Impact Resistance of Polyurea Coating

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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May 2010

CERTIFICATION OF ORIGINALITY

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

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Muhammad Syafeeq b. Ebining Amir

ABSTRACT

Coating failure commonly occurs in industry, and one of the major causes is impact. It is important to study the impact behavior of polyurea. It is expected that coating thickness will play an important role in the impact tolerance of the coating. Several coating fracture initiation has been expected to occur on the impacted surface. Prior to the testing, the substrate underwent surface preparation process. It was then coated up to the specified thickness. The specimen was then cut and prepared for the testing. The testing was done using an impact tester which was constructed by the author, according to ASTM D2794. The damage inspection was done using naked eye and the depth of damage was measured using a depth gauge. Cracking was observed at the coating which failed. The results were tabulated and discussed. It was found that the average impact resistance per millimeter of coating was 32.52 J/ mm. Moreover, it was noted that the thicker the coating, more impact depth is required to fail the coating. In conclusion, coating thickness did play significant impact in impact resistance of polyurea coating.

ACKNOWLEDGEMENTS

Praise to Him the Almighty that in His will and given strength, had I managed to complete this two semesters Final Year Project titled Impact Resistance of Polyurea Coating. Much has transpired during this period of time and I am in debt to so many who had made this project an illuminating and enriching venture. My deepest gratitude goes to my supervisor, Mr Ridzuan for the continuous support, supervision and countless hours spent in sharing his insightful understanding, profound knowledge and valuable experiences throughout the project accomplishment. Appreciation is also forwarded to Dyna Segmen Sdn Bhd, for supplying the specimens for the experiments. Thanks to my sponsor PETRONAS for supporting me throughout the studying phase in UTP. Great appreciation goes to the Final Year Project committee and UTP Mechanical Engineering Department lecturers for their help and kind support. Special recognition goes to the panel of examiners for their affirmative critics and kind evaluation on the assessment of the project. Credit also goes to my colleagues for their support and cooperation towards ensuring the completion of this project. Last but not least, I would like to thank my family for their love and never ending support. May the Almighty bless them all.

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CHAPTER 1

INTRODUCTION

1.1 Background

A tremendous amount of financial loss is incurred every year as a result of premature failures of paints and coatings. The cost to repair such failures far outweighs the initial cost of painting, since excessive rigging may be needed to access the failing areas. Additional liability may also be expected if a facility must stop operation for the necessary repairs to be made. Coating failures can occur for dozens of reasons, although they are typically a result of poor application, a defective coating, or an inadequate specification. A study of the fundamental causes behind coating failures is critical. Not only does this helping assigning financial responsibility, but knowing how a coating has failed is often the first step in understanding how to fix it.

It is common for polyurea like other type of coating, to experience failure, subsequently important for us to study at the causes of this failure, mainly due to physical impact forces. Physical stress can be imparted to a coating in a number of ways. These include post - forming coil coated stock, thermal expansion/contraction, vibration of the substrate due to nearby machinery, impact of falling objects, flexing due to people walking on thin - gauge galvanized roof decking, expansion contraction of coated wood due to changes in moisture content, and so forth. Thus it is important to study the impact resistance of polyurea when it is subjected to various impact forces. It is predicted that coating thickness plays a significant role in impact resistance of polyurea coating.

1.2 Problem Statement

Coatings can be easily damaged due to impact. When impacted, the damage is influenced by the impact force as well as the thickness of the coating. It is therefore significant to study the behavior of polyurea coating when subjected to various impact forces and coating thickness. [2]

1.3 Objectives and Scope of Study

The main objectives of this research project are as the following:

- To study the effect of various thickness of polyurea coating on the impact resistance of the material.

The study will provide us knowledge about impact resistance polyurea, as it is subjected to various impact forces when applied on steel metal plates based on ASTM D2794 standard.

CHAPTER 2

THEORY & LITERATURE REVIEW

2.1 POLYUREA

Polyurea is a special type of elastomeric which is widely used as coating material. It features a fast setting time (few minutes or less) as well as good chemical and fire resistance. Polyurea is frequently used on metallic substrates where it provides corrosion and abrasion resistance in harsh environments. Applications include transportation vehicles, pipelines, steel buildings or marine constructions.

Texaco Chemical , Now Huntsman ICI, developed the chemical concept of 100% solids polyurea spray elastomer coatings, based on the use of Jeffamine polyetheramines. This new chemical compositions displayed much higer physical properties than polyureathanes, was hydrophobic and included much higher temperature stability as well [2].

In 1992, application equipment was developed that provided the spray able capabilities requires for the products wide use. Product development within the industry has been ongoing with present formulations allowing for applications without added heat of high pressure resulting the present formula options of high-pressure spray, low pressure spray, injection, pour, even brush and roll-grade formulations now widely available [2].

Comparing to other type of coating, polyurea have a slight edge in front of them all. Polyurea is known to have extremely fast gel times, usually in seconds. They also contain none solvents or volatile organic compounds. Polyureatoo, if applied, are seamless and extremely durable coating that can be walked on within minutes of application, moreover moisture or adverse temperatures do not affect its cure. The manufacturer believes that the company which uses this type of coating surely would benefit from reduced energy costs, faster in-service times, longer pipeline life and true protection against the problems of older, under-performing coating systems.

2.1.1 Polyurea compositions

Polyurea chemistry is based on similar exorthermic reaction between di,or polyisocynates with the key difference being that the polyurea utilizes active hydrogen groups (amines) to form polyurea instead of polyurethane. This chemical difference causes much faster reaction period giving the polyurea group to faster gel, tack, and cure times critical to pipelines coatings, while providing the diserable cold temperature applicability and unlimited film builds similar to polyurethane.

The basic chemical difference also explains the reason that polyureas resolve the known weaknesses in polyurethanes such as curing problems in the presence of the moisture or high humidity and low chemical resistance.

Figure 1 describes the Polyurea chemical compositions [2].

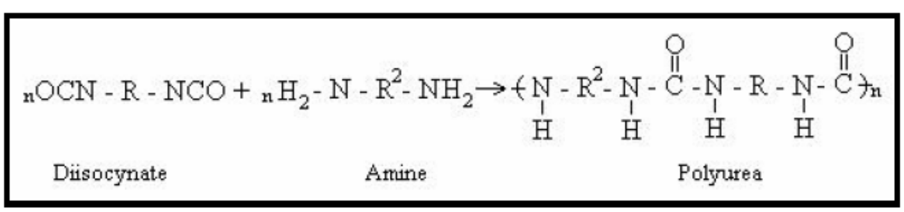

Figure 1: Polyurea chemical compositions

2.2 Type of polyurea

There are a host of polyurea coating that can be choose from, such as to be applied in the industry. The selection of which type of polyurea coating to be used normally based on the type of service, for example high temperature application and marine purposes, for example polyurea coating ST, was used for general purposes, and XT was used for extreme conditions such as high temperature environment.

2.3 Surface preparation process

In industry, the coating usually been applied to a prepared surface, as well as it will be applied to the substrate in the test. This since surface preparation is a critical factor in obtaining good adhesion [8]. Such preparation can affect not only the fundamental forces of bonding, but also the surface tension, and hence wetting. Surface preparation will affect on how well the polyurea coatings will work [10], and this is important to the test, since the result will be better if the coating is at their best during the impact testing.

There is lot of way to achieve the industrial surface finish method, as described in the PETRONAS technical standards. Several types of cleaning method for steels are described below.

2.3.1 Steel surface preparation [5]

2.3.1.1 Hand Tool Cleaning

Hand Tool Cleaning removes all loose mill scale, loose rust and other detrimental foreign matter. It is not intended that adherent mill scale, rust, and paint be removed by this process.

2.3.1.2 Power Tool Cleaning

Power Tool Cleaning removes all loose mill scale, loose rust, and other detrimental foreign matter. It is not intended that adherent mill scale, rust, and paint be removed by this process.

2.3.1.3 White Metal Blast Cleaning

A White Metal Blast Cleaned surface, when viewed without magnification, shall be free of all visible oil, grease, dirt, dust, mill scale, rust, paint, oxides, corrosion products, and other foreign matter.

2.3.1.4 A Brush-Off Blast Cleaned surface

When viewed without magnification, shall be free of all visible oil, grease, dirt, dust, loose mill scale, loose rust, and loose paint. Tightly adherent mill scale, rust, and paint may remain on the surface.

2.3.1.5 Water Blasting

Removal of oil grease dirt, loose rust, loose mill scale, and loose paint by water at pressures of 2,000 to 2,500 psi at a flow of 4 to 14 gallons per minute.

The nearest equivalents of the main surface preparation specifications are as listed in Table 1 below.

Table 1: Surface preparations and its equivalents.

NEAREST EQUIVALENTS OF THE MAIN SURFACE PREPARATION SPECIFICATIONS			
ABRASIVE BLAST CLEANING	**SSPC**	**ISO 8501-1**	**NACE**
EXTREMELY THOROUGH. WHITE METAL BLAST.	SP 5	Sa 3	No 1
VERY THOROUGH. NEAR WHITE METAL BLAST.	SP 10	Sa 2.5	No 2
THOROUGH. COMMERCIAL BLAST.	SP 6	Sa 2	No 3
LIGHT. BRUSH-OFF BLAST.	SP 7	Sa 1	No 4
TOOL CLEANING	**SSPC**	**ISO 8501-1**	**NACE**
EXTREMELY THOROUGH. POWER TOOL CLEANING.	SP 11	-	-
VERY THOROUGH. POWER TOOL CLEANING.	SP 3	St 3	-
THOROUGH. HAND TOOL CLEANING.	SP 2	St 2	-
SOLVENT CLEANING	**SSPC**	**ISO**	**NACE**
SOLVENT CLEANING	SP 1	-	-

2.4 Substrate

Substrate is defined as the surface, or specimen which the coating process will take place. The substrate usually was prepared using the discussed method in section 2.21, e.g. White Metal Blast Cleaning. According to ASTM D-609, substrates for the test preferably are cold rolled mild steel, or carbon steel.

Example of cold rolled mild steel specimen is shown in Figure 2 below.

Figure 2: Example of 0.45mm cold rolled mild steel

2.5 Polyurea coating application

The next step is to apply the coating. After the surface preparation was done, and the specimen was ready, the coating procedure shall take place. NCS Polyurea materials are one and two component, liquid applied polyurethanes. When properly combined and applied they cure to form tough, high strength elastomeric membranes. All specified quantities are minimums and are on an undiluted basis.

In order to apply the coating, there are certain criteria that have to meet. Surfaces must be thoroughly dry to ensure adhesion of all primers and coatings. In case of uncertainty, test the moisture with a moisture meter or 16 hour mat test (ASTM D-4263).

Dirt or dust which settles on surfaces before start of work or between coats must be removed. Surface temperature should be 10° or above because cooler surfaces may have ice, frost or condensation. Application of some coatings can be done at lower temperatures provided the surface is free of moisture. The ideal conditions for curing are 21° and 50% relative humidity [1].

No allowances have been made for material waste, uneven surfaces, spillage, material applied thicker than specified, or material left in containers or equipment [2]. The equipments used for coating application are described in Figure 3 and 4.

Figure 3: High pressure coating application equipment[2]

Figure 4: Low Pressure coating application equipment[2]

Formulations that require minimal applications pressure does not require added heat allow for the use of fewer complexes and less expensive equipment in the application process. These formulations typically exhibit slightly reduced physical properties than the high pressure formulations, but still maintain much higher physicals than traditional and create a wider range of contractors worldwide that are capable of applying the products correctly.

2.6 Mixing

It is important to note that all products must be mixed according to the product data sheets prior to application. The mixing process was usually done by professionals in industry, according to standards given by the manufacturer.

2.7 Impact Testing

The next step is to understand the concept of weight drop test. After the polyurea coating under test is applied to suitable thin metal panels, the coating shall be tested in order to analyze its strength when it was subjected against high impact forces. The test shall be conducted in accordance to Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact) ASTM D2794. [3]

The significant of this testing is that, coatings and substrates are subjected to damaging impacts during manufacture of articles and their use in service. ASTM 2794 has been found to be useful in predicting the performance of organic coatings for their ability to resist cracking caused by impacts.

The weight will drop from a certain position and will strike the indenter which lies on top of the coating. The indentation can be either **intrusion or extrusion** [4]. By gradually increasing the distance the weight drops, the point at which failure usually occurs can be determined. Usually films generally fail by **cracking** which is made more visible by use of magnifier, by applying $CuSO_4$ solution on steel, or by the use of a pin hole detector.

Figure 5 and 6 below describe the impact test. The indenter is located on the top of the substrate, resting on it, while the weight ball is dropped from a certain height. If we vary the height of the weight ball dropped, then we will have different value of force exerted on the coating surface.

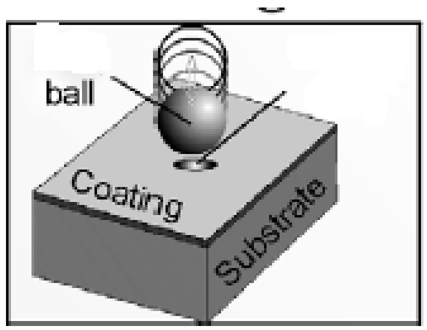

Figure 5: The examples on how the weight will drop onto the lying punch on the surface of the coating, thus indent the coating. Notice the test was done by the intrusion method (coating facing upward)

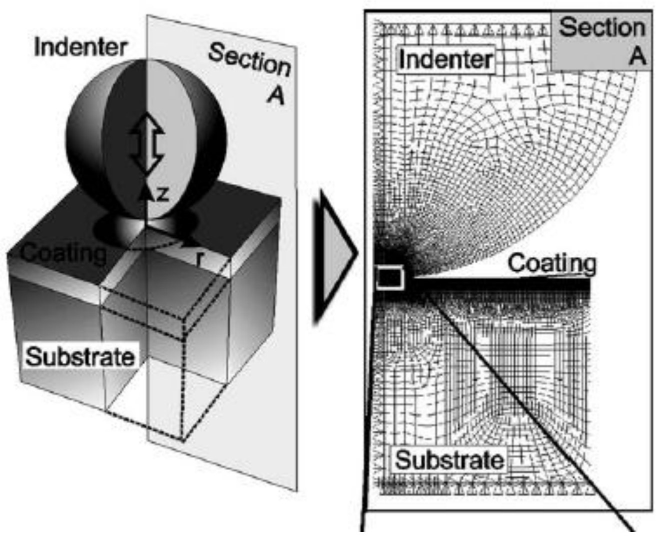

Figure 6: The cross section of the indenter and the impact zone at the coating [9].

2.8 The testing machine

The testing machine is basically the machine which the test will be conducted on. The testing machine for the purpose of the test has been built according to the ASTM D2794 standards. This is due to the unavailability of the campus to provide a suitable testing machine for test.

So the tester was fabricated in accordance with ASTM D2794. The testing rig include several components, such as;

a) Tester
b) A guide tube
c) A drop weight
d) Indenters
e) Panel support

Figure 7 below describes the impact testing rig.

Figure 7: Impact tester

The whole impact testing machine is called tester. The base is called the panel support which the specimen lays, and the pipes act as a guide tube. A guide tube functions to guide the impact so that it will strike the specimen precisely. The machine was designed so that it can withstand the capacity of impact up to 100J and its total height is 1.35 meter.

A weight, or drop weight is a cylindrical weight that was used to be dropped on the specimen. The weight was held stationary and was release as to strike an indenter which was laid on top of the specimen. The weight of the impactor varies depending on requirement of the test. Figure 8 below describes the impactor.

Figure 8: The impacter.

Indenter, or punch, is a steel metal punch with a hemispherical head having a diameter of 7.9mm. The punch laid on the coating panel as the weight is dropped. Figure 9 below describes the indenter.

Figure 9: The indenter

Note that only one indenter was used for every test. This was done to avoid any damaged punch used in any of the following test, thus maintaining the reliability of the results.

2.8.1 Impact energy calculation

Weight drop acceleration is calculated by applying the potential energy theory. Potential energy, or stored energy, is the ability of a system to do work due to its position or internal structure.

For example, gravitational potential energy is a stored energy determined by an object's position in a gravitational field while elastic potential energy is the energy stored in a spring.

As a form of energy, the SI units for potential energy are the joule (J) or newton-meter (N*m). Figure 10 below describes the impact testing procedure. The cylindrical weight will drop on the the indenter or punch, which in turn will indent the specimen.

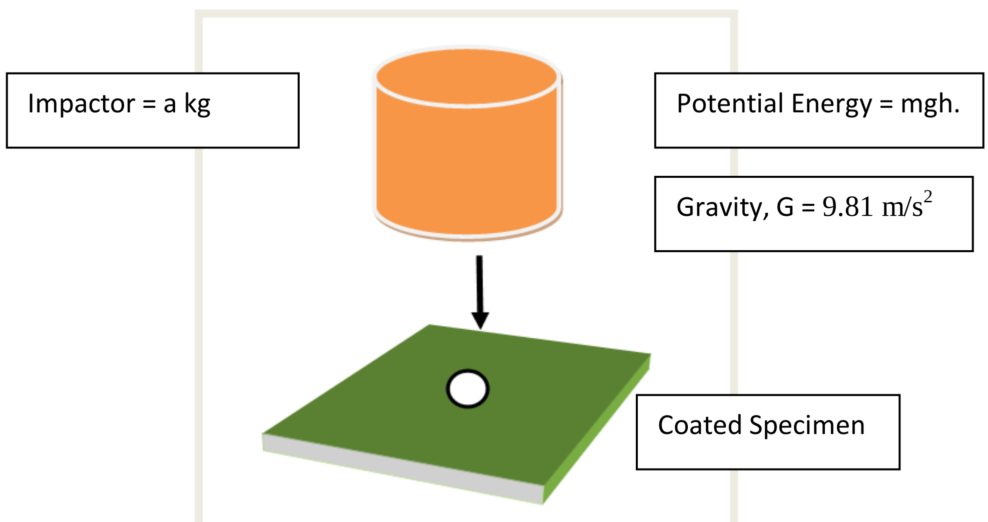

Figure 10: The impact test free body diagram

Let's take a look at an example calculation of the impact force. Let say the impacter weight is 1 kg, and the weight was released at the height of 1m. So the impact force would be,

$$
\begin{aligned}
\text{Impact force} &= \text{mass x gravity x height} \\
&= 1\text{kg x } 9.81 \text{ m/s}^2 \text{ x } 1\text{m} \\
&= 9.81 \text{ J}
\end{aligned}
$$

Note that just increasing the weight of the impacter, the amount of impact force will be increased too.

2.8.2 Related research on impact resistance of polyurea

The range of impact resistance of polyurea if the direct testing was done is about 60 in lb to 200 in lb, or **8 J up to 26.6 J** [12].

Example of impacted surface is shown in Figure 11. The material used was TiAlN, and was coated on a deposited on the typical bearing steel 100Cr6, and the research was done Withthe aid of FEM simulation of the impact test at the maximum ball-indenter penetration and during the specimen relaxation between successive impacts.

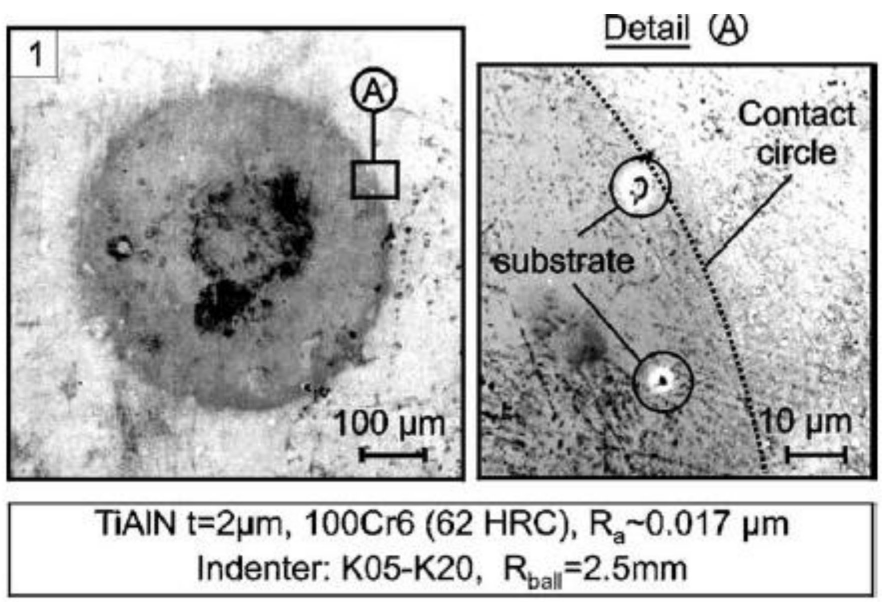

Figure 11 : Failure initiation of a TiAlN coating on a smooth surface deposited The possible causes of fracture are described in the section below [9].

2.8.3 Causes of fractures.

There are a few reasons why the TiAlN coating was fractured [9], which are

2.8.3.1 *Coating fracture initiation mechanisms due to fatigue*

During the impact test a severe plastic deformation of the substrate may occur. In order to determine the stress field in the coating–substrate compound

2.8.3.2 *Coating fracture initiation due to local overloadings, caused by the substrate roughness*

Roughness peaks can lead to local stress concentrations on the surface of bodies in contact, and thus coating damage due to overloading may occur.

2.8.3.3 *Contribution of the abrasive wear to the coating damage initiation during the impact test*

The failure initiation during the impact test of PVD and CVD hard coatings on smooth surfaces usually derives from fatigue phenomena. However, in relatively soft PVD coating cases, especially when the surface roughness is increased, the abrasive wear can represent a predominant film failure initiation mechanism. In a ball-on-flat contact case, the radial displacement of a body depends on its material properties and a relative sliding in the radial direction between the indenter and the coating–substrate compound is expected. This relative sliding is directly related to wear phenomena and its reliable estimation cannot be accurately and effectively achieved by means of FEM supported numerical methodologies

So base on the related research done, the basic expectation about how polyurea would behave under impact can be anticipated, thus makes it easier for the purpose of study.

2.9 The significant of thickness variation

In the industry, lots of cases regarding physical failure have occurred. So physical testing was important, this since it provides important characteristics of a paint or coating specimen which may reveal primary causes for the failure. Important physical tests include thickness test [11]. This is to confirm whether suitable thickness of coating was applied to the substrate,

CHAPTER 3

METHODOLOGY

3.1 Materials

The list of materials for this test will as follows.

1. Polyurea Coating Standard (ST)

Polyurea ST is used. ST stands for NCS's standard polyurea and it is designed for general purpose use. Consequently, it has been developed to perform well for anticorrosion and waterproofing applications on steel, concrete and many other substrates. It is a two component, 100% solids, that significantly reduces the moisture problems that commonly cause the pin holing and blistering in motst polyurethane or polyurethane-hybrid systems [2].

Nukote ST can be applied at temperatures ranging from -30oc to 70oc. Usually gray in color, it contain lots of features interesting features such as excellent elongation properties, seamless, resilient, and will not crack or check, which will be of interest the area of impact test study.

2. Steel Metal Panel

For this test, cold rolled, steel metal panels (compliance with Procedure A of Practice D609) was used. The condition should be 24h at 23 $\pm$ 2^oC and 50 $\pm$ 5% relative humidity. [4] Suitable metal panel dimension would be 100mm x 100mm x 0.63mm with tolerance of $\pm$2%. The total number of specimen are 4 according to ASTM, but considering contingency plan it should be about **8** for each group of specimen.

All of the coated specimens were supplied by Dyna Segmen Sdn Bhd.

3.2 Flow chart of the process

The flow chart for the impact testing is described in Figure 12.

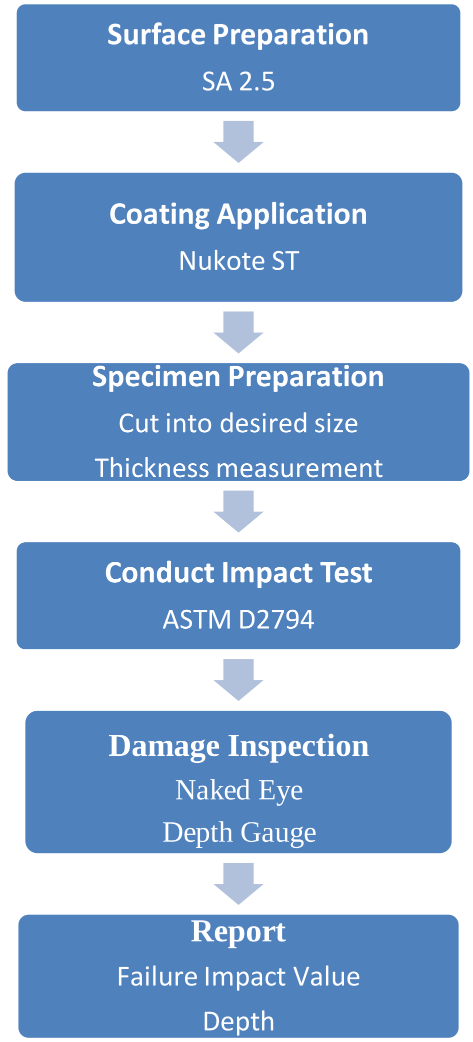

Figure 12: The process flow chart

Initially, the surface preparation, with industrial standards of SA 2.5, for the substrates will be conducted. The next step is to apply the coating. The coating application process will be conducted by industrial experts from Dyna Segmen Sdn Bhd. Nukote ST was the applied polyurea coating. Then the coated specimen will be cut into desired size and be packaged and labeled for test. Later the test will be conducted. Then the damage inspection will be done, through naked eye and depth gauge. The result of the report later will consist of the the impact failure end point, the depth which the coating failed and signs of cracks seen at the impacted area.

3.3 Surface preparation

3.3.1 Applicable standard for substrate

For the purpose of the test, the surface preparation of each of the specimen will be done according to Sa 2.5, as usually being done in industry [10]. This suits the purpose of the test since it will enhance the credibility and reliability of the test by having the industry level standards.

3.3.2 Method of preparation

The surface preparation for the steel metal panel was done on site by industrial experts from Dyna Segmen. Sdn Bhd.

3.4 Coating application

3.4.1 Coating Process

Coating application processes were conducted by industrial professionals from Dyna Segmen. The coating process took about 1 or 2 days to be finished.
The equipment that was used for coating will as mentioned in chapter 1, which is the high pressure coating application equipment and it was owned by Segmen Sdn Bhd. Figure 13 shows how polyurea coating being applied in industry.

Figure 13: Example of the polyurea coating is being applied by industrial expert of Dyna

3.5 Specimen Preparation

The coating application by Dyna Segmen was done on a 1m x 1m substrate, which was larger than the required size of 100mm x 100mm. The main reason for this was it was easier for the application process to take place if the specimen size was large enough so that it can withstand the pressure of the coating process.

Figure below shows the coated 1m x 1m specimen which undergoes the cutting process.

Figure 14: 1m x 1m polyurea coating was undergoing the cutting process.

The main purpose of the grinding was to lower the thickness of the coating at certain area so that the coating can be cut easily. After the cutting process was done, the sample was packaged and labeled to differentiate and group each other in their own group of thickness.

3.5.1 Thickness variation of coating

The coated specimens which were cut will be grouped into several groups. For this impact resistance study, the variable thickness would be 1mm, 1.5mm, 2mm and 2.5mm.

There will be about 4 set of specimen per group. The groups are summarized in the Table 2.

Table 2: Summarization of groups and its thickness variations

Groups	Thickness (mm)	Coating Type	Quantity
A1	1	ST	8
A2	1.5	ST	8
A3	2	ST	8
A4	2.5	ST	8

The samples of the coated specimens being cut into 100mm x 100mm, labeled and grouped are shown in figure 15 below.

Figure 15: Group A1, 1mm thickness specimens after the large coated specimens being cut, packaged and labeled. This process was repeated for other groups of thickness as well, namely group A2, A3, and A4.

3.5.2 Thickness verification of the coating

The thickness of the coatings need verification for its to be reliable for testing. Each of the test samples were checked to verify the thickness of each coating Groups. It was noted that the thickness in any groups of the coating did not exceed the coating tolerance which was about $\pm$10%.

3.6 The Impact Test - Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact) ASTM D2794.

In the previous section we have identified the type of polyurea to be used, the surface preparation, and the thickness variation groups for the impact test. The impact test shall be done according to Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact) ASTM D2794. [3] This test was conducted using the tester fabricated and was done in a controlled laboratory environment. The general procedure of the test was discussed in the next section.

3.6.1 Test general procedure

The general procedure for the impact test is as follows. The procedure was done according to the ASTM D2794 standards.

a) The coated polyurea was placed at the base support with the coated side up. The coated specimen was flat against the base support and that the indenter was placed on the top of the specimen.
b) The weight was raised up the tube to a height where it is expected that no failure will occur.
c) The weight was released so that it drops on the indenter.
d) The coated specimen was removed from the apparatus and observed are the impact area for cracks in the coating. If no cracks are evident, the procedure was repeated at a greater impact force.
e) The impacted was examined areas for cracking by one of the following methods
   i. By using naked eye. Use a magnifier to examine area of cracks
   ii. Depth gauge. To inspect the depth which the coating failed
f) For impact force level (J), the result were tabulated either the coating passed or failed.

This general method was used in determining the impact resistance of the polyurea coating. As discussed earlier, a punch or indenter only will be used once per testing. The summarization of impact force used in the test was attached in attachment1, and the impact force sample calculation was discussed earlier.

3.7 Damage inspection techniques

After the completion of the test, the coated specimen will undergo damage inspection process. There are lots of available techniques of non- destructible inspection techniques, but due to unavailability, damaged equipments and several of those techniques are being not feasible only visual inspection method can be used together with the depth gauge to monitor the depth which the coating failed.

3.7.1 Visual Inspection

To determine the type and extension of damage in the specimens, visual inspection was used. External damage caused by the impact is observed by visual inspection of the specimens. Usually, the impacted face of the specimen (the one on which the striker bar contacts) shows a concave indentation caused by the edge of the striker bar. The curvature of the indentation zone coincides with that of the striker tip. Damage inspection to CFRPs due to low velocity impact at low temperature [14] was done using this method.

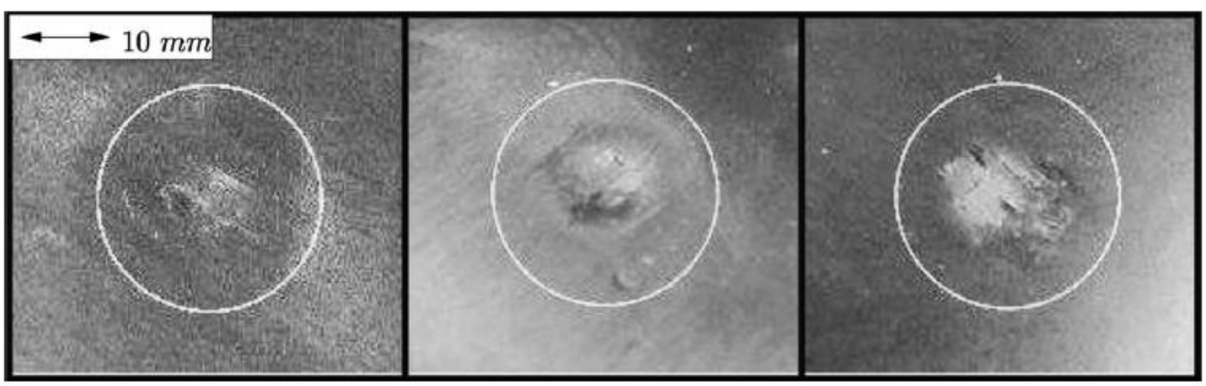

Figure 16: Effect of the temperature on the impacted side damage. Quasi-isotropic laminate impacted at 5 J. 20 (left), 260 (center) and 2150 8C (right)[14].

Indentation grows as impact energy increases and as temperature decreases. The depth of the indentation measured for each specimen varied between no indentation (cross-ply laminate impacted with 1 J at 20 8C) and 1.1 mm (woven laminate tested with impact energy of 13 J at 2150 8C). In all the laminates and test temperature conditions, fibre fracture and matrix cracks transverse to the fibres are seen in the indentation crater at the highest impact energies

3.7.2 Depth measurements

The depth of each impacted coating also being taken; this was mainly to determine the depth of which the failure occurred. The reading was taken by a depth gauge. A depth gauge micrometer is a precision measuring instrument, used to measure depths. Each revolution of the rachet moves the spindle face 0.5mm towards the bottom of the blind hole. The ratchet is turned clockwise until the spindle face touches the bottom of the blind hole. The scales are read in exactly the same way as the scales of a normal micrometer. The depth of impacted area will be tabulated in a table.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Surface preparation

The surface of the substrate after it was prepared with SA 2.5 industrial standards as shown in Figure 17.

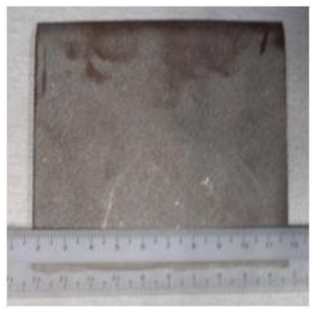

Figure 17: Cold rolled substrate after been prepared with SA2.5 industrial standards.

After the surface preparation has been done, the coating application process took place.

4.2 Coating application

The coating application process was done by Dyna Segmen industrial experts. The specimens were prepared using large steel plates, 1m x 1m in size and were cut into small pieces. Figure 18 below describes the specimen after being cut into desired dimension (100mm x 100mm).

Figure 18: Specimen A1 after being cut into desired dimension.

4.3 Impact Test Result for Group A1

After the specimen was prepared and ready, the testing was conducted. The test was done according to ASTM D2794, and below are results for various thickness groups.

4.3.1 Specimen No 1 /1mm

Figure 19 describes the results for specimen no 1 /1mm.

Figure 19: Specimen 1/1mm after being impacted with 3.15 J

It was observed that no indentation occurred and the coating had passed.

Table 3 below summarizes the results for impact testing on this specimen

Table 3: Results for Specimen No 1/1mm

Impact Force (J)	3.15
Impact Depth (mm)	0
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.3.2 Specimen no 7/1mm

Figure 20 below describes the results for specimen no 7 /1mm.

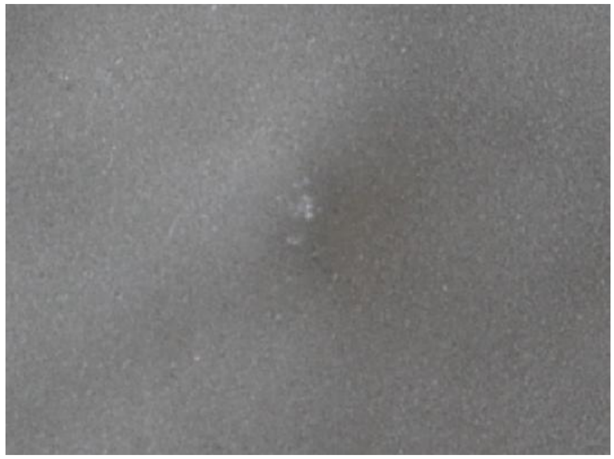

Figure 20: Specimen 7/1mm after being impacted with 23.02 J. Very minor crack observed.

Indentation was observed at the impacted area. No sign of cracking observed. Table 4 below summarizes the results for impact testing on this specimen

Table 4: Results for Specimen No 7/1mm

Impact Force (J)	23.02
Impact Depth (mm)	0.65
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.3.3 Specimen No 3/1mm

Figure 21 describes the results for specimen no 3 /1mm.

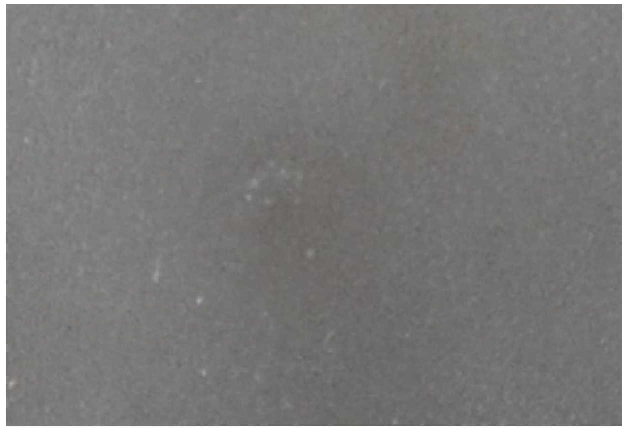

Figure 21: Specimen 3/1mm after being impacted with 25.01J. Notice the slight indentation.

For this specimen, indentation can be seen at the impacted area. The slight crack signs were there. Table 5 summarizes the results for impact testing on this specimen

Table 5: Results for Specimen No 3/1mm

Impact Force (J)	25.01
Impact Depth (mm)	0.69
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.3.4 Specimen No 4/1mm

Figure 22 describes the results for specimen no 4 /1mm.

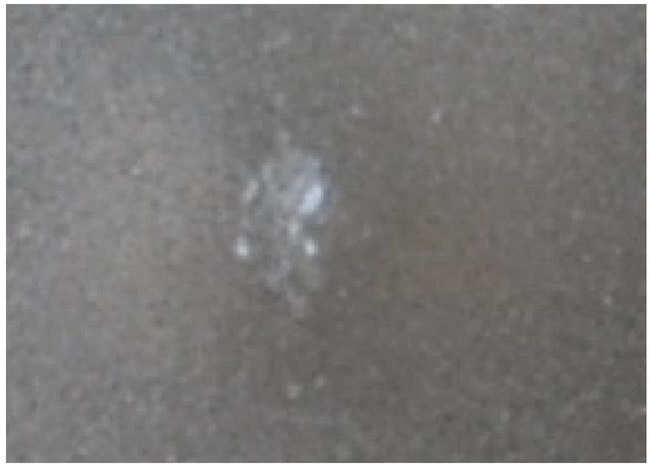

Figure 22: Specimen 4/1mm after being impacted with 31.09 J. Crack observed.

Indentation noted on the surface. The steel plates are damaged due to the impact forces. Cracking sign observed at the center of the impacted surface. The coating failed. Table 6 below summarizes the results for impact testing on this specimen

Table 6: Results for Specimen No 4/1mm

Impact Force (J)	31.09
Impact Depth (mm)	0.78
Pass/ Fail	Fail
Coating Type	ST
Punch dia.(mm)	7.9

4.4 Impact Test Result for Group A2

4.4.1 Specimen no 3/1.5mm

Figure 23 describes the results for specimen no 3 /1.5mm.

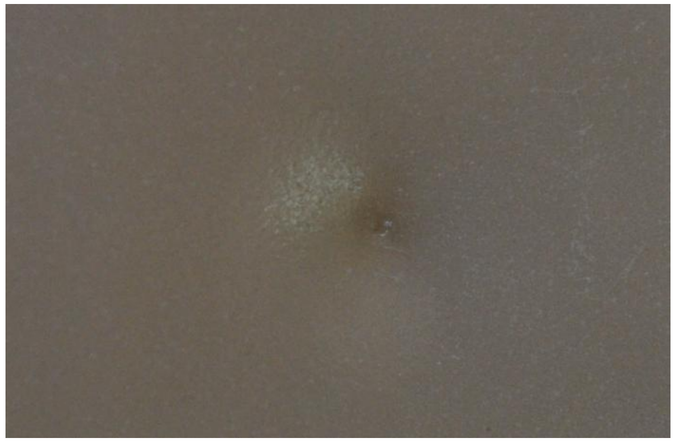

Figure 23: Specimen 3/1.5mm after being impacted with 25.30 J.

Indentation was noted, but the cracks sign was not there. The coating passed the test. Table 7 below summarizes the results for impact testing on this specimen.

Table 7: Results for specimen number 3/1.5mm

Impact Force (J)	25.30
Impact Depth (mm)	0.61
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.4.2 Specimen no 4/1.5mm

Figure 24 describes the results for specimen no 4 /1.5mm.

Figure 24: Specimen 4/1.5mm after being impacted with 31.62 J.

Deeper indentation was noted, 0.87mm, but the cracks sign was not there. The coating passed the test. Table 8 below summarizes the results for impact testing on this specimen.

Table 8: Results for Specimen No 4/1.5mm

Impact Force (J)	31.62
Impact Depth (mm)	0.87
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.4.3 Specimen no 1/1.5mm

Figure 25 describes the results for specimen no 1 /1.5mm.

Figure 25: Specimen 1/1.5mm after being impacted with 45.76 J.

From the figure above it can be seen that indentation, much deeper than specimen 2 was noted, but the cracks sign was not there. The coating passed the test. Table 9 summarizes the results for impact testing on this specimen.

Table 9: Results for specimen no 1/1.5mm

Impact Force (J)	45.76
Impact Depth (mm)	1.11
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.4.4 Specimen no 5/1.5mm

Figure 26 below describes the results for specimen no 5 /1.5mm.

Figure 26: Specimen 5/1.5mm after being impacted with 49.80 J.

Slight crack signs are visible at the center of the impacted area. The coating failed. Impact depth is about 1.31 mm depth. Table 10 below summarizes the results for impact testing on this specimen

Table 10: Results for specimen no 5/1.5mm

Impact Force (J)	49.80
Impact Depth (mm)	1.31
Pass/ Fail	Fail
Coating Type	ST
Punch dia.(mm)	7.9

4.5 Impact Test Result for Group A3

4.5.1 Specimen no 4/2mm

Figure 27 below describes the results for specimen no 4 /2mm.

Figure 27: Specimen 4/2mm after being impacted with 31.09 J.

For this specimen, a very minor indentation can be seen at the impacted area. No signs of cracking observed. It was important to note that 1mm coating failed at this 31.09 J impact force whilst the 2mm coating did not. Table 11 below summarizes the results for impact testing on this specimen

Table 11: Results for specimen no 4/2mm

Impact Force (J)	31.09
Impact Depth (mm)	0.87
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.5.2 Specimen no 5/2mm

Figure 28 describes the results for specimen no 5 /2mm.

Figure 28: Specimen 5/2mm after being impacted with 37.96 J.

Indentation was noted, but with no crack signs. Table 12 summarizes the results for impact testing on this specimen.

Table 12: Results for specimen no 5/2mm

Impact Force (J)	37.96
Impact Depth (mm)	0.65
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.5.3 Specimen no 6/2mm

Figure 29 describes the results for specimen no 6 /2mm.

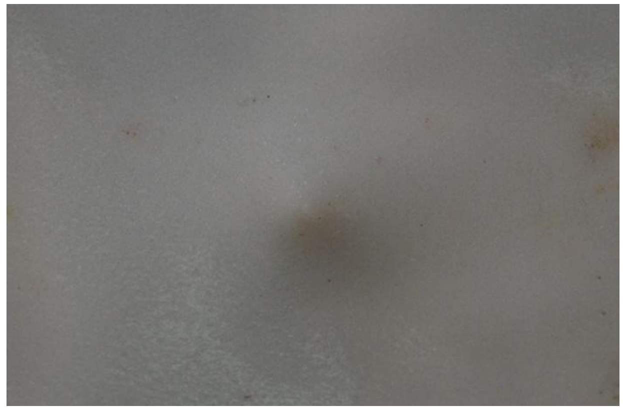

Figure 29: Specimen 6/2mm after being impacted with 51.24 J.

Deeper indentation was noted, but with no visible crack signs. The coating still passes the test. Table 13 below summarizes the results for impact testing on this specimen.

Table 13: Results for specimen no 6/2mm

Impact Force (J)	51.24
Impact Depth (mm)	1.35
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.5.4 Specimen no 7/2mm

Figure 30 describes the results for specimen no 7 /2mm.

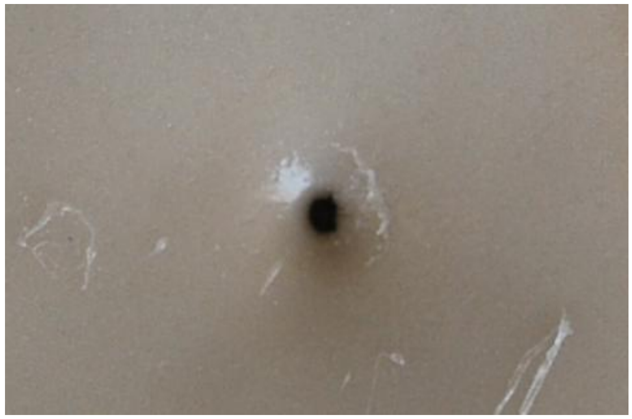

Figure 30: Specimen 7/2mm after being impacted with 65.28 J.

The specimen failed catastrophically. Coating at the impacted area was tear from the substrate, and the impact force was high enough for the punch to make hole at the coating. The coating failed. Table 14 below summarizes the results for impact testing on this specimen.

Table 14: Results for specimen no 7/2mm

Impact Force (J)	65.28
Impact Depth (mm)	2.0
Pass/ Fail	Fail
Coating Type	ST
Punch dia.(mm)	7.9

4.6 Impact Test Result for Group A4

4.6.1 Specimen no 1/2.5mm

The figure below describes the results for specimen no 1 /2.5mm.

Figure 31: Specimen 1/2.5mm after being impacted with 44.28 J.

Indentation was noted, but with no visible crack signs. The coating passed the test. Table 15 below summarizes the results for impact testing on this specimen.

Table 15: Results for specimen no 1/2.5mm

Impact Force (J)	44.28
Impact Depth (mm)	1.01
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.6.2 Specimen no 3/2.5mm

Figure 32 describes the results for specimen no 3 /2.5mm.

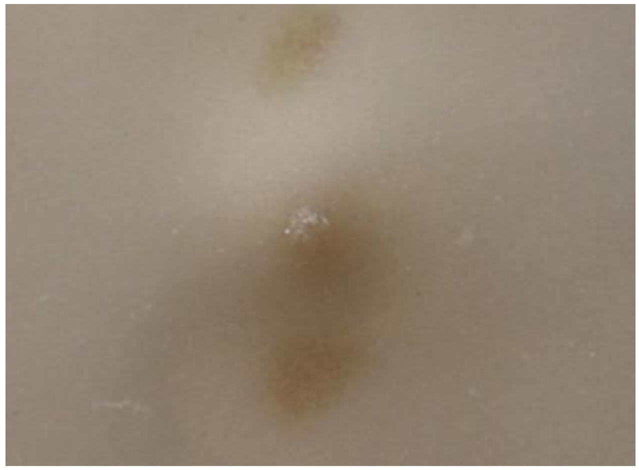

Figure 32: Specimen 3/2.5mm after being impacted with 62.61 J.

For this specimen it was observed that there was a deeper indentation, with 1.87mm depth, but with no visible crack signs. The coating passes the test. Table 16 summarizes the results for impact testing on this specimen.

Table 16: Results for specimen no 3/2.5mm

Impact Force (J)	62.61
Impact Depth (mm)	1.87
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.6.3 Specimen no 4/2.5mm

Figure 33 below describes the results for specimen no 4 /2.5mm.

Figure 33: Specimen 4/2.5mm after being impacted with 72.71 J.

A deep indentation spotted, with 2.1mm depth. There was a very minor sign of cracking at the center of the specimen but not that observable. The coating passes the test. The coating passes the test. Table 17 summarizes the results for impact testing on this specimen.

Table 17: Results for specimen no 4/2.5mm

Impact Force (J)	71.71
Impact Depth (mm)	2.1
Pass/ Fail	Pass
Coating Type	ST
Punch dia.(mm)	7.9

4.6.4 Specimen no 5/2.5mm

Figure 34 describes the results for specimen no 5 /2.5mm.

Figure 34: Specimen 5/2.5mm after being impacted with 82.22 J

The specimen failed. Similar observation was noted; with the base of the coating at the impacted area tear from the substrate. Crack signs observed at the impacted area. The coating failed. Table 18 below summarizes the results for impact testing on this specimen.

Table 18: Results for specimen no 5/2.5mm

Impact Force (J)	82.22
Impact Depth (mm)	2.32
Pass/ Fail	Fail
Coating Type	ST
Punch dia.(mm)	7.9

4.7 Discussion

The results of the impact testing were obtained after the testing was done for each group. The impact force of each group of thickness is put on view on Table 19

Table 19: Results for impact testing for each group of thickness

Group (Coating Thickness)	Impact Force (J)
A1 (1mm)	31.09
A2 (1.5mm)	49.80
A3 (2mm)	65.28
A4 (2.5mm)	82.82

And Figure 35 below describes the obtained value of impact resistance in a graphical form.

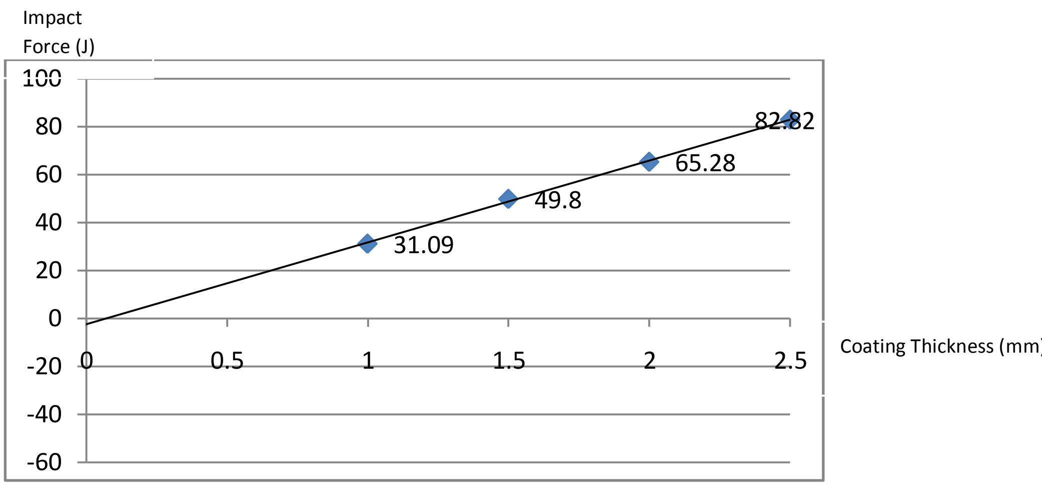

Figure 35: Impact Force vs. Coating thickness graph.

From the graph, it can be observed that different thickness of polyurea failed at different impact force value. 1mm coating failed at 31.09 J. 1.5mm coating failed at 49.8 J, 2mm coating failed at 65.28 J, and 2.5mm coating failed at 82.82 J. Each of the failed coating too, was observed to be cracking, which was a predicted observation prior to the testing. Most of the observed cracks too, were located at the center of the impact load where the impact force was the highest. From the observed trend, it can be said that the thicker the thickness of the coating, the higher the impact resistance will be. These value, of course, were not the exact point of which the coatings will crack. The range of impact resistance per mm of thickness was calculated and the results were shown below.

Table 20: Results for impact testing for each group of thickness

Group (Coating Thickness)	Impact Force (J)	Impact Force / mm thickness
A1 (1mm)	31.09	31.09 J/mm
A2 (1.5mm)	49.80	33.20 J/mm
A3 (2mm)	65.28	32.64 J/mm
A4 (2.5mm)	82.82	33.13 J/mm

So, from the obtained value, it can be stated that the range of polyurea impact resistance per mm of thickness is in the range of 31.09 J/mm – 33.20 J/mm. Compare this to the value of literature review, which was 26.6 J [12], it seems that the obtained range of value was slightly above the range of 26.6 J. These, however, could be caused by several reasons, such as the type of polyurea used in the test. The thickness of the coating under testing also was not known. Moreover, the comparability of the impact testing results was limited to only, one laboratory, and comparison of results between laboratories might result in poor comparison [3].

So the average value of failure per mm thickness after it was calculated from the range was **32.52 J/ mm**, and this value can be used to *predic*t the failure point of any value of thickness of the coating. So if let say 3mm coating was applied, the predicted impact force which the coating would fail is,

$$32.52 \text{ J/ mm} \times 3\text{mm} = 97.55 \text{ J}$$

This, again, is not the exact point which the coating would fail if force were put on the coating. However, the obtained value will provide a good estimation of how much impact resistance of a specimen which the coating thickness was 3mm.

Furthermore, it was shown that more thick the coating gets the more impact depth it needs to crack. Table 21 below summarizes the coating thickness depth and the depth which it failed.

Table 21: Results for impact depth of failure for each group of thickness

Group (Coating Thickness)	Impact Force (J)	Impact Depth (mm)
A1 (1mm)	31.09	0.78
A2 (1.5mm)	49.80	1.31
A3 (2mm)	65.28	2.0
A4 (2.5mm)	82.82	2.32

From the table, it can be observed that it required more impact depth for thicker coatings, for example, for group A1 1mm coating, it failed at 0.78 mm whilst for group A4 2.5mm coating, it failed at 2.32 mm. Figure 36 below describes the impact force against the impact depth which the coating failed.

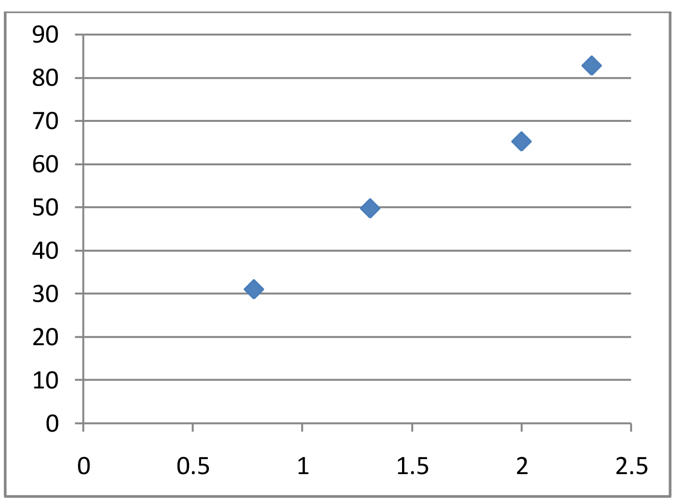

Figure 36: Impact Force vs. Impact Depth graph

This graph will provide a good estimation about the depth of how much the depth will be if certain amount of force is imparted on a coating.

Generally, the reason for failure for each of the coating was due to failure due to fatigue.

4.7.1 Coating fracture initiations due to fatigue[9].

During the impact test a severe plastic deformation of the substrate may occur. KD Bouzakis, using the FEM model investigate the fracture initiation during the impact test of a TiAlN film deposited on the typical bearing steel 100Cr6.

The model was developed considering not a pressure distribution, but an elastic–plastic ball indenter penetration into an elastic– plastic film-substrate compound as well. The indenter contact with the coated specimen was described with the aid of contact elements and the occurring pressure distribution determined. The figure below describes the model.

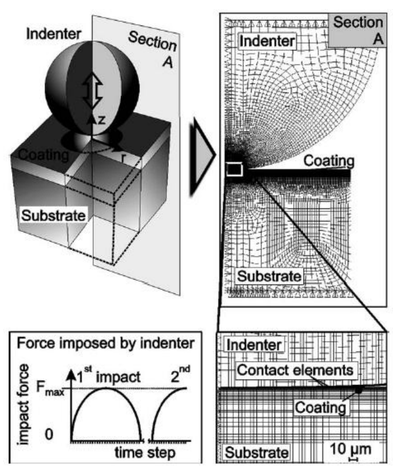

Figure 37: The developed impact test FEM model with deformable ballindenter.

According to the results obtained, the most loaded region is shifted slightly towards the contact area centre, just before the maximum impact load. Hence, the maximum von Mises equivalent stresses, according to the differences in principal stresses, are encountered very close to the imprint vicinity. The equivalent stress increase at the crater vicinity is caused by the deformation occurring in the substrate, which forces the coating to ‘bend’.

It was observed that similar scenario happened at polyurea coating, and it was expected that this was the main failure mode for the coating

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As a conclusion, it was clear that thickness of a coating did play a significant role in impact resistance of the polyurea coating. The thicker the thickness gets, the higher the impact force can be withstand. So, the objectives of this research which is to study the effect of varying surface preparation of which various thickness of polyurea coating was applied, and its effect to the impact resistance had been achieved.

The study too had come out with the average of impact resistance per mm of thickness, which was 32.52 J/ mm. So this value can be used to predict the failure point of any thickness of ST polyurea coating.

So it can be concluded that, this impact test is important since polyurea as qualified coatings should be able to resist mechanical damage during the coating process through installation stages, and maintain its durability over the designated service life, and fall within industry standards on a cost basis. Plus, thickness does play a significant role in impact resistance of polyurea coating.

5.2 Recommendation

A few improvements could be done for future testing. First of all, the testing, if possible, to be conducted using the proper ASTM build testing machine. This should increase the reliability of the testing itself

Another area of improvement in the experiment was the damage inspection method. Using the X-RAY, comparisons between the coatings before and after the impact test had been done to the coating can be made and clearer representation of the impact force and its damage to the coating can be observed. Plus it will be interesting to observe the significant of thickness in impact resistance of the coating itself.

REFERENCES

1. Michael S Osbourne, 2003, *" NCS Product Books"* Nukote Coating Systems
2. Michael S Osbourne, 2003,*"Superior Coating, Membrane and Lining Solution",* Nukote Coating International.
3. ASTM Standard D2794 "*Test Method For Resistance of Organic Coatings to the Effect of Rapid Deformation (Impact)*[1] " ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/C0033-03E01, www.astm.org.
4. ASTM Standard D609 "*Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, Lacquer and Related Coating Products"* ASTM International, West Conshohocken, PA, 2003, DOI: 10.1520/C0033-03E01, www.astm.org.
5. The Sherwin-Williams Company,2009, "*Surface Preparation*" , The Sherwin-Williams Company, http://www.sherwin-williams.com
6. Selvaraj et al, , 2008, *"Studies on the evaluation of the performance of organic coatings used for the prevention of corrosion of steel rebars in concrete structures*", Central Electrochemical Research Institute, Karaikudi 630006, Tamilnadu, India
7. Design And Engineering Practice (Core), 1999, *"Technical Specification : Protective Coatings and Lining"* , PETRONAS Technical Standards, PETRONAS
8. Dwight G Weldon, 2009, "*Failure Analysis of Paints and Coatings"* John Wiley and Sons Limited, United Kingdom.
9. K.-D. Bouzakis*, A. Siganos, 2004, *"Fracture initiation mechanisms of thin hard coatings during the impact test"* Laboratory for Machine Tools and Manufacturing Engineering, Mechanical Engineering Department, Aristoteles University of Thessaloniki, GR-54124 Thessaloniki, Greece
10. Interview with Industrial expert Mr Nasrul (Dyna Segmen)
11. George T. Bayer, Ph.D, Mehrooz Zamanzadeh, Ph.D., 2004, *"Failure Analysis of Paints and Coatings"* Matco Associates, Inc.Pittsburgh, Pennsylvania
12. Shiwei William, 2003 *"100% Solids Polyurethane and Polyurea Coatings Technology*", Madison Chemical industries.

14. T. Go´mez-del Rı´o et al, 2004, *“Damage in CFRPs due to low velocity impact at low temperature”,* Department of Continuum Mechanics and Structural Analysis, Carlos III University of Madrid, Avda. de la Universidad 30, 28911 Legane´s, Madrid, Spain