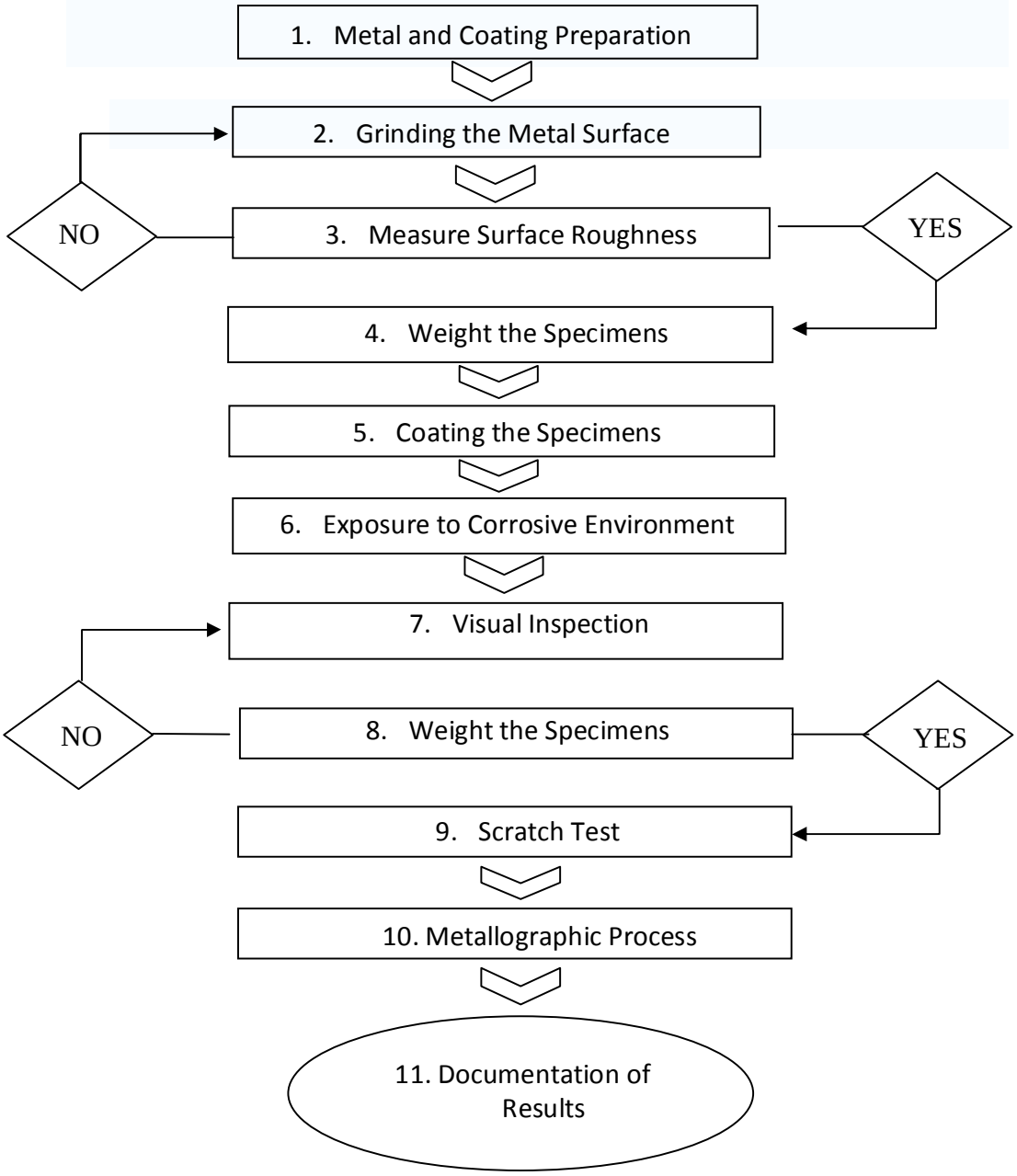


Chart 2: Project Flowchart

3.3 ACTIVITIES DESCRIPTIONS

3.3.1 Metal and Coating Preparation

This stage is to find the metal and paint as the coating system in this project. In this study, the type of metal used is Mild Steel or Low Carbon Steel. The metal is then cut into 70 x 20 x 4.5 mm size. The size is determined that way in order to make later stage of the research easier to handle without damaging the specimens.

Paint that has been chosen for the research is Nippon 9000 Gloss Finish formulated for interior and exterior metal and wood surfaces. This type of paint is chosen due to its availability and the quality that it offers.

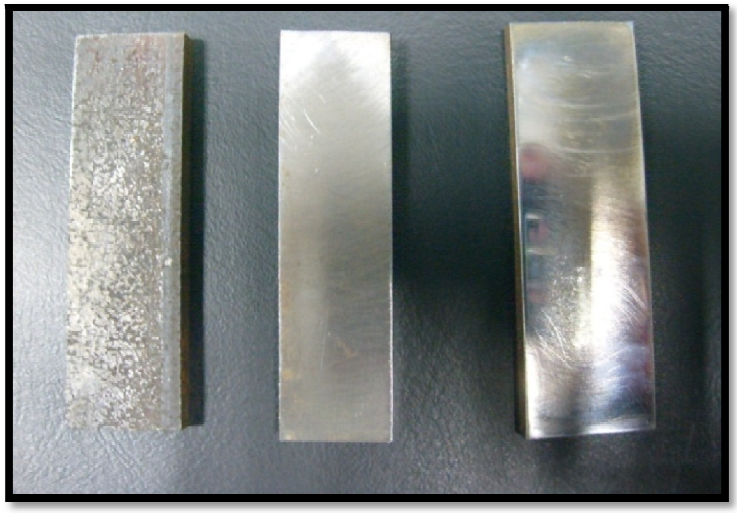


Figure 2: Prepared Samples

3.3.2 Grind the Specimens.

Specimen that has been cut is then polished using Polish and Grinded Machine using different Grit Paper. In this study, three samples have been prepared. These three samples were prepared to have different surface roughness from one another. These samples were marked as Smooth, Medium, and Rough. Grit paper that has

been used was Grit 80 for Rough surface, Grit 280 for Medium and Grit 600 for Smooth.

Rough surface sample is polished using only one grit paper which is Grit 80, but for Medium surface the sample is first polished with the Grit 80 and then Grit 280, and the same thing goes for Smooth surface sample. Time taken for each polishing process is 15 minutes for Smooth, 10 minutes for Medium, and 5 minutes for Rough as each grit paper use 5 minutes with constant speed through out all polishing processes.

Figure 3: Grinding and Polishing Machine

3.3.3 Measure Surface Roughness

The three samples are then measured to obtain the reading of surface roughness for each sample. The measurement is done using Profilometer to indicate the roughness different between each surface significantly with the name given to each sample. If there is any reading that unconvincing to the surfaces, polishing processes is going to be repeated again to obtain the desired reading. If the reading of taken of the

sample is significant enough with the name given to the sample, proceed to the next step.

3.3.4 Coating Specimen.

Three specimens is then coat with Nippon 9000 Gloss Finish according to the Nippon product datasheet. [6] Recommended paint system is according to the data sheet as well as recommended paint application method. The weight measurement of the samples is then taken before undergo next process.

Figure 4: Nippon Paint Three Coat System for Metal

3.3.5 Exposure to the Corrosive Environment

Three samples is place inside the corrosion chamber and the practice of ASTM B 117 – 09[7] is followed through out this process. Exposure period for the samples are eight days starting April 2nd to 9th. [8]

Before the exposure, each of the samples was weight to obtain the original weight before undergone the exposure.

Figure 5: Cyclic Corrosion Chamber Model SF/450/CCT

3.3.6 Weight the Samples.

After taking off from the corrosion chamber, visual inspection going to be done on the sample to take note any visible changes occur towards the coated surface of the sample. Some blistering and peeling are expected to occur on the paint of the sample. Sample is not to be touched and none of the paint on the metal is removed.

The samples are then weight on the scientific balance to determine of weight loss of the metal. If the result of weight measurement is shown clear different between initial and final condition, project work proceed to the next stage. [8]

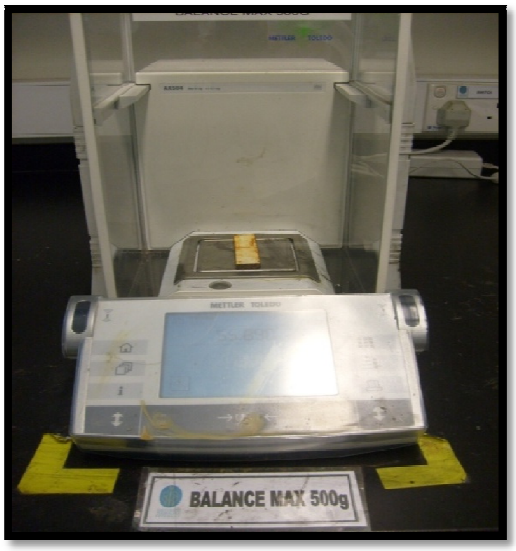


Figure 6: Scientific Balance to Weight the Samples

3.3.7 Scratch Test

Scratch test is one of the tests that can be performed in order to obtain the adhesion properties of the coating system. Some other test that can be done such as three point bend test, tape test and bend test. Based on the availability of the test to be performed, scratch test is chosen.

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 delamination or chipping of the coating. The critical normal force at which the first failure of the coating is detected is termed the critical load Lc [9].

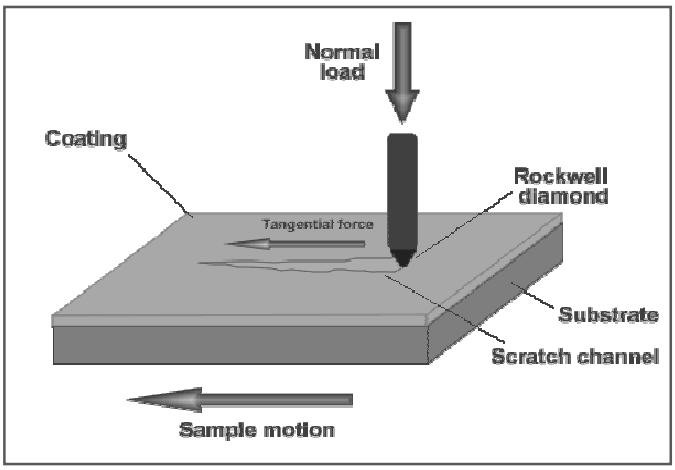


Figure 7: Diagram of Scratch Test

Scratch Test machine is dedicated instruments for characterizing the surface mechanical properties of thin films and coatings, e.g. adhesion, fracture and deformation. The tester has the ability to characterize the film-substrate system and to quantify parameters such as friction and adhesive strength, using a variety of complementary methods, makes it an invaluable tool for research, development and quality control [10].

This test is performs to study the adhesion properties of the coating system that has been applied with the effect of different surface roughness. Based on general understanding of adhesion properties of organic coating, the coating will fail as the load is over the adhesion properties of the coating.

3.3.8 Metallographic Process

Metallographic is the study of a materials microstructure. Analysis of a materials microstructure aids in determining if the material has been processed correctly and is therefore a critical step for determining product reliability and for determining why a material failed. The basic steps for proper metallographic specimen preparation include Sectioning and Cutting, Mounting, Planar Grinding, Rough Polishing, Final Polishing, Etching, Microscopic Analysis, and Hardness Analysis. [11]

3.3.9 Documentation of Result

All the finding within the research period is documented to finally produce a research paper for this research entitles Effect of Surface Roughness to the Adhesion and Corrosion Properties of Organic Coating on Metal Surface.

CHAPTER 4

RESULT

4.1 Coating Specification

Coating system that going to be used in the research work is Nippon tri-coat coating system Nippon 9000 Gloss Finish, Red Oxide Primer and Nippon Undercoat. These paints are oil modified alkyd-based enamel paint, specially formulated for interior and exterior metal and wood surfaces giving them a touch of brilliance.[12]

This gloss paint will provide a lasting beauty even in harsh weather and helps prevent fungus. It is recommended use for decoration and protection of internal and external wood and metal surfaces.

This organic paint is composing of three major parts which are:

Pigments	Mainly Titanium Dioxide, Iron Oxides, Carbon Black, Organic Pigments
Binders	Soya Bean Oil modified Long Oil Alkyd
Thinner	White Spirit or Mineral Turpentine

Table 1: Nippon 9000 Gloss Finish Composition

Recommended Number of Coats

Recommended No. of Coats	2-3
Drying Time	
➢ Touch Dry	2 hrs (depend on temperature and humidity)
➢ Hard Dry	Maximum 8 hrs
Recoating Interval	16 hrs

Table 2: Recommended Paint Applications

Recommended Paint System for Steel and Iron:

Sequence	Product Name	No of Coats
Primer	Nippon Red Oxide Primer/ Nippon Zinc Chromate Primer	1
Undercoat	Nippon 9000 Undercoat/ Economy Undercoat	1
Finish	Nippon 9000 Gloss Finish	2-3

Table 3: Recommended Paint System

4.2 Mild Steel Selection

Mild steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Low carbon steel contains approximately 0.05–0.15% carbon and mild steel contains 0.16–0.29% carbon, therefore it is neither brittle nor ductile. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. [3]

Mild steel is chosen due to it availability and it is easy to process to produce the work piece with the size that suit the work later on. The plate cut into that size due to some size limitation to work with scratch test machine afterward.

If the metal is already cut into the size of allowable work piece to work on the bench of scratch test machine, the sample will no be damage and the test can be conducted as original state as possible as it is taken out from the corrosion chamber without has to be cut off.

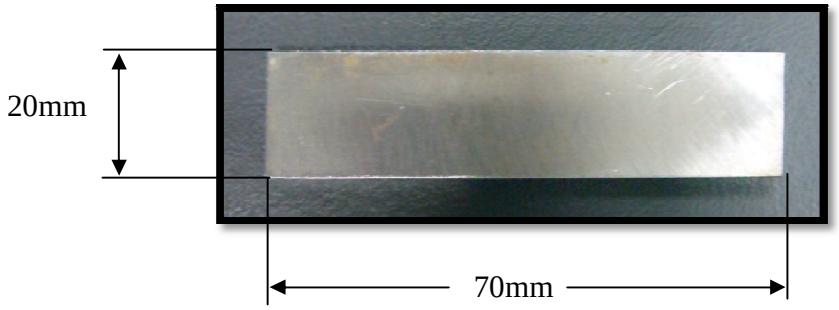


Figure 8: Metal Sample Size

4.3 Grinding Process.

In order to differentiate the roughness of the surface of the samples, grinding process is done. Three samples prepared shown different surface roughness. The surface of each sample is observed under the Optical Microscope to get a clear view of the real surface.

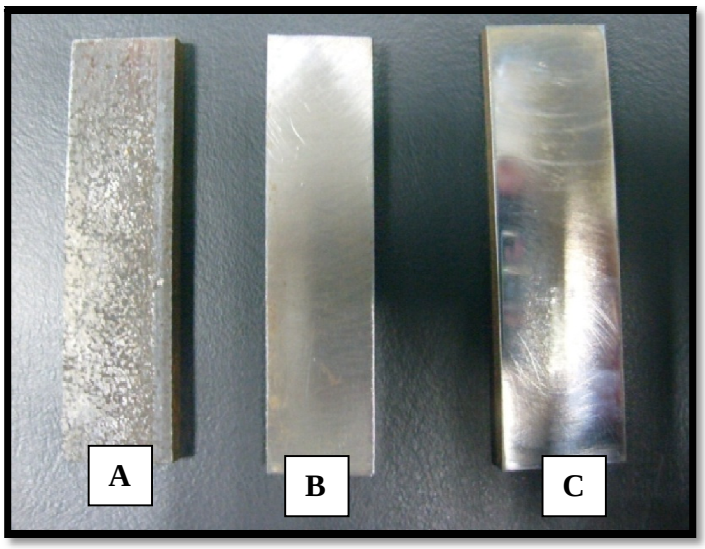
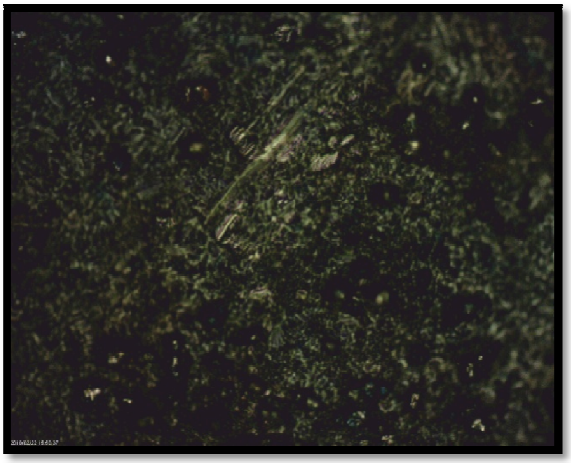


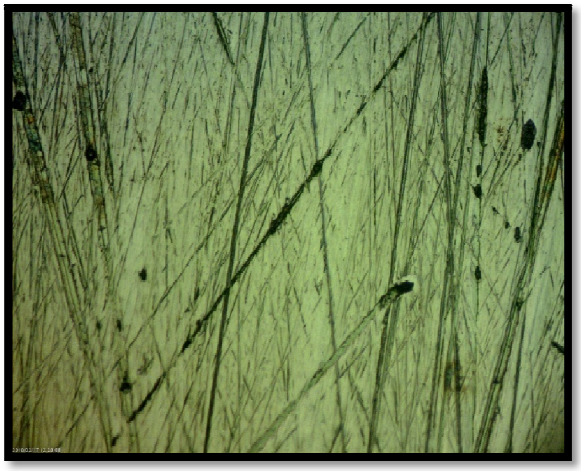
Figure 9: Three samples prepared with different surface roughness.

Sample A is indicated as Rough surface sample, Sample B is Medium surface sample, and Sample C is Smooth Surface sample.

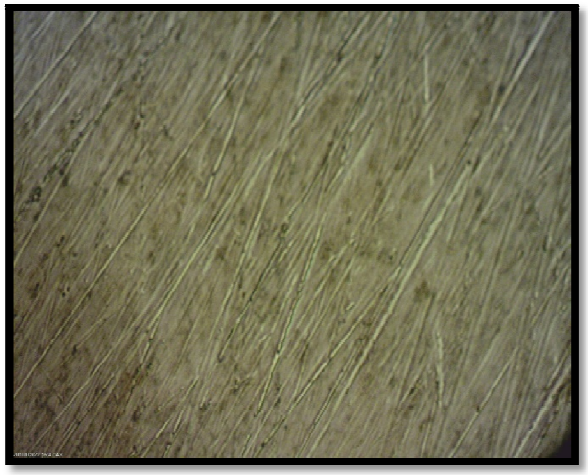
Figures below show the microscopic condition of each surface under the Optical Microscope.



Sample A: Rough



Sample B: Medium



Sample C: Smooth

Figure 10: Microscopic View of Each Surface at Mag 5x.

4.4 Profilometer

This test is to measure the exact surface roughness of each sample. After the measurement is complete, the sample will be coated according to the product data sheet from the paint manufacturer. If the measurement of the profile of the surface don not shows significant different in the reading of the each surface roughness, samples will be polished again accordingly. Mahr Perthometer basic specification and information:

- Tactile measuring system, profilometer
- Drive unit PGK-20, tracing length 20 mm
- Pick-up, RFHTB-50, RFHTB-250, MFW-250
- Dynamic noise < 8 nm, Static noise Rz < 2 nm
- Max. resolution vertical: 1 nm, horizontal: 100 nm
- Static measuring force 0.6 mN, 1 mN
- Evaluation software Mahr and PTB-Reference Software RPTB [11]

The reading was taken three times at different places to detect the surface roughness of the workpiece, and then the average of the reading is calculated and assumed as the overall surface roughness of the workpiece. The reading measured shows that the surface roughnesses were different from one another as it is polished using different grit paper.

	Sample A	**Sample B**	**Sample C**
1st reading	0.53	0.46	0.19
2nd reading	0.74	0.37	0.18
3rd reading	0.49	0.30	0.16
Average	0.60	0.37	0.17

Table 4: Surface Roughness Measurements

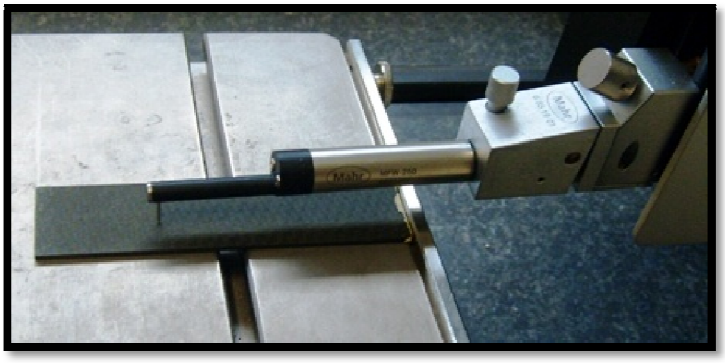


Figure 11: Surface Roughness of the Sample Is Measured Using Perthometer

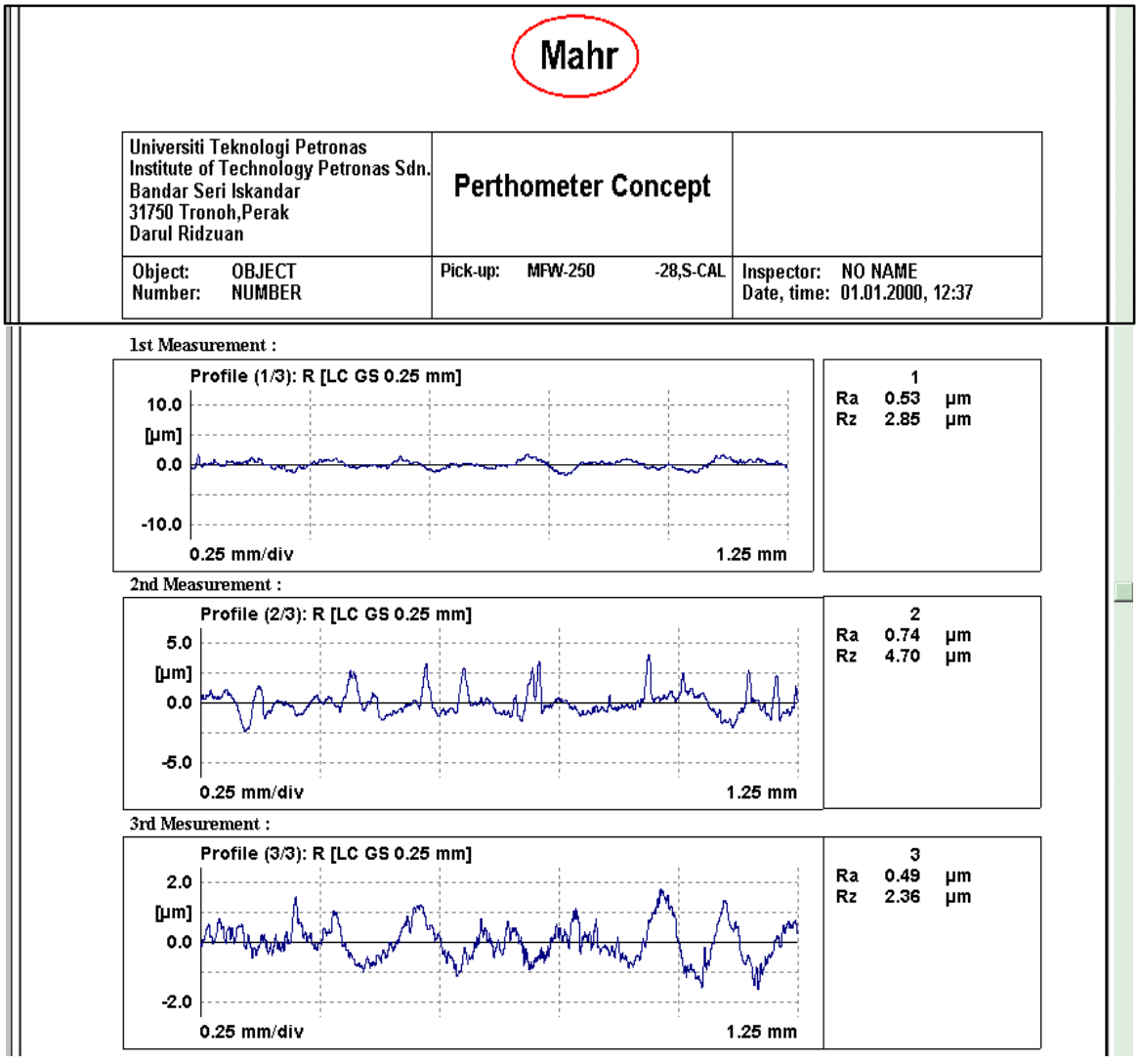


Figure 12: Data Sheet of Sample A using Perthometer

4.5 Coat The Samples.

The coating process will be done according to method recommended in the product data sheet using a paint brush. To make the coat almost identical to one another, 3 layer of 3rd coat Gloss Finish will be apply to each sample after the application of 1st coat of Red Oxide, and White Undercoat as 2nd coat. The application of the coating will be in one single direction and path.

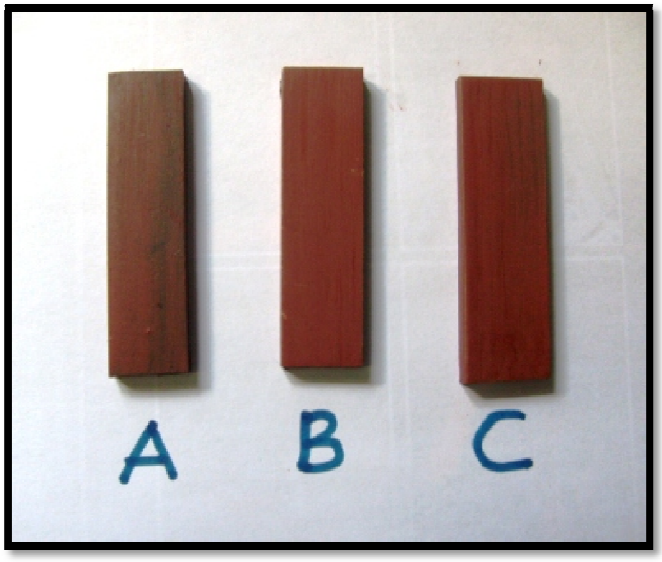


Figure 13: Samples Coated with 1st Coat: Red Oxide Primer

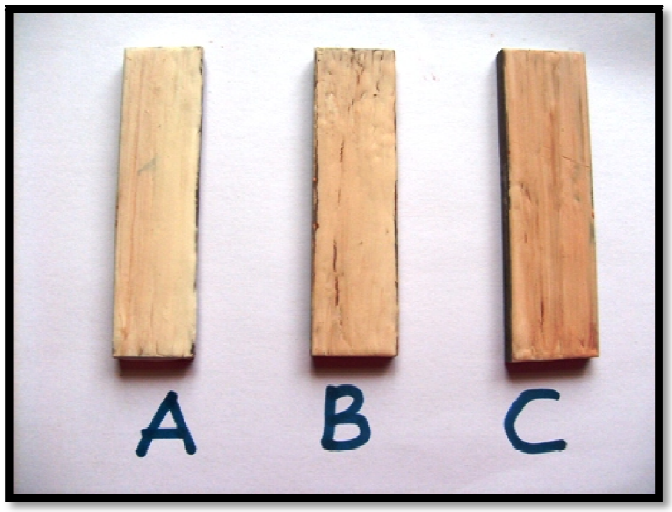


Figure 14: Samples Coated with 2nd Coat: Undercoat

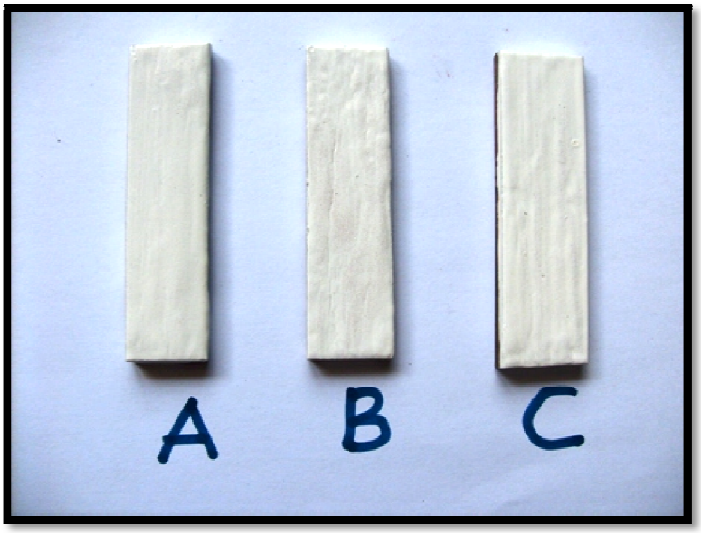


Figure 15: Samples Coated with 3rd Coat: Gloss Finish

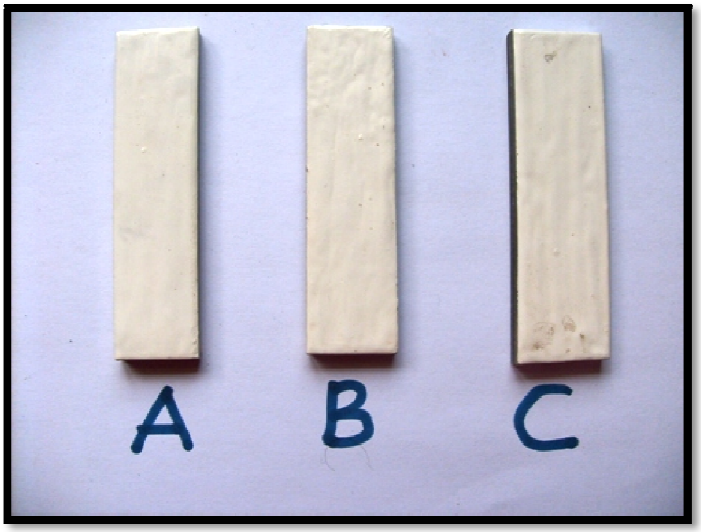


Figure 16: Samples Coated with 4th Coat: Gloss Finish

4.6 Weight The Sample after Coating.

All coated sample that has reach the drying time recommended is then weight for the records. The weight of each samples are taken into account to make sure that the deposited amount of thickness layer of coating is almost equal in every pass for all three samples. This practice is to monitor the consistency of the coating applied on top of the metal surface every single time. Samples will be weighted using scientific balance with normal precautions such as take the average reading and etc.

	Raw	Primer Oxide	Undercoat	1st Coat	2nd Coat
Sample A	54.173	54.676	55.107	55.501	55.795
Sample B	51.275	51.732	52.031	52.41	52.831
Sample C	60.106	60.517	60.907	61.217	61.697

Table 5: Sample's Weight after Particular Process

4.7 Corrosion Chamber Exposure.

Corrosion chamber is acting like an accelerated environment for the corrosion process to occur. In this research Sodium Chloride (NaCl) is used for the salt solution. 5 +/- 1 part of NaCl will be dissolved in 95 part of water. The salt used shall be NaCl with not more than 0.3% by mass total impurities. [7]

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

$$0.053 \times \text{Mass of Water} = \text{Mass of NaCl Required}$$

Equation 1: Salt Solution Equation

The mass of water is 1g per 1mL. To calculate the mass of salt required in grams to mix 1L of a 5% salt solution, multiply 0.053 by 1000g. This formula yields a result of 53g of NaCl required for each liter of water to achieve a 5% salt solution by mass. [7]

The pH of the salt solution shall be such that when atomized at 35ºC, the collected solution will be in the pH range from 6.5 and 7.2. [7]

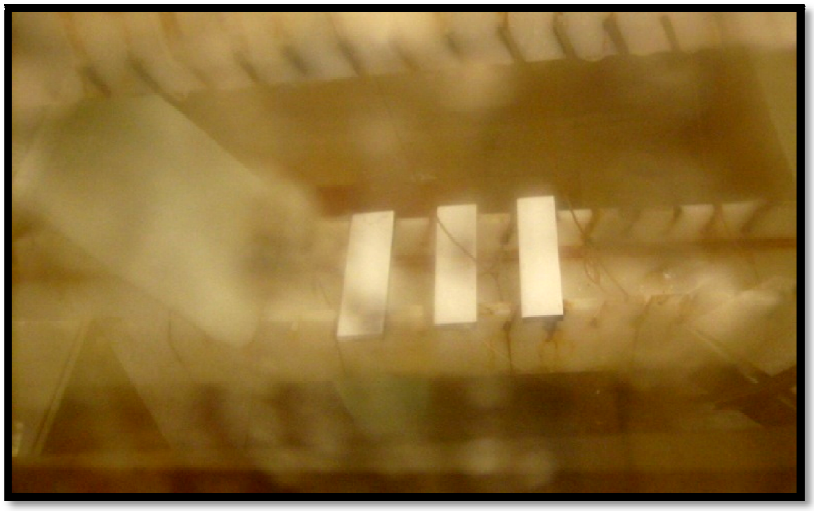


Figure 17: Samples Expose in Cyclic Corrosion Chamber Hour 1

Figure 18: Samples Expose in Cyclic Corrosion Chamber Hour 200.

4.8 Visual Inspection

As the samples are taken out from the corrosion chamber, the samples are inspected visually to identify any abnormalities that has happen to all the samples after 200 hours of exposure. Some of the noticeable changes that obviously seen is the yellow brownish sediment on the sample surface. As the coating system is coated in white color, it is much easier to have the contrast between the coating and the foreign elements. The

photo of each sample is captured for further analysis. The coating failures that had occurred on the coating surface such as cracks, peeling and pinhole.

Table below summarize all the failure that occurred for all the samples.

Failure / Sample	Cracking	Peeling	Discoloration
A	Yes	Yes	Yes
B	Yes	No	Yes
C	Yes	No	Yes

Table 6: Samples Failures

Cracking is small breaks in coating to substrate of various geometries normally resulting from stresses due to continued polymerization or oxidation. Peeling on the other hand is strips or sections of paint peel loose from the surface, usually due to moisture and/or inadequate surface preparation. Meanwhile discoloration is the looks of some yellowish, grayish, or darkening on the coated surface as a result of weathering or chemical reaction.[2]

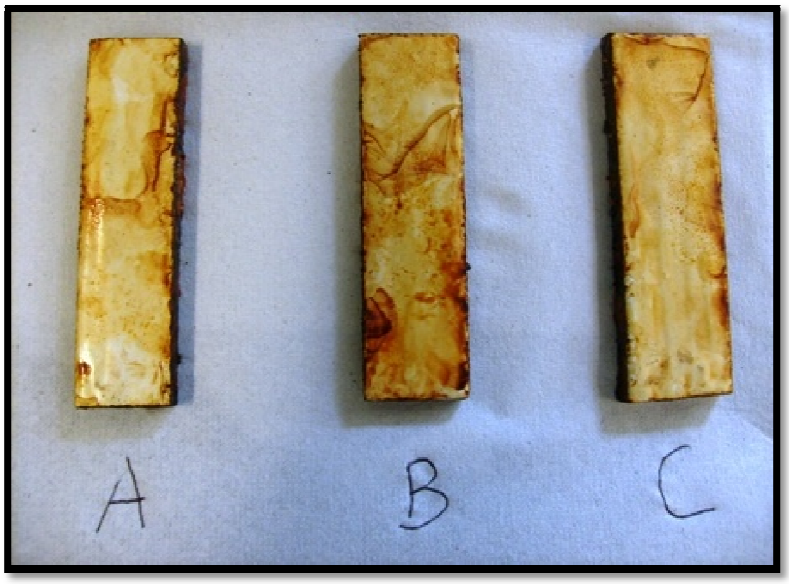


Figure 19: Overall View of Samples After Taken Off From Corrosion Chamber

4.9 Weight the Samples.

After 8 days in cyclic corrosion chamber, samples are about to be weighted again to obtain the final weight of the samples. This measurement is taken to calculate the percentage of weight different for each step for the whole process.

The samples is weighted in three condition which are, at first it is weight directly after taking out from the cyclic corrosion chamber, secondly the cleaning using soft cloth and the thirdly using a Ultrasonic Cleaner. These cleaning processes are to make sure that the foreign elements are taken out from the coated surface and the final weight of the samples can be obtained.

Sample	After Exposure	First Cleaning	UT Cleaning
A	55.589	54.937	54.138
B	53.426	53.262	52.935
C	61.773	61.549	61.107

Table 7: Samples Weight after Cleaning Processes

4.10 Scratch Test

The typical scratch tester has three methods of detecting coating failure; a load cell to measure the change in friction, acoustic emission or observation of the scratch channel using an attached optical microscope. 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 delamitation (adhesive failure). It is therefore important to observe the coating failure after the adhesion test using an optical microscope to confirm the critical load. [9]

4.10.1 Features of the Scratch Test Machine:

> Proven method to quantify adhesion of coatings

> Acoustic Emission, Frictional Force, Penetration Depth and optical observation

> Unique force feedback actuator

> Wide range of different indenters

> Very high throughput and reproducibility

> Handling of large samples (up to 300 mm)

> Works for both hard and soft materials

> Wear testing in multi pass mode

> Automated optical microscope inspection

> Industrial platform for quality control [10]

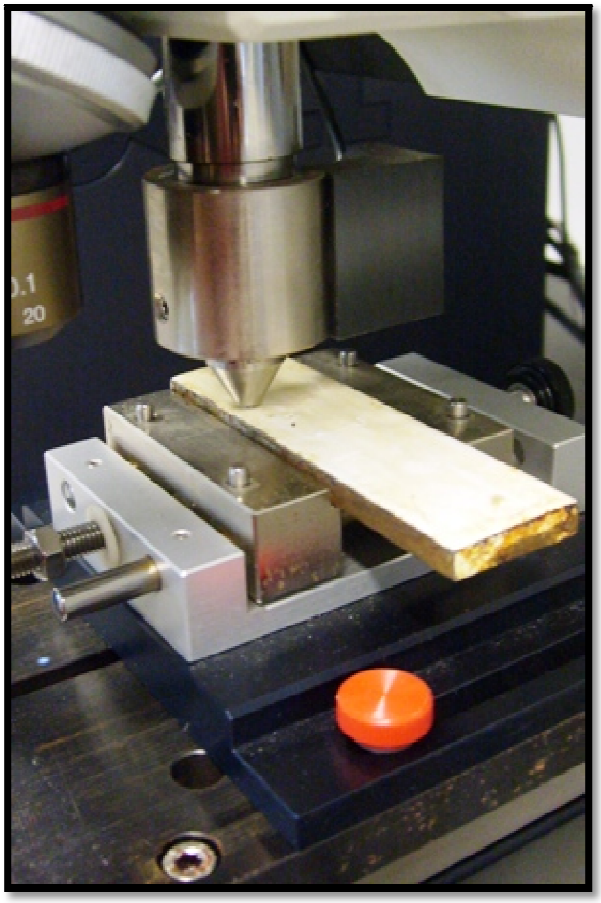
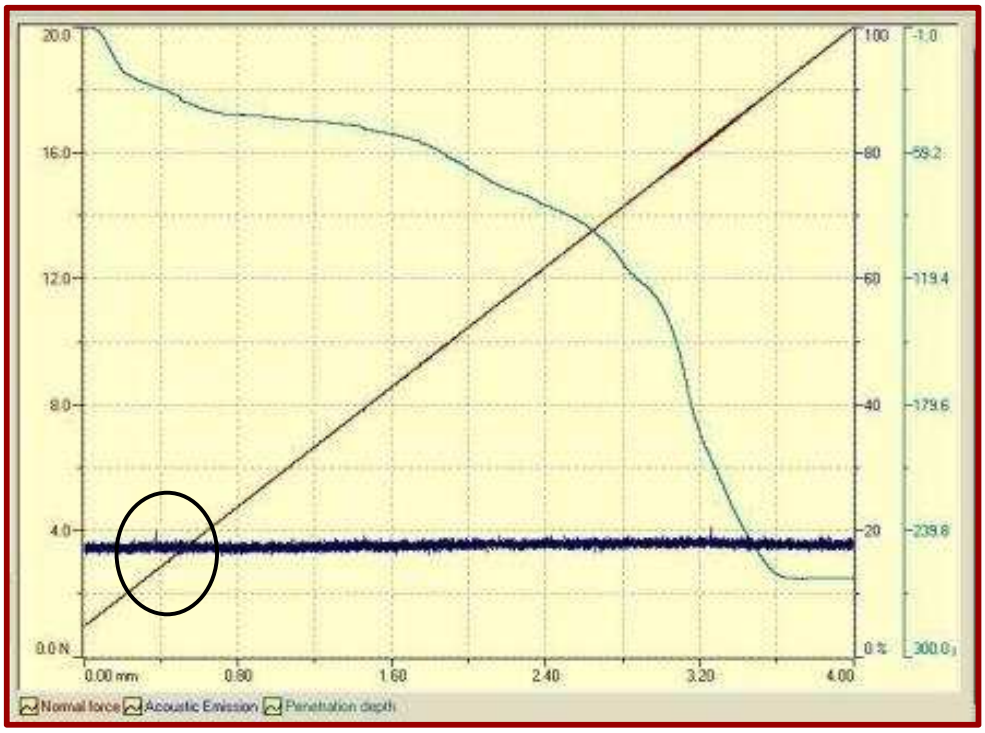
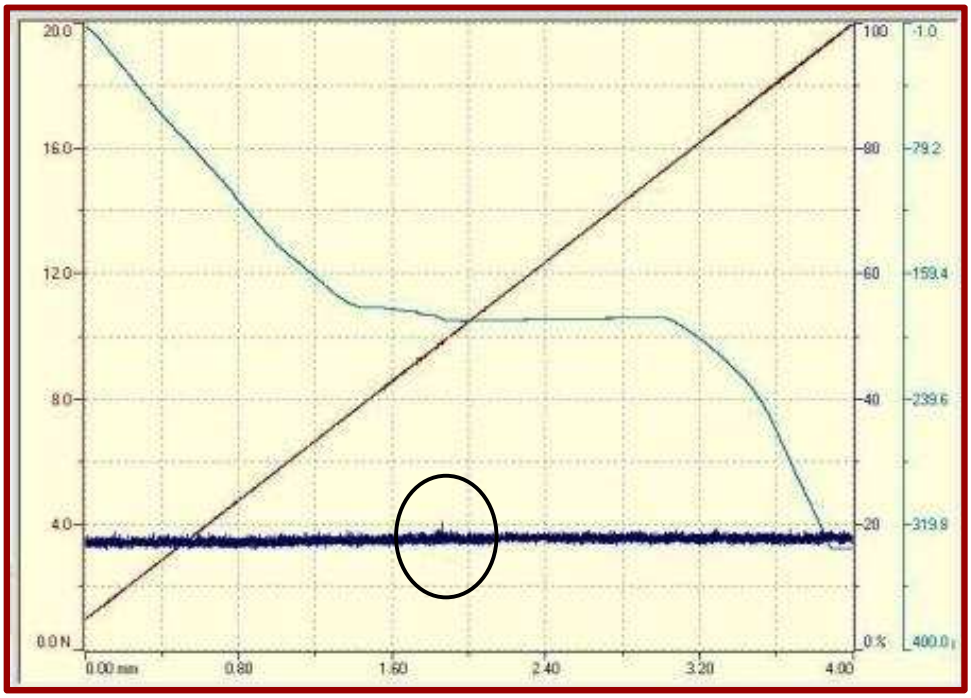


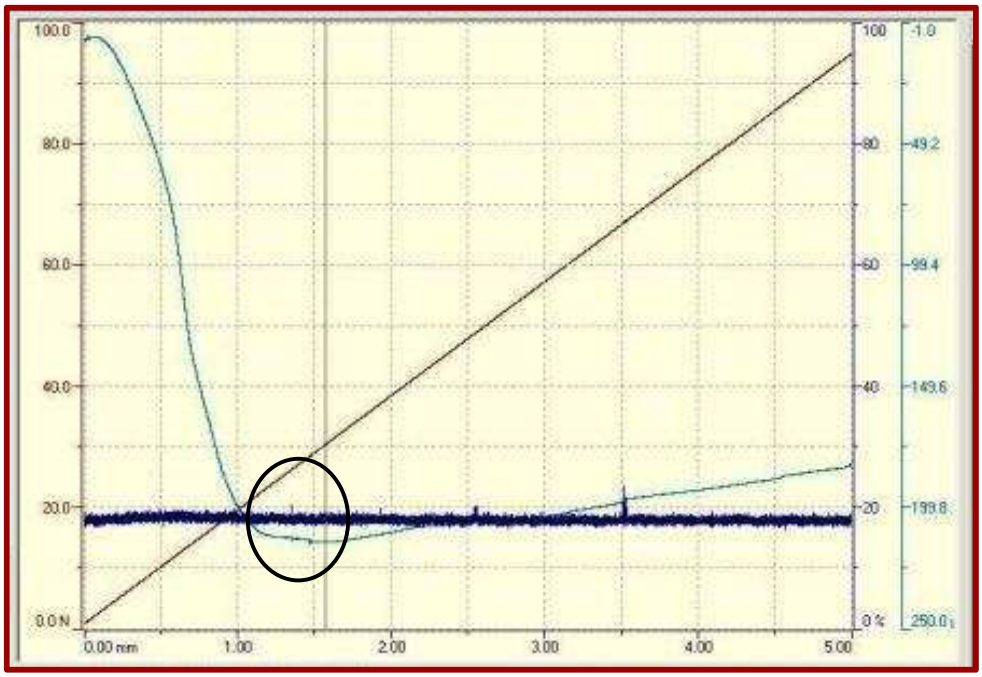
Figure 20: Sample Being Test by Scratch Tester



Graph 1: Sample A Coating Failure ≈ 3 N



Graph 2: Sample B Coating Failure ≈ 10N



Graph 3: Sample C Coating Failure ≈ 25N

4.11 Metallographic Processes

Method that going to be practiced during metallographic are:

4.11.1 Sectioning and Cutting

Proper sectioning is required to minimize damage, which may alter the microstructure and produce false metallographic characterization. Proper cutting requires the correct selection of abrasive type, bonding, and size; as well as proper cutting speed, load and coolant. [11]

Cutting and section has to be done properly to avoid any peeling and of the coating system which would affect the result and finding.

4.11.2 Mounting

The mounting operation accomplishes three important functions (1) it protects the specimen edge and maintains the integrity of materials surface features (2) fills voids in porous materials and (3) improves handling of irregular shaped samples.

For metals, compression mounting is widely used. Phenolics are popular because they are low cost, whereas the diallyl phthalates and epoxy resins find applications where edge retention and harder mounts are required. The acrylic compression mounting compounds are used because they have excellent clarity. [11]

4.11.3 Planar Grinding

Grinding is required to planarize the specimen and to reduce the damage created by sectioning. The planar grinding step is accomplished by decreasing the abrasive grit/ particle size sequentially to obtain surface finishes that are ready for polishing. Care must be taken to avoid being too abrasive in this step, and actually creating greater specimen damage than produced during cutting. [11]

4.11.4 Rough Polishing

The purpose of the rough polishing step is to remove the damage produced during cutting and planar grinding. Proper rough polishing will maintain specimen flatness and retain all inclusions or secondary phases. By eliminating the previous damage and maintaining the micro structural integrity of the specimen at this step, a minimal amount of time should be required to remove the cosmetic damage at the final polishing step.

Rough polishing is accomplished primarily with diamond abrasives ranging from 9 micron down to 1 micron diamond. Polycrystalline diamond because of its multiple and small cutting edges, produces high cut rates with minimal surface damage, therefore it is the recommended diamond abrasive for metallographic rough polishing on low napped polishing cloths. [11]

4.11.5 Final Polishing

The purpose of final polishing is to remove only surface damage. It should not be used to remove any damage remaining from cutting and planar grinding. If the damage from these steps is not complete, the rough polishing step should be repeated or continued. [11]

4.11.6 Etching

The purpose of etching is to optically enhance microstructural features such as grain size and phase features. Etching selectively alters these microstructural features based on composition, stress, or crystal structure. The most common technique for etching is selective chemical etching and numerous formulations have been used over the years. Other techniques such as molten salt, electrolytic, thermal and plasma etching have also found specialized applications.

Chemical etching selectively attacks specific microstructural features. It generally consists of a mixture of acids or bases with oxidizing or reducing agents. For more technical information on selective chemical etching consult corrosion books which discuss the relationship between pH and Eh (oxidation/reduction potentials), often known as Eh-pH diagrams or Pourbaix diagrams. [11]

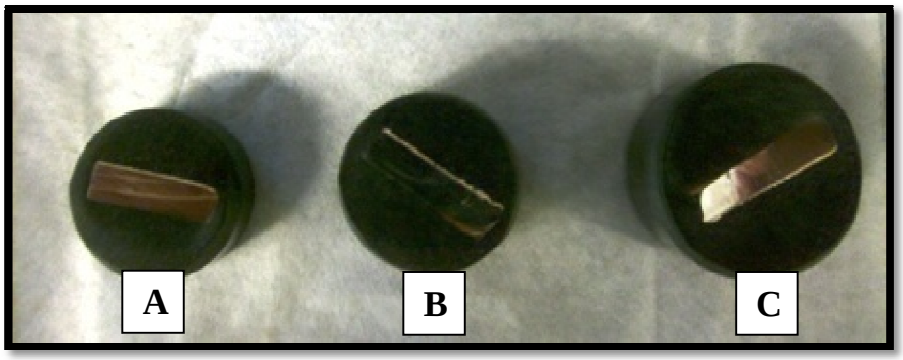


Figure 21: Samples after being mounted

4.12 Microscopic Analysis

Optical Microscope is used to observe the condition of the microstructure and the coating layer on the metal.

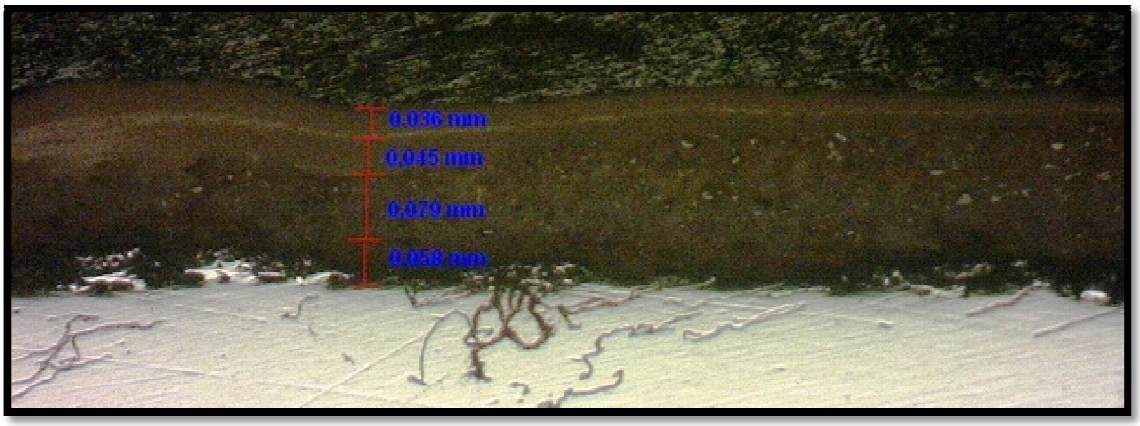


Figure 22: Micrographic View of Sample A

Figure 23: Microscopic View of Sample B

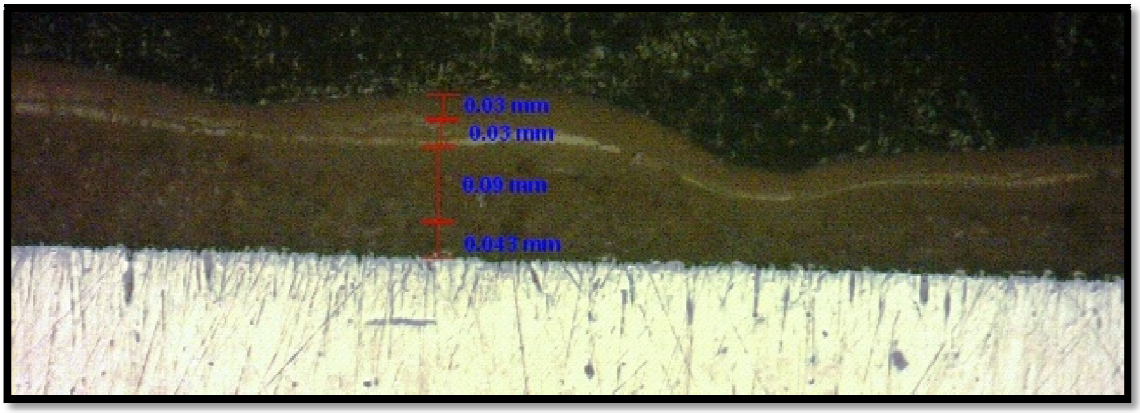


Figure 24: Microscopic View of Sample C

Sample / Layer	Sample A (µm)	Sample B (µm)	Sample C (µm)
Red Oxide Primer	58	79	43
Undercoat	79	85	90
First Coat	45	36	30
Second Coat	36	36	30

Table 8: Samples Coating Thickness Measured under Microscope

Result obtain from the measurement shows that the thickness is almost precise from one to another. The differences were in the acceptable range and the different was not too big.

CHAPTER 5

DISCUSSION

5.1 Mild Steel

Mild steel is sized 70 x 20 x 4.5 mm. The metal is cut into that size to ensure that later stage of testing will not be affected. Size of metal is about to fit the testing bed of Scratch Test Machine which the maximum width of allowable work piece on the testing bed is about 1.5 inch width.

Therefore, the work piece is prepared earlier to fit the testing bed. Sizing the work piece that already fit to the testing bed will avoid cutting and sectioning the work piece after the exposure in the Corrosion Chamber. Cutting and sectioning the work piece after the exposure might affect the condition of the coating system of the work piece. Some defect that would occur due to cutting and sectioning are cracking and peeling which then lead to the early failure of the coating system before endure the scratch test.

5.2 Grinding

The grit paper is chosen with different number to demonstrate the significant different of the surface roughness after the grinding process done. The entire specimen is grinded using the same speed, 150 rpm for 10 minutes for each paper individually.

Sample A was grind with grit No. 80, Sample B was grind with grit No. 80 and grit No. 280, meanwhile Sample C was grinded 3 times using No. 80, No. 280 and finally No. 600.

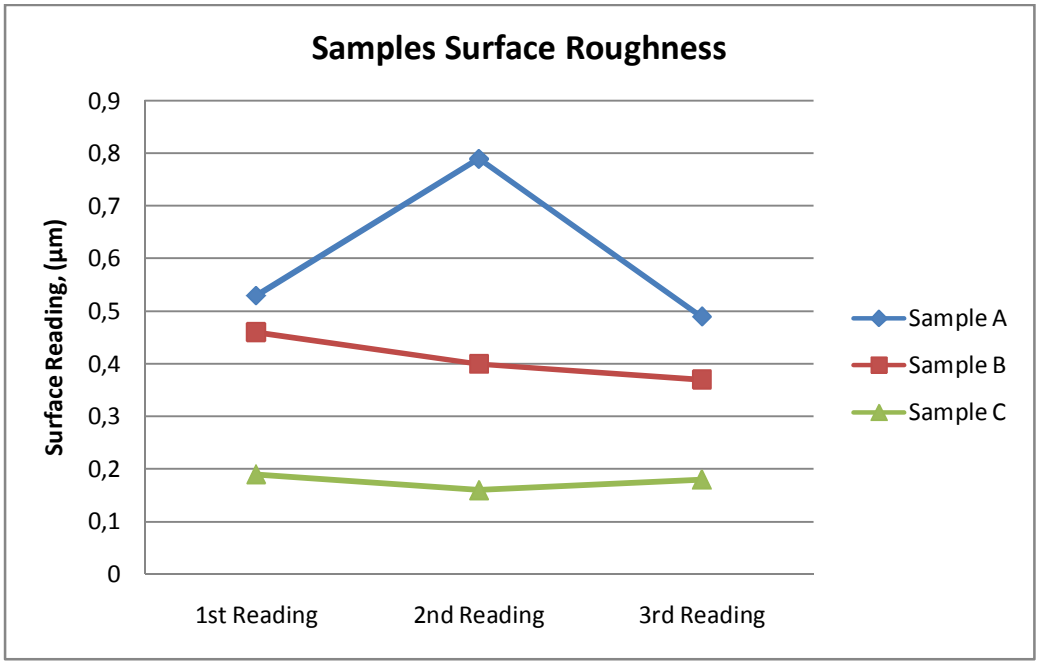


Chart 3: Samples Surface Roughness

From the chart above, it is noticeable that each sample has its own surface roughness patterns that differ from one another. For each sample, the reading is taken at different spot which lead to the different of reading of the roughness. Based from these three reading for each samples, the average of the reading is taken as the sample's surface roughness. The roughness reading is 5 mm for each specimen.

This practice can avoid the same reading is taken on the continuous pattern on the surface but the reading is taken adjacent to one another. The average of the readings will provide enough amount of information required to take into account as the surface roughness of the metal.

Notice that for Sample A, there is a highest measurement taken about 0.8µm recorded. This may due to the lack of surface contact towards the SiC Grit paper during grinding process. This condition is preferable for this study as it is concerning with the variation of the surface roughness. It shows that on that particular rough metal surface sample the variation of peak and valley present there.

On the other hand, Sample B and C shows a very small different of variation from three reading which mean the measurement of the surface roughness is consistent and precise with the average surface roughness taken. Even though Sample A has a wide variation from 1st reading to the 2nd reading, the 1st time reading and 3rd time reading is taken and recorded with small measurement variation from one another.

5.3 Weight the Samples

For this research, the method to determine the preciseness and consistency of each coating process is by the weight measuring method. Using this method, we can determine the amount of coating being applied and deposited on the metal surface every single time.

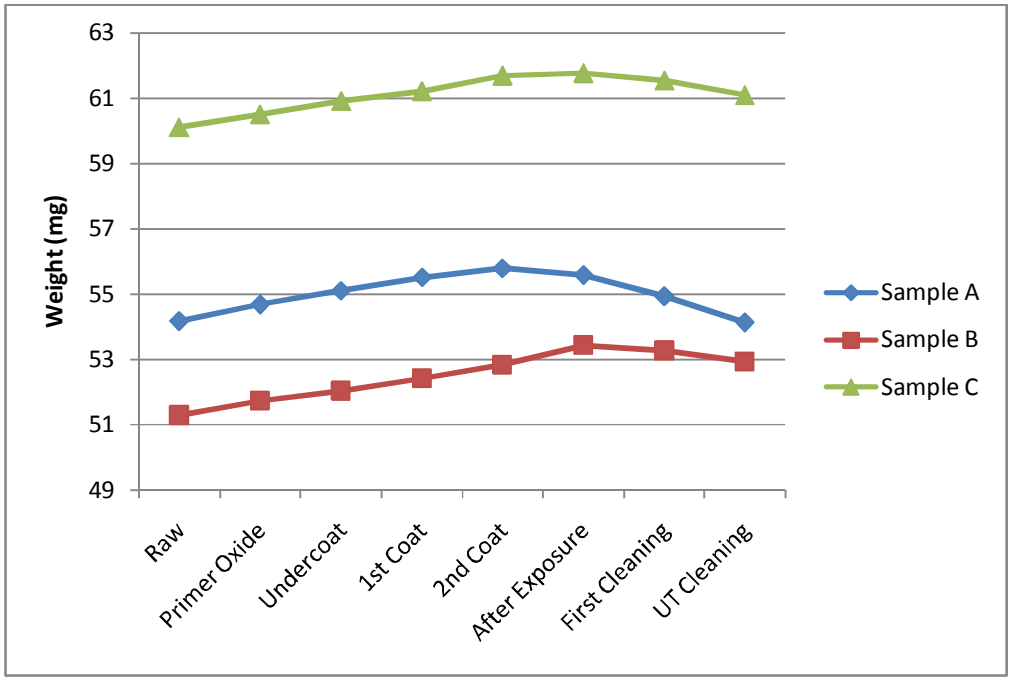


Chart 4: Samples Weight Curve

To observe the consistency of the deposited layer of coating the percentage different of every single coating is calculated using the equation:

$$\% \text{ different} = \left| \frac{\text{Current Weight} - \text{Previous Weight}}{\text{Previous Weight}} \right|$$

Equation 2: Coating Percentage Different

	% Diff Raw-Primer	% Diff Prim- Udrcoat	% Diff Under-1st
Sample A	0.93	0.79	0.71
Sample B	0.89	0.58	0.73
Sample C	0.68	0.64	0.51

% Diff 1st-2nd	% Diff 2nd-Aft	% Diff Aft-1st Clean	% Diff 1st Clean - UT
0.53	-0.37	1.17	1.45
0.80	1.13	0.31	0.61
0.78	0.12	0.36	0.72

Table 9: Percentage Weight Different of the Samples

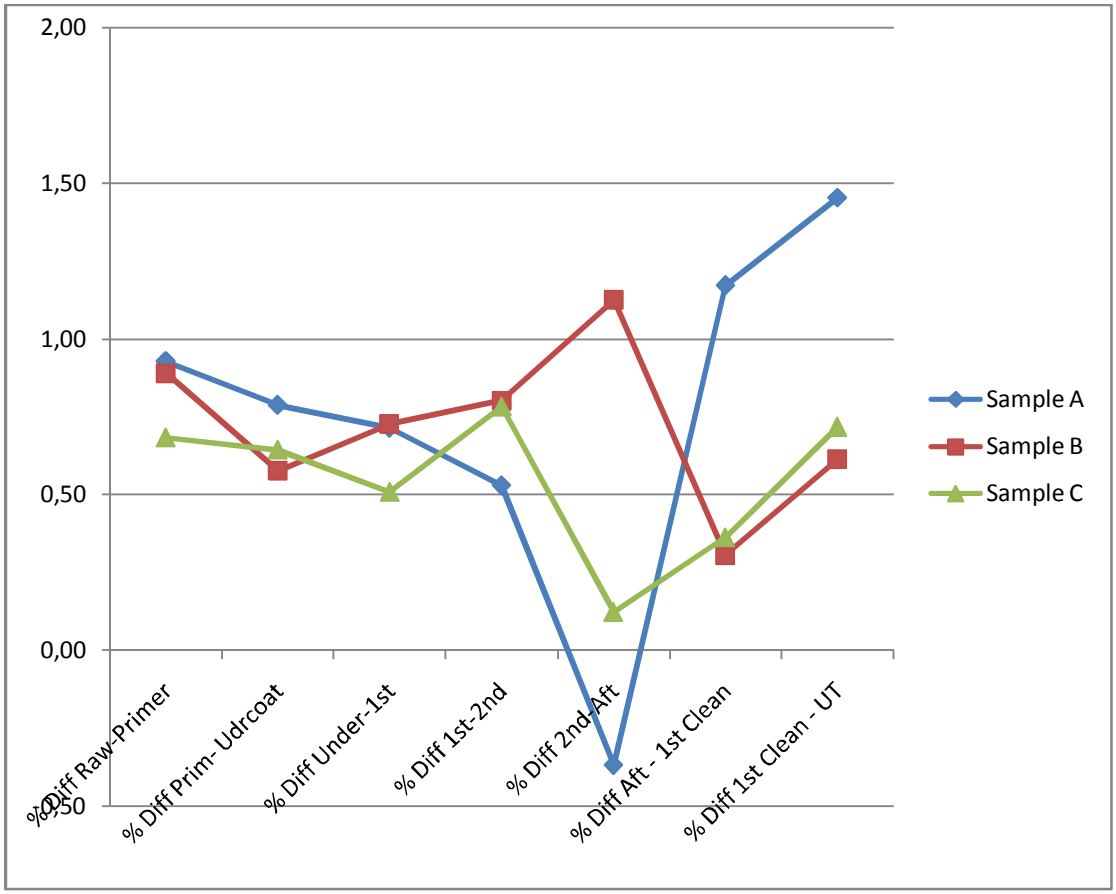


Chart 5: Scatter Plot of Samples Percentage Different

As this study is using the sample's weight to measure the consistency of the applied coating, it is noticed that during the process of coating the samples, percentage different of the applied coating is almost uniform and consistence with one another. From the scatter plot above, we can say that the average percentage different is about 0.75%.

From the scatter plot, it is noticeable that sample A and Sample C have almost identical physical plot meanwhile Sample B have slightly different from those two. Sample B has one inclined point taken for the percentage different for the second coat weight and the weight taken after one week exposure in corrosion chamber.

This is might be the result of the corrosion and other sediments forming on the bare surface of the metal such as water or air trapped inside the corrosion area as the samples is taken to the scientific balance straight away after being removed from the corrosion chamber. No cleaning is involved for this process therefore no foreign material or corrosion precipitate is removed from the surface.

For sample A and C, there are significant different percentages of the sample's weight during the surface measurement of the sample after the 1st cleaning and the freshly taken out sample from the corrosion chamber. This may due to the loss of contaminant, sediment or any foreign material that attached to the samples during the exposure.

This first cleaning is the process of removing noticeable and physical contaminant that is precipitated on the surface. For this purpose, simple hand tool such as wire brush, and scrapper gently used to remove all the foreign material that precipitated on the surface. Then the samples are dried using hair drier to remove the entire water particle on the surface in order to keep the surface dry.

5.4 Coating

Aside from surface preparation, the actual coating application is the most visible and important aspect of the coating work.

For brush application, the brush should be dipped approximately one half of its bristle length into the coating. The bristle tips should be brushed lightly against the side of the container to prevent dripping, and as fully a loaded a brush as possible should be maintained. This will result in a more even coating film and help ensure thorough wetting of the surface.

Brushing is more effective than spraying for working paint into depressed irregularities, pits, or crevices. Care should be taken to ensure that the coating is not brushed out too thin, especially on projections and corners.

	Sample A (µm)	Sample B (µm)	Sample C (µm)
Red Oxide Primer	58	79	43
Undercoat	137	164	133
First Coat	182	200	163
Second Coat	218	236	193

Table 10: Collective Thickness of Coated Sample

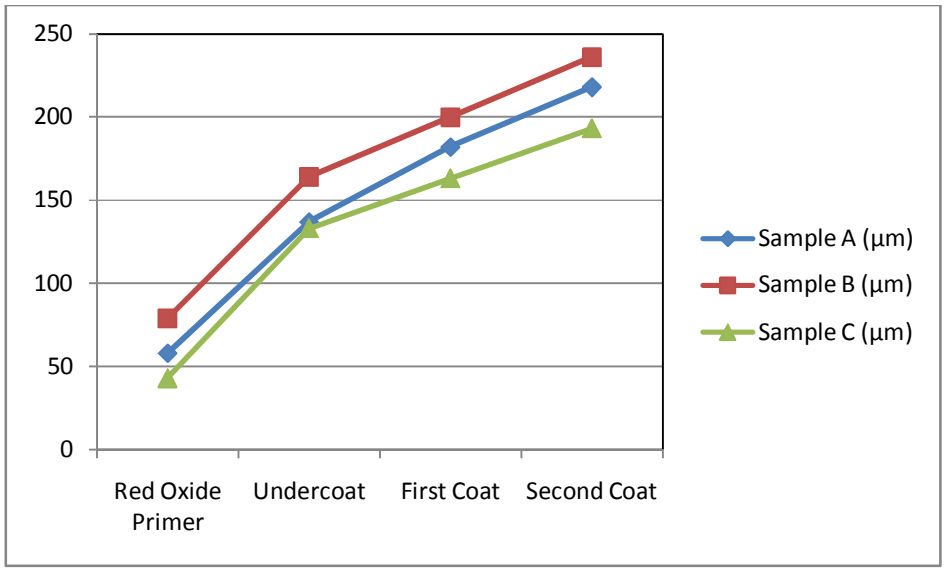


Chart 6: Collective Thickness of Coated Samples Curve

From the curve, it is noticeable that the thickest coating applied is on Sample B measured about 236 µm, and the least thick is on Sample C measured about 193 µm. The curve has shown no significant different between those three samples.

The percentage different of Sample A to Sample B is 7.6%. Percentage different between Sample B to Sample C is 18.2% and percentage different between Sample A to Sample C is 11.5%. Average percentage different between these three samples is 12.4%.

5.5 Visual Inspection

Sample A with surface roughness 0.60 µm shows some significant defect such as discoloration, peeling and cracking on the metal surface after being exposed for 8 days in cyclic corrosion chamber. Sample B and Sample C on the other hand only show the sign of cracking and discoloration without any indication of peeling found.

Figure 25: Peeling on Sample A

This situation might be the result of roughest surface on Sample A compare to the other sample. Rough surface will affect the coating adhesion strength on the metal surface. The adhesion properties of the coating material rely on the roughness of the metal surface. This condition might also be one of the results if the surface preparation is not performed adequately to overcome this problem as one of the affected area of surface preparation is surface roughness.

On Sample A, peeling only occurred at one side of the metal at two spot along the edge of the sample like shown in Figure 24. First defect was measured and read the length at 25.2 mm and the other location measured to be 30.8mm. This giving the coating adhered length to be around 14mm only out of total length of 70 mm. Only 20% of the length of the applied coating is adhered and the other 80% is completely peeled off from the metal surface.

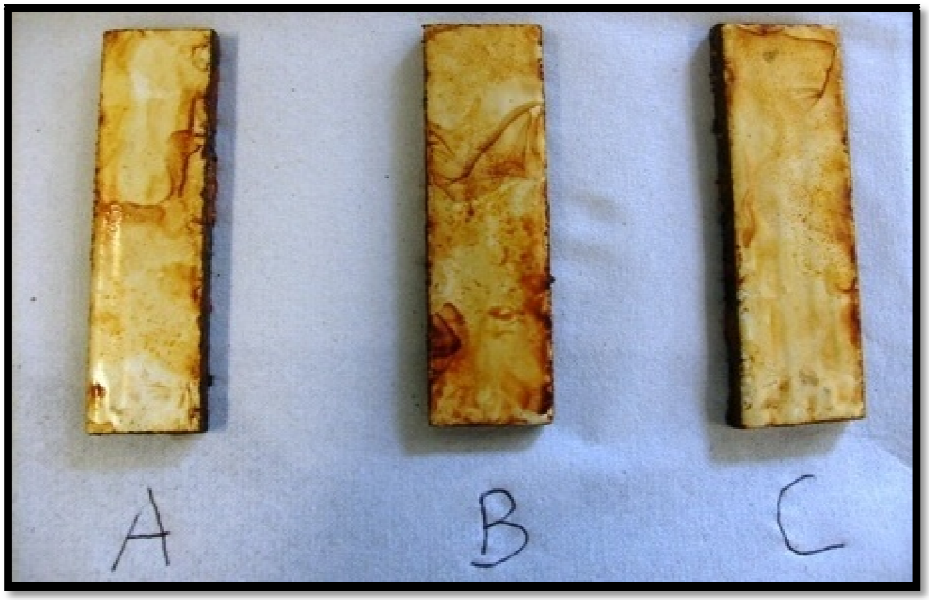


Figure 26: Sample After Taken Out From Corrosion Chamber

Sample A has 4 different spots with cracks shows that the coating is very weak and easily influences by the corrosive environment. All of the cracks are originated at the corner or the edge of the samples with none of them originated from the center which indicates that edge and corner area should not be taken for granted during surface preparation. The coating system provide greater adhesion towards the better surface roughness sample such as sample B and C and corrosion can be reduce with only two cracking found each.

5.6 Scratch Test

Scratch Test is performed using CSM Instrument and it is conducted in the progressive loading test. Three reading was taken as precaution measure. The orientation of the samples also varies from one run to the other. Meanwhile the location for the test is randomly chosen of the coated surface.

Scratch Test is conducted after the sample is dried overnight inside the moisture absorber tray in order to make sure that the samples are completely dry.

Figure 27: Scratch Test Done On Random Location

After underwent Scratch Test, Sample A demonstrate further cracking and severe peeling of the coating system which initiated from the scratch test area. This also may due to the rough surface of the sample.

Figure 28: Further Peeling and Cracking on Sample A

CHAPTER 6

RECOMMENDATION

Further study on this topic can be done in many ways possible:

6.1 Full Coating of Samples

For this study, the sample is coated on one surface only and the rest were left bare and uncoated. Having full coated samples will reduce the possibility of edge peeling of the coating system towards the sample surface. However, having full coated sample has another problem which is the entire surface of sample must have almost equal surface roughness from one another to obtain the precise result. When the samples coated on every faces of the samples, the scratch also need to be done on every single faces, therefore using thicker samples is possible with dimension of 70 mm x 20 mm x 20 mm. If the sample is cut in this size, scratch test can be conducted easily.

6.2 Longer Exposure Time

Exposure time in the cyclic corrosion chamber for this study is 8 days continuously. In order to obtain greater visible result, the samples shall be exposed for a longer period such as one whole month and meet and follow all the requirement from ASME B117. This practice will allow the failure, if there is any will appear more significantly on the samples surfaces.

6.3 Coating Thickness Measuring

Coating thickness measuring is the process of measuring the wet and dry coating thickness using specific film thickness gauge. However for this study, weight different is use instead. Using film thickness gauge is better than measure the weight of the coated sample because, each of the coating layers applied on metal surface can be determined its thickness during the coating is wet an dry. The information gathered from the measurement can be used to calculate overall coating thickness applied on the meatal surface straight away.

6.4 Focusing On One Major Factor

This study is conducted for two major results which are the adhesion and corrosion properties towards the variety of surface metal roughness. Further study can be conducted if more concentrate on one major result either adhesion properties or corrosion properties.

Further study on one major result will allow deeper understanding and development of the process. For example the adhesion properties, for this study there is only one single test could be perform to determine the adhesion properties which by mean of scratch test alone. However if there is one major outcome is targeted, several type of adhesion testing could be performed such as tape test and bend test.

Meanwhile, for corrosion properties for the organic coating, beside visual inspection, corrosion penetration rate could be considered if allocation time for cyclic corrosion chamber exposure is long enough to have the failed the coating system. Further inspection also could be done using modern gadget such as Ultrasonic Test to obtain the coating thickness should it loss some.

CHAPTER 7

CONCLUSION

Based on the research work that has been completed, the flow of this project is constructed firmly and structurally. Coating is very ideal for decorative and corrosion protection purpose but it is really related with the surface preparation done. By varies the method of surface preparation, the surface roughness of the metal is varied and produce different result from one another in term of adhesiveness to the organics coating applied.

Direct relationship is clearly obtained from the study that has been completed that the one of the concern of having surface preparation is roughen the metal surface. Different level of surfaces roughness affected the adhesion properties of the coating system. For example surface roughness of Rough Sample, Ra = 0.60 µm has the Critical Load about 3 N which represent the adhesion strength of the organic coating applied. Meanwhile, Smooth Sample with surface roughness, Ra = 0.17 µm has Critical Load about 25 N.

Different level of surfaces roughness affected the adhesion properties of the coating system. The corrosion rate also depends on the adhesion properties of the coating material towards the surface. Rough surface provide less adhesive between coating material and the metal surface.

Original cracking found of the coating at four different spots on Sample A compare to Sample B and C both with two original cracking found right after 200 hrs of exposure. It was found out that the coating on sample A has peel off about 56 mm at the edge of the sample which is about 80% from sample's total length after the exposure to corrosive environment. Evident from the scratch testing on the other hand shows that sample A had peel off in the brittle manner and continues to crack further more.

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