Comparative Study of Polyurea and Epoxy Protective Coating via Salt Spray Testing.

By

Mohd Ariff Bin Mohd Tahir

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

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 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.

MOHD ARIFF BIN MOHD TAHIR

ABSTRACT

Coating is a covering that is applied to an object. The aim of applying coating is to improve surface properties of a bulk material namely against environmental attacks, corrosion attacks and other harmful agents. This study reports on the salt spray testing done polymer coating on steel substrate to simulate testing under corrosive environment. In the process, firstly, steel panels were sand blasted to SA2.5 and primed with Halgen primer, then coated with polyurea coating to 2000µm and epoxy coating to 100µm and then they are cured for 7 days. Specimens were then divided into scribed and unscribed specimens, the former having a cross pattern running through the coating up to the substrate surface. Specimens were then exposed in the salt spray chamber in two durations of 7 days for Set A and 14 days for Set B in 5% NaCl salt solution at 35ºC temperature and 100% relative humidity. The specimens were then examined in terms of scribed and unscribed areas of coating quantitatively. It was found that the best results were obtained for polyurea coating as it suffered near zero changes for its unscribed specimen throughout the whole 14 days exposure having unscribed rating of 10. It was observed that epoxy coating was inferior in terms of corrosion protection and coating degradation as compared polyurea. Epoxy suffered decolourization, blistering and flaking after the exposure and also the moisture ingression is up to 44 times as compared to polyurea. In conclusion, polyurea coating is the superior coating when compared to epoxy.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Coating is a covering that is applied to an object. The aim of applying coating is to improve surface properties of a bulk material usually referred to as a substrate. Physically, polyurea coating is a seamless membrane that can be handled and walked on within five minutes or less from the time it is sprayed. Developed in the early 1980s for rapid prototyping process, polyurea is currently widely established in USA with a choice of specifiers in a number of industries [1]. The latest formulation allows polyurea to be applied without heat and pressure. Number of application methods includes high/low pressure spray, injection, and roller/brush application. This is also accompanied by architectural formulations that allow polyurea to be developed with very thin, high gloss, and high color physical properties.

The history of epoxy chemistry began in the early 1900s, when Russian chemist Prileschajev discovered that olefins react with peroxybenzoic acid to form epoxides. In the mid-1930s, the German P. Schlack applied for a patent on the preparation of high molecular weight polyamines by making the amines react with epoxide compounds that contain more than one epoxide group [2]. Epoxy coatings offers rust stabilising properties with tough finish and excellent physical properties to withstand extreme condition such as high temperature application, and chemical attacks. [3]

1.2 Problem Statement

Polyurea and epoxy coatings claims to be able to resist salinity attack when exposed to salt water concentration in its service life, maintain its durability over the designated service life, and falls within industry standards on a cost basis. Consequently it is significant to study the behaviour of polyurea and epoxy coatings when subjected to salt spray testing to quantify its performance under such environment.

1.3 Objective of Study

The objective of this study is to investigate the performance polyurea coatings and epoxy coating when exposed to salt spray testing. Any evidence of failure due to degradation of polymer or failure due to corrosion on the substrate will be monitored and investigated.

1.4 Scope of Study

The scope of this study will mainly revolve around the followings;

- To monitor and note extent of failure of polyurea coating & epoxy coating when exposed to salt water condition via Salt Spray Chamber.
- To evaluate the degree of material degradation on both coatings, if any.

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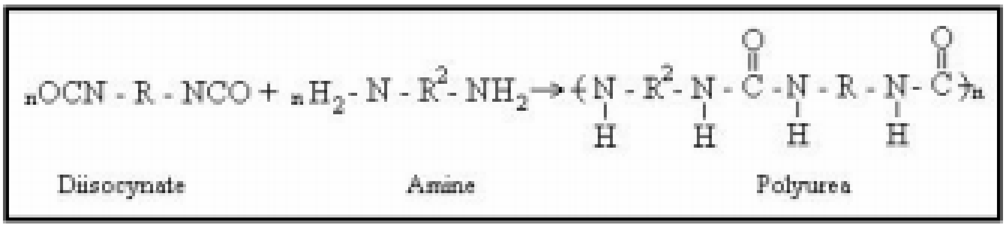
CHAPTER 2

THEORY & LITERATURE REVIEW

2.1 Polyurea

Polyurea is a two-component, 100%-solids, polymer that significantly reduces the moisture problems that commonly cause pin holing and blistering in most polyurethane or polyurethane-hybrid systems. Polyurea in general can be applied at temperatures ranging from -30ºC to 177ºC [4].

Although different manufacturer consists of different formulation, the basic structure of a polyurea membrane is a type of elastomer that is derived from the reaction product of an isocyanate component and resin blend component through step-growth polymerization. The isocyanate can be aromatic or aliphatic in nature, which dictates different grades and its application purposes.



$${}_nOCN-R-NCO+{}_nH_2-N-R^2-NH_2\rightarrow(\underset{H}{\underset{|}{N}}-R^2-\underset{H}{\underset{|}{N}}-\overset{O}{\overset{\|}{C}}-\underset{H}{\underset{|}{N}}-R-\underset{H}{\underset{|}{N}}-\overset{O}{\overset{\|}{C}})_n$$

Figure 1 : Polyurea composition

2.1.1 Polyurea Coating

This aromatic polyurea elastomer displays excellent chemical resistance, thermal stability and UV resistance with theoretical coverage for 1 mm thickness is one litre per m^2. Tables 1 and 2 below shows its physical properties and processing properties [4];

Table 1: Physical properties of polyurea (Nukote ST) at 24ºC

PHYSICAL PROPERTIES @ 24ºC	
Solids by Volume	100%
Volatile Organic Compounds	0g/l
Theoretical Coverage @ 1000 µms	1 m^2/Litre
Weight per litre in kilograms	A:0.58 B:0.51
Number of Coats	1-2
Mix Ratio	1A : 1B
Viscosity (cps) @ 25 °C	A:689
Viscosity (cps) @ 25 °C	B:650
Shelf Life @ 0-50°C	6-12 months
Tensile Strength ASTM D-412	29.99 MPa
Elongation @ 25 °C ASTM D-412	430%
Hardness (Shore A) ASTM D-2240	100
Hardness (Shore D) ASTM D-2240	55
Flexibility 3mm mandrel ASTM D-1737	PASS
100% Modulus ASTM D-412	1400
200% Modulus ASTM D-412	1800
300% Modulus ASTM D-412	2800
Tear Strength Die C ASTM D-624	101.5 kN/m
Fire Rating UBC	Class 2
Flash Point Pensky-Martin	>93°C
Service Temperature Range	-35° to 135°C
Abrasion Resistance ASTM D-4060 (1kg for 1000 Cycles CS 17 Wheel)	<20 mg loss

Table 2: Processing properties @125 µms 24ºc/54% Rh

PROCESSING PROPERTIES @125 µMS 24ºC/54% RH	
Gel Time (Adjustable)	6-20 sec.
Tack Free (125 µms Brushed)	45 sec.
Post Cure	24 hrs.
Volume Ratio (A: B)	1:01
Block Temperature	60°C- 71°C
Hose Temperatures (A and B)	60°C- 71°C
Constant Pressure	2000 psi

Two-component polyurea systems are typically known for a very rapid dry time, typically less than 30 seconds, achieved without the use of a catalyst as in the two-component polyurethane systems. This rapid dry time is very consistent over a very broad ambient temperature range. Furthermore, polyurea is not affected by ambient temperature which allows it to be applied during rain as long as the substrate is physically dry. This is all made possible by a unique chemistry of raw materials used to develop the two-component polyurea systems.

2.2 Epoxy

Epoxy is a thermosetting polymer formed from reaction of an epoxide with polyamine. Epoxies are formed from two different chemicals, referred to as the "resin" and the "hardener". The resin consists of monomers or short chain polymers with an epoxide group at either end. Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A, though the latter may be replaced by similar chemicals. The hardener consists of polyamine monomers, for example triethylenetetramine (TETA). When these compounds are mixed together, the amine groups react with the epoxide groups to form a covalent bond. Each NH group can react with an epoxide group, so that the resulting polymer is heavily cross linked, and is thus rigid and strong [4][5].

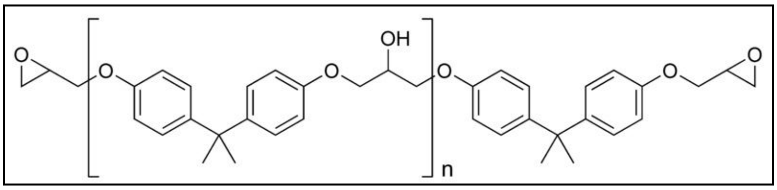


Figure 2: Epoxy Formulation

Figure 2 above depicts the formulation of an Epoxy. The applications for epoxy-based materials are extensive and include coatings, adhesives and composite materials such as those using carbon fibre and fibreglass reinforcements (although polyester, vinyl ester, and other thermosetting resins are also used for glass-reinforced plastic). The chemistry of epoxies and the range of commercially available variations allows cure polymers to be produced with a very broad range of properties. In general, epoxies are known for their excellent adhesion, chemical and heat resistance, good-to-excellent mechanical properties and very good electrical insulating properties. Many properties of epoxies can be modified to suit different application purposes demanded [6].

2.2.1 Epoxy Coating

An epoxy based protective coating was introduced into the project to provide comparison between polyurea coatings against the industry's standard. The Epoxy coating used for this project is the CORROSTABIL 'E' – Rust Stabilising Primer (2 Pack Epoxy) by Applied Corrosion Engineering Services Aunt Pty. Ltd.

Two part epoxy coatings were developed for heavy duty service on metal substrates and use less energy than heat-cured powder coatings. These systems used dries quickly providing a tough, UV resistant, protective coating with excellent ultimate hardness. Their low volatility and water cleanup makes them useful for factory cast iron, cast steel, cast aluminium applications and reduces exposure and flammability issues associated with solvent-borne coatings. They are usually used in industrial and automotive applications since they are more heat resistant than latex-based and alkyd-based paints.

Epoxy coatings are extensively used for corrosion protection of steel pipes and fittings used in the oil and gas industry and steel potable water transmission pipelines. Epoxy coatings are also widely used as primers to improve the adhesion of marine paints especially on metal surfaces where corrosion resistance is important [7].

The most significant difference between epoxy coatings when compared to polyurea coating is it's drying times. Polyurea's rapid drying time allows it to be tack free within 30 seconds and cures within 24 hours. At the recommended 50µm dft and a constant average temperature of 30ºC, epoxy requires up to 2 hours to be tack free and 10 hours for it to be touch dry. Curing for epoxy may take up to 7 days depending on the humidity and temperature. Epoxy is also requires exact stoichiometry for it to perform at its rated performance. Any imbalance ratio during mixing will cause the epoxy to lose its properties such as longer drying times, reduce in strength and abrasion resistant.

2.3 Salinity

According to M. Morcillo & B. Chico (2000), saline particles accelerate metallic corrosion as chlorides give rise to soluble corrosion products rather scarcely soluble products. Marine chlorides dissolved in the layer of moisture raise the conductivity of the electrolyte layer on the metal and tend to destroy any film existing on the metallic surface [8]. Here, polyurea will be the layer preventing saline particles from seeping into the metallic substrate.

Wayt (2004) revealed that there are no variations in the result regardless of the duration tested on polyurea coating [9]. For the test, Wayt prepared specimens measuring 150mm x 450mm of carbon steel panel and exposed them at durations of 2,000, 4,000, 6,000, 8,000 & 10,000 hours following ASTM D1654 testing procedures. Prior to coating with polyurea, each specimen was sand blast using -20grit to SA 2.5 Blast profile and then primed using Nukote Metal Prime to 100µms before coating it with Nukote ST to 1060µms dry film thickness (dft). Specimens were then left to cure for 7days. The salt water solution used then throughout the testing consisted of 60% NaCl/40% H20 solution.

Throughout the progression of the testing, Wyatt noted there was no evidence of cracking, checking or blistering on top of the coating even after 10,000hours. Though there is a slight gloss reduction, aesthetic is not the main concern in industrial protective coating. And for the scribed area, there is less than 1mm prohesion, with a small amount of flash rust noted. This is well expected since the area is left unprotected from the coating.

Meanwhile on a similar testing, Anees U. Malik, Ismail Andijani, Shahreer Ahmed and Fahd Al-Muaili [10]showed that Epoxy coating showed little creepage (0.09 mm) after 25 days (600 hours) of exposure but it increased considerably (2.06 mm) after 100 days (2400 hours) exposure although no blistering in the coating was found. The scribed specimens showed a number of blisters where as unscribed specimens show no sign of blister.

These literatures showed that under the same condition imposed by the accelerated testing, epoxy coating has showed early sign of failure as early as 600 hours while polyurea coating is able to withstand up to 10,000 hours without any variation.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Research Methodology

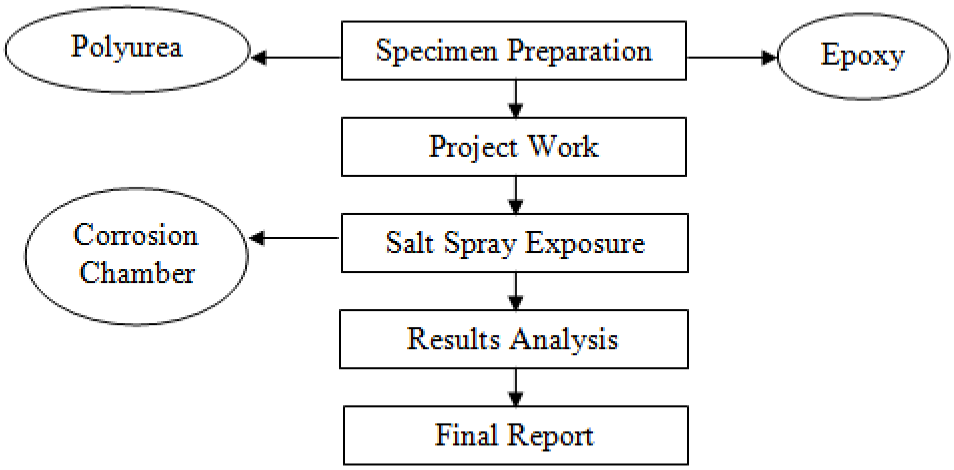


Figure 3 : Project flow

The testing followed closely to what have been done by Wyatt (2004) in terms procedural and analysis stand. All the method and preparation were referred to ASTM B117, D609 and D1654 and will be discussed in details in this chapter.

3.2 Specimen Preparation

3.2.1 Substrate

Substrate used is Type III Cold Rolled Steel, in accordance to ASTM D609-00 [11]. The characteristic of the panel is as follows:

Table 3 : Type III cold- rolled steel characteristic

Type No.	Description	Thickness (mm)	Hardness (Rockwell B)
III	Cold-rolled steel, as rolled (smooth)	0.25-0.6	760-1650

Type III steel plate have smooth finish production steel mill rolls which have been smooth ground. This finish is useful for measuring paint properties such as colour, gloss, flexibility, or adhesion, where it is desirable to minimize effect of variation in surface roughness. The 4 panels were cut to measure 100mm x 100mm x 2mm for epoxy coating and 4 panels were cut to 150mm x 100mm x 2mm for polyurea coating. This variation in dimension was due to the limitation on polyurea coating equipment that required the above as the minimum coating size. Regardless of the different surface area, only 100mm x 100mm of the primary surface of both specimens are examined and rated.

3.2.2 Polyurea

Nukote ST polyurea was acquired from Dyna Segmen Sdn. Bhd. (DSSB) in Kuala Lumpur. Nukote ST is a standard polyurea coating and is designed for general purpose use. It has been developed to perform well for anticorrosion and waterproofing applications on steel, concrete, and many other substrates [12].

3.2.3 Epoxy

CORROSTABIL 'E' is a two-component epoxy rust stabilising primer. Material were obtained from Applied Corrosion Engineering Services (ACES) Sdn. Bhd. Industrial applications for CORROSTABIL 'E' includes structural steel, cranes, mechanical equipment, bridges, railings and tank externals [3] which should match closely of Nukote ST application.

Table 4 : Summary of specimens

Specimen	Coating	Scribed / Unscribed	Exposure (days)	Set
P1-U	Polyurea	Unscribed	7	A
P2-S	Polyurea	Scribed	7	A
P3-U	Polyurea	Unscribed	14	B
P4-S	Polyurea	Scribed	14	B
E1-U	Epoxy	Unscribed	7	A
E2-U	Epoxy	Unscribed	14	B
E3-S	Epoxy	Scribed	7	A
E4-S	Epoxy	Scribed	14	B

3.3 Project Work

To ensure the success of any surface coating, the utmost attention were paid to the surface preparation and coating process. Surface preparation and surface repair are the most important requirements for maximum durability from any paint system. Because the results of surface preparation and repair are quickly concealed by the first coat of paint, the effects are not usually evident until premature paint failure occurs. [13] The following sections will discuss in detail the surface preparation, coating procedures and the pre-treatments before exposure.

3.3.1 Surface Preparation

The specimens were prepared in accordance with ASTM B117-03 [14] and its referenced documents. The CR steel panel were first sand blasted to SA2.5 to obtain the required anchor pattern for optimum coating adhesion. SA2.5 surface finish is a "Near-White Blast Cleaning". A Near-White Blast Cleaned Surface Finish is defined as one from which all oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint or other foreign matter have been completely removed from the surface except for very light shadows, very slight streaks or slight discolorations caused by rust stain, mill scale oxides, or light, tight residues of paint or coating that may remain.

After achieving the surface profile, the panels are primed with Halgen primer to ensure proper adhesion of the coating to substrate as specified in PETRONAS Technical Standard [15]. These measures are very much similar to what is being done in the industry; therefore it should provide the most similar testing condition in the laboratory

3.3.2 Coating

With the help of DSSB the polyurea specimen were coated with Nukote polyurea ST to 2000μm as recommended using the Graco E-10 coating machine. The procedure was done at four pass of 500μm per pass at 30°C ambient temperature. After each pass, the layer is left to dry for three minutes before overcoat. Specimens were then left to cure for 7 days. This was done at their site and later delivered to UTP.

As for epoxy specimens, under the supervision of Dr. Zakaria Man and his post graduate student Ms. Arin, both have assisted in the preparation of the Epoxy specimens. The epoxy was applied onto the substrate using lamb's wool roller. The primary coat process was done in an ambient of ±25°C and left to dry for 24 hours at room temperature of 30°C before over coating the next day at the same environment condition. A total of two layers of CORROSTABIL 'E' were applied on to the primary face of the substrate and left to cure for 7 days before exposure in the Salt Spray Chamber.

3.3.3 Specimen Pre-treatment

Before exposing the specimen to the Salt Spray chamber, the specimens were divided into two groups of Scribed and Unscribed specimens.

The scribed specimens were prepared so that it is exposed lengthwise when positioned in test cabinet. This allows droplets to run lengthwise along the scribe. The specimens were scribed by holding a straight shank tungsten carbide lathe cutting tool (ASNI B94.50, Style E) at 45º angle to surface and position tool so that only carbide tip is in contact with surface. Scribe should be sufficient length to cover significant test area, but should not contact edge of specimen and must penetrate all organic coating layers on metal, leaving uniformly bright lines of burrs.

3.4 Salt Spray Exposure

3.4.1 Salt Spray Chamber

Salt spray test is an accelerated corrosion test that produces a corrosive attack to the coated specimens in order to predict its suitability in use as a protective finish. The appearance of corrosion products (oxides) is evaluated after a period of time. Test duration depends on the corrosion resistance of the coating; the more corrosion resistant the coating is, the longer the period in testing without showing signs of corrosion. For the purpose of this study, the specimens were exposed for a total duration of 7 and 14days. The Salt Spray Chamber that will be used is "*Cyclic Corrosion Cabinet (CCT)*" model: SF/450 CCT.

Figure 4 : "Cyclic Corrosion Cabinet (CCT)" model: SF/450 CCT

For a total of 14 days exposure in the chamber, it was expected that 8kg of sodium chloride is used for the Saline Solution. The solution is prepared by mixing 5part by mass of sodium chloride to 95part of distilled water. The specimens are then placed inside the chamber at 45degree with the primary face of the specimens facing the fog outlet.

Figure 5: Polyurea specimens in salt spray chamber

Figure 6: Epoxy specimens in salt spray chamber

3.4.2 Salt Solution

As a general guideline for the controlled salt solution, the solution was prepared by dissolving 5±1 part by mass of sodium chloride in 95parts of water. The sodium chloride contained not more than 0.3% by mass of total impurities and contained no anti-caking agents as such agent may act as corrosion inhibitors. The pH of salt solution was at 6.99 when tested at 35'C. pH measurement was made using pH meter.

3.4.3 Exposure

The testing was done at two duration of 7 days and 14 days exposure, the former labelled Set A and the later Set B. The test was done continuously for the duration of the entire test period with the chamber remained closed and sprays operating continuously without any interruption, except in between Set A and Set B specimen removal. On the final day of 7th day (Set A removal), the exposure was put on hold from 10.00am until 10.52am. Exposure and spray continued operating afterwards without any further interruption until the 14th day for Set B.

3.4.4 Post Exposure Treatment

After exposure, each specimen removed was individually and gently washed with clean running water to remove salt deposits from surface, then immediately dried using paper towel and followed by hair dryer.

3.5 Evaluation

3.5.1 Evaluation of Scribed Specimens.

Specimens were first be rinsed after completion of exposure using gentle stream of water. Holding the nozzle at 45° angle, air blasting was done along the entire scribe line using hair dryer. Specimens were then photographed and rated. Corrosion or loss of paint extending from scribe mark were rated as prescribe in Table 2 ASTM

D1654. Representative mean, maximum and minimum creepage from scribe were then recorded as well as creep values in millilitres.

Table 5 : Rating of failure at scribe

Representative Mean Creepage from Scribe	
Millimetres	**Rating Number**
0	10
0-0.5	9
0.5-1.0	8
1.0-2.0	7
2.0-3.0	6
3.0-5.0	5
5.0-7.0	4
7.0-10.0	3
10.0-13.0	2
13.0-16.0	1
16.0-MORE	0

3.5.2 Evaluation Of Unscribed Area

Specimen is evaluated for corrosion spots, blisters, and any other types of failure. Size, frequency and/or area affected was Record with corrosion within ½in of edges is discounted. Percent failed area was recorded and convert percent failure to rating number in accordance to Table 6 [16].

Table 6 : Rating of unscribed areas

Area Failed, %	**Rating Number**
No Failure	10
0-1	9
2-3	8
4-6	7
7-10	6
11-20	5
21-30	4
31-40	3
41-55	2
56-75	1
Over 75	0

3.5.3 Wet Weight Difference

In theory, after the exposure, the specimen will considerably suffer a mass gain due to the water absorbed into the pores of the coating and into the substrate. The percent changes of initial weight of the plate and after exposure will be calculated as the Wet Weight Difference ;

Equation 1: Wet Weight Difference

$$\boxed{Wet\ Weight\ Difference = \left(\frac{W_2 - W_1}{W_1}\right) x\ 100\%}$$

Where;

W_1 = Weight before exposure

W_2 = Weight After Exposire

The more water absorbed or retained in the specimen should give us an early indication which of the specimen will suffer more damaged due to corrosion and degradation of the specimen.

3.5.4 Dry Weight Difference

Dry weight difference is the weight of the specimen after water has been fully drained from the specimen after the exposure. This is done by leaving the specimen to dry at room temperature for four days before measuring its weight. The mass difference here should give us a reading on the mass lost suffered by the substrate due to corrosion from exposure.

Equation 2 : Dry Weight Difference

$$\boxed{Dry\ Weight\ Difference = \left(\frac{W_3 - W_1}{W_1}\right) x\ 100\%}$$

Where;

W_1 = Weight Before Exposure

W_3 = Weight After Drying

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Set A – 7 days Exposure

4.1.1 Specimen P1-U : polyurea – unscribed

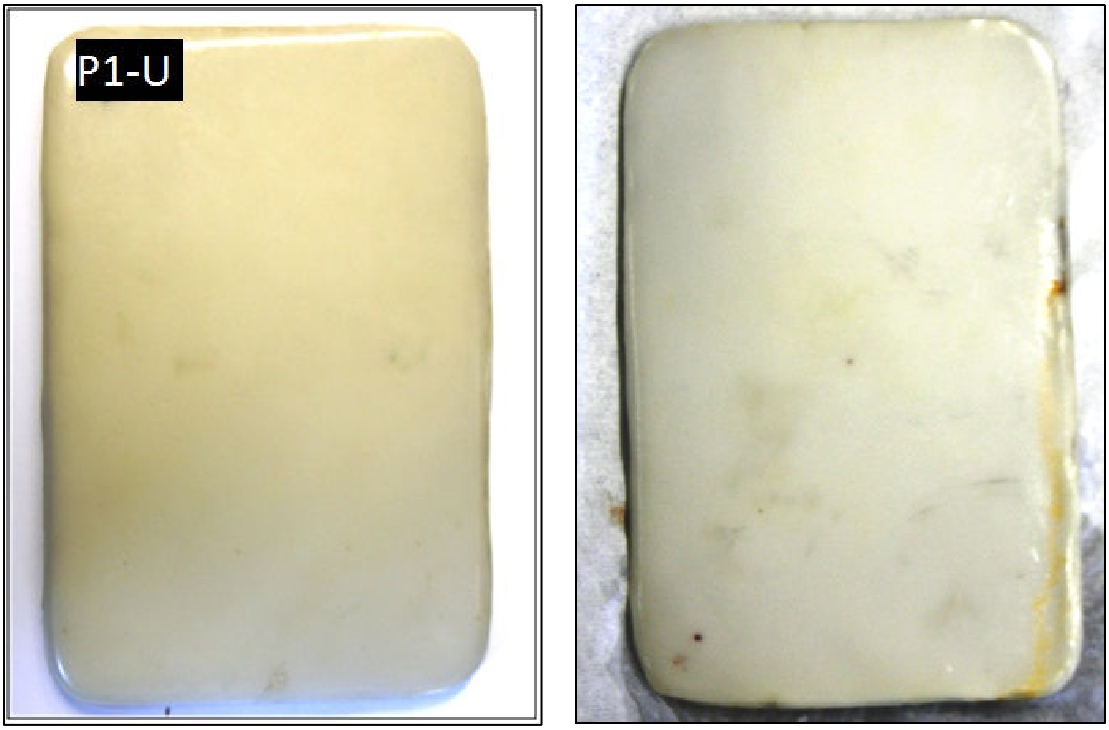


Figure 7 : Specimen P1-U – primary face (left) & reverse face (right)

On the primary face of exposure, no physical changes were noted for Specimen P1-U. Salt deposition was found on the surface prior cleaning, but was easily rinsed off with running water. Specimen suffered no colour or gloss reduction, maintaining aesthetic appearance. No particular changes were noted on the reverse face as well. Specimen is rated 10 on unscribed rating.

There was an 11mm opening on the side of the specimen, which was filled with Vaseline prior to exposure. After the 7 days exposure, 2mm spot rust could be observed at the opening. Nevertheless, any reading 1/2inch from the sides can be discounted from the experiment, therefore the spot rust area can be neglected for the sake of study.

4.1.2 Specimen P2-S : polyurea – scribed

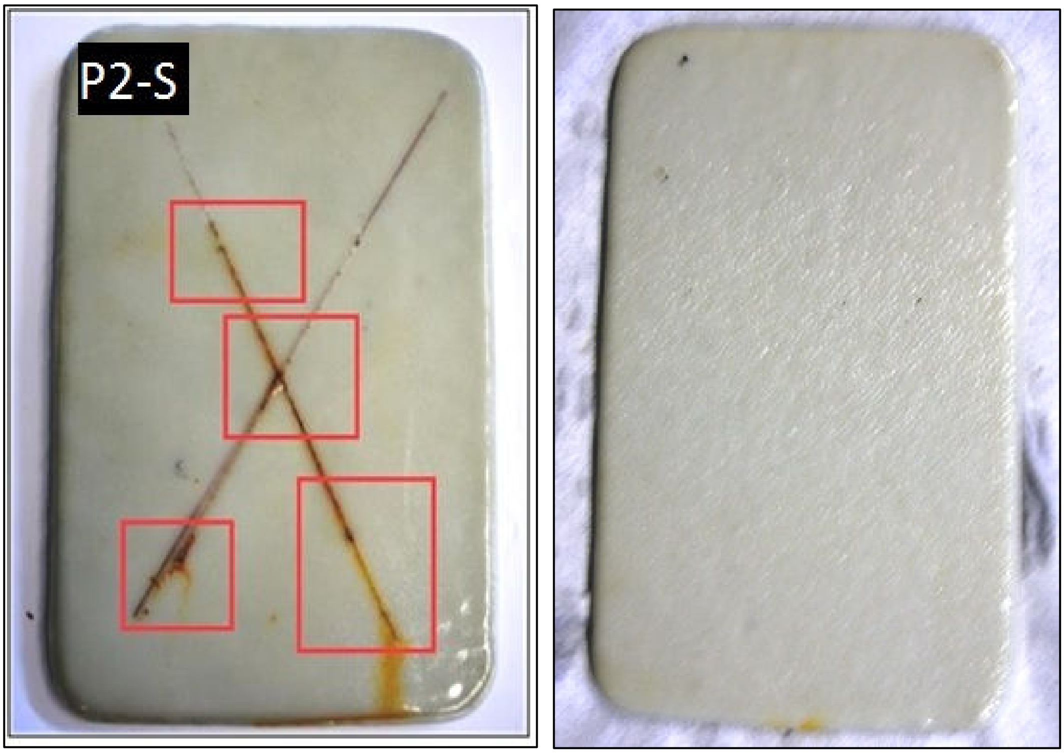


Figure 8 : Specimen P2-S – primary face (left) & reverse face (right)

For Specimen P2-S, four distinctive rust areas were spotted along the scribed lines. These rusts were already anticipated for these (scribed) specimen. Mean creepage value for the specimen is rated 9. The reverse side seems to suffer no changes after the exposure as well. No discoloration was noted on the specimen and no sign of delamination or lost of adhesion was seen on the scribe line. Only the reverse face of the specimen which was not scribed appeared to be undisturbed and suffered no change throughout the exposure in the corrosion chamber.

4.1.3 Specimen E1-U: epoxy – unscribed

Specimen E1-U is the first Epoxy Coating Specimen to be evaluated in this study. Preliminary inspection shows signs of blistering and cracking on the coating after the exposure on the primary face. The reverse face, unlike the primary face only received a single layer of coating. This surface also exhibits signs of coating flaking, which could have been caused by insufficient curing. Unscribed rating 9 is given.

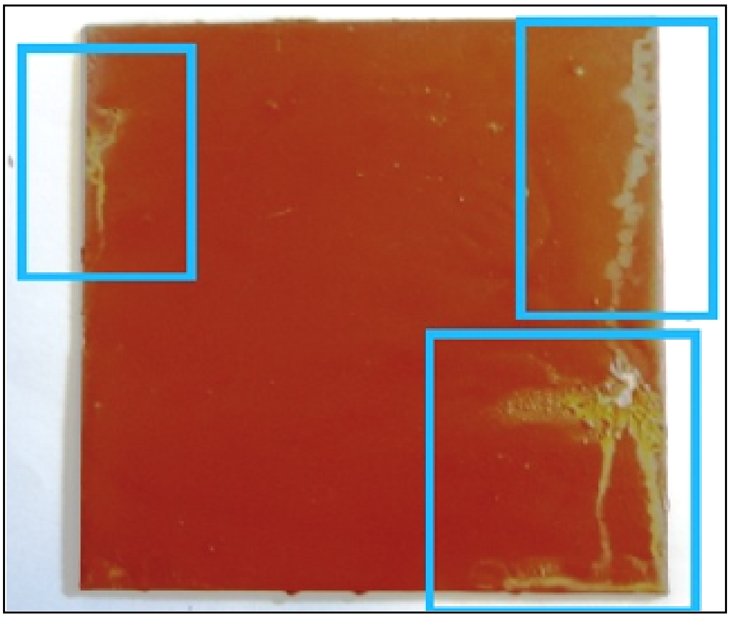


Figure 9: Specimen E1-U - primary face

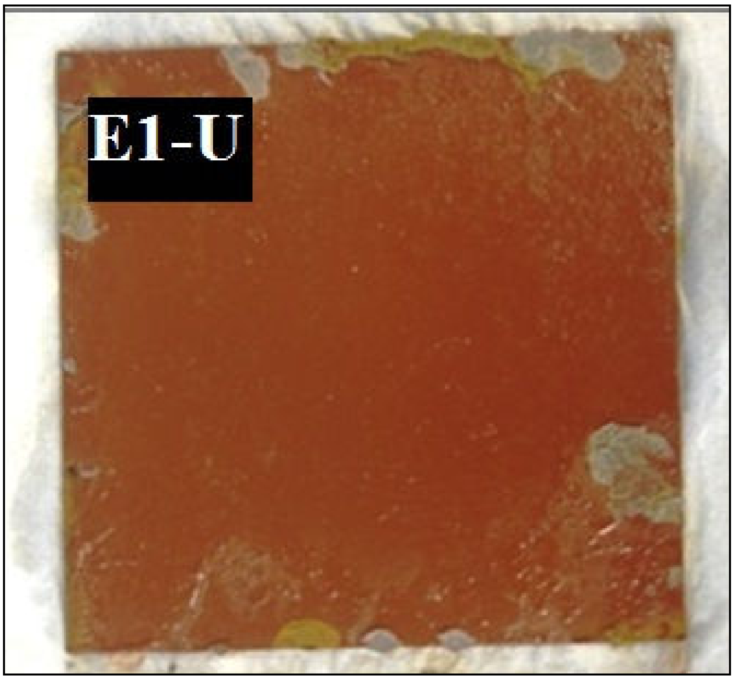


Figure 10 : Specimen E1-U - reverse face

4.1.4 Specimen E3-S: epoxy – scribed

On the primary surface, the rust has spread throughout the coating and not just along the scribed lines. Areas along the scribe line also suffered decolourization. Water build up inside the coating causes the coating to dissolve and yellowish fluid which resembles the epoxy in liquid form can be seen seeping out from the scribe line. Paint cracking was seen on the edges of the coating, and certain area of the coating suffered lost of adhesion of the coating to the substrate. Rating 6 is given.

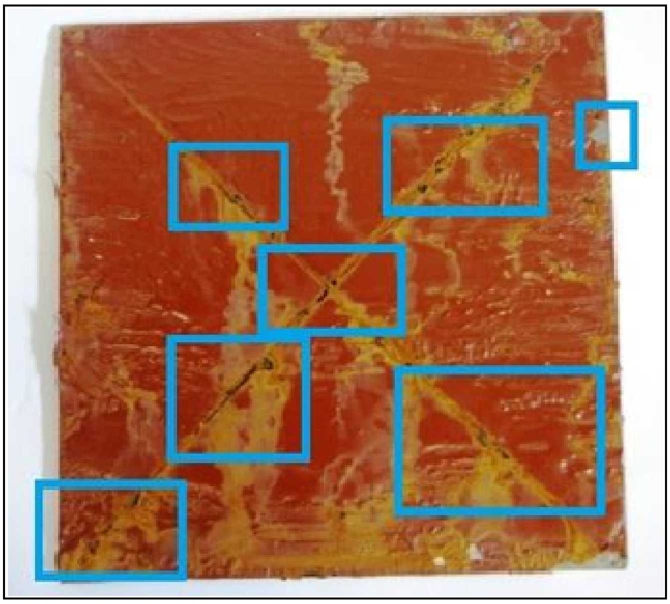


Figure 11: Specimen E3-S - primary face

Figure 12 : Specimen E3-S - reverse face

4.2 Set B – 14 days Exposure

4.2.1 Specimen P3-U – polyurea unscribed

Figure 13: Specimen P3-U – primary face (left) & reverse face (right)

Much like P1-U, specimen P3-U shows very promising result with no changes on the physical feature of the coating as seen in Figure 13. No dimension change or decolourization is noticed. No blistering or paint cracking is noticed on the coating. Both primary and reverse face appears to be superior to the testing. The specimen receives a rating 10 for the corrosion rating.

4.2.2 Specimen P4-S – polyurea sribed

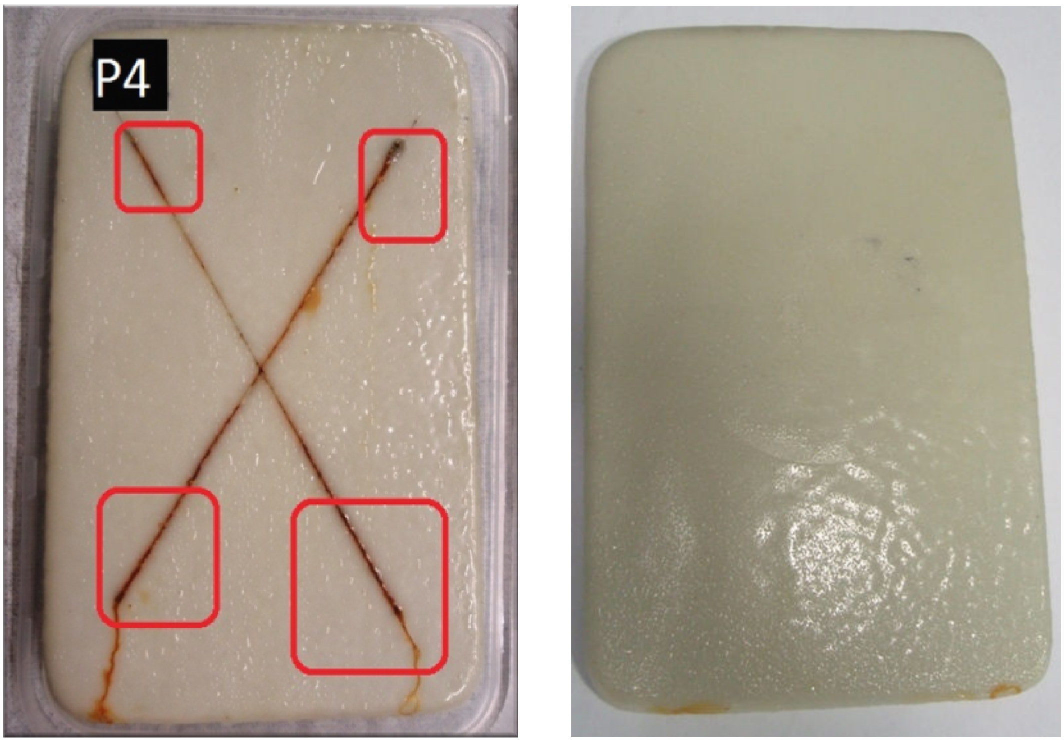


Figure 14 : Specimen P4-S – primary face (left) & reverse face (right)

Much like specimen P1-S, the specimen suffers minimal effect on the coating after the exposure as seen in Figure 14. No decolourization is noted with any changes in physical dimension due to blistering or paint cracking. But as the exposure is increased, the degree corrosion on the scribe line extends. It is expected with prolong exposure, the corrosion will continue to worsen. Nevertheless, up to 14 days of exposure, no lost of lamination or adhesion to the surface is observed on the coating. Specimen receives a rating of 9.

4.2.3 Specimen E2-U – epoxy unscribed

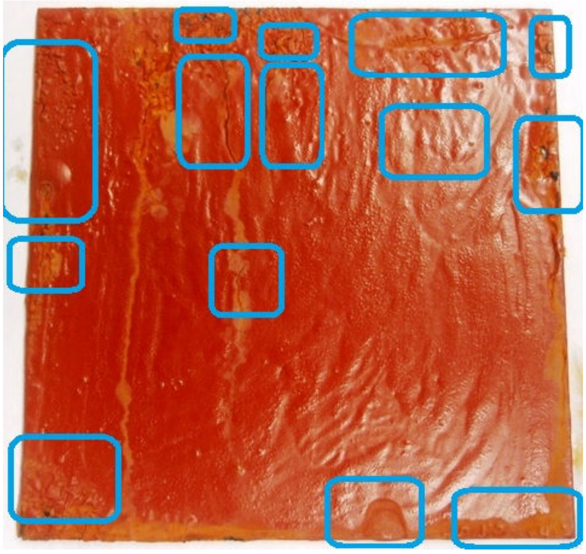


Figure 15 : Specimen E2-U - primary face

Figure 16 : Specimen E2-U - reverse face

Sample appears to lose much of its coating performance after the exposure. On the primary surface, numerous sites suffered pin holing and pitting can be seen on the surface under the naked eye. This suggests that moisture was trapped inside the coating which later breaks the protective film of the coating, causing the bare metal underneath to be exposed. This resulted in corrosion of the substrate at those areas. The reverse side, which was covered with only a single layer of epoxy, appeared to have degraded after the exposure. Surface coating suffered thinning in certain areas with some having lost of adhesion of the coating to the substrate. Nevertheless, the reverse area is not the main concern of the study and will be neglected. Specimen received a rating of 8.

4.2.4 Specimen E4-S – epoxy scribed

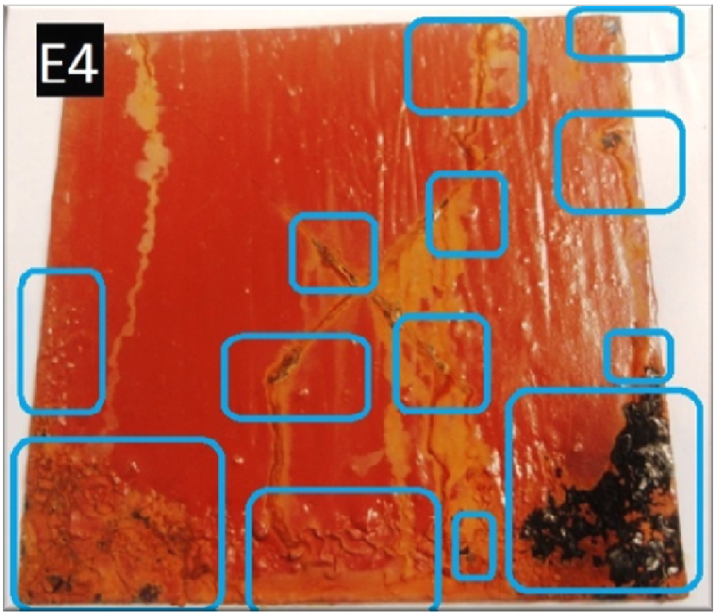


Figure 17: Specimen E4-S - primary face

Figure 18 : Specimen E4-S : reverse face

Specimen E4-S appears to have suffered the most damage throughout the testing. From Figure 18, it can seen that approximately 60% of the primary surface coating suffered pitting and blistering caused by moisture ingression. 10% of the surface area also showed heavy rusting on the bottom left of the specimen. Areas along the scribe line suffered extensive decolourization with the substrate exposed through the scribe line having a 6 rating on the damage. The reverse face also showed similar results as specimen E2-U with signs of decolourization, and thinning as towards the edges. This pattern suggest that the moisture ingresses from the edges of the specimen and moves towards the centre of the centre. The centre specimen suffered minimal effect with little decolourization and thinning of the protective coating. If exposure period is prolonged, it is assumed that this sample would have failed catastrophically.

4.3 Discussion

4.3.1 Scribe Rating

Table 7 : Scribe and unscribe rating

Specimen	P1-U	P2-S	P3-U	P4-S	E1-U	E2-U	E3-S	E4-S
Scribe Rating	-	9	-	9	-	-	7	6
Un-scribe Rating	10	-	10	-	9	8	-	-

As we can see here, the scibe rating and unscribe rating increases as exposure is increased. But generally, polyurea have a higher rating than epoxy especially in the unscribe rating whereby no physical changes is observed on the protective coating.

4.3.2 Set A weight difference

Table 8 shows the amount of mass difference of the specimens, in terms of wet weight and dry weight for 7 day exposure period.

Table 8: Weight change for set a – 7 days exposure

Specimen	P1-U	P2-S	E1-U	E3-S
Weight Before (G)	402.317	366.197	90.791	90.592
Wet Weight	403.271	366.622	90.903	90.771
Wet Difference	0.954	0.425	0.112	0.179
% Change (Wet)	2.4e-05	1.2e-05	1.2e-05	2.0e-05
Dry Weight	402.566	366.255	90.702	90.594
Dry Difference	0.249	0.058	-0.089	0.002
% Change (Dry)	6.2e-06	1.6e-06	-9.8e-06	2.2e-07

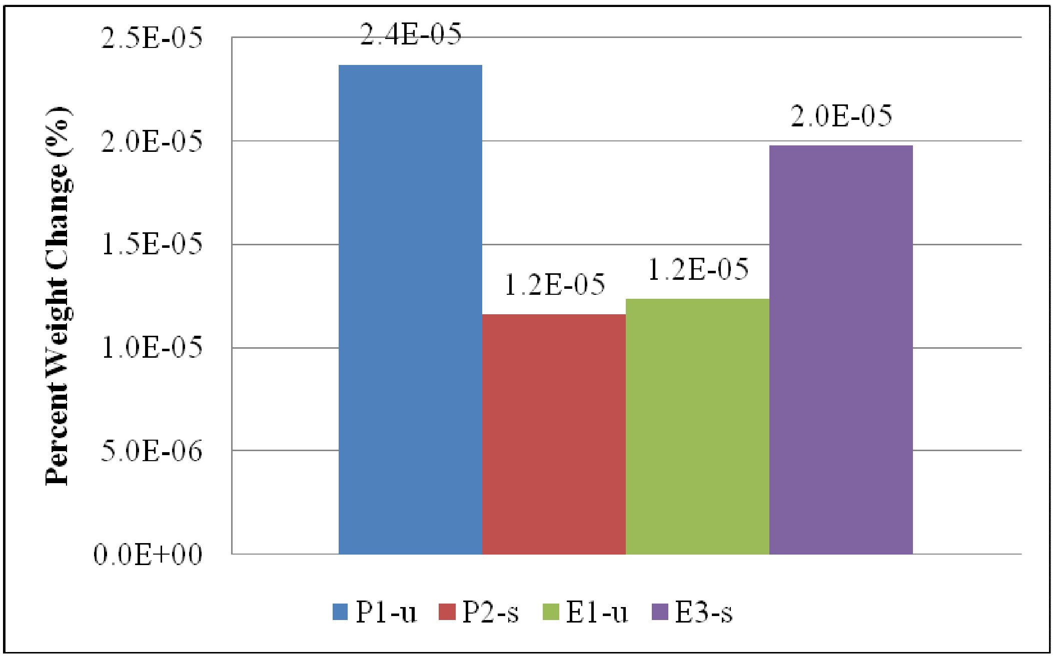


Figure 19 : Wet weight difference after 7 days

As stated earlier in Chapter 3, the wet weight difference signifies the amount of water absorb into the coating after exposure. From the figure 19 above, Specimen P1-U has the highest percentage of weight difference at 2.4E-05 %, followed by specimen E3-S, E1-U and lastly P2-S. Specimen P1-U (polyurea-unscribed) may have the greatest changes due to its ability to absorbs the moisture completely, but takes longer time to release the moisture as there is little seepage point in the coating as it is fully encapsulated with the coating. Specimen P2-S (polyurea-scribed) has the least wet weight changes because it is able to completely drain the moisture due to the opening from the scribed lines. Specimen E1-U & E3-S exhibits similar behavior to P1-U & P2-S. Scribed Specimen retained more moisture than unscribed.

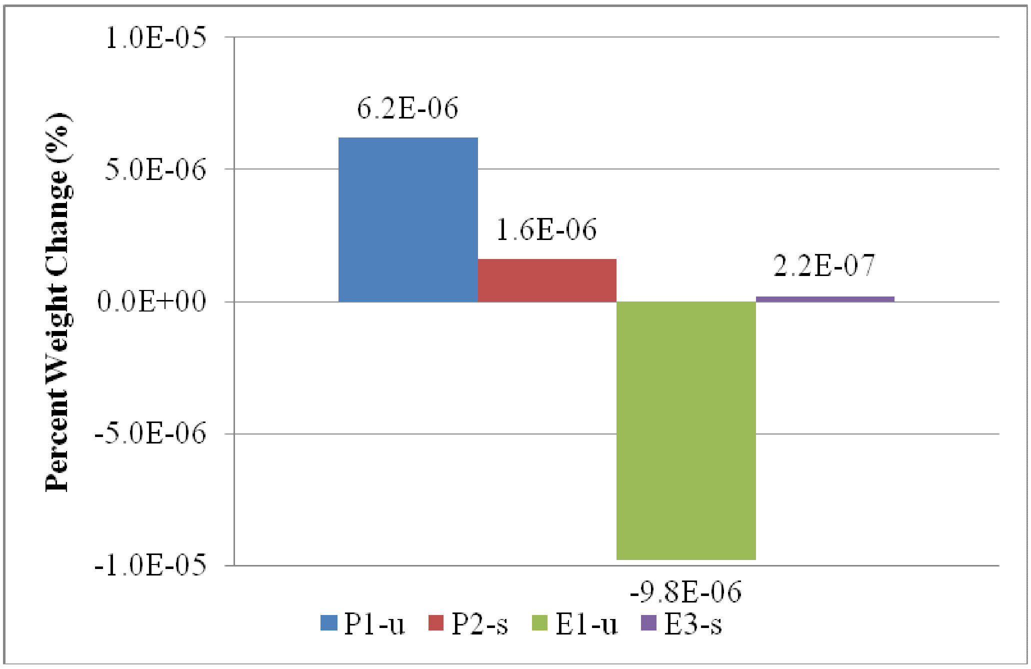


Figure 20 : Dry weight difference after 7 days

For the dry weight changes both specimen E1-U & specimen P1-U (unscribed specimens) have unexpected results. Specimen P1-U displayed the highest weight change in positive value (6.2E-06%), which according to the formulation suggests weight gained experience by the specimen. Specimen E1-U on the other hand experienced a negative value (-9.8E-06%) change which indicates mass lost. P2-S & E3-S have near similar results which have values ranging from 0~1.5% weight change.

4.3.3 Set B weight difference

Table 9: Weight change for set b – 14 days exposure

Specimen	P3-U	P4-S	E2-U	E4-S
Weight Before (G)	388.193	377.761	90.296	90.766
Wet Weight	389.026	378.529	95.251	94.82
Wet Difference	0.833	0.768	4.955	4.054
% Change (Wet)	2.1e-05	2.0e-05	5.5e-04	4.5e-04
Dry Weight	388.294	377.738	90.592	90.943
Dry Difference	0.101	-0.023	0.296	0.177
% Change (Dry)	2.6e-06	-6.1e-07	3.3e-05	2.0e-05

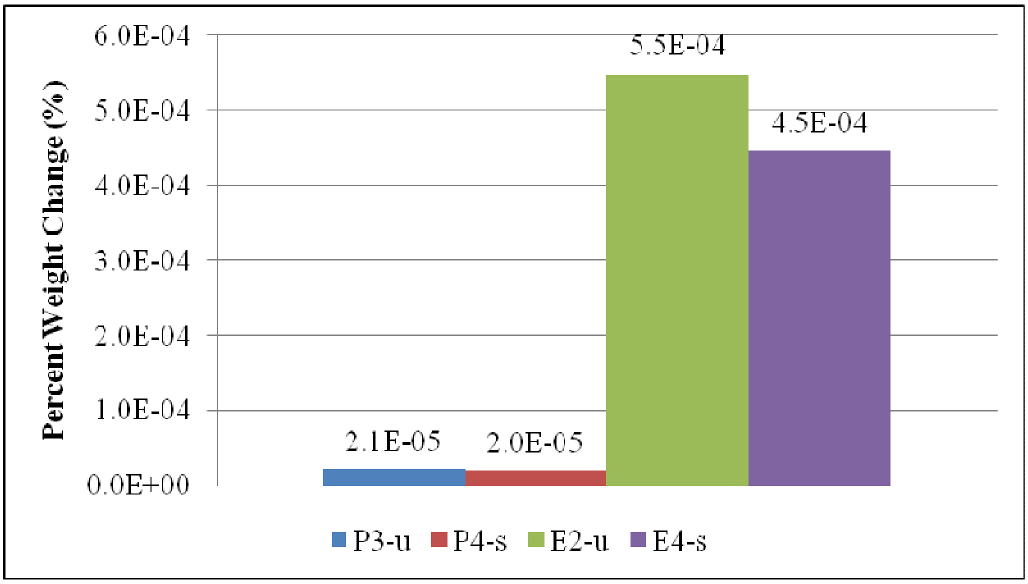


Figure 21 : Wet weight difference after 14 days

From Figure 21 , both epoxy coatings whether scribed or unscribed has gained tremendously in terms of weight change as compared to polyurea. The positive value suggests that epoxy has absorbed more moisture than the polyurea coating. This could be the reason why epoxy coating displayed patterns of dissolution upon inspection. Both polyurea coating on the other hand showed near similar weight difference which leads to believe that both polyurea have nearly the same amount of moisture ingression whether scribe or unscribed specimen.

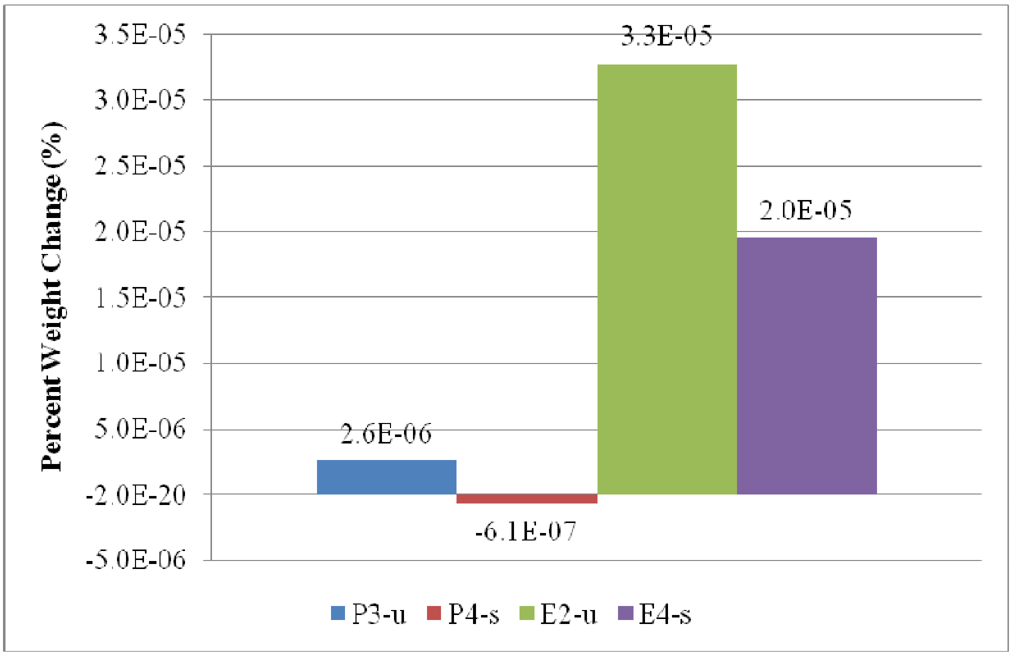


Figure 22 : Dry weight difference after 14 days

After drying the specimens, epoxy still has the highest weight difference between the two coatings. From the figure above specimen E2-U (epoxy unscribed) has the highest weight difference due to its inability to dissipate the moisture it retained, unlike E4-S which has a scribe line which allows moisture to dissipate through it. For polyurea specimen, specimen P4-S displays a negative value of -6.1E-07% change which could mean it has suffered mass lost. This could be due to part of the coating or substrate is gnawed away due to corrosion. Specimen P3-U (polyurea unscribed) shows positive weight difference, but a lower value than the Wet Weight Difference which leads us to believe that it has dissipated the moisture it absorbed during the exposure. The remaining positive value could possibly mean that it has yet to fully dissipate all of the moisture inside the coating due to little seepage point unlike the scribed specimen. Or it could also mean that there is an under film corrosion which could have transformed part of the substrate into oxides.

4.4 Combined Analysis

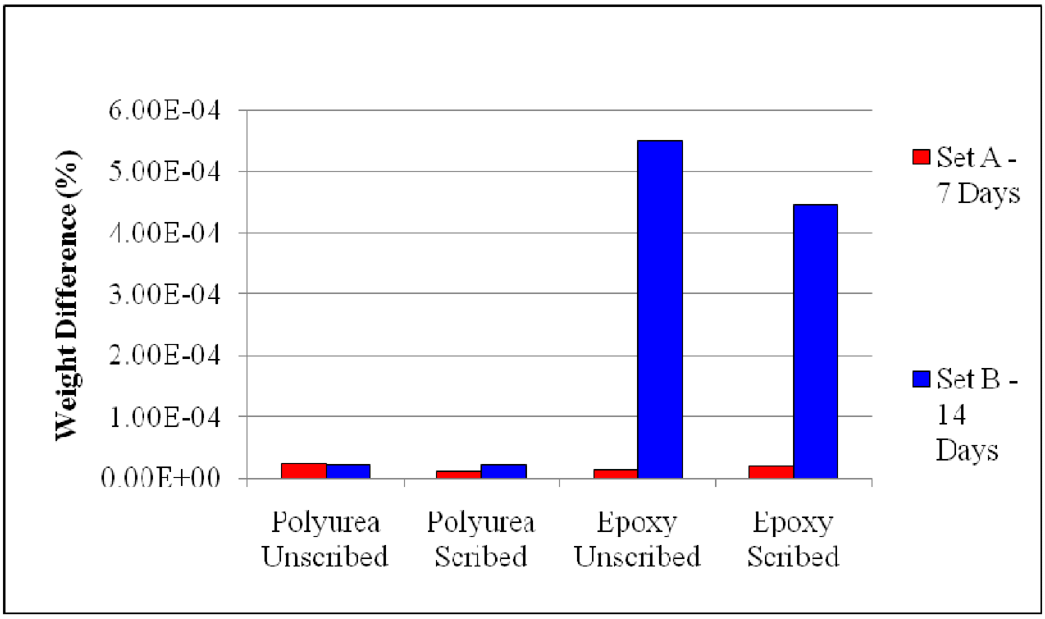


Figure 23 : Combined wet weight difference

The wet weight difference is relatively small amount for polyurea coating, which means there is little moisture ingress for polyurea specimens compared to epoxy. Set B epoxy specimen shows up to 44times more weight difference than the set a.

Difference is expected to be higher if exposure is continued on epoxy coating. Lower moisture ingress is the desired quality of protective surface coating as it will help to reduce possibility of blistering, cracking and other coating failure. Lower moisture ingress could also help to reduce the likely hood of corrosion of the substrate.

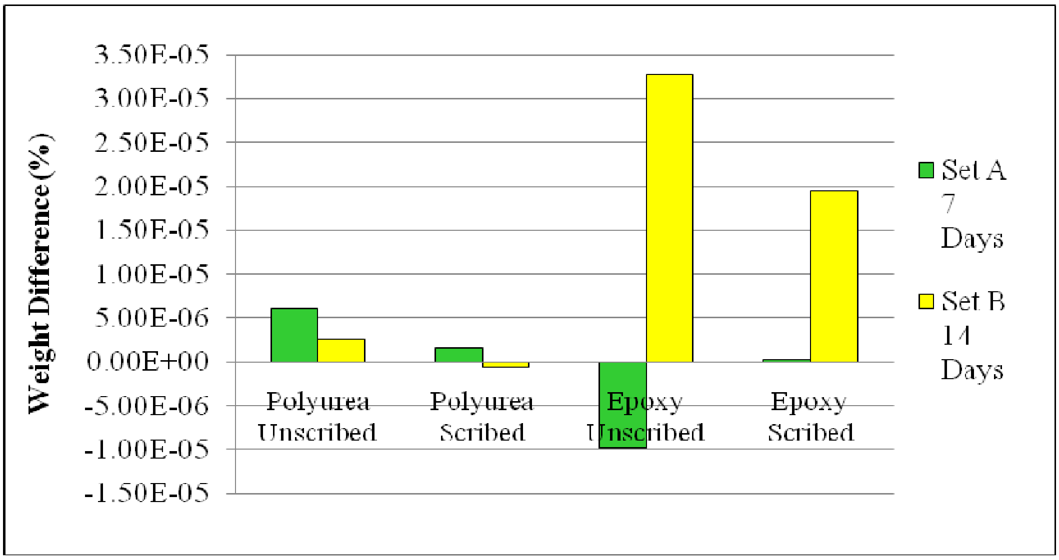


Figure 24 : Combined dry weight difference

Weight difference for polyurea decreases as the exposure increases from 7 days to 14 days exposure. Epoxy specimens shows high weight difference similar to wet weight difference. Negative value here suggest mass is lost after exposure due to coating degradation and peeling. Again polyurea displayed lower weight difference as compared to epoxy. polyurea scribed has a higher weight difference than unscribed because it has less seepage points to dissipate the moisture. This pattern is also seen on epoxy coating whereby the value of unscribed weight difference is higher than scribed weight difference.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the data obtained, it seems that the results do not have a definitive pattern to the behaviour of both coating under salt spray testing. Nevertheless, one thing clear is that on the physical qualities of the coating, polyurea displays far superior quality than epoxy. polyurea coating suffered no physical changes such as decolourization, blistering, pitting or thinning to its unscribed specimen. Both polyurea unscribed (P1-U & P3-U) specimens from Set A and Set B received a rating 10. Epoxy on the other hand suffered decolourization, blistering and a few areas of pitting. Specimen E2-U suffered 60% damage on its primary face of testing. This indicates the poor performance of epoxy coating in the salt spray testing.

As for the scribed specimens, polyurea also outshine epoxy coating with ratings of 9 and 9 for specimen P2-S and P4-S. Specimen E3-S and E4-S received ratings of 7 and 6. This is also another clear indication of polyurea’s superiority over epoxy coating.

Another point worth mentioning is the effect of time for the study. From Epoxy samples from Set B suffered tremendous change in Weight Difference as compared to Set A. This shows that if the exposure is prolonged, the extent of damage might increase exponentially until total failure of coating.

The results obtained were enough to conclude that polyurea is the better coating for salt spray testing. The result shown proves and also identifies the lack of performance epoxy coating under saline environment. The degree and characteristic were also identified and reported.

5.2 Recommendation

In accordance to PETRONAS Technical Standard (PTS), it is recommended that the ASTM D1654 procedure is carried out for a total duration 7 months. Unfortunately, due to limited resources and period of study, the testing was cut down to 14days. Nevertheless, results were obtained and were able to deliver early indication of performance of those coating in service.

Thus, it is suggested that for future study, the test period be prolonged to 7 months. This will give a better understanding on the long term effect of the accelerated testing. Furthermore, it also allows the researcher to better note the progression of corrosion and degradation of material if any.

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APPENDICES

APPENDIX A: Project Gantt chart

Semester 1

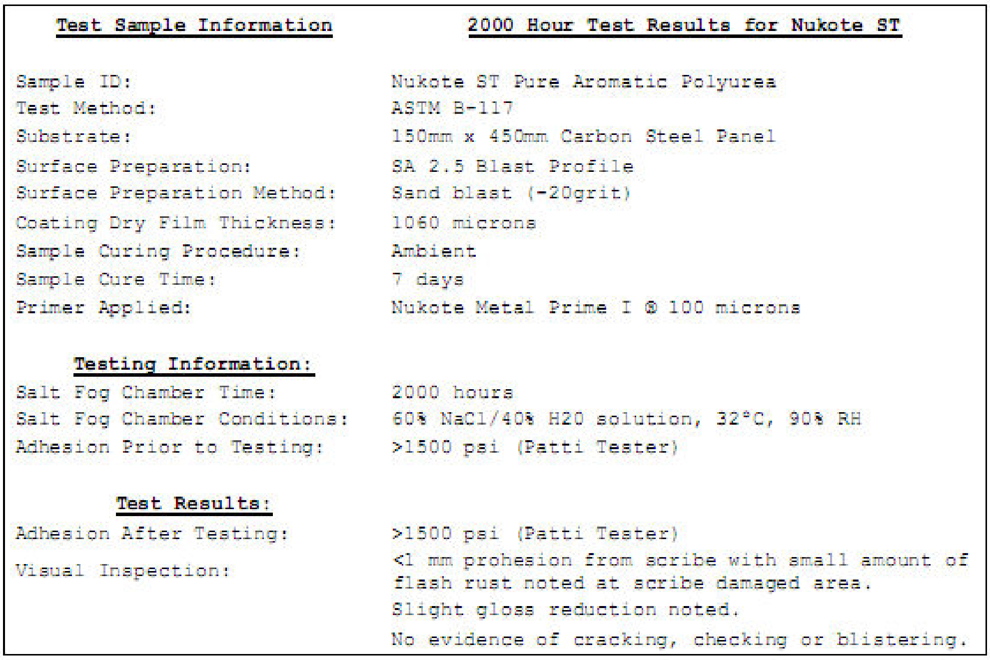
No	Progress Work	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	🟥	🟥												
2	Preliminary Research Work		🟥	🟥	🟥										
3	Submission of Preliminary Report				X										
4	Study of Polyurea Coating					🟥	🟥	🟥							
5	Locate Coating Supplier							🟥	🟥	🟥	🟥				
6	Submission Of Progress Report								X						
7	Acquire Substrate												🟥	🟥	🟥

Semester 2

No	Progress Work	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Obtaining Steel substrate	■	■												
2	Coating Scheduling			■											
3	Project Work														
	- Surface preparation				■										
	- Coating					■									
	- Curing						■								
4	Acquire NaCl							■							
5	Salt Spray Testing								■	■					
6	Result Analysis										■	■			
7	Final Dissertation												■	■	■

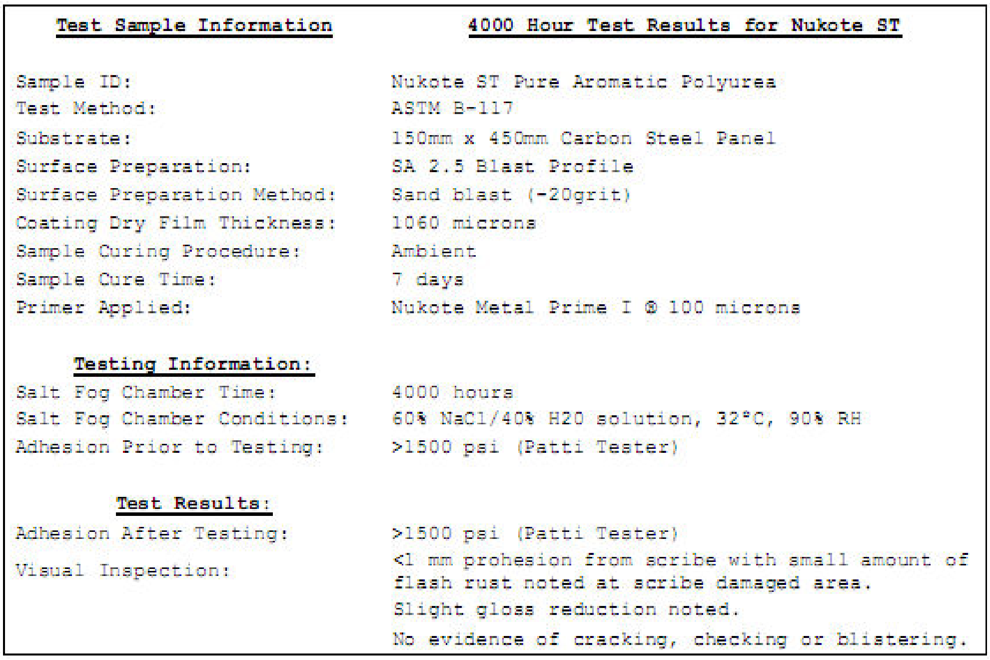
APPENDIX B: Wyatt Test Results

Nukote ST at 2,000 hour test results



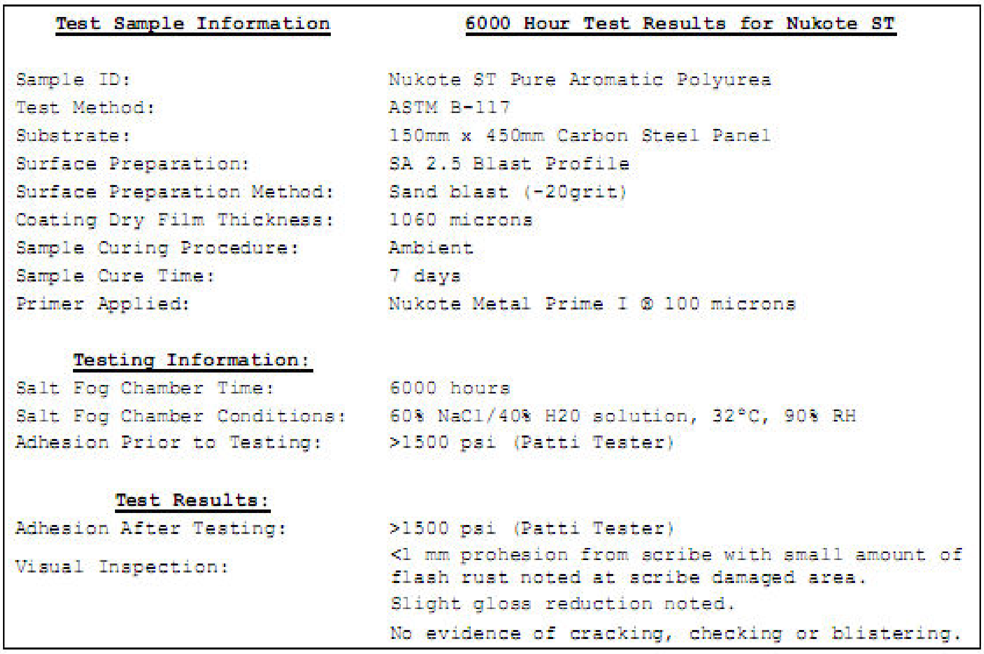
Test Sample Information	**2000 Hour Test Results for Nukote ST**
Sample ID:	Nukote ST Pure Aromatic Polyurea
Test Method:	ASTM B-117
Substrate:	150mm x 450mm Carbon Steel Panel
Surface Preparation:	SA 2.5 Blast Profile
Surface Preparation Method:	Sand blast (-20grit)
Coating Dry Film Thickness:	1060 microns
Sample Curing Procedure:	Ambient
Sample Cure Time:	7 days
Primer Applied:	Nukote Metal Prime I @ 100 microns
Testing Information:	
Salt Fog Chamber Time:	2000 hours
Salt Fog Chamber Conditions:	60% NaCl/40% H20 solution, 32°C, 90% RH
Adhesion Prior to Testing:	>1500 psi (Patti Tester)
Test Results:	
Adhesion After Testing:	>1500 psi (Patti Tester)
Visual Inspection:	<1 mm prohesion from scribe with small amount of flash rust noted at scribe damaged area. Slight gloss reduction noted. No evidence of cracking, checking or blistering.

Nukote ST at 4,000 hour test results



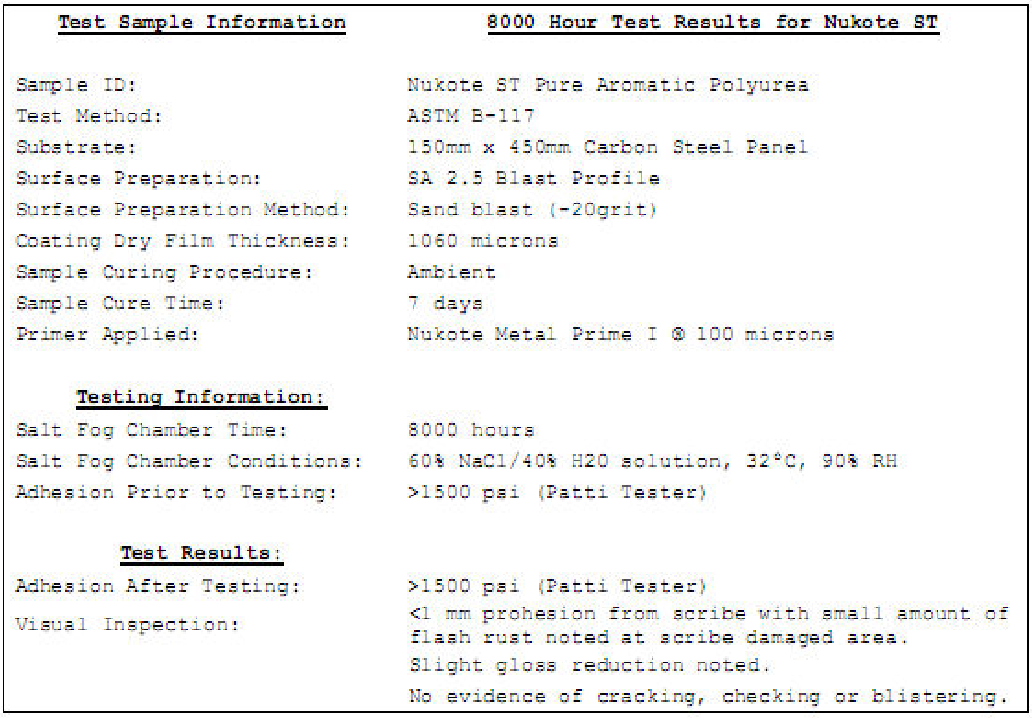
Test Sample Information	**4000 Hour Test Results for Nukote ST**
Sample ID:	Nukote ST Pure Aromatic Polyurea
Test Method:	ASTM B-117
Substrate:	150mm x 450mm Carbon Steel Panel
Surface Preparation:	SA 2.5 Blast Profile
Surface Preparation Method:	Sand blast (-20grit)
Coating Dry Film Thickness:	1060 microns
Sample Curing Procedure:	Ambient
Sample Cure Time:	7 days
Primer Applied:	Nukote Metal Prime I @ 100 microns
Testing Information:	
Salt Fog Chamber Time:	4000 hours
Salt Fog Chamber Conditions:	60% NaCl/40% H20 solution, 32°C, 90% RH
Adhesion Prior to Testing:	>1500 psi (Patti Tester)
Test Results:	
Adhesion After Testing:	>1500 psi (Patti Tester)
Visual Inspection:	<1 mm prohesion from scribe with small amount of flash rust noted at scribe damaged area. Slight gloss reduction noted. No evidence of cracking, checking or blistering.

Nukote ST at 6,000 hour test results



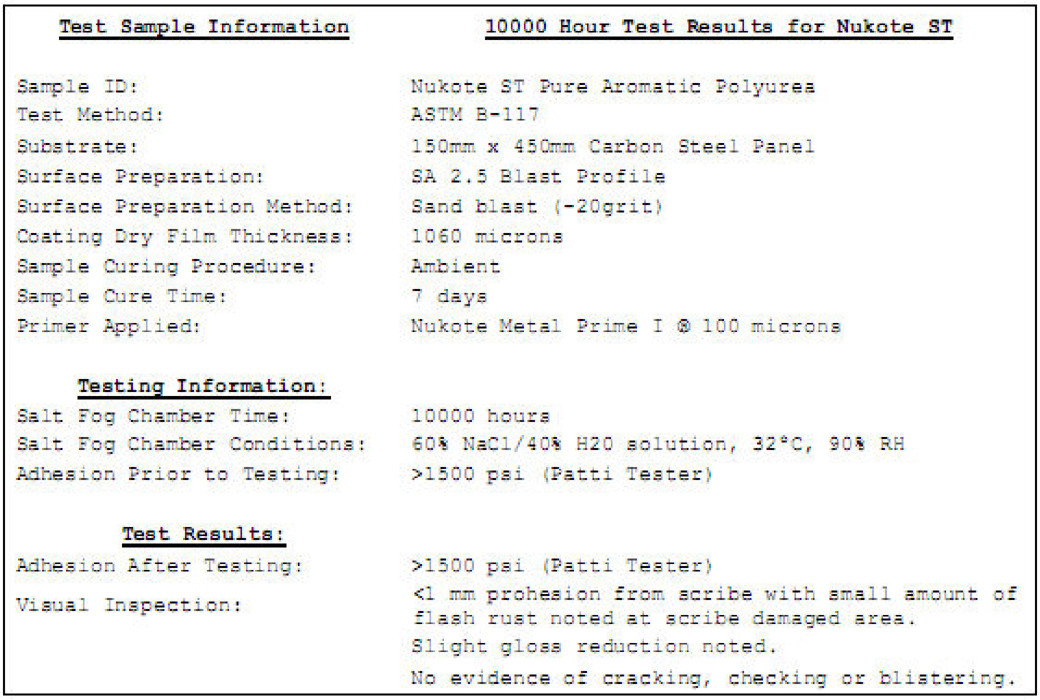
Test Sample Information	**6000 Hour Test Results for Nukote ST**
Sample ID:	Nukote ST Pure Aromatic Polyurea
Test Method:	ASTM B-117
Substrate:	150mm x 450mm Carbon Steel Panel
Surface Preparation:	SA 2.5 Blast Profile
Surface Preparation Method:	Sand blast (-20grit)
Coating Dry Film Thickness:	1060 microns
Sample Curing Procedure:	Ambient
Sample Cure Time:	7 days
Primer Applied:	Nukote Metal Prime I @ 100 microns
Testing Information:	
Salt Fog Chamber Time:	6000 hours
Salt Fog Chamber Conditions:	60% NaCl/40% H20 solution, 32°C, 90% RH
Adhesion Prior to Testing:	>1500 psi (Patti Tester)
Test Results:	
Adhesion After Testing:	>1500 psi (Patti Tester)
Visual Inspection:	<1 mm prohesion from scribe with small amount of flash rust noted at scribe damaged area. Slight gloss reduction noted. No evidence of cracking, checking or blistering.

Nukote ST at 8,000 hour test results



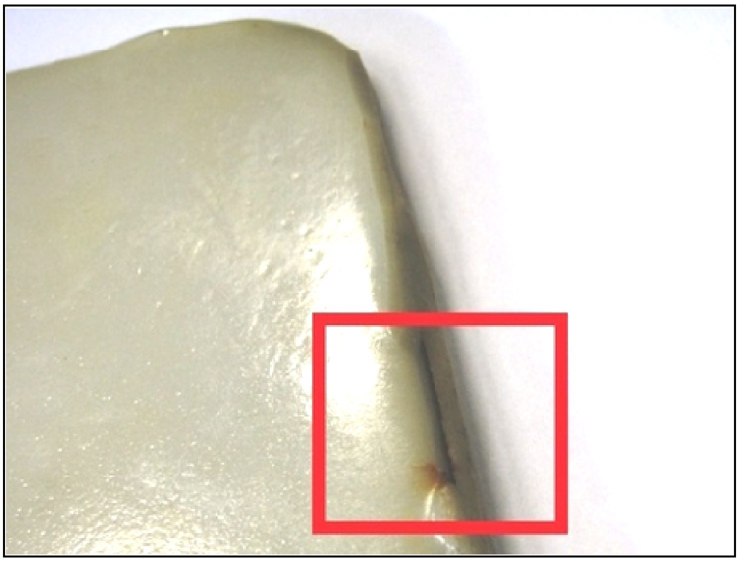
Test Sample Information	**8000 Hour Test Results for Nukote ST**
Sample ID:	Nukote ST Pure Aromatic Polyurea
Test Method:	ASTM B-117
Substrate:	150mm x 450mm Carbon Steel Panel
Surface Preparation:	SA 2.5 Blast Profile
Surface Preparation Method:	Sand blast (-20grit)
Coating Dry Film Thickness:	1060 microns
Sample Curing Procedure:	Ambient
Sample Cure Time:	7 days
Primer Applied:	Nukote Metal Prime I @ 100 microns
Testing Information:	
Salt Fog Chamber Time:	8000 hours
Salt Fog Chamber Conditions:	60% NaCl/40% H20 solution, 32°C, 90% RH
Adhesion Prior to Testing:	>1500 psi (Patti Tester)
Test Results:	
Adhesion After Testing:	>1500 psi (Patti Tester)
Visual Inspection:	<1 mm prohesion from scribe with small amount of flash rust noted at scribe damaged area. Slight gloss reduction noted. No evidence of cracking, checking or blistering.

Nukote ST at 10,000 hour test results

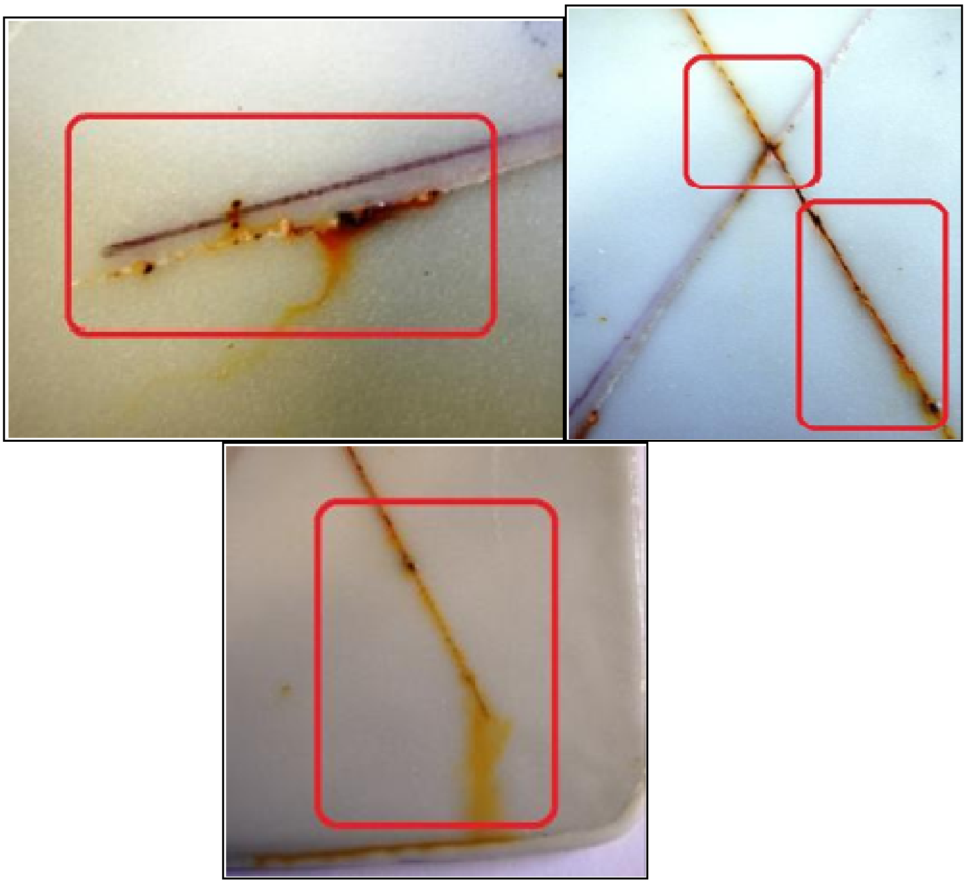


Test Sample Information	**10000 Hour Test Results for Nukote ST**
Sample ID:	Nukote ST Pure Aromatic Polyurea
Test Method:	ASTM B-117
Substrate:	150mm x 450mm Carbon Steel Panel
Surface Preparation:	SA 2.5 Blast Profile
Surface Preparation Method:	Sand blast (-20grit)
Coating Dry Film Thickness:	1060 microns
Sample Curing Procedure:	Ambient
Sample Cure Time:	7 days
Primer Applied:	Nukote Metal Prime I @ 100 microns
Testing Information:	
Salt Fog Chamber Time:	10000 hours
Salt Fog Chamber Conditions:	60% NaCl/40% H20 solution, 32°C, 90% RH
Adhesion Prior to Testing:	>1500 psi (Patti Tester)
Test Results:	
Adhesion After Testing:	>1500 psi (Patti Tester)
Visual Inspection:	<1 mm prohesion from scribe with small amount of flash rust noted at scribe damaged area. Slight gloss reduction noted. No evidence of cracking, checking or blistering.

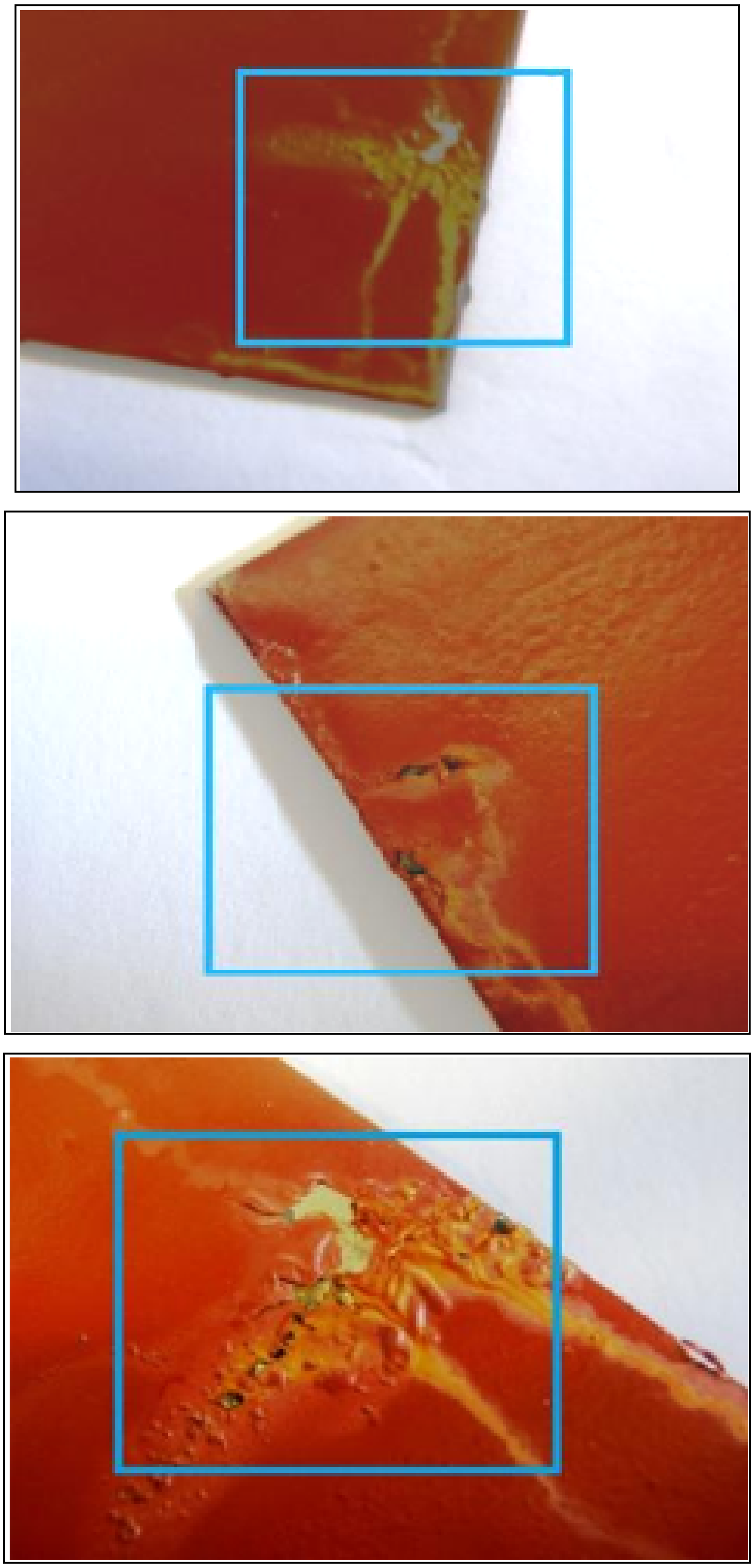
APPENDIX C: Defect Areas



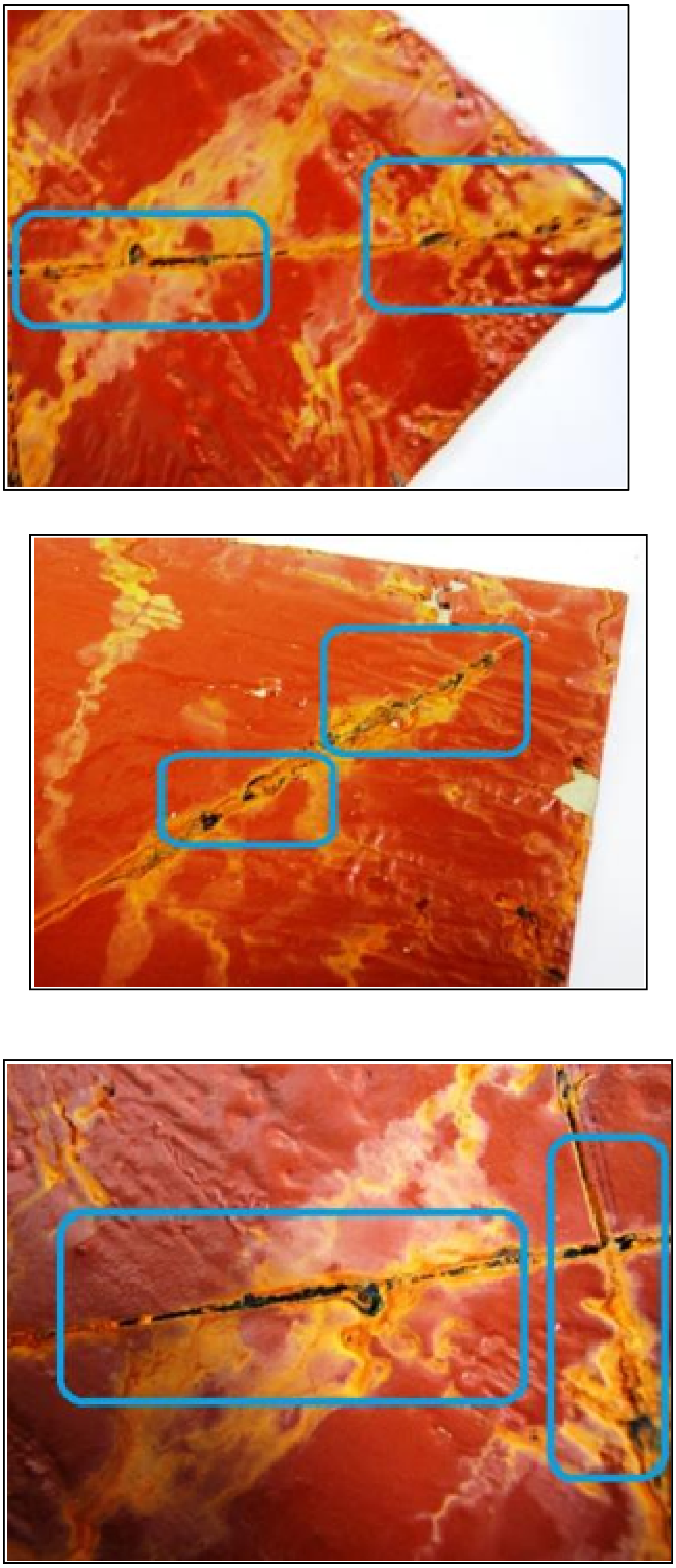
Rectangle area indicates 11mm opening on specimen a1



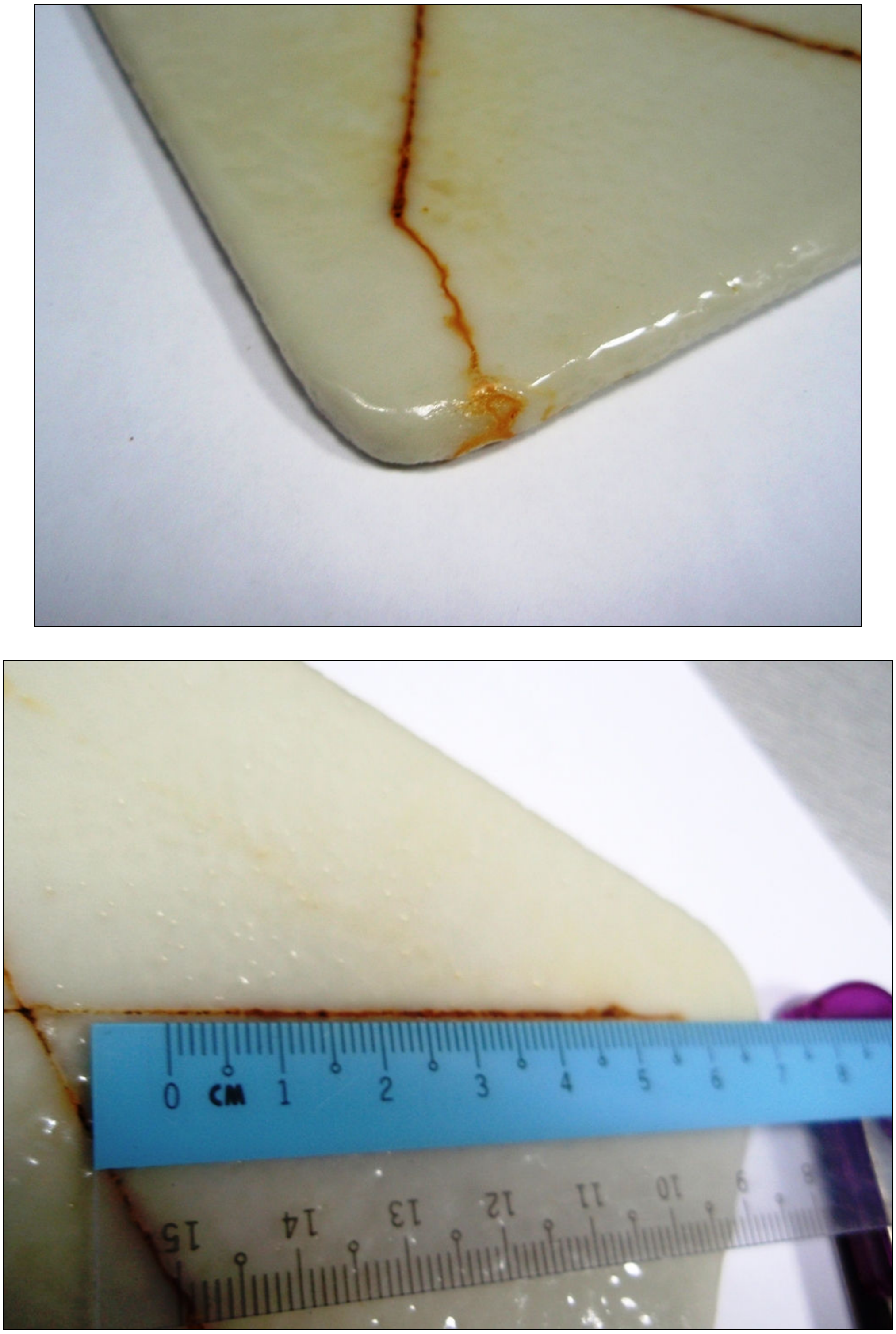
Specimen P2-S - defect areas



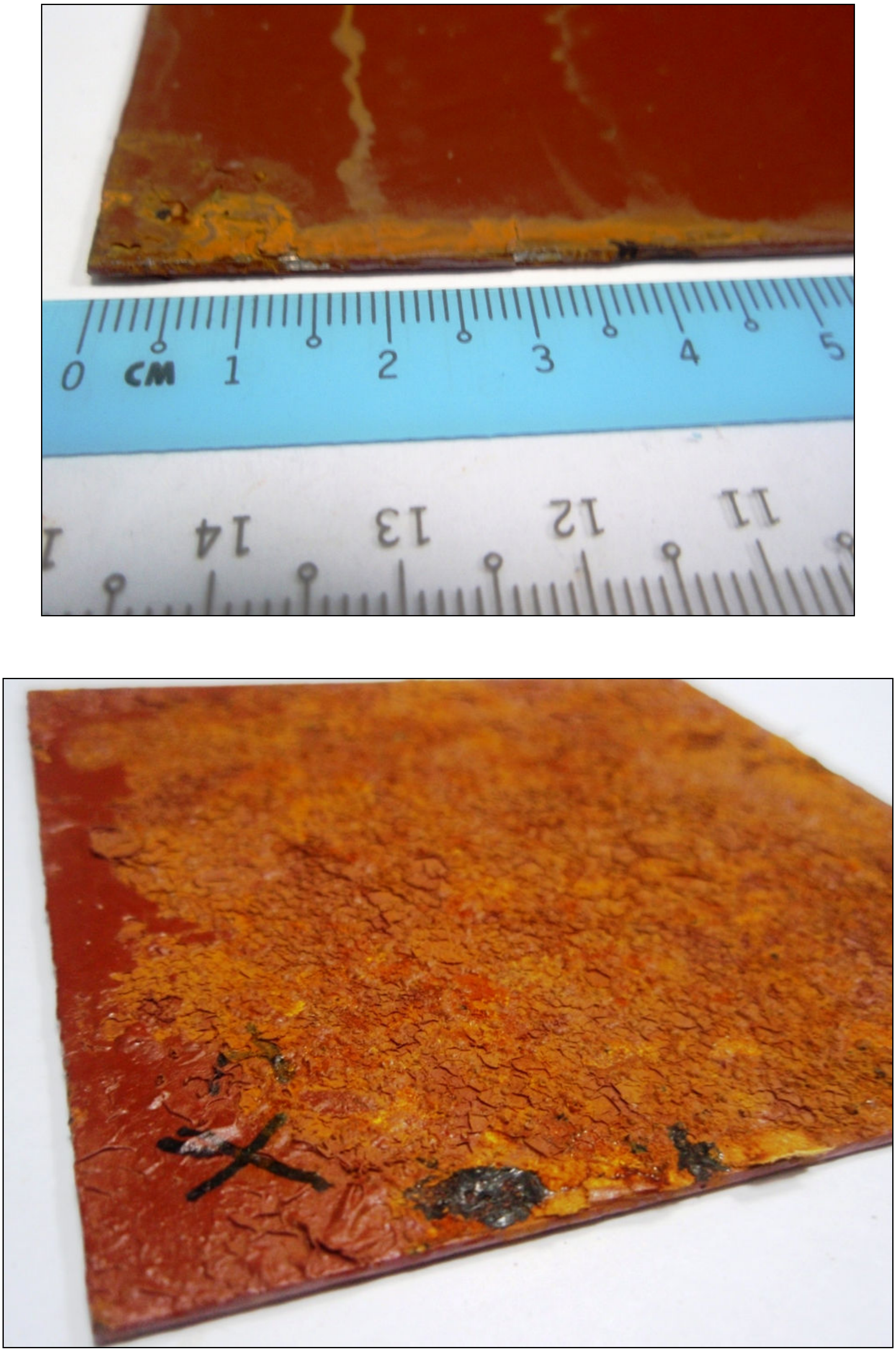
Specimen E1-U, From top; cracking – blistering - blistering



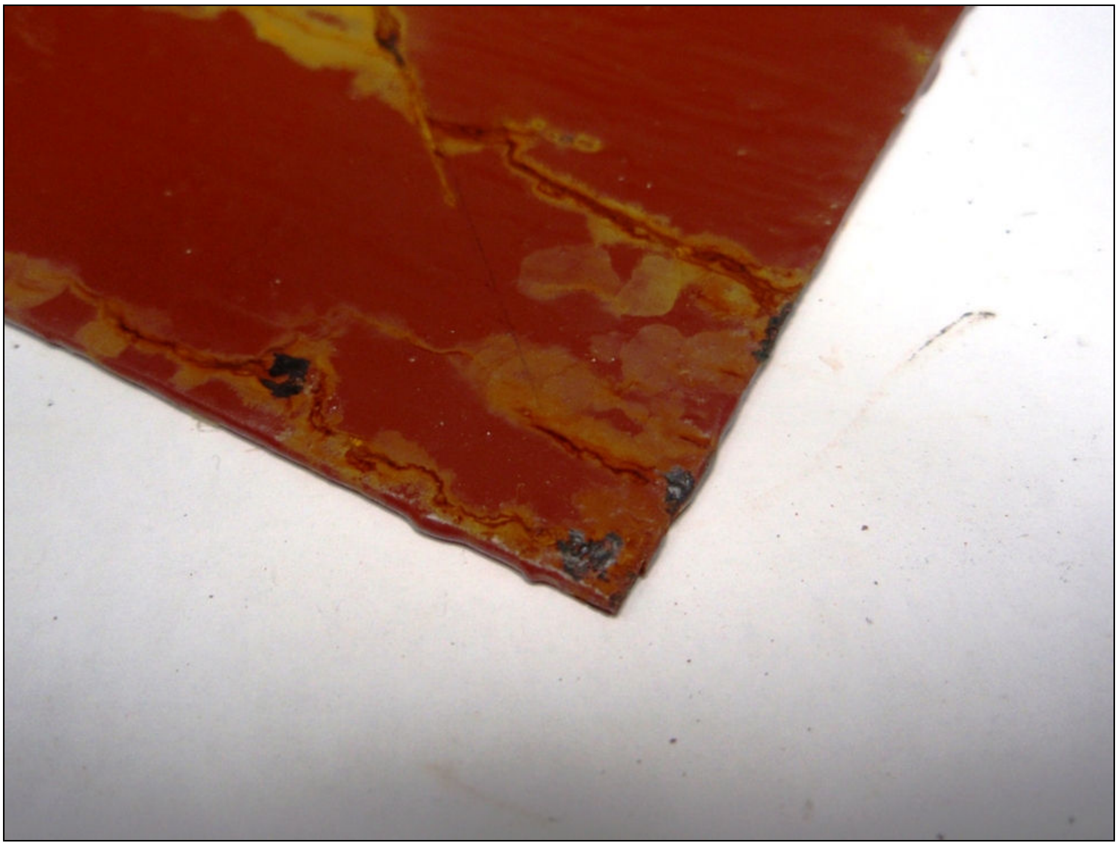
Specimen E3-S - Heavily corroded area on scribed lines

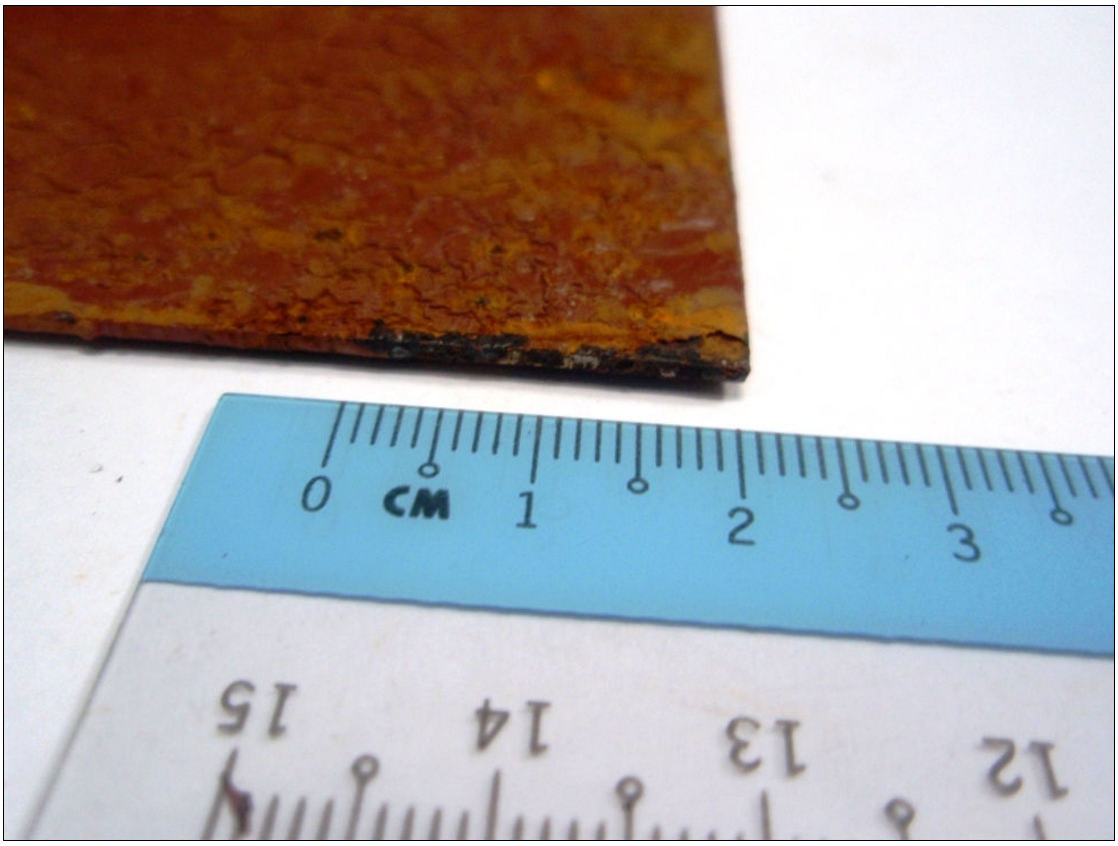


Specimen P3-S – Scribed lines



Specimen E2-U – Blisters and lost of adhesion failures

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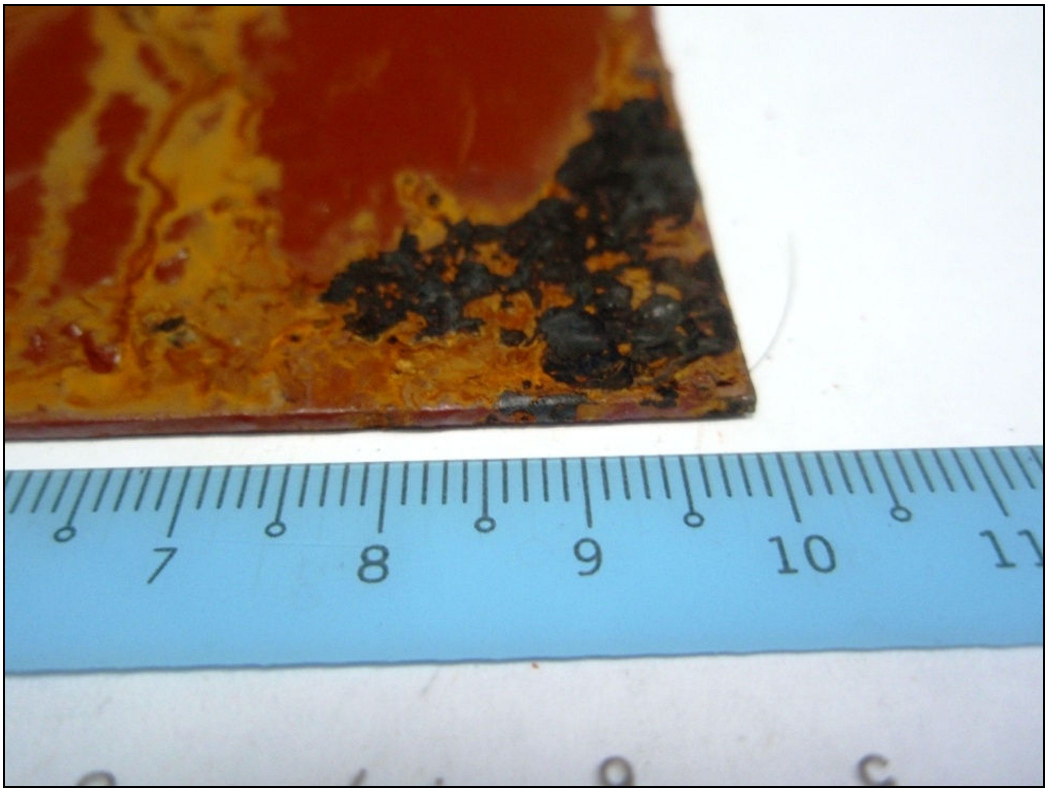
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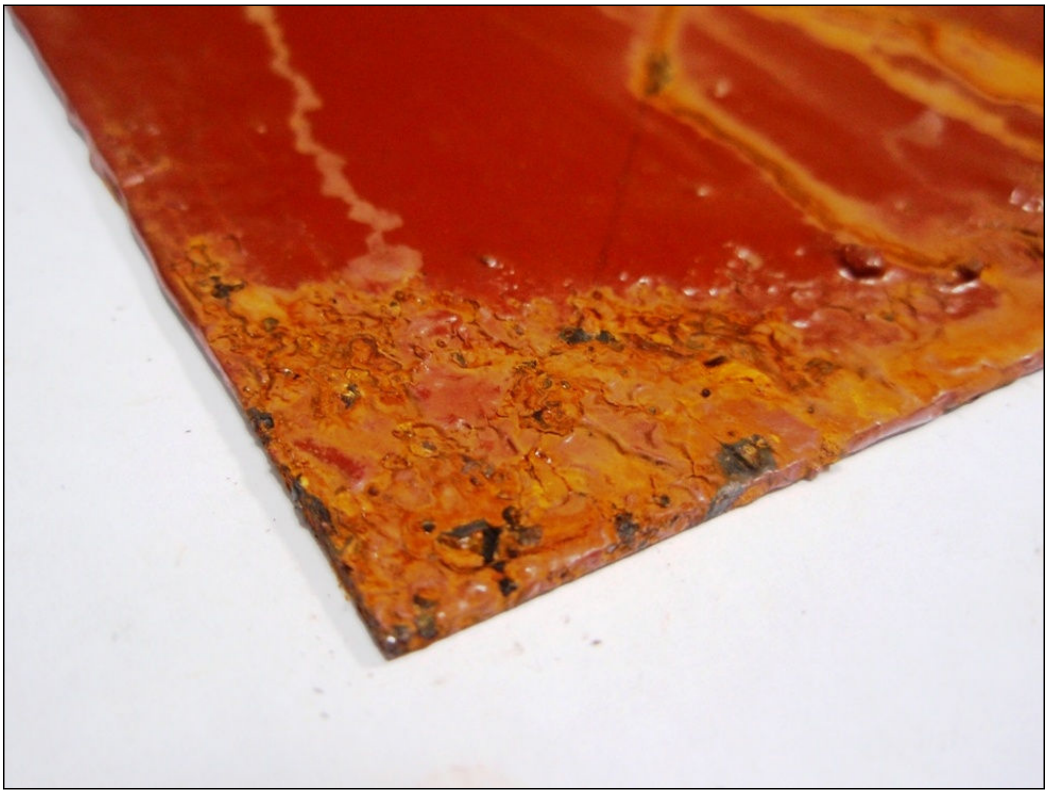

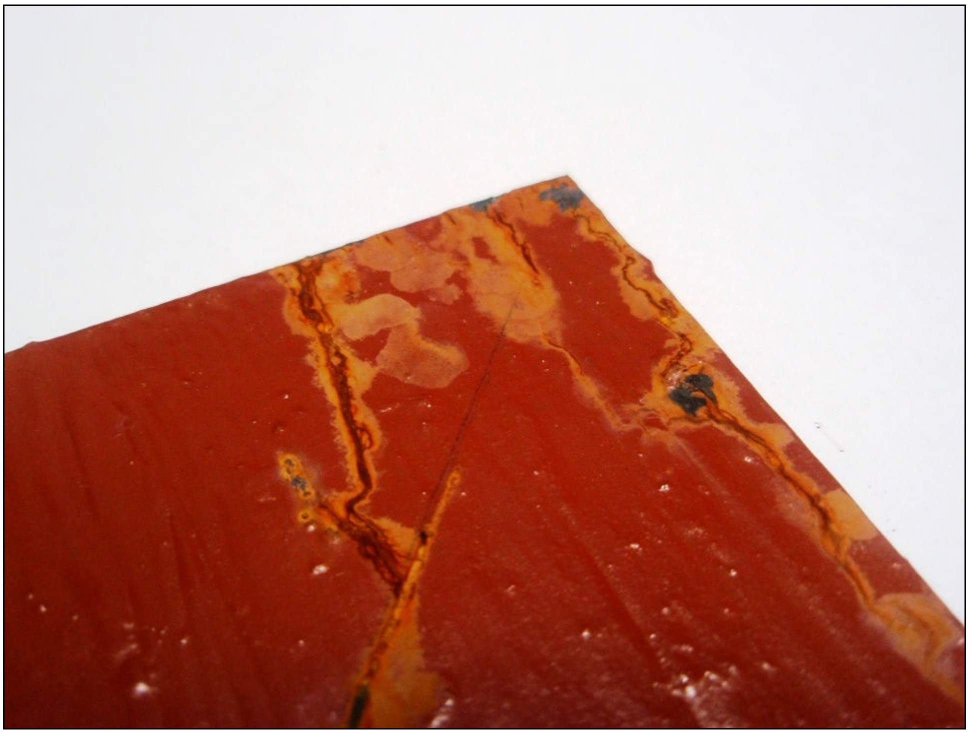

Specimen E4-S : Heavily corroded areas