Effect of Surface Roughness to the Adhesion Strength of Polyurea

by

Ahmad Nadim Bin Faisal

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

ABSTRACT

Adhesion of coating to a substrate depends on many factors including surface roughness of the substrate. This study investigates the effect of surface roughness on adhesion properties of polyurea coating on a metal substrate. Metal substrate was prepared to an SA 2.5 blasting grade and was then coated to a thickness of 1 mm with polyurea. Elcometer 106 adhesion tester is used to measure the adhesion strength of polyurea. The surface roughness was then measured by using a Perthometer and Ra and Rz parameters were recorded. The relationship between surface roughness and adhesion strength was investigated. A higher surface roughness resulted in a higher adhesion strength. The highest average adhesion strength of polyurea to a steel substrate was found to be 3.03 Mpa, which is lower than the literature review of 6.9 Mpa. This is probably due to premature peel off attributed to specimen cutting process or rather caused by poor surface preparations. Recommendation of using primers during coating process is rather essential in order to get higher adhesion value.

.

ACKNOWLEDGEMENT

I would like to praise Allah the Almighty, who gives me strengths to complete my Final Year Project, entitled – **‘Effect of Surface Roughness to the Adhesion Strength of Polyurea’**. My deepest gratitude goes to Mr. Muhamad Ridzuan Abdul Latif as kindly being my great supervisor and his guiding, sharing and teaching really helped me to finish this project smoothly.

I would like to express the warmest and greatest gratitude, appreciation to all parties who have contributed towards the success of this project. I was indebted to many individuals who contributed to the development of my project. Special thanks to all the staff at Mechanical Material Department and Chemical Department at block 4 for helping me throughout the project.

Next, to all lecturers and staffs of Universiti Teknologi PETRONAS, especially Mechanical Engineering Department where I was trained with essential skills and knowledge in order to be a well rounded student.

Last but not least, to my beloved parents, fellow friends and community of Universiti Teknologi PETRONAS who directly or indirectly involves in completing this project.

Thank You.

TABLE OF CONTENT

CERTIFICATION OF ORIGINALITY i

ABSTRACT ii

ACKNOWLEDGEMENT iii

LIST OF FIGURES vi

LIST OF TABLES vii

CHAPTER 1: INTRODUCTION

1.1 Background of Study 1

1.2 Problem Statement 2

1.3 Objectives and Scope of Study Background . . . 3

CHAPTER 2: LITERATURE REVIEW

2.1 Concept on adhesion measurement on thin films . . . 4

2.2 Adhesion test on TiN film using steel 42CrMo4 as substrate . 5

2.3 Adhesion Studies On Polyurea 6

2.4 Examination of polyurea adhesion using steel sandwich specimens . 7

2.5 Polyurea Adhesion: The influence of temperature and humidity . 8

2.6 Study of polyurea coating failures 8

2.7 Effect of surface roughness to adhesion strength of coatings. . 9

2.8 Components of surface topography 11

CHAPTER 3: METHODOLOGY

3.1 Project flow chart 13

3.2 Procedure identification 14

3.2.1 Blasting Grades 14

3.2.2 High Pressure Polyurea Equipment Spray . . . 16

3.2.3 Portable adhesion tester: The Elcometer 106 . . 17
3.2.4 Measuring Surface Roughness 20

CHAPTER 4: RESULT AND DISCUSSION
4.1 Data Gathering and Analysis 21
4.1.1 Relative Humidity and Temperature 21
4.1.2 Substrate Surface Roughness 21
4.2 Results of the surface roughness and the adhesion strength . . 22
4.3 Discussions 29

CHAPTER 5: CONCLUSION AND RECOMENDATIONS
5.1 Conclusion 31
5.2 Recommendations 31

REFERENCES 32

APPENDIXES 34

LIST OF FIGURE

Figure	Caption	Page
Figure 1	Simultaneous deposition on TiN films	5
Figure 2	Surface characteristics and terminology	11
Figure 3	The key Surface parameters	12
Figure 4	Work Flow and Methodology	13
Figure 5	High pressure polyurea equipment	16
Figure 6	The Elcometer 106	17
Figure 7	Elcometer 106 adhesion tester scale ranges	18
Figure 8	Ra and Rz parameters	20
Figure 9	Sample 1 - Surface Roughness vs Adhesion Strength	22
Figure 10	Sample 2 - Surface Roughness vs Adhesion Strength	23
Figure 11	Sample 3 - Surface Roughness vs Adhesion Strength	24
Figure 12	Sample 4 - Surface Roughness vs Adhesion Strength	24
Figure 13	Sample 5 - Surface Roughness vs Adhesion Strength	25
Figure 14	Sample 6 - Surface Roughness vs Adhesion Strength	26
Figure 15	Scatter of adhesion data with respect to surface roughness parameter Ra	27
Figure 16	Scatter of adhesion data with respect to surface roughness parameter Rz	27
Figure 17	Scatter of data for average value of Ra, Rz, and Adhesion Strength	28
Figure 18	Sample 1 Perthometer Readings	35
Figure 19	Sample 2 Perthometer Readings	36
Figure 20	Sample 3 Perthometer Readings	37
Figure 21	Sample 4 Perthometer Readings	38
Figure 22	Sample 5 Perthometer Readings	39
Figure 23	Sample 6 PErthometer Readings	40
Figure 24	Failed Sample A	41
Figure 25	Failed Sample B	41
Figure 26	Failed Sample C	42
Figure 27	Sample 1	42
Figure 28	Sample 2	43
Figure 29	Sample 3	43
Figure 30	Sample 4	44
Figure 31	Sample 5	44
Figure 32	Sample 6	45

LIST OF TABLE

Table	Caption	Page
Table 1	Polyurea adhesion values on different substrate	6
Table 2	Adhesion on concrete (N/mm^2)	8
Table 3	Various modes of polyurea failures(based on actual case)	9
Table 4	The Rz and Ra roughness values, the c/a ratios and the calculated interfacial fracture toughness values for all samples	9
Table 5	Standard blasting grades	14
Table 6	Sample 1 Surface Roughness and Adhesion Results	22
Table 7	Sample 2 Surface Roughness and Adhesion Results	23
Table 8	Sample 3 Surface Roughness and Adhesion Results	23
Table 9	Sample 4 Surface Roughness and Adhesion Results	24
Table 10	Sample 5 Surface Roughness and Adhesion Results	25
Table 11	Sample 6 Surface Roughness and Adhesion Results	26
Table 12	Average Ra, Rz, Adhesion Strength Data	28
Table 13	Adhesion results taken from international journals	30
Table 14	Gantt chart for FYP II	34

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

An industrial coating is a paint or coating defined by its protective, rather than its aesthetic properties, although it can provide both. In industrial world nowadays, Polyurea coating has become the leading coating due to its superior performance and reliability [5]. Polyurea has recently being added as comprehensive line of industrial coatings for almost any application, with physical properties that dramatically exceed those of other products. These polyurea materials differ from plural component polyurethane's in chemical composition and performance. Pure polyureas are the next generation of plural component polymers and outperform older polyurethane systems' physical characteristics, ease of application, application temperature and humidity ranges [1].

Adhesion is the tendency of certain dissimilar molecules to cling together due to attractive forces. There are several types of adhesion mechanisms but the one that this report stresses is the mechanical adhesion of between two materials. Mechanical adhesion happens when adhesive materials fill the voids or pores of the surfaces and hold surfaces together by interlocking [16]. A critical issue for the reliability of polyurea coatings is their adhesion to substrates. However, to the best of our knowledge, very little, if any, data have been obtained for the adhesion of polyurea coatings, particularly in the form of traction–separation laws [1].

1.2 PROBLEM STATEMENT

Polyurea coating has been used widely in industrial world nowadays. It is being used to protect and prolong the life of streamline drains and pipelines. However, even though polyurea has exceptional mechanical and chemical properties, investigations on polyurea coating that has been done shows that polyurea failures were not necessarily formulation or product-related, but rather caused by product mis-use and poor installation practices [14].

A pure polyurea will cure within 5-15 seconds. This relatively short surface-wetting time limits the adhesion properties of the coating. Without intimate contact with a properly prepared surface, the coating cures without forming an initial bond (anchor) to the substrate. This is where the relationship of surface roughness and adhesion strength of polyurea is investigated [14].

Therefore, the pull-off (known as adhesion) strength of a coating is an important performance property and there is a need to investigate and evaluate the effect of surface roughness to the adhesion strength of polyurea.

1.3 OBJECTIVE

The main objective of this research is:

- To study the effect of surface roughness on the adhesion strength of the polyurea coatings to a metallic/steel substrate based on ASTM D4541 - 95.

1.4 SCOPE OF STUDY

The adhesion test is only used on steel panel subsrate. A pure polyurea ST mixture is used on every test in this project. The thickness of coating is 1mm on every sample tested. Typical surface preparation requirements include ST 3 and a minimum near-white blast (SSPC-SP10) is subjected on each substrate. Adhesion test procedure is solely based on ASTM 4541 using the Elcometer 106. Surface parameters of Ra and Rz are the main data taken from the surface roughness measurement.

CHAPTER 2
LITERATURE REVIEW

Literature review of this particular study has been based on readings on journals, conference papers, and also the internet.

2.1 Concept on adhesion measurement on thin films

Practical adhesion tests are generally of two categories: "implied" and "direct". "Implied" tests include indentation or scribe techniques, rub testing, and wear testing. Criticism of theses tests arises when they are used to quantify the strength of adhesive bonding. But this, in fact, is not their purpose. An "implied" test should be used to assess coating performance under actual service conditions. "Direct" measurements, on the other hand, are intended expressly to measure adhesion. Meaningful tests of this type are highly sought after, primarily because the results are expressed by a single discrete quantity, the force required to rupture the coating/substrate bond under prescribed conditions. Direct tests include the Hesiometer and the Adherometer. Common methods which approach the direct tests are peel, lap-shear, and tensile test [2].

2.2 Adhesion test on TiN film using steel 42CrMo4 as substrate

The 42CrMo4 steel is used as a substrate material and having dimensions of 6 x 8 x 60 mm, which were determined by the requirements of the four-point bending test. Before the film deposition, the steel samples were quenched and tempered to a hardness of 350 HV. The surface was polished to a roughness, R_a of 0.05 µm. Afterwards, the sample were annealed at 560°C in vacuum so as to become stress-free. TiN films with a thickness of 1.2-2.4 µm were deposited by ion plating on the surface of the 42CrMo4 steel [8].

The adhesion was varied by using different pre sputtering time, t_s (with plasma gas argon). The best film adhesion was expected for t_s = 15 and the worst adhesion t_s = 0.5. The technology for depositing TinN films with different adhesion is shown schematically in figure 1. Two reference specimens with t_s = 15 min have been additionally prepared in each deposition run to identify the variations in stoichiometry of the film which could acompany the adhesion effect. This was done by covering the samples intended for poorer adhesion with an aluminum foil in the first phase of the pre-sputtering process. Therefore, only the surfaces of the two reference samples were cleaned by argon etching during t_p [8].

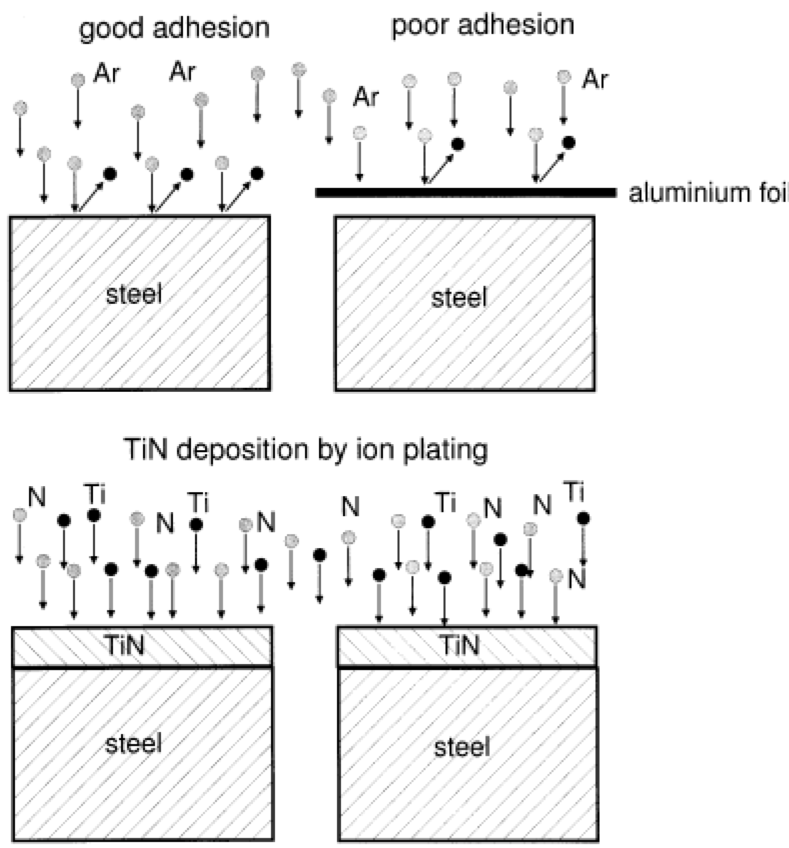


Figure 1: Simultaneous deposition of TiN films with poor and good adhesion with different times, t_s of pre-sputtering argon ions.

2.3 Adhesion Studies on Polyurea

Polyurea spray elastomer systems exhibit excellent adhesion to a variety of sustrate. By careful formulation development and selection, elastomer substrate adhesion valuescan be achieved which exceed the cohesive strengthof the elastome system or substrate. Even with the, rapid system reactivity of the polyurea elastomer technology, adhesion values are quite good [10].

Many factors affect the adhesion of polyurea spray elastomer system, including the substrate surface condition/preparation, elastomer system formulation, elastomer system reactivity(surface wetting effect), and service and exposure of the coated substrate. All these factors should be considered in the development of a system for specific applications [10].

Table 1 gives some typical adhesion values to select substrates for a basic Enviroline aromatic polyurea spray elastomer system. For adhesion testing, an Elcometer Adhesion Tester was used according to ASTM D-4541. This test evaluates the pull-off strength(commonly referred to as adhesion) of a coating by determining the greatest perpendicular force that a surface can bear before plug off material is detached. The adhesion values are reported as the perpendicular force (MPa) needed to remove the polyurea elastomer coating from the substrate. In some cases, failure of the substrate or cohesive elastomer failure is noted before adhesion is lost [10].

Table 1: Polyurea adhesion values on different substrate

SUBSTRATE	ELCOMETER ADHESION, MPa
Concrete, dry	2.8, SF
Concrete, primed	6.9, SF
Steel, 2-mil blast profile	>13.8
Aluminum, cleaned	>13.8
Wood	1.7, SF

2.4 Examination of polyurea adhesion using steel sandwich specimens

A practical approach for characterizing the adhesion of polymer coatings to metal substrates is to use sandwich specimens, which can be analyzed using interfacial linear elastic fracture mechanics (LEFM) concepts. However, there can be limitations to the use of LEFM in sandwich structures. The first is that the assumed stress fields are not rigorously correct, for example, in the case of large-scale plasticity or in the case of very thin layers where the K-dominant field cannot develop. The second is that some joints may not have macroscopic defects large enough to be considered cracks for the purpose of fracture mechanics. These issues can compromise the utility of LEFM and alternative approaches must be sought. Cohesive zone modeling is one such approach. The key concept of cohesive zone modeling is that the failure process zone can be described by a traction–separation law; more specifically, the cohesive traction, $\sigma(\delta)$, can vary along the failure process zone, but only depends on the local opening, δ. The specimens for measuring the unconfined tensile behavior of the polyurea were obtained from thin films. In this case, the polyurea fluid was sprayed on top of a Teflon block to form a thin film with thickness of 0.7 ± 0.1 mm. After the film was peeled from the Teflon block, tensile coupons were cut from the film using a stamp that produced the geometry with $l = 50.4$ mm and $w = 2.1$ mm [12].

Steel/polyurea/steel sandwiches were used for examining the confined stress–strain response in tension and shear and determining the mode 1 and 2 traction–separation laws. The specimens were processed as follows: cold rolled steel adherends (Westbrook Metals, Austin, TX) were sandblasted and degreased with acetone prior to spraying. The polyurea formulation was developed by Texas Research International, Inc. (Austin, TX). The polyurea fluid, coming from two separate reservoirs of resin and hardener, were combined in a single jet and sprayed on top of two steel plates that were 150 mm square by 4.76 mm thick. Immediately after the spraying was completed, the plates were joined and held together by four strong clamps at the corners. This process had to be accomplished within 10 s, the approximate reaction time. The adhesive thickness was basically controlled by the clamp pressure which gave rise to a uniform polyurea thickness of 0.7 ± 0.05 mm throughout the entire sandwich. The sandwich plates were left for at least 10 days for hardening at room temperature in an ambient environment before being subsequently machined into specimens [12].

2.5 Polyurea Adhesion: The influence of temperature and humidity

The influence of temperature and humidity content on the adhesion performance on concrete is summed up in table 2, The following conclusions can be made:

- For all systems applied at 23°C, a cohesive substrate failure is observed [10].
- Without primer, the adhesion is insufficient at 8°C. A primer is recommended [10.
- At 8°C, epoxy primer 1 performs better than epoxy primer 2 [10].

Table 2: Adhesion on concrete (N/mm^2)

	Dry		Wet	
	8° C	23° C	8° C	23° C
No primer	0.75	> 4.45*	1.30	> 4.45
Epoxy primer 1	> 4.45	> 4.45	> 4.45	> 4.45
Epoxy primer 2	2.70	> 4.45	1.75	> 4.45

2.6 Further study of polyurea coating failures

While inadequate surface preparation has caused the majority of of the polyurea adhesion failures, use of the product in an environment for which it was not designed was a minor but notable cause of failure. Even though polyurea coatings and its hybrid has excellent chemical resistance, but they have limitations. Pure polyurea coatings should not be exposed to service temperatures in excess of 200°F in combination with hydrocarbons such as gasoline or kerosene. These hydrocarbons will plasticize the coating. Chlorinated materials, dilute acids or caustics should also intolerable for polyureas. Ultraviolet light/sunlight will degrade aromatic based systems and cause the film the chalk and color fade. Table3 below provides a cross-section of examples of various failure modes exhibited by polyurea coatings [14].

Table 3: Various modes of polyurea failures(based on actual case)

Failure Mode	Description
Adhesion (Disbonding)	Polyurea coating applied to ceramic tile surface.
Adhesion (Disbonding)	Polyurea coating applied to surfaces abrasive blast cleaned to SSPC-SP10/NACE No. 2 (near-white metal). Surface contained abrasive blast residue and an inadequate 1-2 mil surface profile depth.
Severe Discoloration & Cracking	Polyurea coating subjected to service conditions of pH 3-4 and intermittent 200°F temperature.
Yellowing and Delamination	Polyurea coating applied to exterior surfaces abrasive blast cleaned to SSPC-SP5/NACE No. 1 (white metal) with a 2 mil surface profile. Film contained dry spray. Moisture present on surface during application (surface temperature at or below dew point temperature).

2.7 Effect of surface roughness to adhesion strength of coatings $^{-2}$

Table 4: The Rz and Ra roughness values, the c/a ratios and the calculated interfacial fracture toughness values for all samples [21].

Sample no	Rz (nm)	Ra (nm)	c/a	G (J m^-2)
1	278 ± 96	34.2 ± 8	2 ± 0.04	0.32 ± 0.02
2	268 ± 52	32.7 ± 8	2.21 ± 0.03	0.24 ± 0.01
3	230 ± 37	25.7 ± 6	2.36 ± 0.06	0.20 ± 0.02
4	145 ± 47	14 ± 2	2.96 ± 0.18	0.10 ± 0.02
5	92 ± 28	10.9 ± 4	2.41 ± 0.05	0.19 ± 0.01

Sample No.1, which was etched, had an Rz roughness of 278 nm and the fracture toughness was calculated as 0.32 Jm–2. Sample No.5, which was etched, as with sample No.1 but subsequently mechanically polished, had a roughness of 92 nm and fracture toughness of 0.19 Jm–2. The mechanical polishing reduced the surface roughness and there was also a clear reduction in the measured fracture toughness. Sample No.3, which was etched and pickled, had an Rz roughness of 230 nm and fracture toughness of 0.20 Jm–2. Sample No.4 was etched and pickled but also mechanically polished. This sample had an Rz value of 145 nm and a fracture toughness of 0.10 Jm–2. Again the mechanical polishing process reduced the surface roughness, which resulted in a reduction in the calculated fracture toughness. It appears from the results obtained that the smoother surfaces, with lower roughness values, have the lowest interfacial fracture toughness. This trend is also seen when sample 2 and sample 4 are compared. Samples No.4 and No.5 show an exception to the trend of lower roughness resulting in lower fracture toughness. No.4 has an Rz roughness of 145 nm and fracture toughness of 0.10 Jm–2, while No.5 has a roughness of 92 nm and fracture toughness of 0.19 Jm–2. It may be the case that the surface chemistry and surface energy of the wire samples is altered by the various surface treatments the wires received, and not just the surface roughness, which was examined in this study. As mentioned already surface chemistry and energy can affect adhesion at interfaces. While it was possible to analyse the affect of surface roughness on the adhesive strength, it was not possible to study the influence of the individual surface treatments, as these procedures were carried out at the site of manufacture. The results of this study show that the polymer adhesion is dependant on the surface roughness. The surface roughness of the substrate is, therefore, an important parameter that must be considered when studying adhesion between coatings and substrates. However, other parameters, such as, surface chemistry and surface energy must also be considered. Overall, our results agree with previous studies that suggest substrate roughness has an affect on the strength of adhesion when films are coated to substrates [21].

2.8 Components of surface topography

The term topography itself represents all the spatial structure of peaks and valleys that exist on a surface. Once again the roughness consists of the closely spaced irregularities and these may be cutting tool marks or may be produced by the grit of a grinding wheel. The waviness consists of more widely spaced irregularities, which might be produced by vibration or chatter in the machine. Error of form consists of long-period or noncyclic deviations in the surface profile, and these could have been produced by errors in the machine ways or spindles, or by uneven wear in the machine. Finally, flaws are discrete and infrequent irregularities; these might include cracks, pits, and scratches [18].

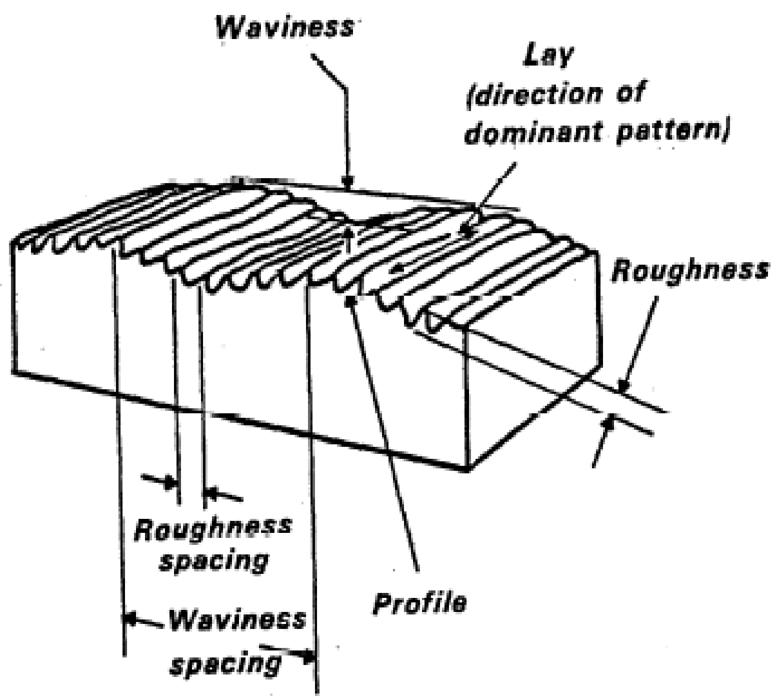
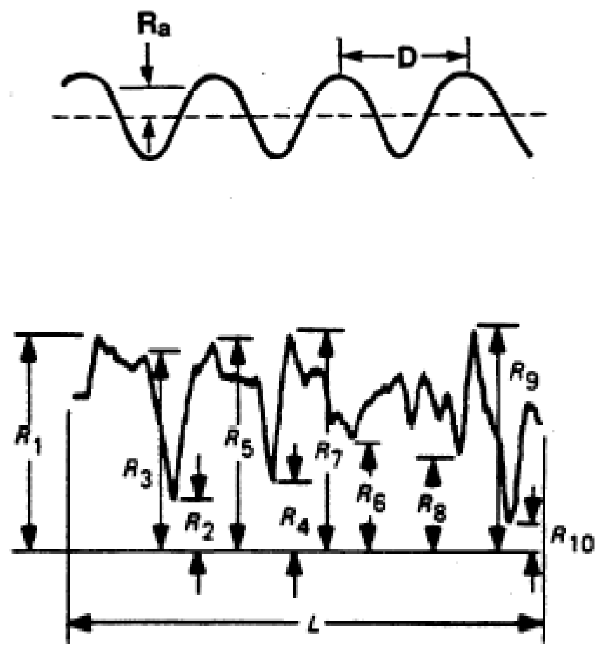


Figure 2: Surface characteristics and terminology

The two quantities that are of primary importance here; a measure of surface height indicated by the roughness average parameter, Ra, and a measure of ten point mean roughness, Rz, and also a measure of the spacing of the peaks and valleys of the surface roughness, indicated on this periodic surface profile by the wavelength parameter, D [18]. Both the Rz and Ra roughness values were analysed to obtain as much information about the surface as possible. While the Rz and Ra roughness values are related to each other, the Rz roughness averages the highest and deepest peaks; therefore extremes have a great effect on the final Rz value. This is a good roughness parameter for analysis of metal surfaces, due to the irregularities that result from the preparation procedures [21].



$$R_z = \frac{(R_1 + R_3 + R_5 + R_7 + R_9) - (R_2 + R_4 + R_6 + R_8 + R_{10})}{5}$$

Figure 3: The Key Surface Parameters

CHAPTER 3

METHODOLOGY

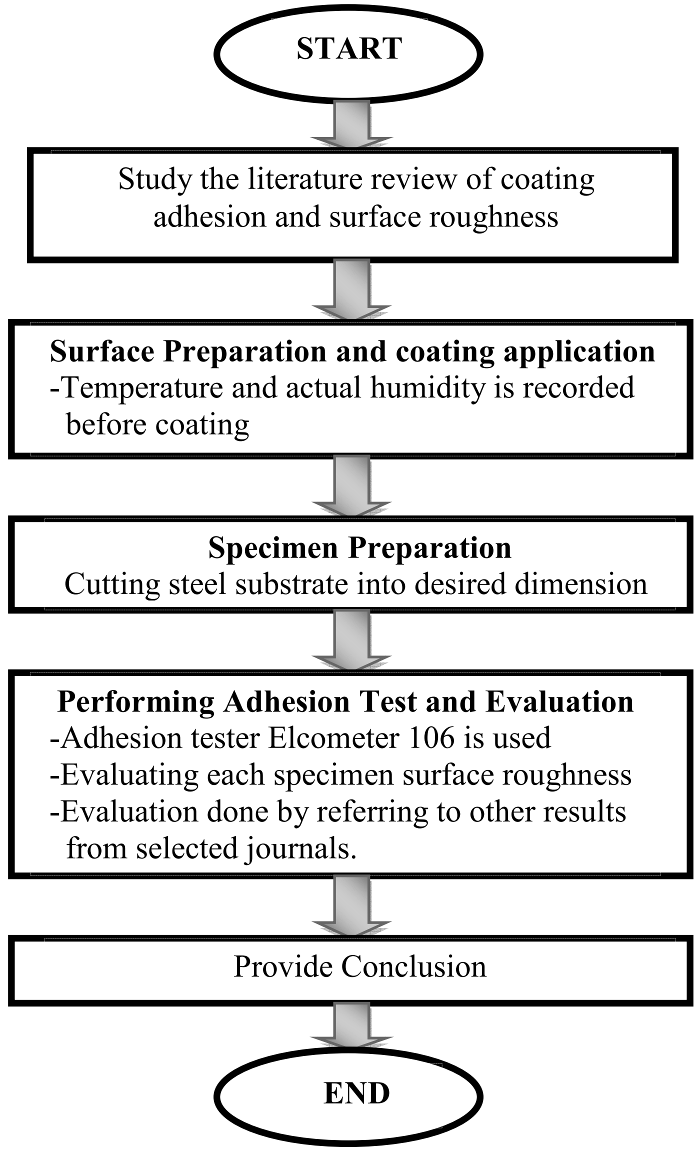


Figure 4: Work Flow and Methodology (brief of methodology)

Figure 4 shows the basic work flow of the project, showing all necessary steps taken right from understanding the adhesion and surface roughness concept to the adhesion evaluation and analysis.

3.2 Procedure identification

Basically, this project is about researching and understanding the concept of adhesion strength of polyurea coatings. By having done literature review by using reference books, internet, journals and paperwork research that has been done before, the level of knowledge on the failures of polyurea and its causes now has been further widen. Based on the research done, the author decides to use steel panel plate 100 x 100 x 1 mm as the substrate to be used in the test later on.Polyurea with thickness of 1 mm will be coated on each steel plate. Surface profiles of SA 2.5 grade will be applied on each substrate based on standard abrasiveness used in the industry. Sand blasting will be the main method on achieving all these surface abrasiveness profile.

3.2.1 Blasting Grades

Following is a table giving a clear indication of the comparative blasting grades, applicable to national and international standards. Table taken from Abrassive Blasting Data Chart [7].

Table 5: Standard blasting grades

SSPC (Steel structures painting council)	**BS 7079** (British Standards) **SS 05 59 00** (Swedish Standards)	**BS 4232**	**NACE** (National Association of Corrosion Engineers)
White Metal (SP5)	SA 3	1st quality	Grade 1
Near White Metal (SP10)	SA 2.5	2nd quality	Grade 2
Commercial Finish (SP6)	SA 2	3rd quality	Grade 3

For this particular test, before polyurea is coated onto the substrate, two surface preparation will be applied on substrate. These operations are conducted by Dyna Segmen Sdn Bhd at their facility in Kuala Lumpur:

a) Power Tool Cleaning (ST 3)

Removal of all rust scale, mill scale, loose paint, and loose rust to the degree specified by power wire brushes, power impact tools, power grinders, power sanders or by a combination of these methods. The substrate should have a pronounced metallic sheen and also be free of oil, grease, dirt, soil, salts and other contaminants. Surface should not be buffed or polished smooth [7].

b) Near White Blast Cleaning (SA 2.5)

Removal of nearly all mill scale, rust, rust scale, paint, or foreign matter by the use of abrasives propelled through nozzles or by centrifugal wheels, to the degree hereafter specified. 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. At least 95 percent of each square inch of surface area shall be free of all visible residues, and the remainder shall be limited to the light discoloration mentioned above [7].

3.2.2 High Pressure Polyurea Equipment Spray

A pure polyurea elastomer coating is used on each substrate. The steel panel substrate will be sprayed with polyurea coating for approximately 1 mm of thickness. A portable high pressure 3000 Psi polyurea equipment will be used to apply the coating on the substrate [1].

Figure 5: High pressure polyurea equipment

High pressure formulations that require heat and pressure to initiate curing remain the product types that provide the highest physical properties of any pure polyurea product and are most often specified in applications where strict compliance with specified properties is required [1].

3.2.3 Portable adhesion tester: The Elcometer 106

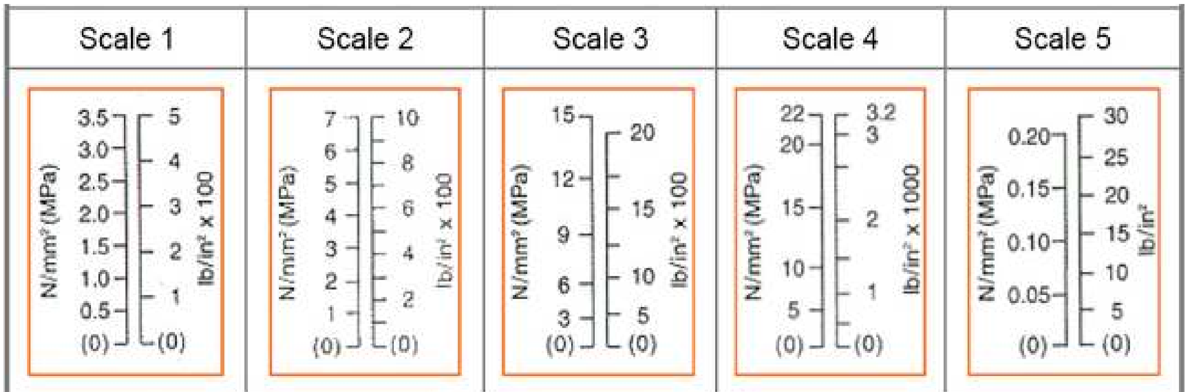
Next, for measuring adhesion strength of the polyurea coating, Elcometer 106 is the best equipment to be used. The elcometer 106 is easy to operate and fully portable, plus provides a numerical value for adhesion measurement [20]. The basic Elcometer test method is as follows:

1. A test dolly is bonded to the coating using an adhesive [5].
2. The 106 houses a spring arrangement which applies a lift force to the dolly [5].
3. When the dolly is pulled off the surface, an indicator on the scale shows the numerical value of adhesion expressed in terms of the force required to remove the dolly [5].
4. Test range from low adhesion values of 5-30PSI (0.05 - 0.2 N/mm²) up to 500 - 3200PSI (5 - 22 N/mm²) [5].

The adhesion measurement will be conducted in specific humidity level to demonstrate the affect of humidity on the adhesion strength of the polyurea. Humidity will be measured by using anemometer. The results of the adhesion strength on every samples will be compared and discussed.

Figure 6: The Elcometer 106

This Elcometer 106 uses the pull off test method. Tensile Dollies (or stubs) are glued to the coating and, once the adhesive has cured, the force required to pull the dolly off the surface is measured [20]. The Elcometer 106 adhesion tester is available in 5 scale ranges. For this particular adhesion test, Elcometer 106/2 (scale 2) will be used.



Instrument Dimensions	*Height*: 152mm (6.0")	*Diameter*: 76mm (3.0")	
Dolly Size	*Diameter*: 20mm (0.76")	*Area*: 314mm² (0.5sq inch)	
Gross Weight of Kit in Case	*Scales 1, 2 & 5*: 2.1kg (4.7lb)	*Scale 3*: 3.4kg (7.5lb)	*Scale 4*: 3.6kg (8.0lb)

Figure 7: Elcometer 106 adhesion tester scale ranges

The procedure of using the Elcometer 106 adhesion tester will be based on ASTM 4541. The general pull off test is performed by securing a loading fixture (dolly,stud) normal to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then gradually increased and monitored until either a plug of material is detached, or a specified value is reached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved [5].

For this particular test, the pull off strength is computed based on the maximum indicated load, the instrument calibrated data, and this result will be evaluated by comparing with other results done in the journals and outside research studies. Pull off strength results obtained using different devices maybe different because the results depend on instrumental parameters [5].

The ASTM 4541 test method serves as a means for uniformly preparing and testing coated surfaces, and evaluating and reporting the results. This test method is applicable to any portable apparatus meeting the basic requirements for determining the pull-off strength of a coating. However, variations in results obtained using different devices or different substrate with the same coating are possible. Therefore, it is recommended that the type of apparatus and the substrate be mutually agreed upon before test is conducted [5].

3.2.4 Measuring surface roughness

In measuring surface roughness of the substrate, Perthometer Concept PGK 120 is used. The surface parameters that are the main concern is the roughness average, Ra and ten-point mean roughness, Rz [9].

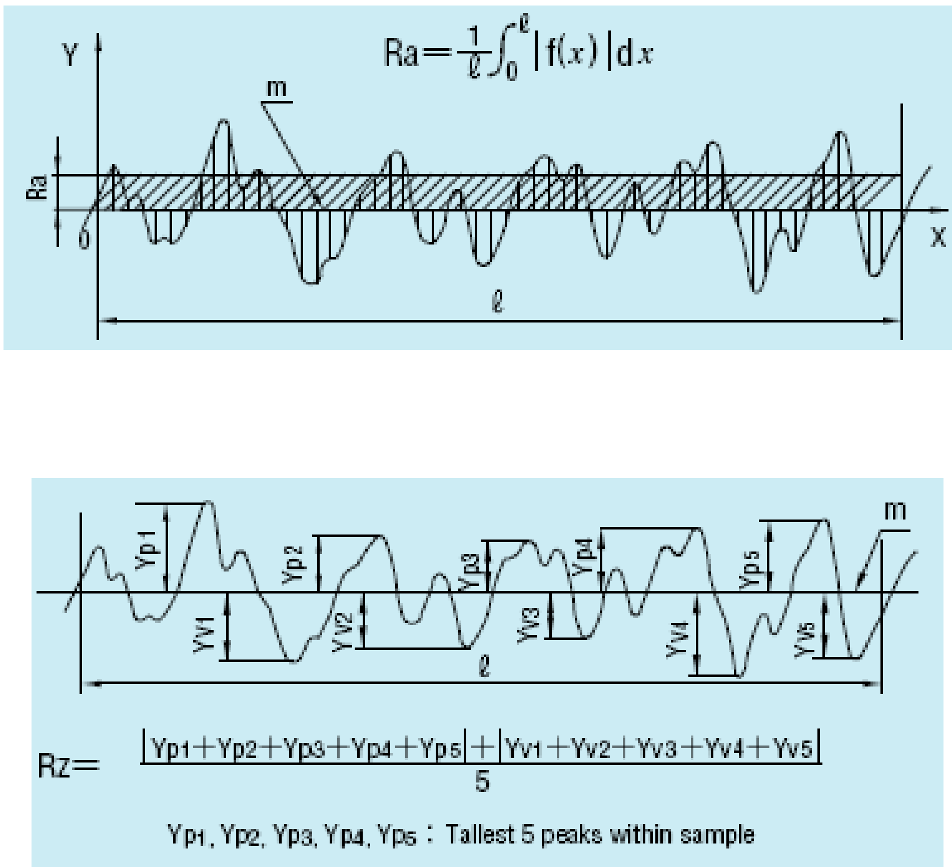


Figure 8: Ra and Rz parameters

CHAPTER 4

RESULTS AND DISCUSSION

Based on the objective of this report, the result of adhesion strength of polyurea coating needs to be based on the substrate surface roughness. There are 3 points of interest on each substrate where the parameters Ra and Rz are measured. All the substrates were coated at a specific relative humidity and temperature.

4.1.1 Relative Humidity and Temperature

Temperature and vapor actual density was measured by Dyna Segmen Sdn Bhd before the coating being applied. For all 9 samples being provided, the temperature and actual vapor density are recorded 38˚C and 22.71gm/m^3 respectively. Based on the relative humidity converter, for an air temperature of 38˚C, the saturated vapor density is 46.262gm/m3. Provided the actual humidity in the air is 22.71gm/m3, the relative humidity is 49.07% for all specimens. All of the results on this test only relevant and applicable on these values only.

4.1.2 Substrate Surface Roughness

The average roughness Ra, is a section of standard length is sampled from the mean line on the roughness chart. The mean is laid on a Cartesian coordinate system wherein the the mean line runs in the direction of the x-axis and magnification is the y-axis. The value obtained is expressed in micrometer. The ten point mean roughness Rz, is the distance between peaks and valleys of the sampled line measured in y direction. Then, the average peak is obtained among 5 tallest peaks as is the average valley between 5 lowest valleys. The sum of these two values expressed in micrometer [9].

4.2 Results of the surface roughness and the adhesion strength

On each substrate, 3 points will be selected to be measured its surface roughness. The sum of surface roughness value and adhesion strength of each points for overall 6 samples are as follows:

Table 6: Sample 1 Surface Roughness and Adhesion Results

Sample 1:

Points	Ra (µm)	Rz (µm)	Adhesion Strength
1	5.16	32.37	2.1 Mpa
2	8.82	53.23	2.5 Mpa
3	4.94	32.42	Test Failed

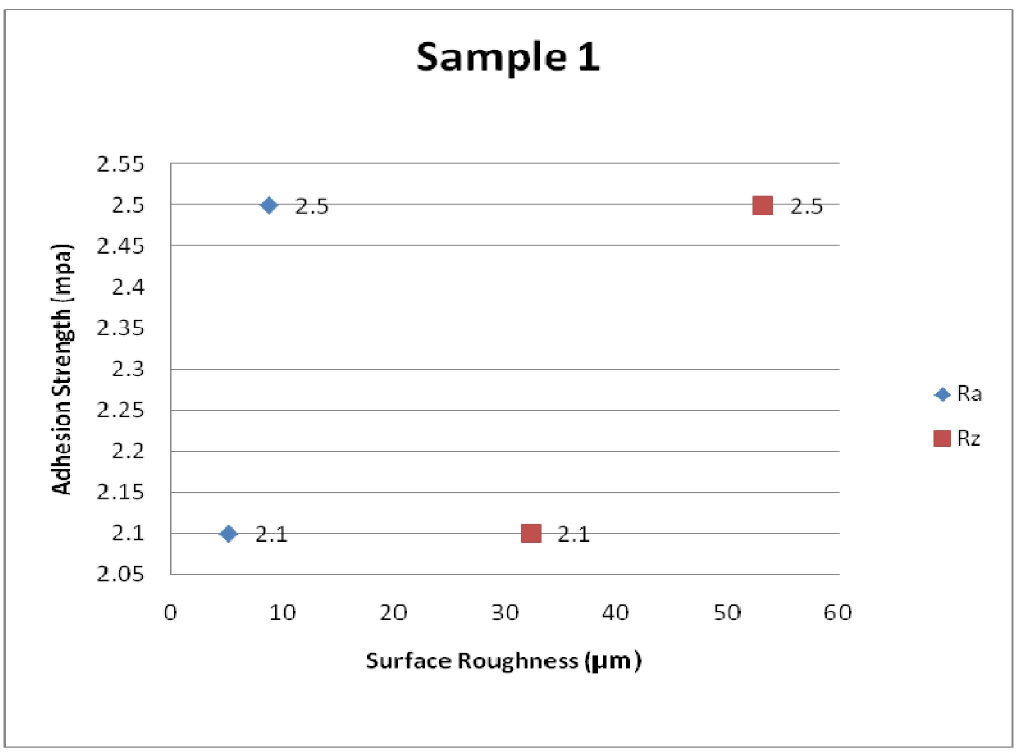


Figure 9: Sample 1 - Surface Roughness vs Adhesion Strength

Table 7: Sample 2 Surface Roughness and Adhesion Results

Sample 2:

Points	Ra (μm)	Rz (μm)	Adhesion Strength
1	6.81	38.67	Test Failed
2	6.85	41.07	2.2 Mpa
3	9.17	56.47	2.7 Mpa

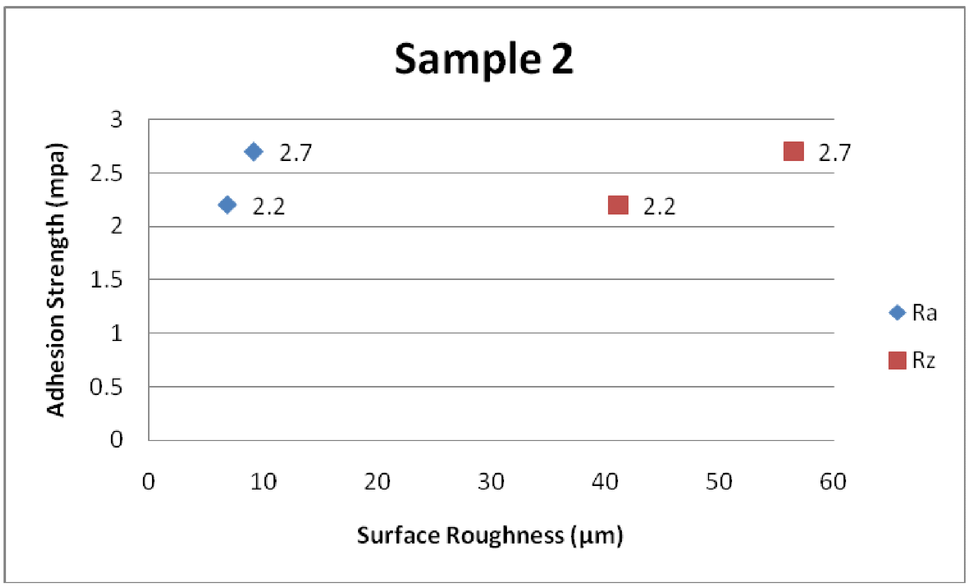


Figure 10: Sample 2 - Surface Roughness vs Adhesion Strength

Table 8: Sample 3 Surface Roughness and Adhesion Results

Sample 3:

Points	Ra (μm)	Rz (μm)	Adhesion Strength
1	5.69	37.94	2.5 Mpa
2	5.49	32.21	2.2 Mpa
3	8.56	49.95	2.8 Mpa

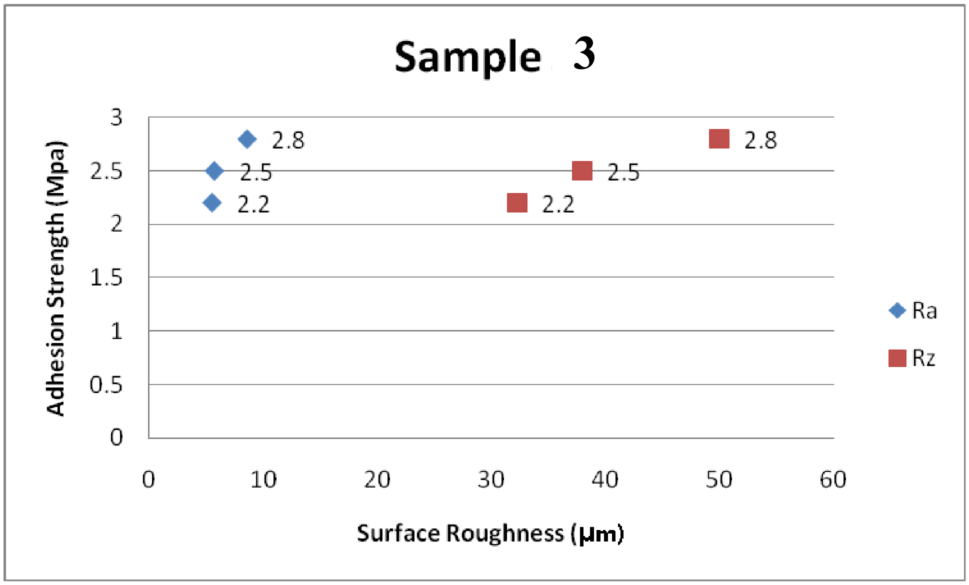


Figure 11: Sample 3 - Surface Roughness vs Adhesion Strength

Table 9: Sample 4 Surface Roughness and Adhesion Results

Sample 4:

Points	Ra (µm)	Rz (µm)	Adhesion Strength
1	8.35	52,10	3.1 Mpa
2	5.75	31.61	2.6 Mpa
3	14.04	71.85	3.4 Mpa

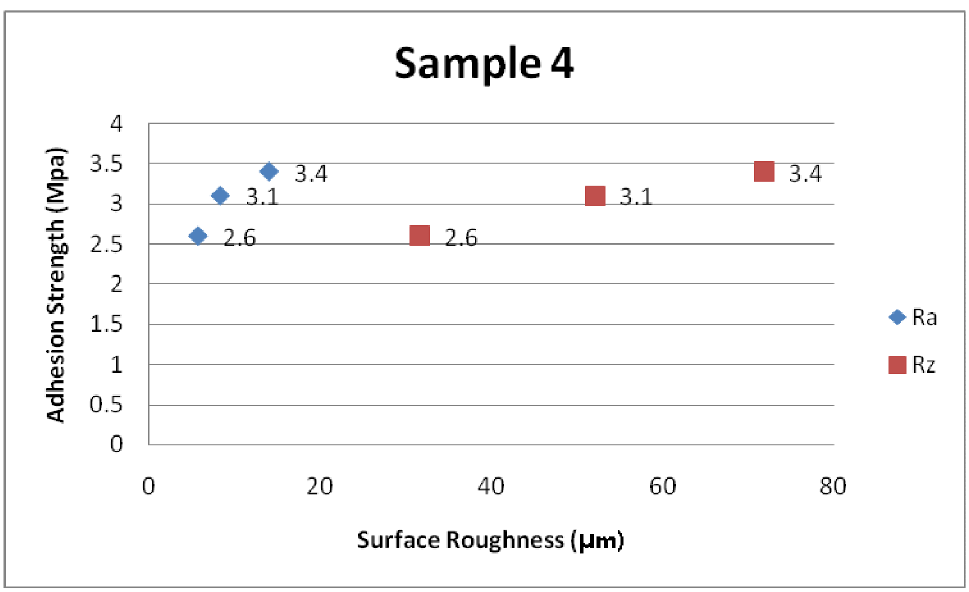


Figure 12: Sample 4 - Surface Roughness vs Adhesion Strength

Table 10: Sample 5 Surface Roughness and Adhesion Results

Sample 5:

Points	Ra (μm)	Rz (μm)	Adhesion Strength
1	8.60	53.35	3.0 Mpa
2	7.51	47.35	2.6 Mpa
3	6.72	43.44	2.2 Mpa

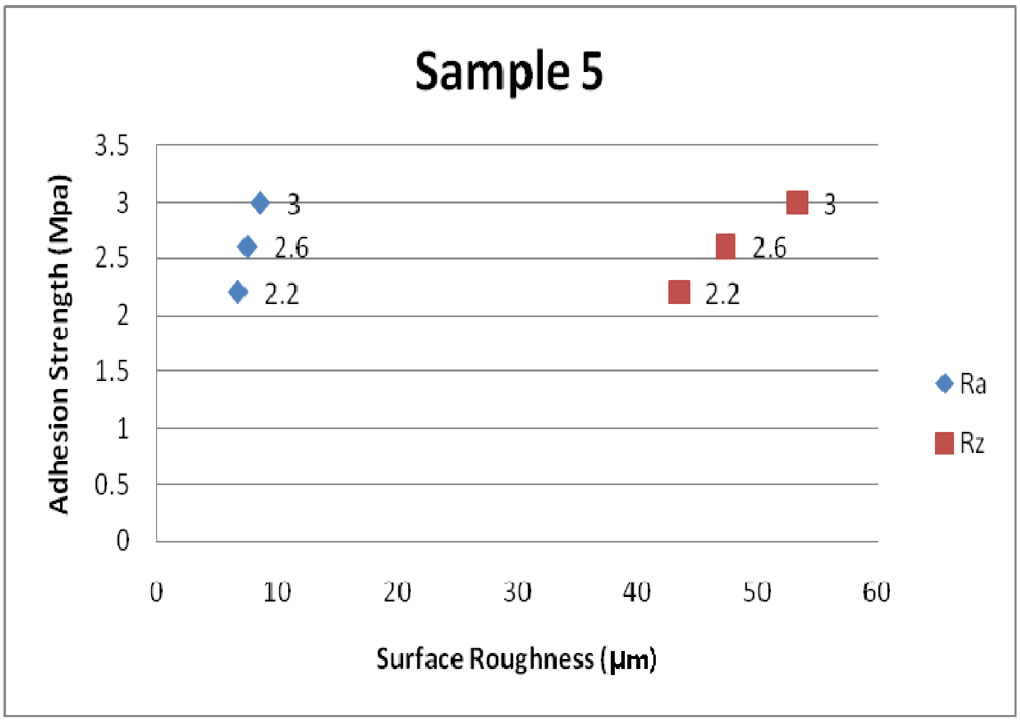


Figure 13: Sample 5 - Surface Roughness vs Adhesion Strength

Table 11: Sample 6 Surface Roughness and Adhesion Results

Sample 6:

Points	Ra (µm)	Rz (µm)	Adhesion Strength
1	7.80	44.68	2.8 Mpa
2	10.13	58.40	3.2 Mpa
3	9.12	49.94	3.0 Mpa

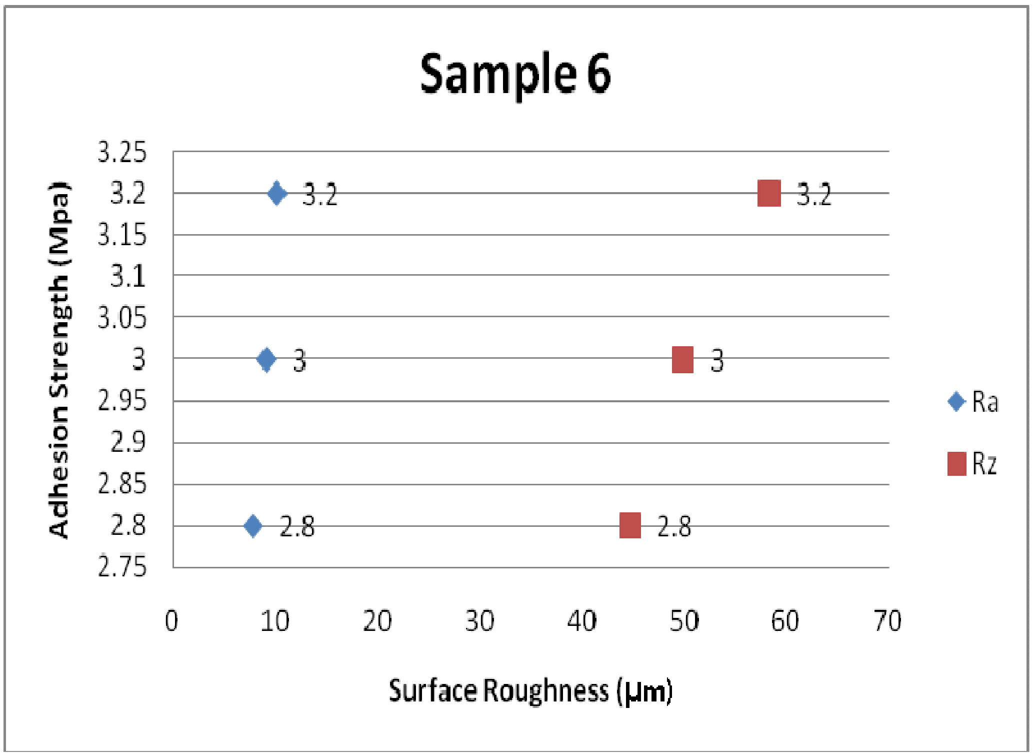


Figure 14: Sample 6 - Surface Roughness vs Adhesion Strength

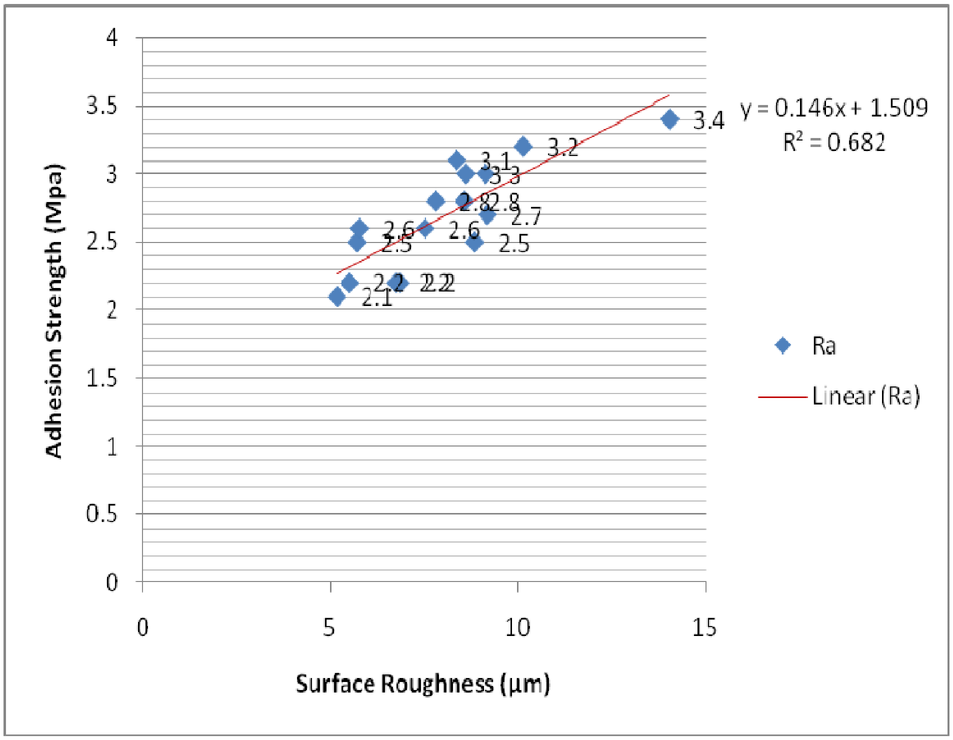


Figure 15: Scatter of adhesion data with respect to surface roughness parameter Ra

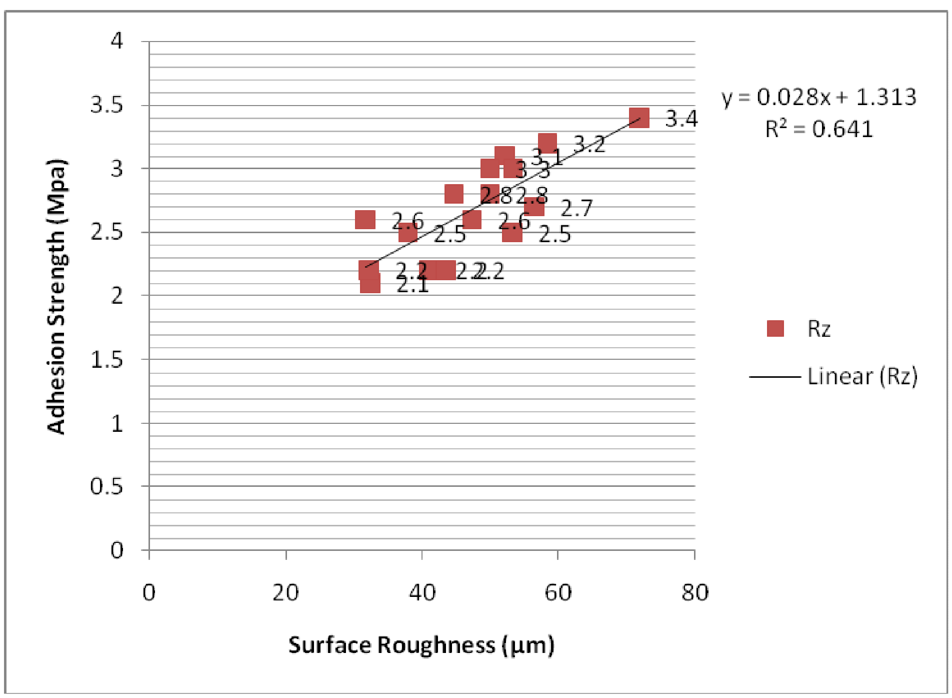


Figure 16: Scatter of adhesion data with respect to surface roughness parameter Rz

Table 12: Average Ra, Rz, Adhesion Strength Data

	Average Ra (µm)	Average Rz (µm)	Average Adhesion (Mpa)
Sample 1	6.99	42.8	2.3
Sample 2	8.01	48.77	2.45
Sample 3	6.58	40.03	2.5
Sample 4	9.38	51.85	3.03
Sample 5	7.61	48.0467	2.6
Sample 6	9.0167	51.0067	3

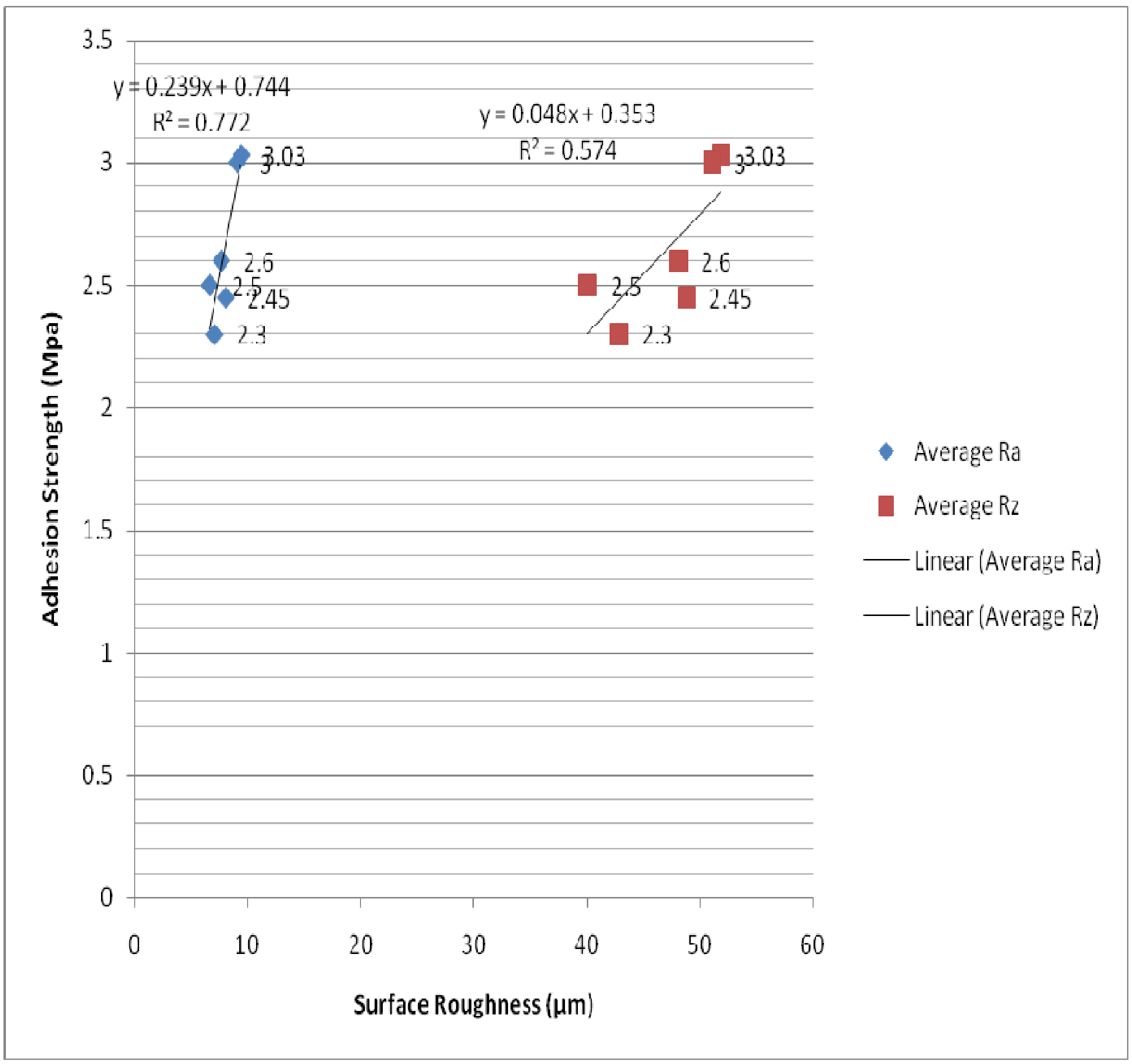


Figure 17: Scatter of data for average value of Ra, Rz, and Adhesion Strength

4.3 Discussions

From the results obtained, there are a couple of results that are labeled as failed. This is mainly due to cohesive failure of the epoxy adhesive between polyurea film and the pull-off adhesive test's dolly. Three out of nine samples were considered failed due to this failure thus only leaves 6 samples yet to be analyzed. The mixture of the dolly's adhesive is the main culprit as it needs to be perfectly balanced mixture and unfortunately this test was not guided by an experienced nor by a skilled worker. Pictures of failed samples can be viewed at appendix page 40 and 41.

From all the value recorded, the highest perpendicular force recorded during the test is 3.4 Mpa, with Ra and Rz value of 14.04 μm and 71.85 μm respectively and the lowest is 2.2 Mpa, where the Rz values are 43.44 μm, 32.21 μm, and 41.07 μm. These perpendicular forces value are also the adhesion strength of polyurea coating. The values recorded are the force required to peel off the coating completely from the substrate. Overall analysis on each of the samples' result shows that the higher the surface roughness, the higher the adhesion strength of the coating. Data for surface roughness for each sample can be viewed at appendix page 35 until 40 accordingly. Then, data collected on all the samples are calculated for average value and those values are plotted on the respective graphs. From the graph, it can now confirm the relationship between surface roughness and the adhesion strength. It appears from the results obtained that the smoother surfaces, with lower roughness values, yield the lowest adhesion strength for the polyurea coating.

By comparing this result with other selected journal, the adhesion strength recorded are significantly lower than it should be. Results taken from other journal showed that the average value of polyurea adhesion strength on steel substrate without using primers is 6.9 Mpa.

Table 13: Adhesion results taken from international journal [15].

	No primer	Acrylic	Epoxy	Emulsifiable MDI	2-Component Polyurethane
Dry Concrete	2.1	2.6/3.4*	3.4/3.4	4.1/4.0	3.8/4.3
Wet Concrete	4.0	2.2/2.9	1.4/0.1	1.7/1.7	1.6/1.9
Steel	6.9	7.4/6.9	6.9/7.4	5.5/5.5	6.9/7.6
Plywood	3.3	2.8/2.9	3.2/3.3	2.9/2.8	4.3/5.7
Fiber Cement Board	1.9	1.2/1.0	1.5/1.2	1.4/2.1	1.7/1.4

This is far ahead from the results obtained from this test. However, results obtained from most adhesion test are usually varies due to different equipment used and inappropriate service environment during coating itself. The cutting process of the samples could also be the culprit of lower adhesion value. There is some premature peel-off of the coating noticed at the edge of the sample after cutting. Likewise, the result from this test is only valid for coating environment at air temperature of 38˚C, and relative humidity of 49.07%.

CHAPTER 5

CONCLUSION AND RECOMENDATION

5.1 Conclusion

The conclusions derived from this project work are below:

1. From the graphs obtained, the relationship between surface roughness and adhesion strength of the polyurea is now found. The higher the surface roughness, the better the adhesion of polyurea coating to a metal/steel substrate.
2. The results of this study also show that the polymer adhesion is dependant on the surface roughness. The surface roughness of the substrate is an important parameter that must be considered when studying adhesion between coatings and substrates.
3. The results of this study also show that the polymer adhesion is dependant on the surface roughness. The surface roughness of the substrate is an important parameter that must be considered when studying adhesion between coatings and substrates.

5.2 Recommendations

1. A proper coating site with well-equipped surface preparation machine should be provided by Universiti Teknologi Petronas laboratory to make this project more easily managed, hence providing me with a lot of parameters to be set on.
2. If cost is not a factor, the risk of failure can be limited by the use of a system consisting of a suitable primer/sealer combined with a polyurea coating [15].
3. For future development of this project, adhesion testing on digital adhesion tester is required to verify the results accurately. The Elcometer106 that is currently used can be read mistakenly by human error.

REFERENCES

1. Nukote Coating Systems,. "*General Guideline, Measurement & Conversion Chart, Care & Maintenance"* Polycoat Products 2005
2. K. L. Mittal, "*Adhesion measurement on Thin Films, Thick Films and Bulk Coatings*" STP 640, American Society For Testing and Materials (ASTM).
3. American Society for Testing and Materials (ASTM), 2001, "*ASTM D3359 - 97 Standard Test Method for Measuring Adhesion by Tape Test*" – Annual Book of ASTM Standards Volume: 06.01.
4. American Society for Testing and Materials (ASTM), 2004, "*ASTM D609 -00 Standard Practice for P of Cold-Rolled Steel Panels for Testing Paints, Varnish, Conversion Coatings, and Related Coating Products*" – Annual Book of ASTM Standards Volume: 06.04.
5. American Society for Testing and Materials (ASTM), 2001, "*ASTM D4541 - 95 Standard Test Method for Pull-Off strength of coatings Using Portable Adhesion Tester*" – Annual Book of ASTM Standards Volume: 06.02.
6. *"Surface preparation standard"* http://www.corrosion.com
7. *"Abrassive Blasting Data"* http://www.afrigrit.co.za/blastspecs.htm
8. H. Ohmori, K. Katahira, J. Komotori, M. Mizutani, F. Maehama, M. Iwaki 1RIKEN (The Institute of Physical and Chemical Research), Saitama, Japan Keio University, Kanagawa, Japan. *"Investigation of Substrate Finishing Conditions to Improve Adhesive Strength of DLC Films".*
9. Excerpt from JIS B 0601 and JIS B 0031, *"Surface Roughness Technical Data Sheet*", 1994.
10. Marc Broekaert, Application and Product Development Manager – Coatings, Huntsman Polyurethanes, *"Polyurea Spray Applied for Concrete Protection"* 2003.

11. Dudley J. Primeaus 11, Primeaux Associates LLC/LnviroLine Technologies LLC, "*Polyurea spray elastomer technology*".
12. Yong Zhu, Kenneth M. Liechti and K. Ravi-Chandar, "*Direct extraction of rate-dependent traction–separation laws for polyurea/steel interfaces*".
13. H. Olendorf, D. Schneider, Fraunhofer Institut fur Werkstoff-und Strahltechnik, Winterbergstrabe 28, 01277 Dresden Germany. "A *comparative study of adhesion test method for hard coatings*".
14. Cynthia L. O'Malleym Laboratory Manager, KTA Tator Inc, Pittsburgh, Pensylvania, USA. "*Polyurea Coatings. If You Knew What Could Go Wrong…*"
15. Mark Broekaert, Huntsman Polyurethanes, Belgium. *"Polyurea Spray Coatings: The Technology and Latest Development.*
16. *"Adhesion"* http://en.wikipedia.org/wiki/Adhesion
17. Catherine Creath and James C. Wyant. *Absolute Measurement of Surface Roughness",* 1990.
18. T. V. Vorburger and J. Raja, "*Surface Finish Metrology Tutorial",* 1990
19. Dudley J. Primeaux II, *"Polyurea Elastomer Technology: History, Chemistry, and Basic Formulating Techniques",* 2004-2008.
20. *"Elcometer 106 Pull off Adhesion Tester",* www.elcometer.com
21. Martin Burke, Brenda Clarke, Yuri Rochev, Alexandar Gorelov, William Carroll, *"Estimation of the strength of adhesion between a thermoresponsive polymer coating and nitinol wire",* 2008.

APPENDIXES

Table 14: Gantt chart for FYP II

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Final Year Project II															
1	Project Work Continue										**Mid-semesrer break**					
2	Submission of progress report 1															
3	Project Work Continue															
4	Submission of progress report 2															
5	Seminar (compulsory)															
6	Project Work Continue															
8	Poster Exhibition															
9	Submission of Dissertation (soft bound)															
10	Oral presentation															
11	Submission of Dissertation (hard bound)															

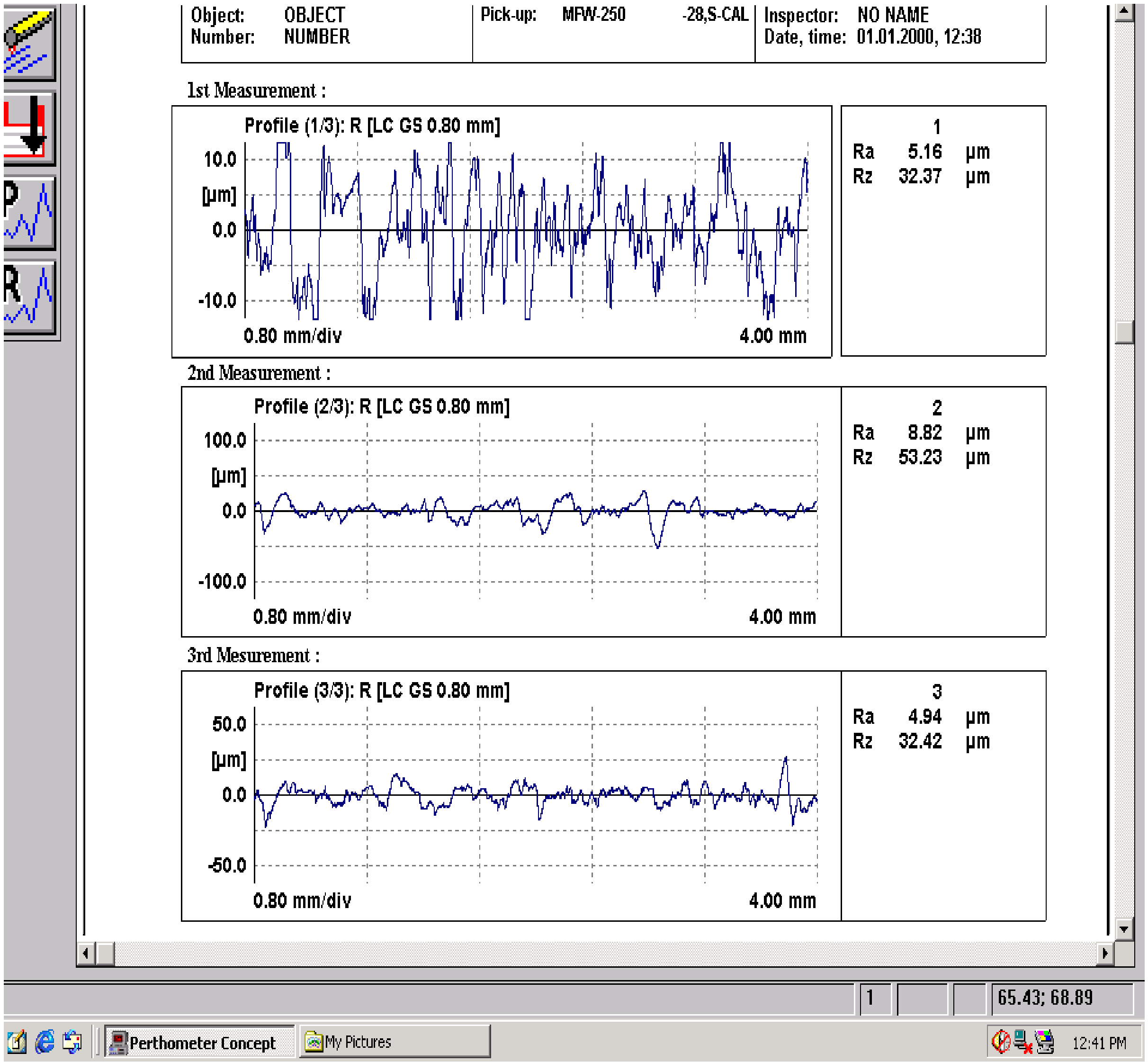


Figure 18: Sample 1 Perthometer Readings

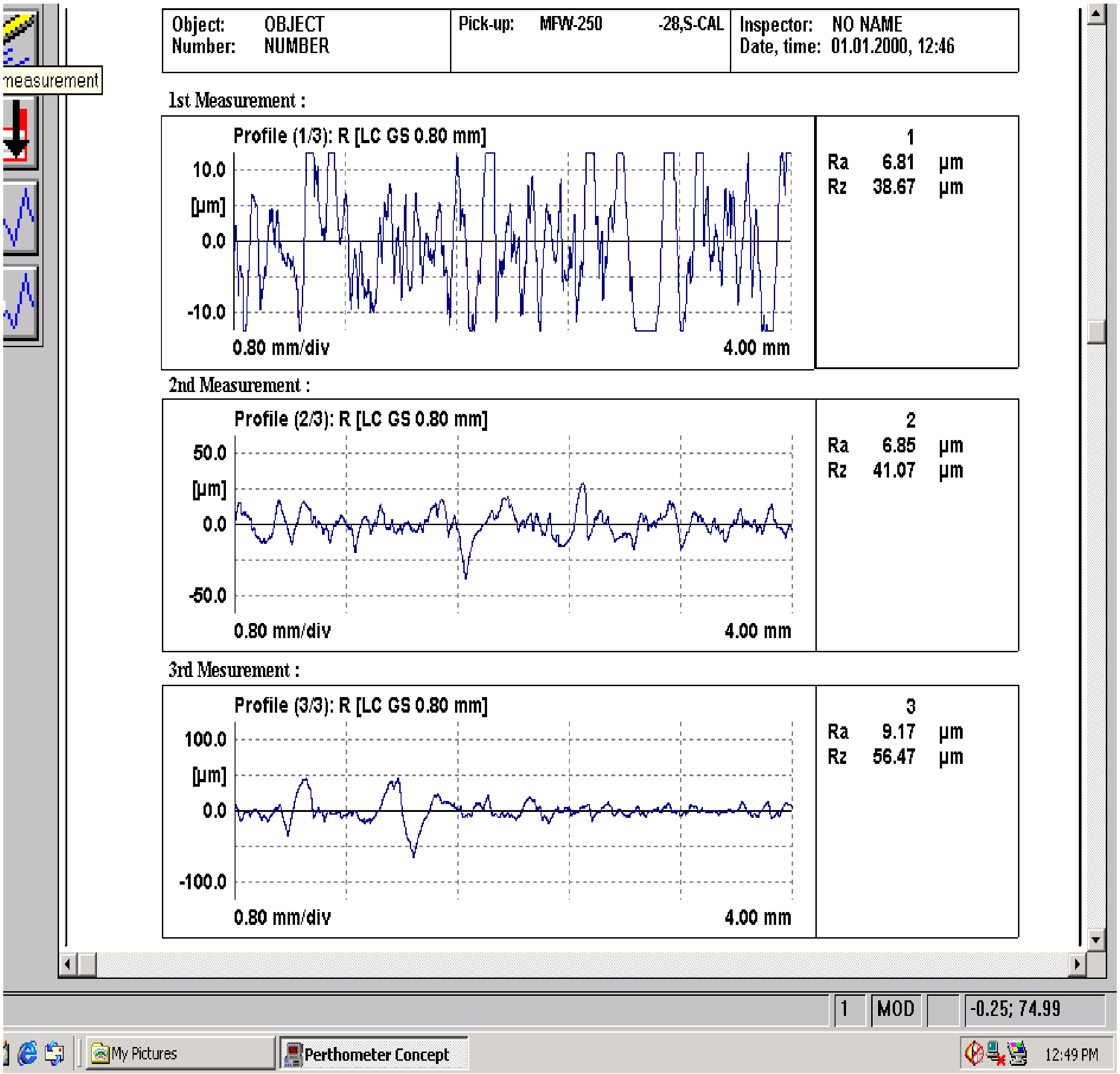


Figure 19: Sample 2 Perthometer Readings

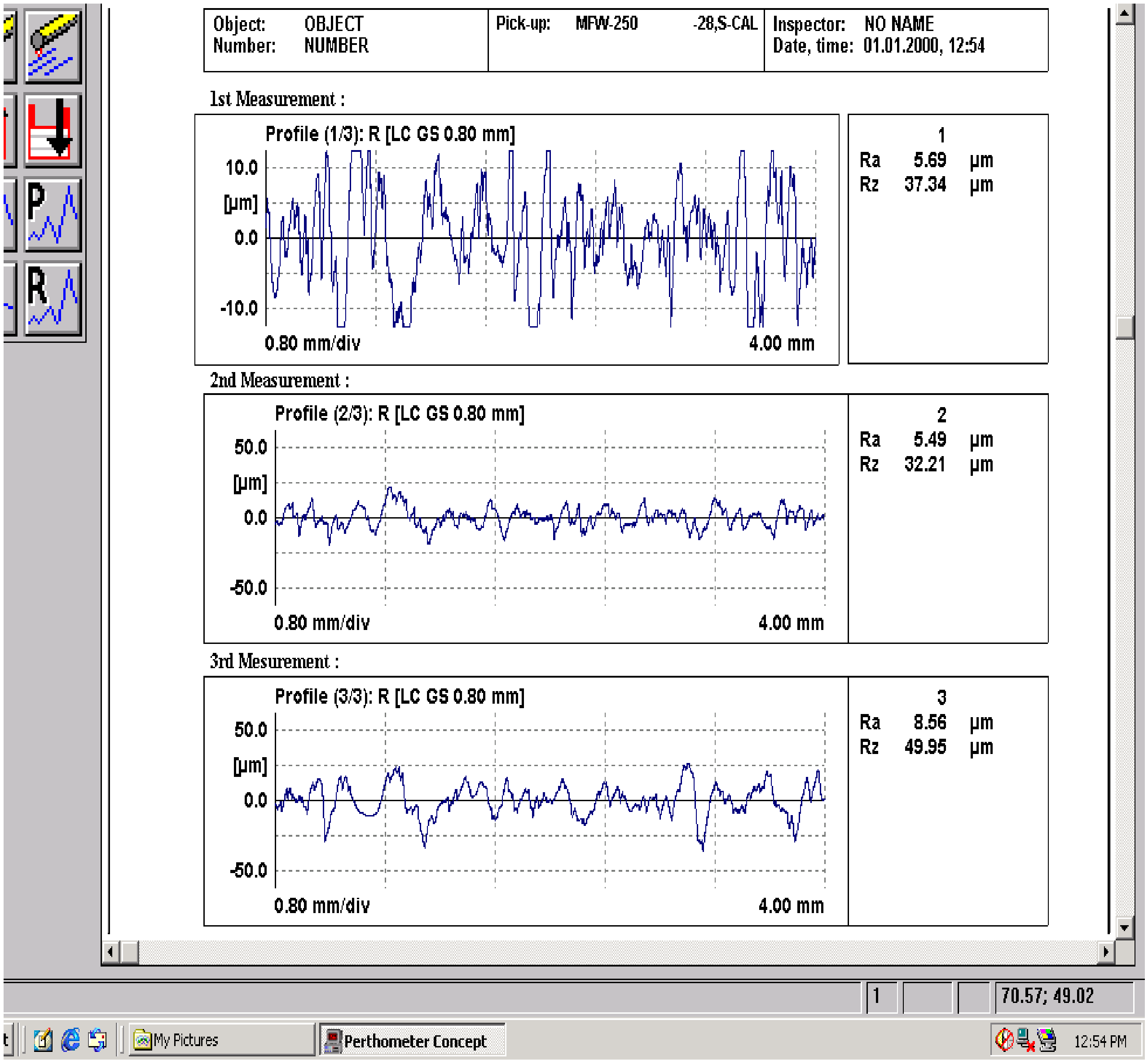


Figure 20: Sample 3 Perthometer Readings

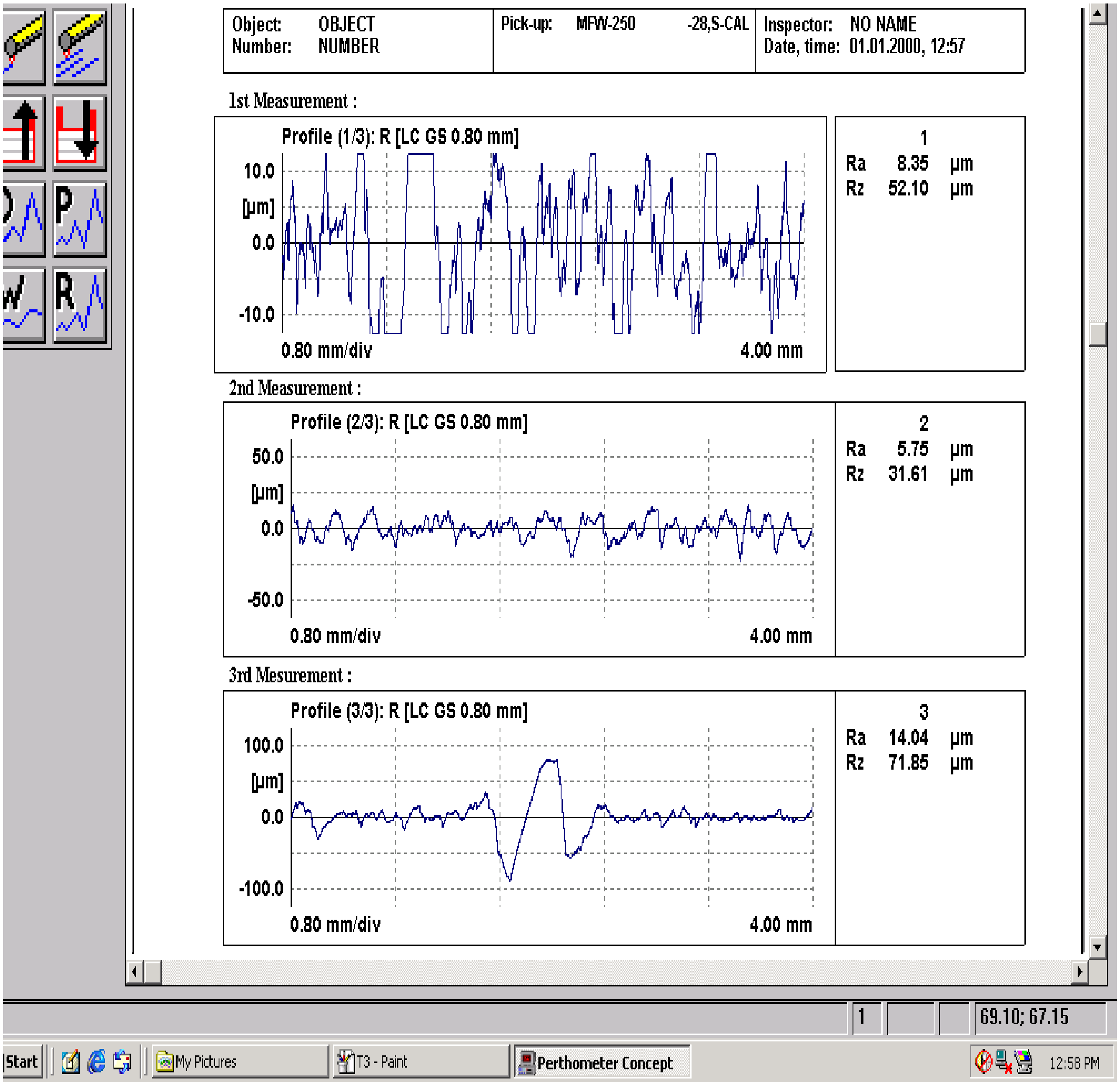


Figure 21: Sample 4 Perthometer Readings

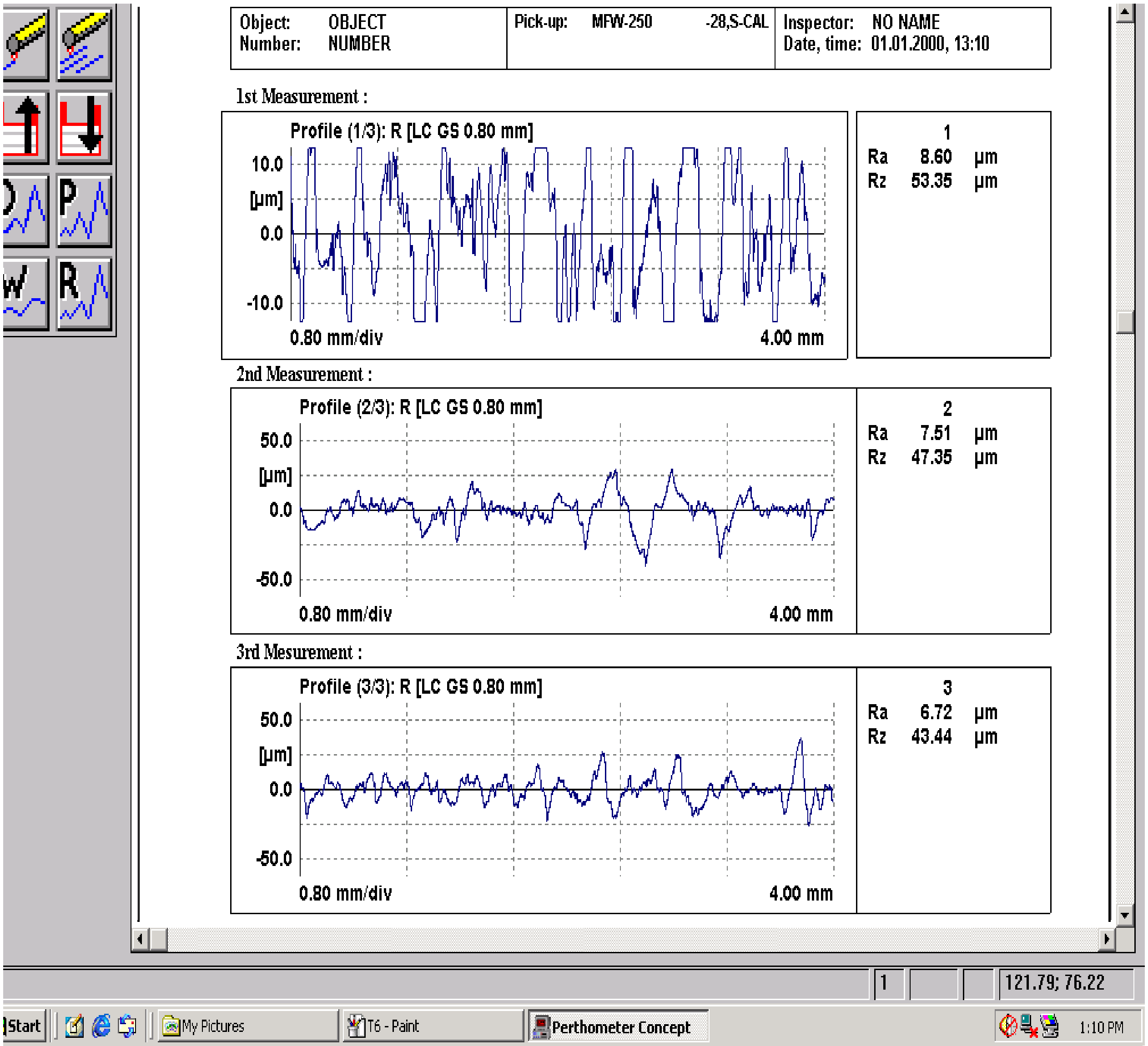


Figure 22: Sample 5 Perthometer Readings

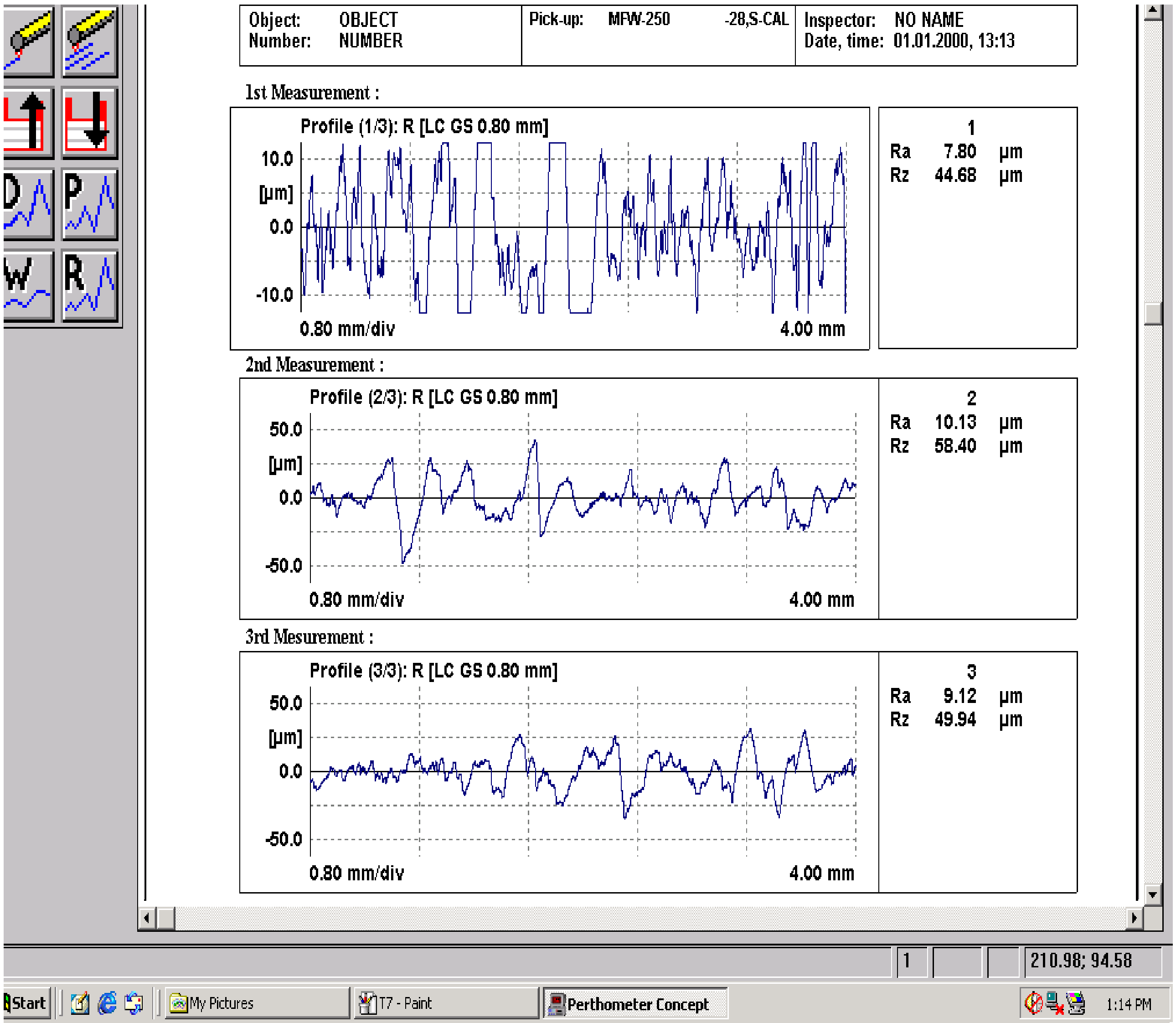


Figure 23: Sample 6 Perthometer Readings

Figure 24: Failed Sample A

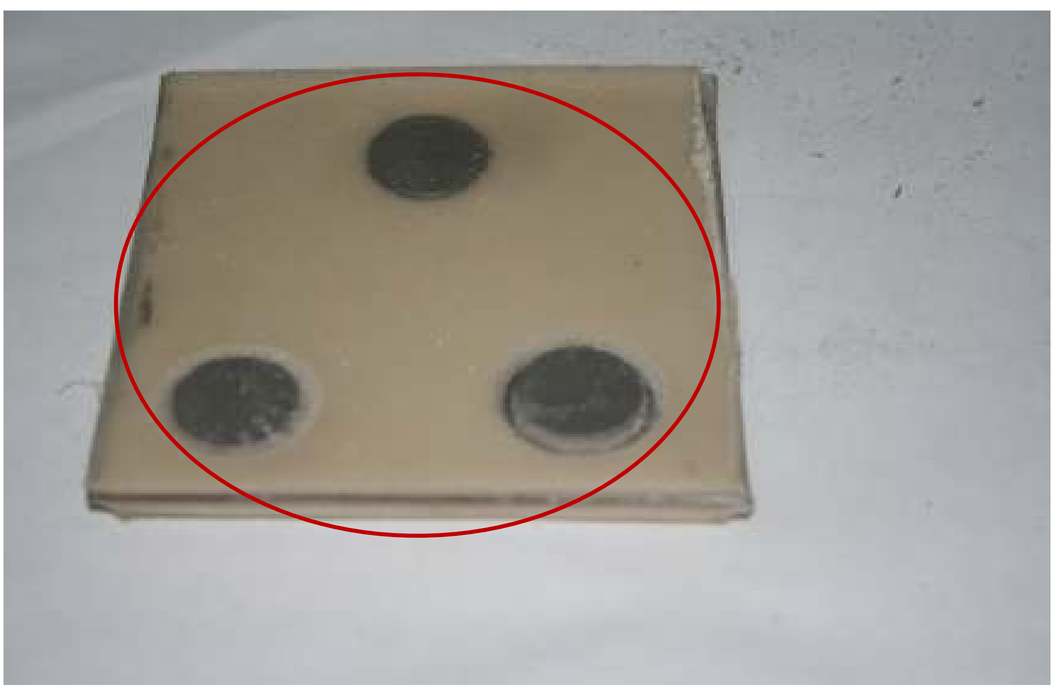


Figure 25: Failed Sample B

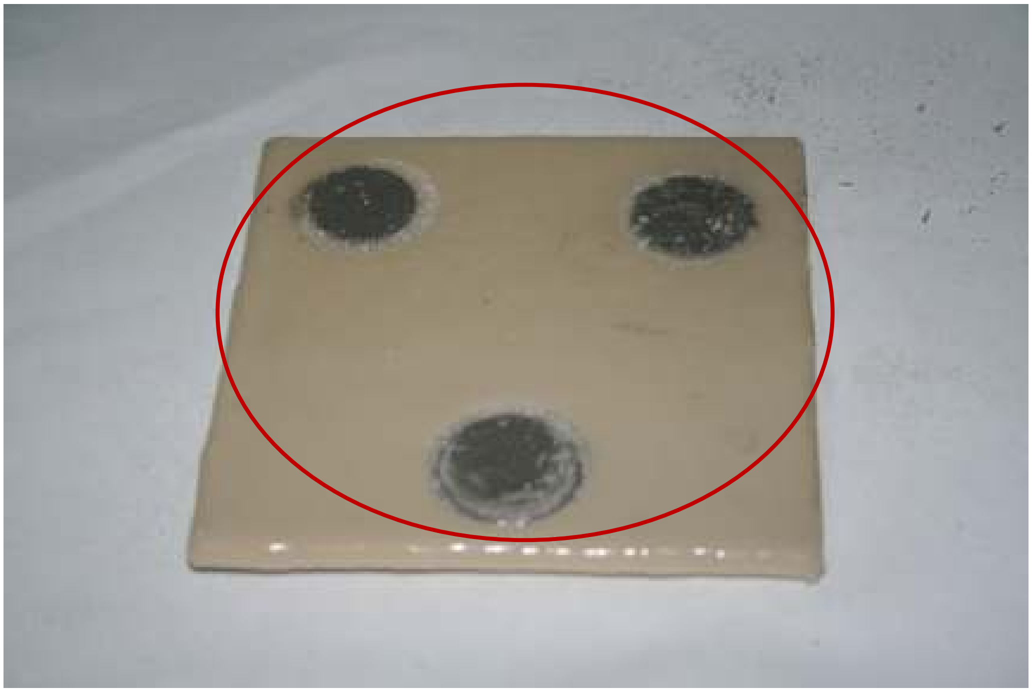


Figure 26: Failed Sample C

Figure 27: Sample 1

Figure 28: Sample 2

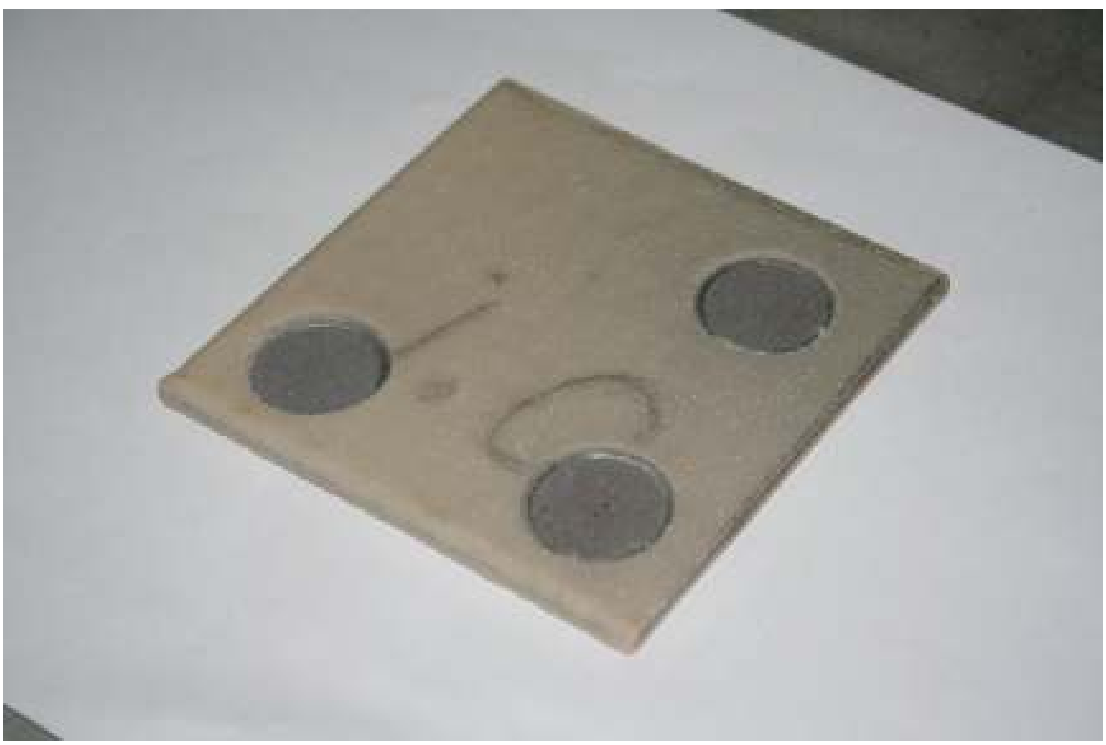


Figure 29: Sample 3

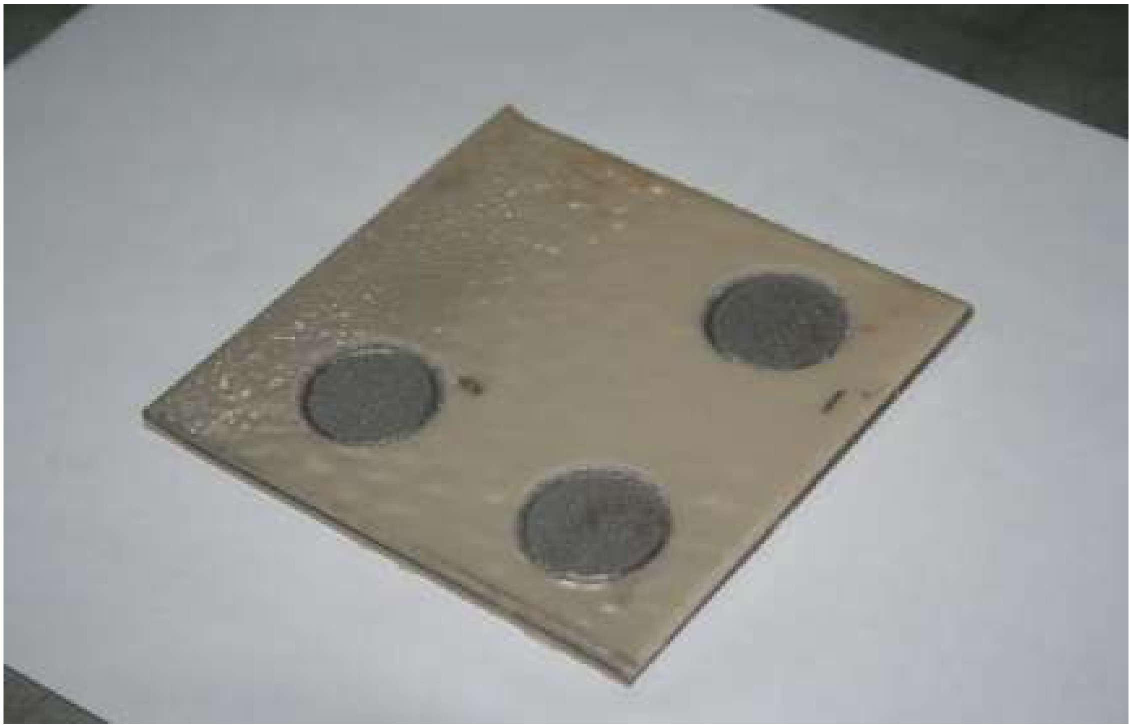


Figure 30: Sample 4

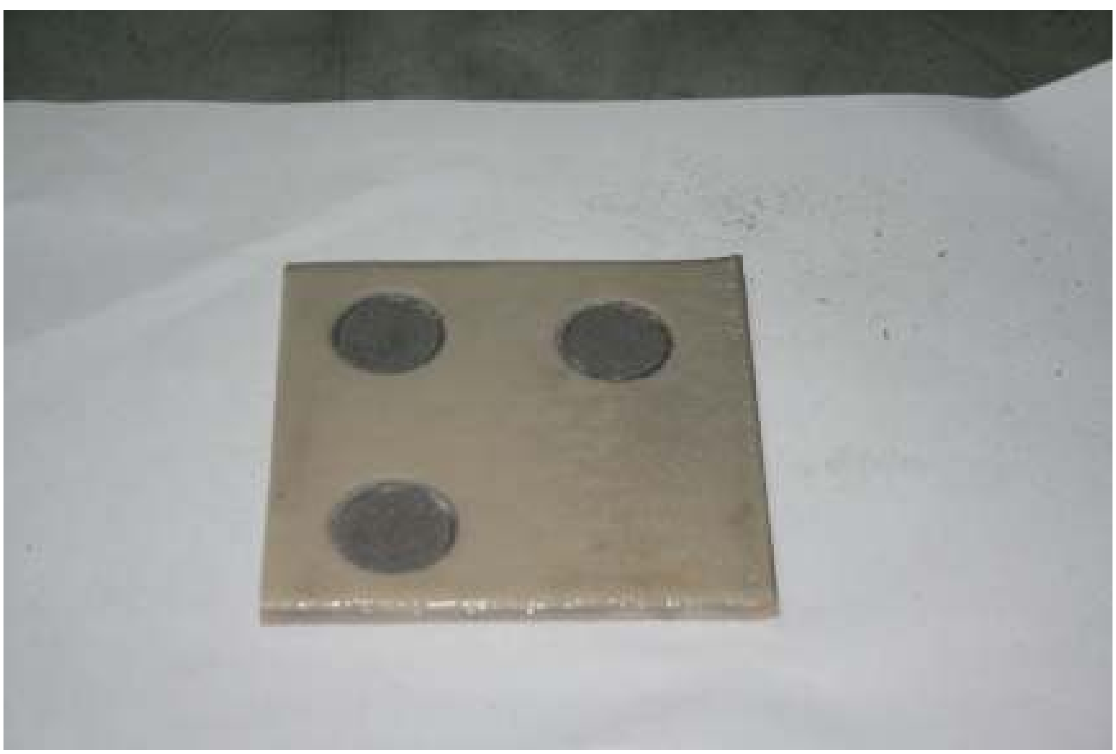


Figure 31: Sample 5

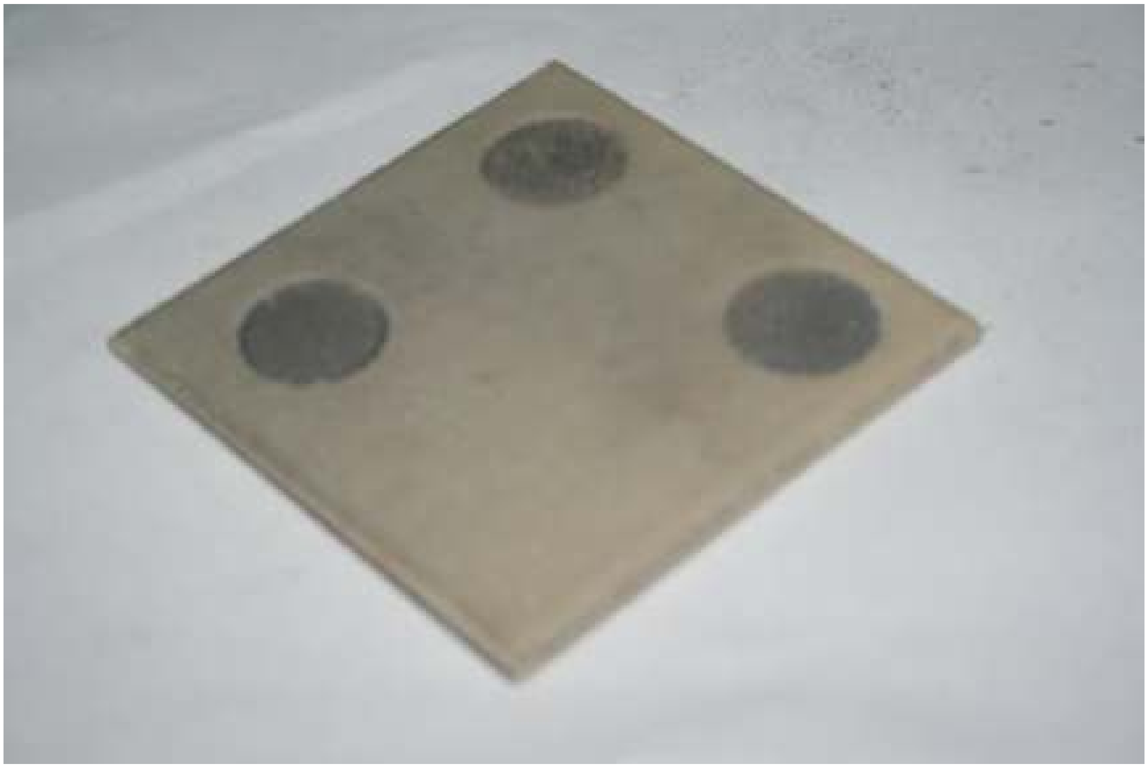


Figure 32: Sample 6