Evaluation on Rust Stabilizer Paint for Maintenance Painting of Internal Pipeline

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

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(Ir. Dr. Mokhtar Che Ismail)

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TRONOH, PERAK

Jan 2009

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 SAFWAN BIN MOHD ISA)

ABSTRACT

Maintenance painting is important in order to reduce the further damage to the equipment from corrosion attack. The challenge is what type of paint that can work properly under minimum surface preparation especially for internal pipeline surface during maintenance painting. The main objective of this project is to evaluate the rust stabilizer paint performance which will be applied for internal pipelines coating for maintenance purpose. The methodologies to evaluate the paint performance are pull-off adhesion test (ASTM D4541) to test the paint strength, Taber abrasion test (ASTM D4060) to test paint wear index, salt spray test (ASTM B117) to test the paint corrosion protection barrier level and immersion test (ASTM D870) to test water and petrol absorption rate. The result from pull-off adhesion test is 967 psi. For the Taber abrasion test, the wear index obtained is 7.28×10^{-5} g/rev for 1000 revolutions with 1000 g loads. For the salt spray test, there is no significant defect after 336 hours of exposure. For the immersion test, 0.21% weight increased for water immersion and 0.88% weight increased for petrol immersion after 500 hours of immersion. As a conclusion, the tests conclude that the technical specification is met to apply rust stabilizer paint at internal pipeline surface during maintenance painting. Further study need to be done to ensure the capability of the paint to convert rust into stabilizes components for benefits of industrial application.

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LIST OF ABBREVIATIONS

ACES	Applied Corrosion Engineering Services Sdn Bhd
API	American Petroleum Institute
ASTM	American Society for Testing and Material
CO_2	Carbon Dioxide
CRSP	Corrostabil Rust Stabilizer Paint
DFT	Dry Film Thickness
HAZ	Heat Affected Zone
ILI	Inline Inspection
ISO	International Standard Organization
PIG	Pipeline Inspection Gauge
RBI	Risk Based Inspection
WFT	Wet Film Thickness

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Malaysia has many onshore and offshore oil and gas facilities. After years of operation, these facilities will require maintenance painting to avoid corrosion. Corrosion is a destructive attack of a material by reaction with its environment. In pipeline issue, corrosion causes leak to the pipeline's wall, loss of resources, reduction in pipeline transportation efficiency, costly maintenance to either repair or replace the pipeline, expensive overdesign and also jeopardizes safety and environment. Therefore, corrosion prevention must be done to expand maximum service life of the pipeline.

In-situ maintenance painting is very important to reduce the growth of rust. In order to avoid total lost due to corrosion, maintenance painting will be execute on time basis or criticality basis. Risk Based Inspection (RBI) method is widely used to determine the equipments' level of criticality. The higher the criticality level, the higher the corrosion monitoring will be done and if necessary, repair or replace the problem parts must be done. Maintenance painting for external surface is easily done and monitored by workers. But, it is opposite for the internal surface such as internal pipeline. Thus, the idea of in-situ maintenance painting for internal pipeline is promising. However, there are many challenges to execute maintenance painting program for internal pipeline in term of paint formulation and application. Therefore, corrosion inhibitor is normally chose rather than using paint due to cost and technology constraint.

Recently, the new technology of using rust stabilizer paint to stabilize the rust from further growth seems can provide new opportunity on paint formulation for internal pipeline. Rust stabilizer paint will stabilizes the existing rust from further growth. The application for maintenance painting using rust stabilizer paint is preferable when considering the parts are already covered with rust. Rust stabilizer paint has been proven successfully applied at the external surface but it is new for the internal surface.

1.2 Problem Statements

The occurrence of internal corrosion of pipeline can cause failure if not prepared or integrated. The failure occurs due to the growth of rust which is caused by the existence of water and carbon dioxide in internal pipelines. Water and oxygen are the corrosion catalyst and the most important purpose to reduce the rust growth is to eliminate the connection between moisture, oxygen and internal steel surface. The main problem occurs in hydrocarbon pipeline is internal corrosion due to CO_2 corrosion. Another challenge is the application for painting require maximum surface preparation to remove the rust existed on the surface after years of operation. In the pipeline, it is impossible to send people to blast and paint the internal surface manually. Therefore, pigging method is chose but the surface profile result will be not optimum enough. This non-ideal of surface due to rust existence requires new robust surface tolerant paint formulation which led to the rust stabilizer paint formulation. The successful of maintenance painting implementation for corroded internal pipeline using rust stabilizer paint will be assessed in terms of performance and corrosion barrier effectiveness.

1.3 Objective and Scope of Study

The main objective of the project is to evaluate the rust stabilizer paint performance used in pipelines internal coating. The scope of this project will be on the physical evaluation on the rust stabilizer paint which involves level of strength, wear index, fluid absorption and corrosion rate by following ASTM standards respectively. The relevancy of this project is to ensure the compatibility of using rust stabilizer paint for internal pipeline surface purpose.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Internal Pipeline Corrosion

There are many pipelines used nowadays to transport oil and gas from platforms to the buyers. In simple, pipelines play major rules in transporting the product to customers. But, the main problem faced by the oil and gas companies, is the corrosion occurs at the internal and external of the pipelines. Compared to external corrosion, the internal corrosion are more risky and critical to face since corrosion effect cannot be physically monitored by human naked eyes. There are cases related to the pipelines failure due to internal corrosion as per shown in Figure 2.1. Corroded pipelines by internal factors were caused by the debris produced by the medium flow hit the surface of the pipelines. The higher the surface was hit by these particles means the higher the corrosion rate. Rust also can form in the pipelines due to exposed to the water and oxygen to the surface after years of operation. The layer of oxide will form and this will result in failure if no prevent action were taken.

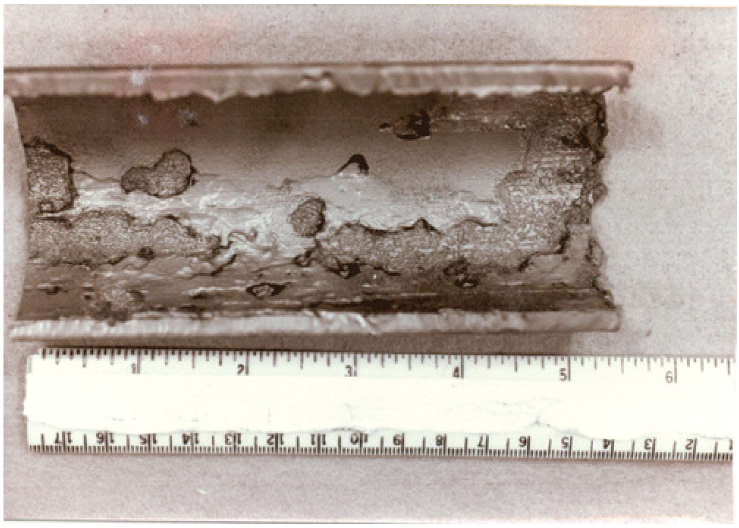


Figure 2.1: Internal corrosion [4]

2.1.1 Corrosion Basic Theory

Corrosion is an electrochemical reaction composed of two half cell reactions, an anodic reaction and a cathodic reaction. The anodic reaction releases electrons, while the cathodic reaction consumes electrons. There are three common cathodic reactions, oxygen reduction (fast), hydrogen evolution from neutral water (slow), and hydrogen evolution from acid (fast).

<u>Anodic reaction:</u>
$M \rightarrow M^{n+} + ne^-$

M stands for a metal and n stands for the number of electrons that an atom of the metal will easily release.

i.e. for iron and steel: $Fe \rightarrow Fe^{2+} + 2e^-$

<u>Cathodic reactions:</u>

$O_2 + 4\,H^+ + 4e^- \rightarrow 2H_2O$ (oxygen reduction in acidic solution)
$1/2\ O_2 + H_2O + 2e^- \rightarrow 2\ OH^-$ (oxygen reduction in neutral or basic solution)
$2\ H^+ + 2e^- \rightarrow H_2$ (hydrogen evolution from acidic solution)
$2\ H_2O + 2e^- \rightarrow H_2 + 2\ OH^-$ (hydrogen evolution from neutral water)

Each half-cell reaction has an electrical potential, known as the half-cell electrode potential. The anodic reaction potential, E_a , plus the cathodic reaction potential, E_c , adds up to E, the cell potential. If the overall cell potential is positive, the reaction will proceed spontaneously.

As shown in Figure 2.1.1, corrosion cells are created on metal surfaces in contact with an electrolyte because of energy differences between the metal and the electrolyte. Different area on the metal surface could also have different potentials with respect to the electrolyte. These variations could be due to i) metallurgical factors, i.e., differences in their composition, microstructure, fabrication, and field installations, and

ii) environmental factors. Carbon and low alloy steels are the most widely used material in the oilfield. Stainless steels (Fe-Cr-Ni), and nickel-base corrosion resistant alloys (CRA), such as Incoloys (Ni-Fe-Cr), Inconels (Ni-Cr), Hastelloys (Ni-Cr-Mo-Fe-Co) etc., are also used in highly corrosive environments.

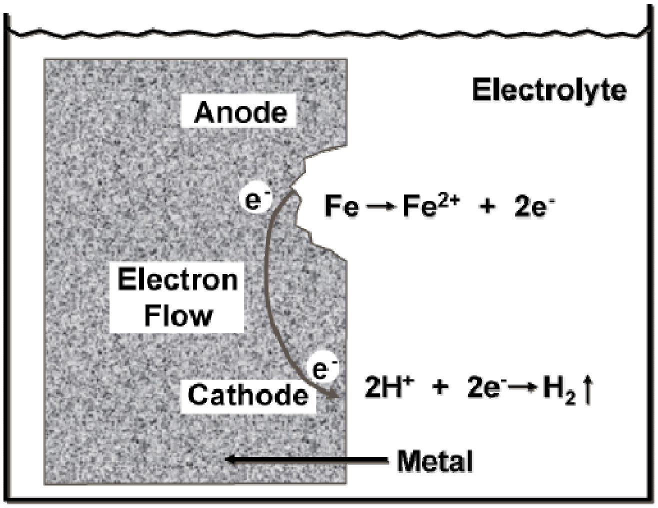


Figure 2.1.1: A corrosion cell [4]

2.1.2 CO_2 Corrosion

The major issues of corrosion at internal pipelines are corrosion that occurred because of carbon dioxide. Carbon dioxide systems are one of the most common environments in the oil field industry where corrosion occurs. Carbon dioxide forms a weak acid known as carbonic acid (H_2CO_3) in water, a relatively slow reaction. However, CO_2 corrosion rates are greater than the effect of carbonic acid alone. Cathodic depolarization may occur, and other attack mechanisms may also be at work.

Corrosion rates in a CO_2 system can reach very high levels (thousands of mils per year), but it can be effectively inhibited. Velocity effects are very important in the CO_2 system; turbulence is often a critical factor in pushing a sweet system into a corrosive regime. This is because it either prevents formation or removes a protective iron carbonate (siderite) scale. Conditions favoring the formation of the protective iron carbonate scale are elevated temperature, increased pH (bicarbonate waters) and lack of turbulence. Magnetite scales are also formed in CO_2 systems, and corrosion product scales often consist of layers or mixtures of siderite and magnetite.

The maximum concentration of dissolved CO_2 in water is 800 ppm. When CO_2 is present, the most common forms of corrosion include uniform corrosion, pitting corrosion, wormhole attack, galvanic ringworm corrosion, heat affected corrosion, mesa attack, raindrop corrosion, erosion corrosion, and corrosion fatigue. The presence of carbon dioxide usually means no H_2 embrittlement. CO_2 corrosion products include iron carbonate (siderite, $FeCO_3$), Iron oxide, and magnetite. Corrosion product colors may be green, tan, or brown to black.

Areas where CO_2 corrosion is most common include flowing wells, gas condensate wells, areas where water condenses, tanks filled with CO_2, saturated produced water and flowlines, which are generally corroded at a slower rate because of lower temperatures and pressures. CO_2 corrosion is enhanced in the presence of both oxygen and organic acids, which can act to dissolve iron carbonate scale and prevent further scaling.

There is an issue on the corroded pipelines had not internally inspected or cleaned by BP Oil in Alaska after at least 14 years operating. The pipelines regulated by the federal government are required to be inspected every five years. The problems start arose after discovery of 25,000 gallons crude oil spill. The results of the problems were almost 73 percent of pipelines need to be replaced since most of the pipelines were experienced 80 percent of wall thinning.

In order to avoid the major losses, lots of companies execute the corrosion prevention programs for the pipelines. The objective is to prolong the pipelines life span before replace them. The most popular program is by executing surface maintenance painting.

2.2 Coating Technology

The coating technology comprised of three aspects to be discussed. Firstly, the coating program to be implemented such as new surface painting or maintenance painting on the used equipment. Secondly, the coating application which is subjective to the type of surface to be applied either external or internal surface. Finally, the paint formulation to be used must match with the operating condition such as internal pipeline.

2.2.1 Maintenance Painting

Maintenance painting is accomplished as part of routine lifecycle maintenance for equipments. The process for repainting the equipments can be done in several ways either by partially or totally remove the previous existing painting and apply new coatings over a mixed substrate of existing paint, bare steel or rusted surface. The applied coatings generally involved the similar to previous paint but usually in practice, further improved types of coatings will be selected in order to have higher durability and longer the equipment life span.

Basically, maintenance painting involved three major steps of operation which are washing, mechanical surface preparation and overcoat system application. Washing is a cleaning process by using pressure washer or steam cleaner to remove dirt, soot, grease and other loose particle on the surface. Some type of washing steps need to be applied in all maintenance painting since it has significant effects to the performance life of applied coating system. The goal is to remove the contaminants but not the existing coating system since they will be removed by using next step, mechanical surface preparation. This operation done by using light hand tool cleaning with scrappers, wire brushes Vacuum shrouded power tools or vacuum blasting machines in order to remove all visible rust and loose paint. The level of cleaning specified is dependent upon the severity of the environment, the extent of paint failure and the degree of corrosion of the steel in the area of failed paint, the expected life of the applied maintenance system, and the budget for the operation. The goal of this step is to remove rust and non-adherent paint while leaving as much of the intact existing coating system as possible. The final step is the overcoating system application, where a new coating is applied onto the washed, blasted surface according to the specification required.

Usual method as mentioned above is done at the external surface. But, different methods have been invented for application maintenance painting at internal pipeline surface. This is due to the factor that pipelines are very lengthy and impossible to apply direct human force for executing maintenance painting. Pigging is the most popular method that has been invented in order to solve the issues on internal pipelines coating for maintenance painting.

2.2.2 Internal Pipelines Coating using Pigging Method

In order to coat the internal pipelines for maintenance painting, pigging methods are used. Pigging came from word pig which is pipeline inspection gauge. Basically, a pipeline inspection gauge in the pipeline industry is a tool, as shown in Figure 2.3(a) and Figure 2.3(b), that is sent down a pipeline and propelled by the pressure of the product in the pipeline itself. There are four main uses for pigs:

a. Physical separation between different liquids being transported in pipelines;
b. Internal cleaning and coating of pipelines;
c. Inspection of the condition of pipeline walls (also known as an Inline Inspection (ILI) tool);
d. Capturing and recording geometric information relating to pipelines (e.g. size, position).

Figure 2.3(a): A 24” dual diameter pig [6]

Figure 2.3(b): Various types of pigs [6]

One kind of pig is a soft, bullet shaped polyurethane foam plug that is forced through pipelines to separate products to reduce mixing. There are several types of pigs for cleaning. Some have tungsten studs or abrasive wire mesh on the outside to cut rust, scale, or paraffin deposits off the inside of the pipe. Others are plain plastic covered polyurethane. Pigs cannot be used in pipelines that have butterfly valves.

Inline inspection pigs use various methods for inspecting a pipeline. A sizing pig uses one (or more) notched round metal plates that are used as gauges. The notches allow different parts of the plate to bend when a bore restriction is encountered. More complex systems exist for inspecting various aspects of the pipeline. Intelligent pigs, also called smart pigs, are used to inspect the pipeline with sensors and record the data for later analysis.

In order to coat the internal pipelines using pigging method, the coating is loaded between two specially designed pigs. Using a pre-determined driving pressure, the correct velocity is maintained to provide a controlled film thickness. Usual specifications would require a minimum of three coating runs, with the coating train driven by completely dry and particulate free compressed air. After each coating run, the same compressed air continues to slightly blow through the pipeline to ensure total evacuation of the released solvents and aid in drying between coats. Realizing every pipeline is unique; analysis study must be prepared to meet the demands of varying wall thickness, valves, bends, and profiles in onshore or offshore pipelines.

In order to apply the internal coating in the pipelines using pigging method, a suitable paint formulation must be chose properly to fit the environment exist in the pipelines itself. The common type of internal coating is immersed paint if the painting is done initially before the pipeline installation or by using corrosion inhibitor since the application is cheaper than using painting during maintenance. For this project, the performance of rust stabilizer paint formulation for internal pipeline coating application is like to be tested rather than normal immersed paint or corrosion inhibitor.

2.2.3 Rust Stabilizers Paint

The technology is unique. Rust stabilizer paint combines two key processes to produce a high performance material with built-in protection. Glass flakes, within the coating, self-leaf to form a resistant finish against the environment, and an actively anti corrosion pigment stabilizes firmly adherent rust into magnetite, providing built-in protections by minimizing risk of sub-film corrosion as per shown in Figure 2.2.3(a). The rust stabilizer paint range of Reinforced Rust Stabilizers has been developed to counter corrosion in the most aggressive and demanding environments – for example, in areas with high levels of chemical contamination and even in underwater applications. Rust stabilizer paint is also approved by Lloyds Register as a corrosion control system for use in ballast tanks.

Rust stabilizer paint contains an active anti corrosion pigment that will react with red iron oxide on the steel substrate and stabilize it to form an inert oxide of iron called magnetite. Because it bonds onto the steel substrate, magnetite will not break or flake away and cause further corrosion. In addition, magnetite is stable, and so prevents blistering and sub-film corrosion should the external damage to the coating occur. Rust stabilizer paint protect in three ways:

a. Being designed to penetrate deeply into the firmly adhered corrosion, rust stabilizer paint forces out all the moisture and oxygen present within the rust strata that would otherwise act as a catalyst to future corrosion.
b. Rust stabilizer paint cure to form a hard, primed surface that is both durable and resistant to abrasion and chemical attack. This serves to protect the steel from moisture and oxygen or other contaminants, and also provides a based for over coating with decorative materials or with reinforced finishes designed to resist particular chemicals or that protect against mechanical and abrasive damage.
c. The unique pigment contained within the coating starts to react immediately on contact with the rust. This electro-chemical reaction stabilizes the rust into magnetite, an inert black iron oxide, to form an integral part of the metal substrate, and so give maximum protection. This is graphically explained in Figure 2.2.3(b).

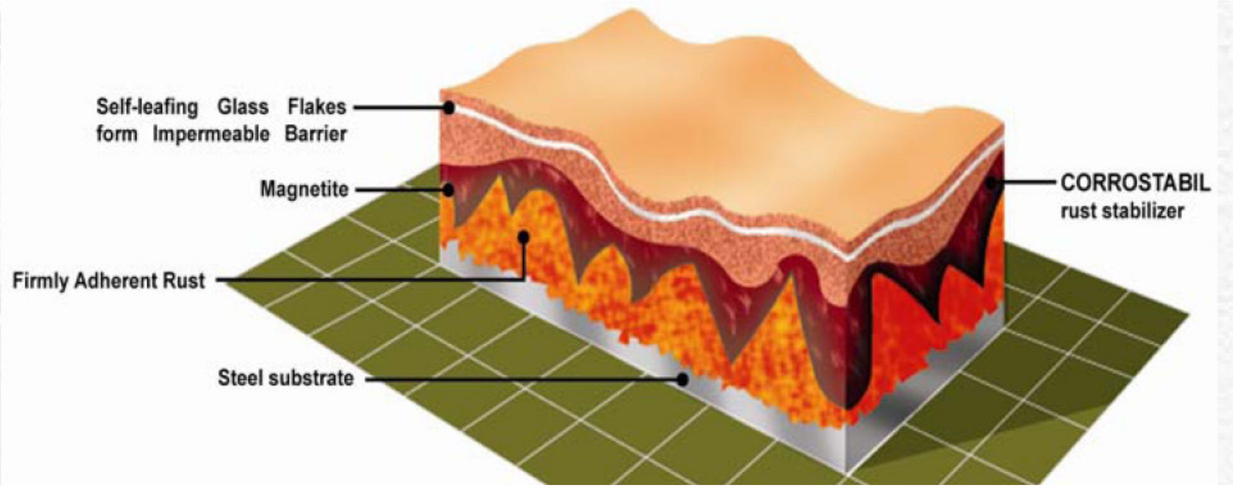


Figure 2.2.3(a): Layer formed after rust stabilizer paint applied onto rusted surface [2]

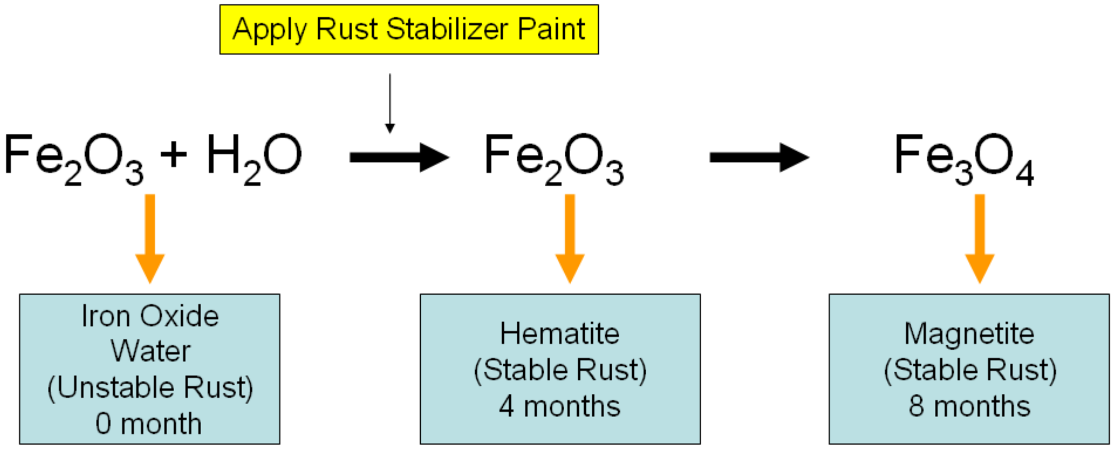


Figure 2.2.3(b): Steps on rust stabilizer paint transforms the rust into magnetite [2]

As per stated above, rust stabilizer paint is epoxy types of coating. Epoxy paints consist of two components that react with each other to form a hard, inert coating. First part typically consists of an epoxy resin with pigments and extenders and second part is the epoxy-curing agent, often called the hardener. This resin is the backbone to most anticorrosive coating systems. Typically the higher the molecular weight the higher the viscosity of the resin produced. These resins are thermosetting polymers and are used as high performance anticorrosive coatings and potting and encapsulating materials. These resins have excellent electrical properties, low shrinkage, good adhesion to many metals and resistance to moisture, thermal and mechanical shock. Epoxy paints are typically referred to as anticorrosive barrier coatings. The excellent adhesion of epoxies coatings is due to the strong polar bonds it forms with the surfaces when it comes in contact and cures on a surface. The cross-linking reaction of epoxies for the most part is independent of the surrounding environment except temperature.

What separates general purpose epoxy paints (and non-epoxy paints) for epoxy and non-epoxy floor paints, plain marine resins, or even water, is their thixotrophic properties. The term has to do with internal gelling of the paint. Thixotrophic additives, such as fumed silica, give the coating the ability to 'gel' after application. This means when applied to a vertical surface, such as a wall, the coating will be as thick at the top of the wall as it is at the bottom of the wall. Regular marine epoxy, floor paints/epoxies, and water, are non-thixotrophic and if applied to a wall would tend to flow or slump to the bottom of the wall, leaving very little of the coating near the top of the wall.

Epoxy paints are used for marine barrier coats, equipment coating, pipelines, tanks and sumps, wastewater applications, and others. The advantages of epoxy paints are that they can handle full time immersion, strong chemicals, and are very impermeable as well as tough. Many are solvent free so wet thickness will equal dry thickness (cracks will not reappear as the epoxy cures) and they are nearly odorless [12] [13]. Some can even be applied underwater. Study on the effect of water immersion will increase the strength of epoxy paint have been made [14] [15]. The disadvantages of epoxies are that they tend to be brittle, quickly yellow in sunlight (white becomes a creamy color, light blue becomes light green, etc.) and lose their shine in sunlight. The yellowing and loss of gloss (even chalking in some cases) is due to the affect of UV on ALL epoxies (some epoxies will yellow in days, others take weeks but they all do eventually).

The application of rust stabilizer paint have been successfully applied for external surface which including sweating pipeline. But for the internal surface, there is still no application are done in field.

The application of rust stabilizer paint for internal pipeline coating must be tested to prove the paint performance. The tests to be carried out must be simulated under the external condition (as datum) and also internal condition (in pipeline). This is to ensure the paint is able to meet the requirement according to the internal pipelines condition before approved it in industrial application.

2.3 Paint Performance Evaluation

The paint formulation that produced from the suppliers must be test before field application since there are various types of conditions must be met to match the suitability paint performance with the operating condition.

The most frequent test done to evaluate paint formulation is adhesion test [16]. For coatings to perform satisfactorily, they must adhere to the substrates on which they are applied. A variety of recognized methods can be used to determine how well a coating is bonded to the substrate. Commonly used measuring techniques are performed with a knife or with a pull-off adhesion tester. After any test it is important to record if the bond failure was adhesive (failure at the coating / substrate interface) or cohesive (failure within the coating film or the substrate).

2.3.1 Test Methods to Evaluate Adhesion by Knife (ASTM D6677)

This simple test requires the use of a utility knife to pick at the coating. It establishes whether the adhesion of a coating to a substrate or to another coating (in multi-coat systems) is at a generally adequate level. Performance is based on both the degree of difficulty to remove the coating from the substrate and the size of removed coating.

Using the knife and cutting guide, two cuts are made into the coating with a 30 – 45 degree angle between legs and down to the substrate which intersects to form an “X”. At the vertex, the point of the knife is used to attempt to lift up the coating from the substrate or from the coating below.

This is a highly subjective test and its value depends upon the inspector’s experience. A coating which has a high degree of cohesive strength may appear to have worse adhesion than one which is brittle and hence fractures easily when probed. There is no known correlation to other adhesion test methods (pull-off, tape, etc.).

2.3.2 Test Methods to Evaluate Adhesion by Tape (ASTM D3359)

On metal substrates, a more formal version of the knife test is the tape test. Pressure sensitive tape is applied and removed over cuts made in the coating. There are two variants of this test; the X-cut tape test and the cross hatch tape test.

The X-cut tape test is primarily intended for use at job sites. Using a sharp razor blade, scalpel, knife or other cutting device, two cuts are made into the coating with a 30 – 45 degree angle between legs and down to the substrate which intersects to form an “X”. A steel or other hard metal straightedge is used to ensure straight cuts. Tape is placed on the center of the intersection of the cuts and then removed rapidly. The X-cut area is then inspected for removal of coating from the substrate or previous coating and rated.

The cross hatch tape test is primarily intended for use in the laboratory on coatings less than 5 mils (125 microns) thick. It uses a cross-hatch pattern rather than the X pattern. A cutting guide or a special cross-hatch cutter with multiple preset blades is needed to make sure the incisions are properly spaced and parallel. After the tape has been applied and pulled off, the cut area is then inspected and rated.

2.3.3 Pull-off Adhesion using Portable Adhesion Tester (ASTM D4541)

A more quantitative test for adhesion is the pull-off test where a loading fixture, commonly called a dolly or stub, is affixed by an adhesive to a coating. By use of a portable pull-off adhesion tester, a load is increasingly applied to the surface until the dolly is pulled off. The force required to pull the dolly off or the force the dolly withstood, yields the tensile strength in pounds per square inch (psi) or mega Pascals (MPa). Failure will occur along the weakest plane within the system comprised of the dolly, adhesive, coating system, and substrate, and will be exposed by the fracture surface.

This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scrape or knife adhesion, and results may not be comparable. Further, pull-off strength measurements depend upon the instrument used in the test. Results obtained using different devices or results for the same coatings on substrates having different stiffness may not be comparable.

Testers operate using either mechanical (twist by hand), hydraulic (oil) or pneumatic (air) pressure. They are classified as being fixed aligned or self aligning depending upon their ability to ensure a vertical pull-off force. Best repeatability is obtained when the pull-off force acts perpendicular to the surface being tested.

The availability of a full range of pull off adhesion tester models facilitates the measurement of coating adhesion on almost any rigid substrate. For example, 20 mm dollies may be ideal for typical coating bond strengths on metal, plastic and wood, where as 50 mm dollies are more ideal for coatings on masonry substrates such as concrete. Many manufacturers also offer custom dolly sizes to address special measurement needs. For example, decreasing the dolly size from 20 mm to 10 mm, increases the pull off range of the gage by 4 times, allowing some manufacturers to accurately measure bond strengths over 12,000 psi. Keeping the dollies inexpensive eliminates the need for reusing dollies, greatly simplifying the preparation process, with an additional benefit of allowing physical samples to be maintained for future reference or evidence of pull off test results.

During paint trials, the adhesion of the primer coat to the steel surface, and the intercoat adhesion between subsequent coats shall be quantified by the “pull-off” test. The glassflake polyester paints shall have a minimum “pull-off” value of 34.5 bars g (500 psi). All other paints shall at least attain 13.8 bars g (200 psi) in order to meet the test requirement. Other than minimum pressure to pull-off the dollies, there is another parameter need to be examined which is failure modes as shown in Figure 3.4.1(b). The pulled out dollies have three types of failure modes which are:

a. Adhesion – failure between both paints layer
b. Cohesion – failure between paint and metal surface
c. Glue – failure between glued layers

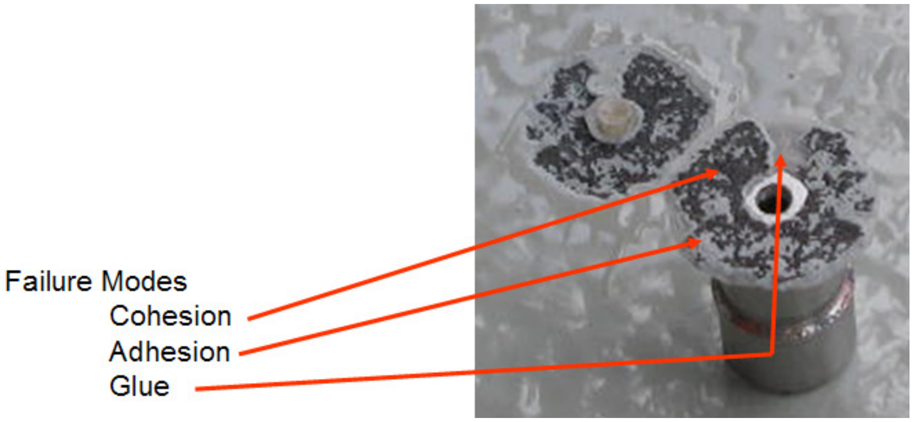


Figure 2.3.3: Failure modes result of paint adhesion test [16]

Any test where the glue failure represents more than 50% of the area, the test may disregard. If a pass or fail criterion is being used and a glue failure occurs at a pull-off strength greater than the criterion, report the result as “pass with a pull-off strength …(value obtained)”

2.3.4 Standard Tests of Organic Coating using Scrape (ASTM D2197)

This test is typically performed in a laboratory and is limited to testing on smooth, flat panel surfaces. Adhesion is determined by pushing the coated panels beneath a rounded stylus or loop that is loaded in increasing amounts until the coating is removed from the substrate surface. A device called a balanced-beam scrape-adhesion tester is used.

2.3.5 Taber Abrasion Test (ASTM D4060)

Test method ASTM D4060 covers the determination of the resistance of coatings to abrasion produced by the Taber Abraser on coatings applied to a plane, rigid surface, such as a metal panel. Abrasive wear can occurred due to hard particles or hard protuberances forced against and moving along a solid surface. The coating to be tested is applied at uniform thickness to a plane, rigid panel and, after curing, the surface is abraded by rotating the panel under weighted, abrasive wheels. ASTM D4060 has been useful in evaluating the abrasion resistance of attached coatings. Abrasion resistance can be calculated as loss in weight at a specified number of abrasion cycles, as loss in weight per cycle, or as number of cycles required to remove a unit amount of coating thickness.

2.3.6 Immersion Test (ASTM D870) [5]

The procedure of using the immersion test is followed exactly from water immersion test according to ASTM D870. There are slightly modification made and the difference is just the medium used are plain water and hydrocarbon solution. Since the coating used for this project is epoxy type, there are two types of effect due to immersion in water can be observed. The first one is the rate and degree of absorption and blistering onto the surface coating after a few period of immersion. Secondly, the water immersion can influence both curing rate and degree of cure of the curing reaction of the epoxy coating. A paint system was applied to various substrate materials and immersed for varying periods of time in the medium. The rate and degree of absorption and blistering were determined by extensive measurements of weight, volume changes and by visual examination. Regardless of the nature of the substrate and immersion bath, the absorption and blistering increased with increasing immersion time but decreased markedly with increasing osmotic pressure of bath.

Factual evidence developed establishes that the medium is transferred through the face of the paint film under the influence of, and at a rate determined by the difference in osmotic pressure of the bath solution and of the solution formed within the paint system by the medium absorbed. If osmotic pressure of the external solution is high enough, blistering does not take place. The minimum osmotic pressure of the external solution required to prevent blistering varies with the nature of the substrate, and is suggested as a basis for measuring the adhesion level of the test coating for the substrate material. Some evidence is presented which indicates that the absorption does not take place by way of pores but by a process related to actual solution.

The current industrial acceptance level for immersion test for any painting product is 4000 hours of immersion without defect

2.3.7 Salt Spray Test (ASTM B117)

The purpose of an accelerated corrosion test is to duplicate in the laboratory the field corrosion performance of a product. This provides scientists and engineers with a means of quickly developing new products. For many years the salt spray test has been used extensively for this purpose by researchers in the evaluation of new metallic coatings, new paint coatings, as well as testing miscellaneous types of chemical treatments and paint pretreatments for use with metallic-coated steel sheet products. For an accelerated corrosion test to be truly useful, a prime requirement is that the results correlate with performance in the real world, something that has never been demonstrated with the salt spray test. This has lead many researchers to conclude that the test has no relevance, and should be discontinued. However, the results of salt spray testing are extensively used in product literature, customer specifications, product data sheets, as well as the technical literature. Typical data gives the "life" of a given type of coating, the benefits of new paint systems, the salt spray requirements for the acceptance by an end customer of an alternative product, etc., so it seems virtually impossible to stop using the salt spray test at this time. In fact, there are so many specifications in use today that require a product to exhibit a *specified number of "hours to failure" in the salt spray test,* that any change to the test or its elimination is improbable. Clearly, any push to eliminate it would require that alternate accelerated corrosion tests be accepted by architects, specification writers, etc. Simply put, the corrosion performance of different products has been compared using this test for so long that it would be difficult for today's researchers to not have salt spray test results when they are presenting performance data on a new product to a potential end user. That's how commonly accepted the test and its data is by the end-user community. Also, salt spray testing, while severe, is a good screening test because results can be generated in a timely manner and "poor contenders" can perhaps be eliminated early on in the evaluation process.

Through the years, various challenges to the applicability of salt spray test data have been made. Clearly, many field applications do not involve exposure to salt chemicals, and rarely at a concentration level of 5%. How meaningful, therefore, can salt fog data be? For example, galvanized steel experiences a higher rate of corrosion in sulphide atmospheres compared to sulphide-free atmospheres, and corrosion reactions will not be the same in a chloride atmosphere as in a sulphide atmosphere, so salt spray test results would not be expected to correlate with outdoor performance in sulphide environments. Also, manufacturers do not recommend the use of coated steel sheets for applications that involve continuous exposure to moisture (as occurs in the salt spray test). In fact, the good performance of zinc based coatings on steel requires drying between periods of wetness, and the need for these wet/dry cycles is generally well known. It is the development of a passive and relatively stable oxide and/or carbonate film during the drying cycle that contributes to the good performance of galvanized coatings. The continual wetness during the salt spray test does not allow this passive oxide/carbonate layer to develop. When painted material is evaluated using the salt spray test, there is no exposure to ultraviolet light, a common cause of deterioration for paints and primers. This is a serious omission, since the failure mechanisms that eventually cause painted steel sheet to deteriorate are typically not included as conditions in the salt spray test. There are other vagaries that often show up in the salt spray test. For example, sample-to-sample variability for supposedly identical samples has been large. Also, test data gathered in two different cabinets, even though they are identical in design and operated as recommended, have shown a high amount of variance. There are many reasons for the salt spray test not correlating with most real world exposure conditions. Three of the most significant are:

- The surface of the test coupons are constantly wet, with no cyclic drying, which does not happen in the field.
- The test chamber temperature is at a constant elevated 95°F, which increases water, oxygen and ion transport compared to the field.
- The chloride content is very high at 5%, preventing zinc from forming a passive film as it does in the field.

2.3.8 Test method for Conducting Exterior Exposure Tests of Paints on Steel (ASTM D1014) [17]

Weather testing of polymers is the controlled polymer degradation and polymer coating degradation under lab or natural conditions. Just like erosion of rocks, natural phenomena can cause degradation in polymer systems. The elements of most concern to polymers are Ultraviolet radiation, moisture and humidity, high temperatures and temperature fluctuations. Polymers are used in every day life, so it is important for scientists and polymer produces to understand durability and expected lifespan of polymer products. Paint, a common polymer coating, is used to change the color, change the reflectance (gloss), as well as forming a protective coating. The structure of paint consists of pigments in a matrix of resin. A typical example is painted steel roofing and walling products, which are constantly exposed to harmful weathering conditions.

Color is determined by light-reflecting chemical particles, pigments, in the paint. These particles can have very different physical sizes, as shown in the diagram in Figure 2.3.8. In this example, the black pigments are the small black dots; red pigments are larger spheres, while the yellow pigments are acicular. This combination of pigments produces the original brown color. The upper diagram has had no weathering, and the surface is still smooth and undamaged. The lower diagram shows the painted surface after weathering has occurred. The surface has eroded with significant loss of the black and red pigments from the surface layer. The pitted surface scatters light, therefore reducing the gloss and creating the chalky affect. The larger acicular yellow pigments are more difficult to remove, resulting in a color change towards a more yellowy appearance. Weather testing was paramount is discovering this mechanism. Pigment composition has recently been modified to help minimize this effect.

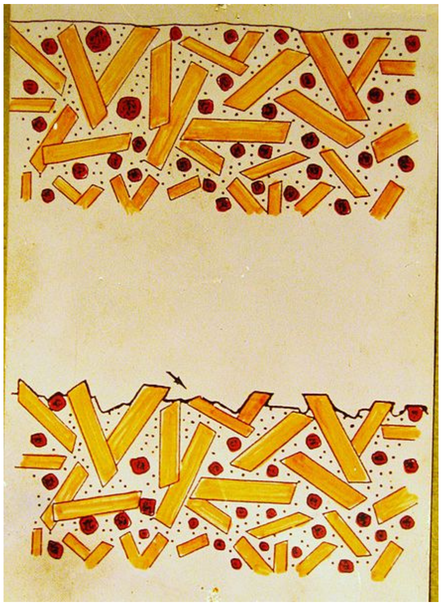


Figure 2.3.8: Diagram showing paint pigments in a resin matrix. It can be seen that weathering only removes the smaller pigments, resulting in the color change [17]

There are 3 main testing techniques; natural weathering, accelerated natural weathering and artificial weathering. Because natural weathering can be a slow process, each of the techniques is a tradeoff between realistic weathering results and the duration of testing before results are collated.

The chosen paint performance testing to be carried out for this project is stated below;

- Pull-off Adhesion Test (ASTM D4541)
- Taber-Abrasion Test (ASTM D4060)
- Immersion Test (ASTM D870)
- Salt Spray Test (ASTM B117)

CHAPTER 3
METHODOLOGY / PROJECT WORK

Practical experiments is further divided into few sub-phases which are test panels preparation, surface preparation, painting application, painting performance test and corrosion test. The detail of the flow project work can be seen in Figure 3.0;

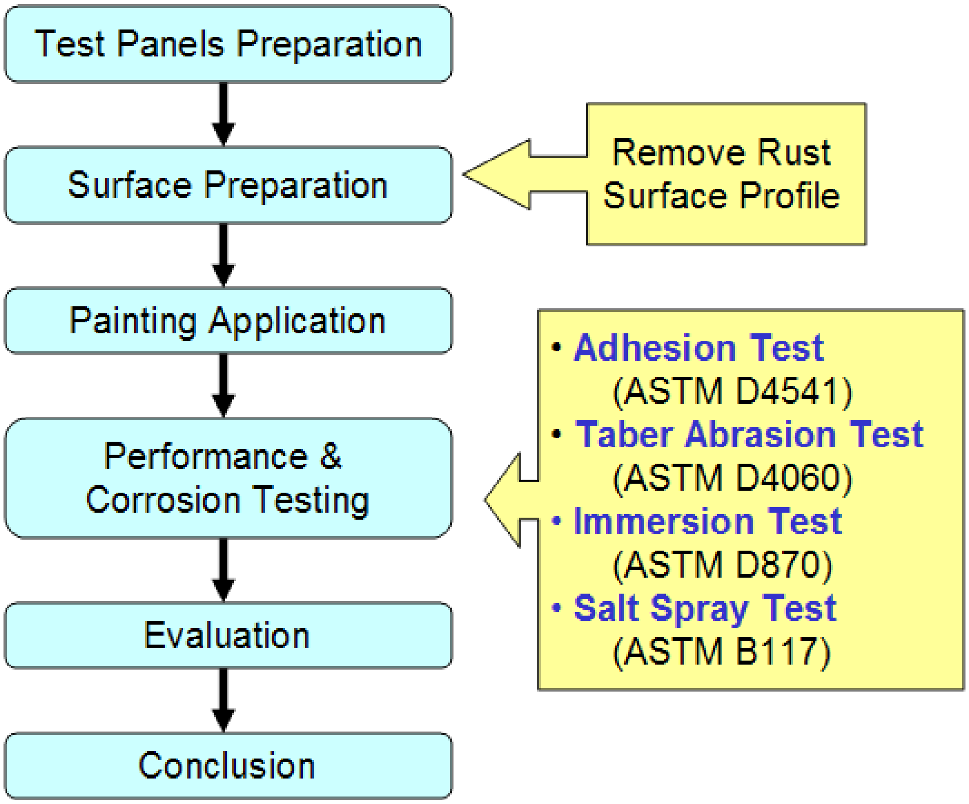


Figure 3.0: Methodology flow process

3.1 Test Panels Preparation

Nine corroded mild steel test panels with dimension of 10 cm x 10 cm were prepared for the adhesion, abrasion, immersion and salt spray. Two paint tablets were prepared for immersion test.

3.2 Surface Preparation

a. The test panels surface were cleaned using water soluble degreaser, followed by fresh water and allow to dry to remove any obvious dirt, salt, chemical or grease contamination
b. Manual cleaning onto the test panels' surface by using standard sand papers were applied until all scales were removed in accordance of ST3 standard of EN ISO 8501-1:1988
c. The new surface then were cleaned using fresh water and allowed to dry
d. The new surface profiles of the manually cleaned surface were measured to find the average roughness. The average surface roughness as shown in Figure 3.2;

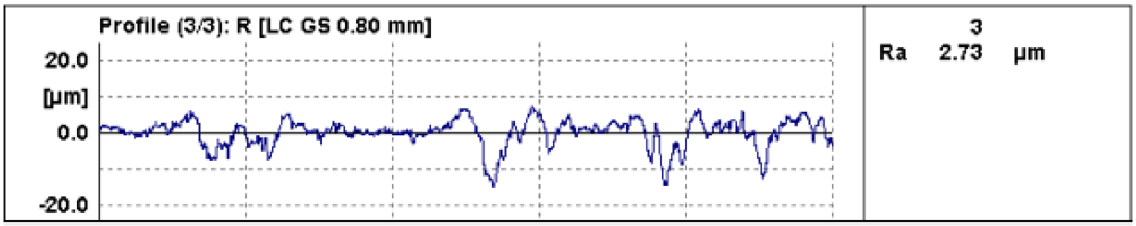


Figure 3.2: Test panel surface profile after surface preparation

The surface profiles are measured by using surface profiling with the sensitivity up to 250 µm and measured 4 mm in length. From figure above, the average surface profile is 2.73 µm, which is categorized as low. The lower the surface average roughness means lesser effective of surface profile to the paint bonding. This is due to the lack of surface preparation because the rust removing procedure was done by using normal sand paper. In order to get a good surface profile, normal average profile height shall be 35 to 65 µm. Good surface profile in current industrial condition can be obtained by using garnet blasting. The low quality of surface profile will affect the bonding between paint layer and the surface metal. This will lead to the poor performance of paint for pull-off adhesion test.

3.3 Painting Application

a. The paint CORROSTABIL E1-BASE and CORROSTABIL E HARDENER from Applied Corrosion Engineering Services (ACES) Sdn. Bhd. was mixed separately at medium speed in about 5 minutes until well mixed
b. By measuring weight 4:1 (base to hardener), both of the solutions were mixed together about 5 minutes in different container until well mixed.
c. By using brush, the paint was applied onto the test panels' surface for first layer
d. For overcoating, the next layer of paint must be applied within 10 hours to 3 days after the first layer was applied.
e. All painted test panels are let dried at the room temperature for at least three days before proceed for paint performance testing.
f. Dry Film Thickness (DFT) calibration was taken for every test panels after drying period had ended.

3.4 Paint Performance and Corrosion Test

In order to measure the paint effectiveness, testing must be done according to ASTM specification. There are three performance test (adhesion, abrasion and immersion) and one corrosion test (salt spray) were carried out for performance evaluation.

3.4.1 Pull-off Adhesion Test (ASTM D4541)

This test method covers a procedure for evaluating the pull-off strength (commonly referred to as adhesion) of a coating on rigid substrates such as metal by using portable adhesion tester as shown in Figure 3.4.1(a). This test determines either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force (pass or fail). This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scratch or knife adhesion, and result may not be comparable. This test can be destructive and spot repairs may be necessary to cover up the involved spots.

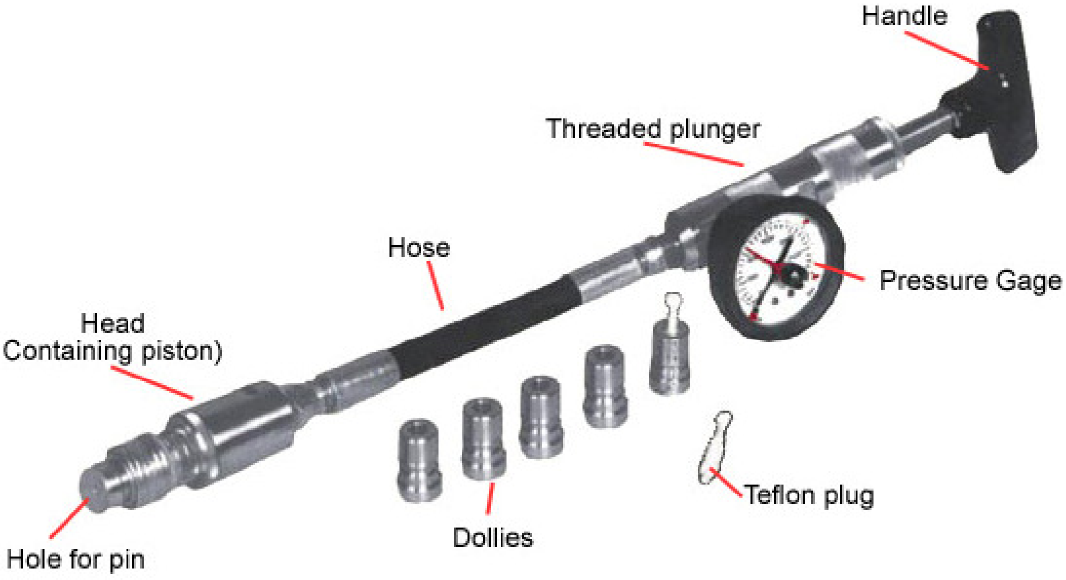


Figure 3.4.1: Portable adhesion tester [10]

A more quantitative test for adhesion is the pull-off test where a loading fixture, commonly called a dolly or stub, is affixed by an adhesive to a coating. By use of a portable pull-off adhesion tester, a load is increasingly applied to the surface until the dolly is pulled off. The force required pulling the dolly off or the force the dolly withstood yields the tensile strength in pounds per square inch (psi) or mega Pascals (MPa). Failure will occur along the weakest plane within the system comprised of the dolly, adhesive, coating system, and substrate, and will be exposed by the fracture surface.

<u>Testing Procedure</u>

a. Three painted test panels were prepared to be glued with the dollies onto the painted surface by using adhesive glue.
b. The glued dollies were then let dried in about 3 days.
c. A portable pull-off adhesion tester is attached to the dolly glued onto the paint
d. Initial reading of the adhesion tester was to be ensured to be at 0 kPa.
e. The tester were applied a little increment of pressure until the dolly was pulled out from the painted surface due to failure
f. The minimum pressure to pull out the dolly is recorded in provided table.

g. The surface of attached dollies were observed and the percentage of failure modes either adhesion, cohesion and glue failure, were analyzed and recorded in the provided table.
h. The same test procedures then were repeated by testing two more test panels to obtain more precise results.
i. All results were recorded in the provided table for evaluation.

3.4.2 Taber-Abrasion Test (ASTM D4060)

Testing Procedure

a. Three painted test panels were prepared for Taber abrasion testing
b. The original weight of each test panels was recorded.
c. The coating thickness of the test panels were measured in several locations along the path to be abraded.
d. The first test panel was mounted on the turntable. The abrasion heads was placed on the test film. The vacuum pick-up nozzle was placed in position and adjusted to a distance of 1/32 inches (1 mm) above the abrasive disk.
e. The load of 500 gram was applied through the abrasive disk to the test panel.
f. The counter was set to “zero” and the suction regulator was set to approximately 50 points on the dial.
g. The vacuum pick-up was started and then the turn table of abrader.
h. The test panel was subjected to abrasion for the 500 of cycle numbers.
i. Any loose abrading remaining was removed by light brush and the final weight of test panel is recorded and pattern is analyzed.
j. Step (d) to (i) was repeated by using same test panel for 1000 and 1500 cycles.
k. Step (d) to (j) was repeated by testing two more test panels but by modify the step (e) by using load of 1000 g and 2000 g for each test panel respectively.
l. The wear index and weight loss for all test panels were recorded and analyzed.

3.4.3 Immersion Test (ASTM D870)

Testing Procedure

a. Two containers were filled with water and petrol respectively.
b. Two test panels and two paint tablet are prepared for immersion test
c. Initial weight and visual inspection for each test panels and paint tablets are recorded
d. One test panel and one paint tablet was tested in each medium.
e. The test panels and paint tablets are need to be fully immersed in the medium for optimum effect
f. The specimens are repositioned on a regular basis so that all specimens spend equivalent amounts of time in the various areas of the apparatus(front, back, left, right, center)
g. The medium were replaced if it becomes cloudy or colored. Continuous replacement of the medium is permitted. If needed, add water to maintain original medium level.
h. The specimens were wipe dry and the evaluation must be done no less than 5 minutes and no more than 10 minutes after removal from the test medium as the effect from the medium exposure can change within a short time.
i. All of samples are weighed in weekly basis until third weeks or 500 hours immersion.
j. The test panels were evaluated in term of weight difference, level of blistering, rust existence, adhesion and physical appearance (color etc)
k. All the results are recorded in the table.

3.4.4 Salt Spray Test (ASTM B117)

The purpose of an accelerated corrosion test is to duplicate in the laboratory the field corrosion performance of a product. Salt spray testing under ASTM B117 conditions subjects the test samples to conditions that are actually more corrosive than usual “real world” exposure. This is because the test uses sodium chloride in de-ionized water and usually lacks the moderating effects of other dissolved salts such as those containing calcium and magnesium, which tend to be protective. Salt spray testing is the most popular form of testing for protective coatings. These tests have been used as accelerated tests in order to determine the degree of protection afforded by both inorganic and organic coatings on a metallic substrate.

The neutral salt spray (fog) test is perhaps the most commonly used salt spray test in existence for testing inorganic and organic coatings, in particular where such tests are used for material or product specifications. The duration of the test can range from 8 to over 3000 hours, depending on the product. A 5% sodium chloride solution containing not more than 200 parts per million (ppm) total solids and with a pH range of 6.5 to 7.2 is used. The temperature of the salt spray chamber is controlled to maintain 35 + 1.1 or – 1.7Þ C (95 + 2 or -3Þ F) within the exposure zone of the closed chamber. The current industrial acceptance level for salt spray test for any painting product is 2000 hours of salt spray condition without defect

Testing Procedure

a. Three painted test panels were prepared for salt spray test
b. All test panels were measured the initial weight before testing
c. The test panels were placed in the salt fog chamber
d. The salt, NaCl, was mixed with tap water with ratio of 5% of NaCl to water.
e. The salt solution was mixed with humidified compressed air at nozzles
f. The compressed air atomizes NaCl solution into a fog at the nozzles
g. The temperature is maintained at 37.7°C by heater.
h. The test duration are set to one week
i. The percentage of rusted surface were estimated and recorded

CHAPTER 4
RESULT AND DISCUSSION

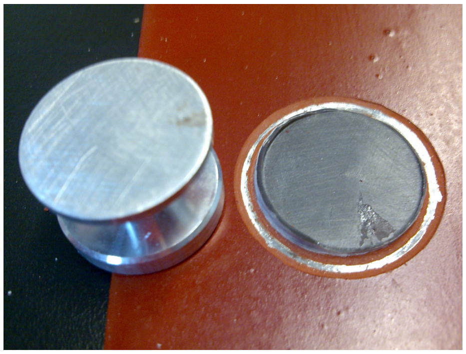
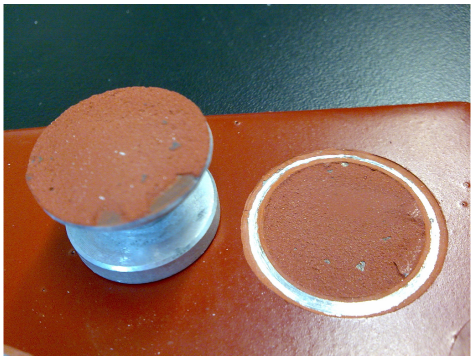
4.1 Pull-off Adhesion Test Results (ASTM D4541)

The results of the pull-off adhesion test obtained based on ASTM D4541 are presented in the Table 4.1

Table 4.1: Pull-off adhesion test result

Dolly Position	DFT (microns)	Acceptance Criteria (Psi)	Strength (Psi)	Failure Modes
1	300	200	900	0 % Adhesive Failure 0 % Cohesive Failure 100 % Glue Failure
2	300		1250	0 % Adhesive Failure 100 % Cohesive Failure 0 % Glue Failure
3	300		750	0 % Adhesive Failure 0 % Cohesive Failure 100 % Glue Failure

From Table 4.1, there are two types of discussion can be done which is the minimum strength needed to pull out the dollies from test panels and the failure modes exist on the detached surface between dollies and coating after the pull-off test have been made. Figure 4.1(b) shows that the adhesion tester took about 900 psi to remove the first position dolly from the paint surface. Figure 4.1(c) shows the failure mode occur that cause the dolly to detached from the paint surface which is due to 100% glue failure. Figure 4.1(d) shows that the adhesion tester took about 1250 psi to remove the second position dolly from the paint surface. Figure 4.1(e) shows the failure mode occur that cause the dolly to detached from the paint surface which is due to 100% cohesive failure. Figure 4.1(f) shows that the adhesion tester took about 750 psi to remove the third position dolly from the paint surface. Figure 4.1(g) shows the failure mode occur that cause the dolly to detached from the paint surface which is due to 100% glue failure.

Position	Pressure Reading	Failure Modes
1	 Figure 4.1(b): Pull-off pressure of 900 psi	 Figure 4.1(c): 100% glue failure mode
2	 Figure 4.1(d): Pull-off pressure of 1250 psi	 Figure 4.1(e): 100% cohesive failure mode
3	 Figure 4.1(f): Pull-off pressure of 750 psi	 Figure 4.1(g): 100% glue failure mode

All the dollies were pulled out at the average pressure of 967 psi which is higher than 200 psi as per acceptance criteria used in the oil and gas industries application. This concludes that the test results are acceptable. The higher the pressure to pull out the dollies from coated surface, the higher the strength of the coating is.

By relating the surface profile for the test, which is range around 1 to 2 microns, the pull-off result produced is acceptable, above 200 psi. By using blasting, the expected surface profile will be around 35 to 65 microns. The pull-off adhesion test results should be higher due to higher grip between paint and metal surface. By doing pull-off adhesion testing, the rust stabilizer paint strength value between paint layer and metal surface is approved to be acceptable. The paint with lower value of strength will result in lower performance and lead to painting failure in very no time if the maintenance painting still executed by using the paint with low strength. Therefore, rust stabilizer paint is surpassed the minimum industrial requirement which is 200 psi and technically able to be applied in maintenance painting.

4.2 Taber Abrasion Test Results (ASTM D4060)

The results of the Taber abrasion test obtained based on ASTM D4060 are presented in the Table 4.2(a) for 500 cycles, Table 4.2(b) for 1000 cycles and Table 4.2(c) for 1500 cycles.

Table 4.2(a): Taber abrasion test results for 500 cycles

Test sample	Load applied (g)	Initial weight (g)	After 500 cycles		
			Weight (g)	Weight loss (g)	Wear index (g/rev)
1	500	88.8480	88.8200	0.0280	5.60×10^{-5}
2	1000	82.8086	82.7765	0.0321	6.42×10^{-5}
3	2000	85.4997	85.4457	0.0540	10.8×10^{-5}

Table 4.2(b): Taber abrasion test results for 1000 cycles

Test sample	Load applied (g)	Initial weight (g)	After 1000 cycles		
			Weight (g)	Weight loss (g)	Wear index (g/rev)
1	500	88.8480	88.7969	0.0511	5.11×10^{-5}
2	1000	82.8086	82.7358	0.0728	7.28×10^{-5}
3	2000	85.4997	85.4033	0.0964	9.65×10^{-5}

Table 4.2(c): Taber abrasion test results for 1500 cycles

Test sample	Load applied (g)	Initial weight (g)	After 1500 cycles		
			Weight (g)	Weight loss (g)	Wear index (g/rev)
1	500	88.8480	88.7737	0.0743	4.95×10^{-5}
2	1000	82.8086	82.7110	0.0976	6.51×10^{-5}
3	2000	85.4997	85.3600	0.1397	9.31×10^{-5}

Figure 4.2(a) shows the results of weight difference for three test panels after Taber abrasion test. Test Panel 1 initially weighed 88.848 g after being painted about 1 week before doing Taber abrasion test. The test was carried out using 500 g loads with 500, 1000 and 1500 revolutions. The Test Panel 1 recorded 88.82 g after 500 revolutions, which was 0.028 g or 0.03% weight loss. For 1000 revolutions, the final weight resulted in 88.7969 g, which was 0.0511 g or 0.06% weight loss. For 1500 revolutions, the final weight was recorded 88.7737 g, which is 0.0743 g or 0.08% weight loss. For the Test Panel 2, which using 1000g loads, the weight loss recorded 0.04% for 500

revolutions, 0.09% for 1000 revolutions and 0.11% for 1500 revolutions. For Test Panel 3, which using 2000 g loads, the weight loss recorded 0.06% for 500 revolutions, 0.11% for 1000 revolutions and 0.16% for 1500 revolutions. The above result shows 2 significant effect of abrasion test on test panels. Firstly, as the loads applied on test panels increased, the weight loss will also increase. Secondly, as the cycle applied on test panels increased, the weight loss will also increase. For this experiment, weight loss recorded is less than 0.2% when applied at 2000g loads for 1500 cycles, which is proved that the rust stabilizer paint has low weight loss to the abrasion force.

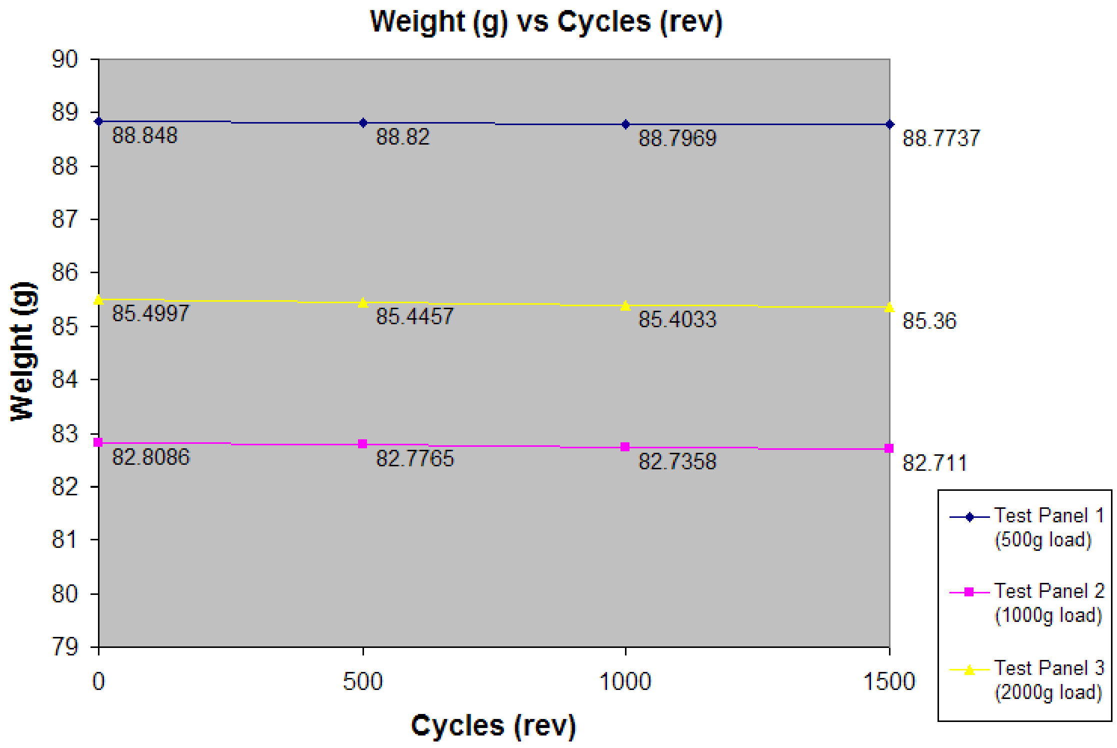


Figure 4.2(a): Graph of test panels' weight versus cycles applied

Figure 4.2(b) show the graph of weight loss amount versus cycles. The presentation of result is to highlight the amount of weight loss for each test panel as the revolution number is increased. The amount of weight loss is result from subtracting initial weight to the final weight. The data of weight loss amount is important to determine the next parameter, which is wear index. Wear index can be achieved by dividing weight loss with the number of cycles. The result of weight loss is greatly affecting the wear index. The higher the weight loss will result in higher the wear index.

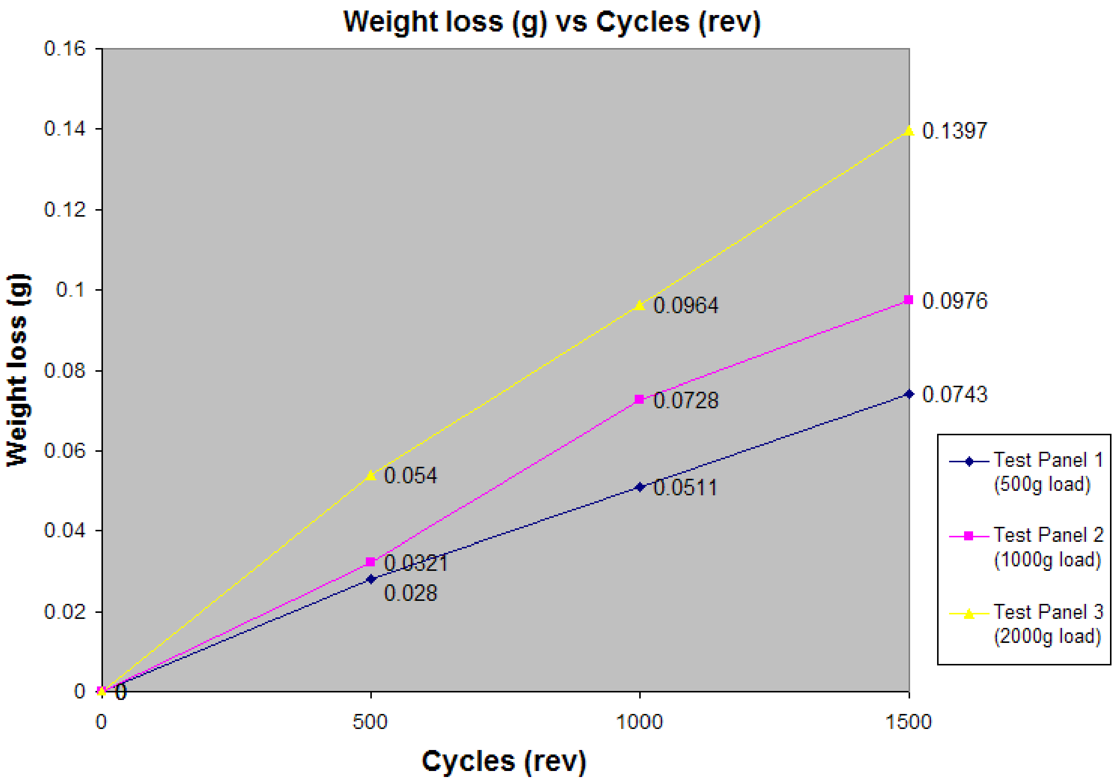


Figure 4.2(b): Graph of test panels' weight loss versus cycles applied

From the Figure 4.2(c), the wear indexes were plot against the number of cycles. Initially, there are great significant of wear index at the first 500 cycles for each test panels. This is due to the soft layer formed at the outermost of paint layer which can easily wear. The soft layer is result due to excessive amount of solvent contains in the paint and it will release to the upper layer during curing period.

For the next 500 cycles, which result in 1000 cycles accumulated, the test panel 1 (with 500g load) and test panel 3 (with 2000g load) show decreasing pattern. This is because there are no more soft layer paint left after the first 500 cycles test. But, it is different for the test panel 2 (with 1000g load). The pattern still show increasing pattern since there is possibility that the test panel has thicker paint layer compared to test panel 1 and test panel 2.

For the final 500 cycles, which result in 1500 cycles accumulated, all test panels show decreasing pattern for wear index. This mean the abrasion testing is done at the paint strongest layer and these proved by the lower wear index achieved when compared to the previous two 500 cycles test before.

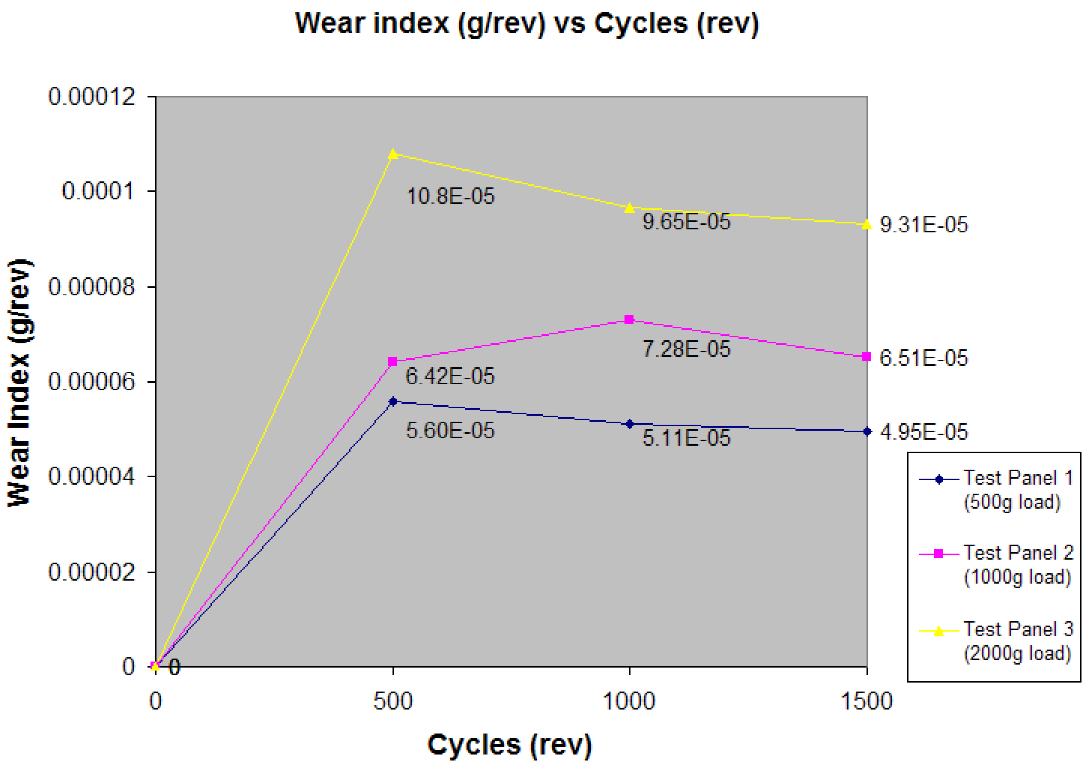


Figure 4.2(c): Graph of test panels' wear index versus cycles applied

By comparing the result with nowadays industrial paint application which is the wear index around 6 x 10^{-5} g/rev, the result of the experiments can be considered as acceptable. Therefore, the assumption of the lower the weight loss and wear index of the paint from abrasion test means the paint has high abrasive resistant that will lead to the better the paint performance to the abrasive resistance.

The two purpose of doing Taber abrasion test are to measure the weight loss and wear index is very important as one of consideration in executing maintenance painting. The paint to choose for maintenance painting must have low weight loss and wear index.

The lower weight loss and wear index indicates the lower the painting erosion rate and lead to the higher life cycle of the paint before next maintenance painting. The higher the value of weight loss and wear index of the paint will lead to higher frequency of maintenance painting. The higher the number of maintenance painting will result in higher cost. Therefore, using rust stabilizer paint that have very low value of weight loss and wear index is recommended for maintenance painting.

4.3 Immersion Test (ASTM D870)

The results of the immersion test obtained based on ASTM D870 are presented in the Table 4.3(a) for water immersion result and Table 4.3(b) for petrol immersion result.

Table 4.3(a): Water immersion test results

Samples	Weight (g)				Visual Inspection
	Initial	After 1 week	After 2 week	After 3 week	
Test Panel 1	81.1774	81.2425	81.2876	81.3475	No defect
Paint Tablet 1	25.8672	24.7106	25.2564	25.7273	No defect

The test panel that immersed in water shows in Table 4.3(a) that there is a little water absorption starting first week until third week of immersion. It is 0.08% in weight increased of the test panel in the first week. This followed by 0.13% and 0.21% weight increased for the second and third week respectively. The paint tablet weight's reduces 4.5% on the first week and gained weight 2.2% and 1.8% on second and third week respectively. There is no significant defect found on the coating surface due to blister, color change and rust existence.

Table 4.3(b): Petrol immersion test results

Samples	Weight (g)				Visual Inspection
	Initial	After 1 week	After 2 week	After 3 week	
Test Panel 2	83.4134	83.8262	83.9365	84.1488	No defect
Paint Tablet 2	18.3044	17.9658	18.0014	18.1827	No defect

The test panel that immersed in petrol shows in Table 4.3(b) that there is slight petrol absorption starting first week until third week of immersion. It is 0.49% in weight increased of the test panel in the first week. This followed by 0.63% and 0.88% weight increased for the second and third week respectively. The paint tablet's weight reduces 1.8% on the first week and gained weight 0.2% and 1% on second and third week respectively. There is no significant defect found on the coating surface due to blister, color change and rust existence.

Figure 4.3(a) shows the test panel for water immersion experienced total of 0.1701 g or 0.21% weight increased and for the petrol immersion, the test panels experienced total of 0.7354 g or 0.87% weight increased. The weight gained for petrol immersion is higher from water due to the density of the petrol is lower than water. This will result in higher penetration of petrol molecules into the paint layer and led to higher weight increased due to higher amount of petrol molecules in the paint layer.

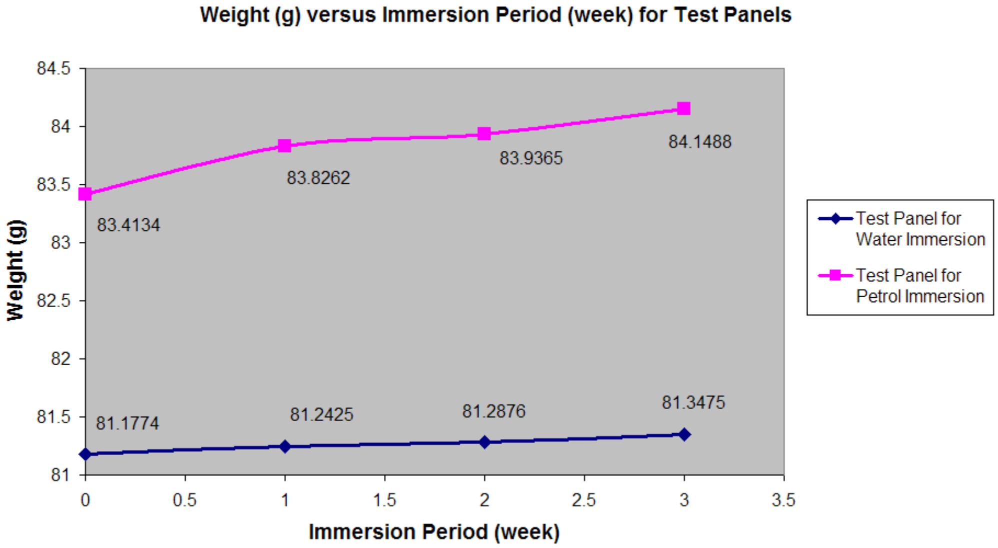


Figure 4.3(a): Graph of test panels' weight versus immersion period

Regarding the paint tablet immersion results as shown in Figure 4.3(b), there is significant weight reduction on the first week of water and petrol immersion. The immersion test should result in weight gain rather than reduction. This is happened due to the paint tablet was still in drying period because of the volume paint used is high compared to the volume used for the test panels. Therefore, the calculation of weight gained of paint tablets should be delayed one week to give chance for the paint tablets to be fully dried before immersion test. If the measurement starts after first week of immersion, which is ignoring the initial weight of paint tablet, the total immersion period will be 2 weeks and shows 3.95% and 1.2% weight increased for paint tablet in water immersion and petrol immersion respectively.

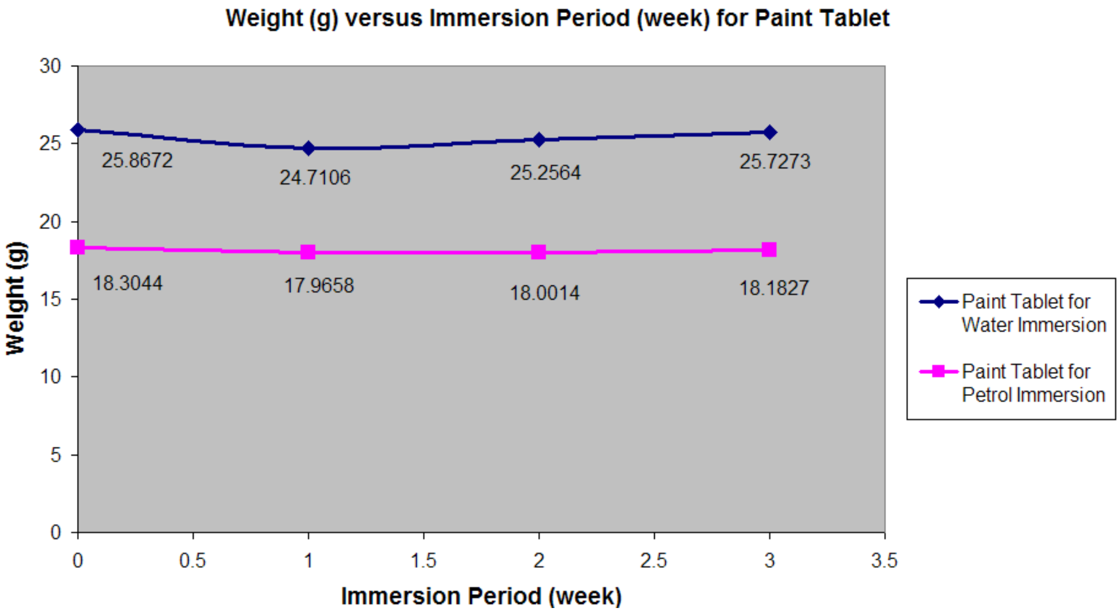


Figure 4.3(b): Graph of paint tablets' weight versus immersion period

The significant of doing immersion test is to measure the rate of water and petrol absorption to the paint layer. The application of rust stabilizer paint for the internal surface will be exposed to the higher level of humidity. Therefore, the painting must have very low absorption rate so that the painting can survive longer period before next maintenance painting program.

4.4 Salt Spray Test (ASTM B117)

The results of the salt spray test obtained based on ASTM B117 are presented in the Table 4.4

Table 4.4: Salt spray test results

Test Panels	Weight (g)			Visual inspection
	Initial	Final	% Difference	
1	86.7943	86.8045	0.012	No surface defect
2	82.1261	82.1285	0.003	No surface defect
3	83.8150	83.8279	0.015	No surface defect

After two week or 336 hours of exposure in salt spray chamber, there are two types of results can be interpreted from the test panels. Firstly, the corrosion rate in terms of weight difference. By observing the results from above table, there are a slightly increase in the final weight of all test panels. The percentage of the weight increment for Test Panel 1 is 0.012% and followed by 0.003% for Test Panel 2 and 0.015% for Test Panel 3. The possible cause of the increased in weight after exposure to salt spray condition is due to the salt deposition onto the surface of the paint. The second interpretation can be done from visual inspection of the surface coating. After two weeks exposure, there is no major surface defect detected from the test panels' surface.

The result of salt spray test shows that using rust stabilizer paint is perfect as a corrosion protection barrier. This is proven by no surface defect can be detected after two weeks of exposure. This mean the paint can protect the metal from corrosive environment without affecting paint qualities. The result can be further improved by introducing scratch to the paint in order to observe how well the paint can protect the painted surface even though there are defects existed. The significant of doing salt spray test to the maintenance painting is to observe the painting barrier performance to the high corrosive environment. A good paint will protect the metal surface and no defect can be detected after the salt spray exposure. A paint that eroded in salt spray test will exposed the metal to the environment and corrosion can occur. Therefore, rust stabilizer paint result in no defect after two weeks of salt spray exposure and really recommended for the maintenance painting.

4.5 Technical Evaluation

The technical evaluation will cover all four painting performance test that have been carried out. All the technical assessment for rust stabilizer paint shown in Table 4.5

Table 4.5: Overall technical evaluation results

Test	Details	Results
Pull-off Adhesion Test (ASTM D4541)	Average pull-off pressure = 967 psi	Acceptable
Taber Abrasion Test (ASTM D 4060)	Wear index at 1000 cycle with 1000g load = 7.28×10^{-5} g/rev	Acceptable
Immersion Test (ASTM D 870)	500 hours without defect	Acceptable
Salt Spray Test (ASTM B 117)	336 hours without defect	Acceptable

Overall technical part for testing the paint to be used in field application is seems to be surpassed the requirement. But, in terms of real application for pipeline internal surface, corrosion inhibitors are more practical compared to painting. Compared to corrosion inhibitor, painting has 2 major disadvantages. Firstly, solvent need to be used in order to execute the painting for maintenance purpose of internal surface. The high humidity plus oily stain at the pipeline internal surface will limit the grip between paint with the surface. Therefore, solvent must be spray to remove the oil and then paint can be applied onto the surface. Without solvent, the paint will not last long on the surface due to oily surface profile. Using solvent brought the paint to the second disadvantage which is very costly. Using solvent for hundreds of kilometer pipelines will consume lots of money as an extra consumable for painting purpose.

The functions of Corrostabil Rust Stabilizer Paint which is converting rust, Fe_2O_3, into magnetite, Fe_3O_4, is very handy and useful for incomplete surface preparation especially for internal pipeline surface since it is not practical to blast it clean without send workers in it. Therefore, if the idea of stabilizing rust can be applied into the corrosion inhibitor, it will be a great use for the oil and gas industry to prolong not only the pipeline but to any equipment.

CHAPTER 5

CONCLUSION AND RECOMENDATIONS

5.1 Conclusion

The overall result of the evaluation on the Corrostabil rust stabilizer paint is promising. Therefore, the objective for this project, which is to evaluate the rust stabilizer paint performance in maintenance painting for internal pipeline surface, is met. In conclusion, the rust stabilizer paint is technically feasible for internal pipeline surface application. This is based on following results;

- high strength paint formulation based on pull-off adhesion test higher than 200 psi pressure requirement.
- low wear index after Taber abrasion test with the result obtained within range of 6 x 10^{-5} g/rev.
- no significant defect and low value of fluid absorption after 500 hours of immersion test period.
- no significant defect and weight loss after 336 hours of salt spray test period.

For the real in-situ field application, more tests need to be carried out to simulate real condition of pipeline.

5.2 Recommendations

There are lots of improvement needs to be done in order to improve this project results. For example,

- increase surface profile average roughness by using garnet blasting instead of create surface profile by using sand paper.
- done X-Ray Diffraction (XRD) test to detect magnetite existence after eight months painting to prove the theory of the conversion from hematite to magnetite by using rust stabilizer paint.

REFERENCES

1. Hasmukharay S., "Analysis of Various Coating Systems for the Internal Corrosion Prevention of Atmospherics Aboveground Storage Tanks", 2006.
2. Applied Corrosion Engineering Services Corrostabil Product Brochure, "Corrostabil Reinforced Rust Stabilizer", 2008
3. Rossland T., "10 Years Experience with Functional Specifications for Surface Maintenance", Paper No. 06022, CORROSION NACExpo, 61st Annual Conference & Exposition, NACE International, 2006
4. Sastri, "Corrosion Prevention & Protection; Practical Solution", 2007, Wiley Publication
5. Kittelberger W. W. and Elm A. C., "Water Immersion Testing of Metals Protective Paints", The New. Jersey Zinc Company (of Pa.), Palmarton, Pa.
6. Pourciau R. D., "Case History: Internally Coated Completion Workstring Successes", paper presented at SPE Annual Technical Conference and Exhibition 2002, San Antonio, Texas.
7. ASTM D 4060-95: "Abrasion Resistance of Organic Coatings by the Taber Abraser" ASTM, Philadelphia, PA.
8. ASTM B 117-03: "Operating Salt Spray (Fog) Apparatus" ASTM, Philadelphia, PA.
9. ASTM D 870-97: "Testing Water Resistance of Coatings Using Water Immersion" ASTM, Philadelphia, PA.
10. ASTM D 4541-02: "Pull-off Strength of Coatings Using Portable Adhesion Testers" ASTM, Philadelphia, PA.

11. PETRONAS Technical Standard, “Painting and Coating of New Equipment”, PTS 30.48.00.31, 1995
12. Fogg G. A., Morse J., “Development of a New Solvent-Free Flow Efficiency Coating for Natural Gas Pipeline”, paper presented at 2005 Rio Pipeline Conference and Exposition.
13. De Paiva M. P., Martins J., “An Edge Retentive Coating Solution Based on a Tolerant, Solvent-Free Epoxy System”, Euronavy International, 2002, Setubal, Portugal.
14. Zhang S.Y., Li S. J., Luo X. W., Zhou W. F., “ Mechanism of the Significant Improvement in Corrosion Protection by Lowering Water Sorption of the Coating”, 2002, Shanghai, People’s Republic of China
15. Wu L., Hoa S. V., Ton-That M. “Effects on Water on the Curing and Properties of Epoxy Adhesive Used for Bonding FRP Composite Sheet to Concrete”, 2003, Concordia Center for Composites, Quebec, Canada.
16. Defelsko, “Test Methods for Coating Adhesion”, 2000, Proctor Avenue, Ogdensburg, New York
17. ASTM D 1014-09: “Test method for Conducting Exterior Exposure Tests of Paints on Steel” ASTM, Philadelphia, PA