EXPERIMENTAL STUDY ON POWDER COATED SURFACE WITH POLYDUR ZINC BASED FILLER.

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DECLARATION

This work has not previously been accepted in substance for any degree and is notbeing concurrently submitted in candidature for any degree.

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This thesis is the result of my own investigations, except where otherwise stated.Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF ABBREVIATION

Abbreviations	Descriptions
DOE	Design of Experiment
SS	Sum-of-squares
Df	Degree of Freedom

EXPERIMENTAL STUDY ON POWDER COATED SURFACE WITH POLYDUR ZINC BASED FILLER.

ABSTRAK

Salutan serbuk merupakan sejenis proses kemasan permukaan yang sering digunakan dalam industri untuk mendapat permukaan yang rata dan memberi perlindungan. Untuk membaiki kecacatan yang kecil, pengisi berasaskan zink polidur digunakan sebelum proses salutan serbuk. Fenomena kulit limau adalah salah satu kerosakan yang sering didapati selepas proses pengawetan dan menyebabkan kadar penolakan yang tinggi. Tujuan kajian ini adalah untuk mengkaji parameter yang mempengaruhi permukaan selepas proses pengawetan. Kesan pada permukaan boleh dikaji dengan menggunakan pecahan factorial dengan lima factor dan dua peringkat variasi. Faktor yang dikaji adalah bahan, ketabalan, voltan, masa pengawetan dan pemanasan profil. Kekasaran pada permukaan merupakan tindakbalas pada permukaan untuk mengkaji fenomena kulit limau. Kesan dari setiap parameter dikaji dengan menggunakan ANOVA dan analisis regresi. Parameter yang optimum telah berjaya didapati dan diverifikasi dengan eksperimen.

EXPERIMENTAL STUDY ON POWDER COATED SURFACE WITH POLYDUR ZINC BASED FILLER.

ABSTRACT

Powder coating is commonly used in industry to provide a smooth surface finish and protection from the atmosphere. To fix minor defects on metal surface, Polydur Zinc based filler is applied on the surface of the metal to achieve smooth surface before powder coating. However, orange peel is one of the common defects found after curing process and it result in high rejection rate. The aim of this research is to study the parameter influencing the surface after curing process. The effect on surface was investigated using a two-level fractional factorial design with five factors and two variation levels. The tested factors were material, thickness, voltage, curing time and heat profile. The response of surface roughness was used to investigate the orange peel. The effect of each parameter on orange peel was studied using ANOVA and Regression Analysis. Optimal combination of parameters was found for optimum response characteristics. The optimum combination was verified through the experiment, and the fractional factorial design method have successfully improved the quality of powder coating.

CHAPTER 1.0 INTRODUCTION

1.1 Brief overview of the overall structure of the project

Powder coating is commonly used as a surface finish on industrial equipment. This process is applied in powder form through an electrostatic process and cured with heat. The powder coating process is well known for providing high-quality finishes with both functionality and an overall look. Instead of being dissolved in a liquid, the powder is applied in a form that is finer than ground pepper but coarser than flour, is applied directly to the surface to be coated.(Jerraya, 2005)

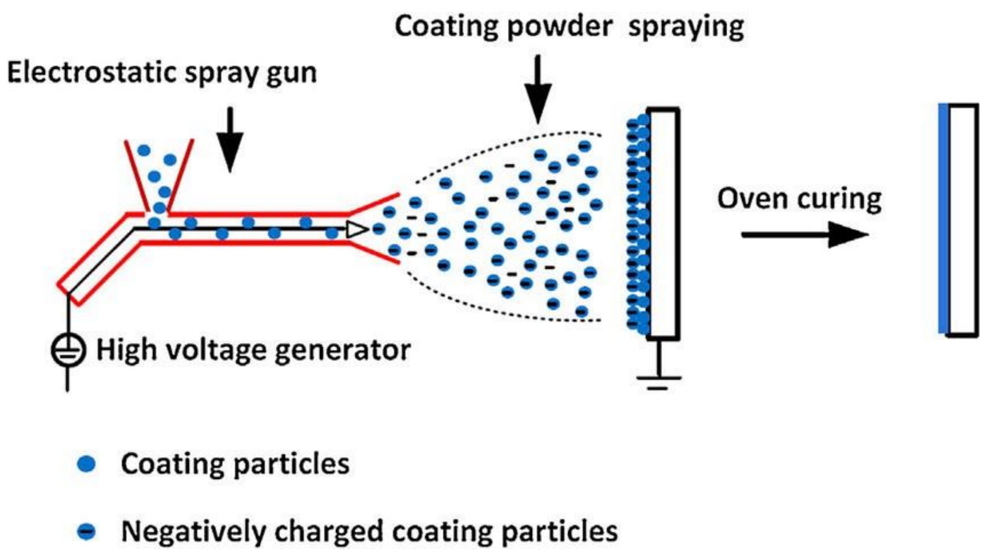

Figure 1.1 Powder Coating Process

The process starts with placing the metal sheets into acidic bath for few minutes and followed by checking the surface flatness. Metal sheets with minor defects or unevenness will need to apply filler on it. Polydur zinc-based filler is used in the company. Putty, a cream or paste form solution is used because it is versatile and easy to apply on irregular shaped dents. The use of putty allows to even out the surface, filling and levelling the area to be repaired. It plays a vital role as support and adhere element for base paints and its correct application will also influence the final outcome of the finishing. To activate the filler, polydur zinc universal polyester putty with 2% of polydur peroxide hardener is mixed according to the technical data sheet. (Lechler, 2007) When the putty is mixed with the hardener, it produces a chemical reaction which causes putty to dry and harden.

Figure 1.2 04380 Polydur Zinc Universal Polyester Putty

Figure 1.3 00281 Polydur Peroxide Hardener

After the filler is applied, grinding will be needed to grind off the excess filler. For best appearance, the surface must be clean, without any oil or stains. The part is placed into the oven for curing. The curing process is a chemical reaction that aims to get a more stable linkage such as an adhesive bond. Curing is a vital step to avoid cracks which will allow harmful materials to pass through and affect the appearance of the surface. Curing is another important step that requires a high temperature of 200 degrees Celsius for around 15 minutes. The curing time and temperature also play a vital role to avoid underbaking. Underbaking of parts may result in low physical properties while overbaking will cause a colour change. Moreover, the performance of the oven can avoid discolouration or inconsistent cure. (Siwek, 2002)

However, defects are frequently discovered after the powder coating process. The high frequency of defects is a pain in the neck for manufacturers since it will increase the rejection rate while manufacturing. As a result, it will need a high repair cost or more parts need to remanufacture to replace the defective part. Defects such as pinholes, blistering, orange peel and high or low film thickness are commonly found on powder coated parts.

According to the engineer in Surface Technology Solution Sdn. Bhd, there are over 30% of rejection rate due to orange peel discovered on the metal surface. According to (Detmer, 2012), orange peel is an imperfection in a paint job. It can be easily seen because of its wavy appearance and reflects light from different angles. A few factors result in orange peel, such as incorrect distance when spraying or surface conditions that contain dirt, oil, or stains. (Keven, 2017)

Figure 1.4 Orange Peel

All of the above brings an increasing significance to the importance of each part of the process which affects the surface finish. The ultimate aim of this experiment is to track the factor that affects the surface's outcome, thus decreasing the rejection rate after the powder coating process.

1.2 Company background

Surface Technology Solution Sdn. Bhd is a surface finishing company which located in Nibong Tebal, Pulau Pinang. Powder coating is commonly used as it is one of the most durable finishes that provides corrosion protection and it is free from organic compounds.(Talbert, 2011)

Figure 1.5 Surface Technology Solutions Sdn. Bhd.

1.3 Problem Statement

Powder coating is one of the surface finishing process in sheet metal industry. Polydur zinc-based filler is applied on the surface when unevenness and minor defects are detected. The filler will be cured in an oven before covering by a layer of powder for coating. However, the area which contain polydur zinc-based filler often result in orange peel. There is limited literature study on the effect of powder coated surface with polydur zinc-based filler. Therefore, this experiment aims to get the most effective process parameters for powder coating with the consideration of cost and effectiveness.

1.4 Research Objective

The specific objective of this research are:

- To investigate the factors significant to the filler performance on curing process in powder coating.
- To optimise the filler performance of curing process in powder coating.

1.5 Scope of the project

The aim of this research is to study the parameter influencing the surface after curing process. Fractional factorial design is used to analyse the relationship of the parameters with the surface roughness after curing process. The specimen will be tested according to the standard powder coating process with the surface will be measured using Mitutoyo Surface Roughness Tester. The optimal combination of designed parameters that result in minimum surface roughness will be determined.

CHAPTER 2.0 LITERATURE REVIEW

2.1 Factors that cause orange peel

Among the defects, orange peel is mostly discovered on the metal surface. According to (Detmer, 2012), orange peel is a textured imperfection in a paint job. It can be easily seen because of its wavy appearance and reflects light from different angles. A few factors result in orange peel, such as incorrect distance when spraying or surface conditions that contain dirt, oil, or stains. (Keven, 2017)

Adhesion is another property that needs to take into consideration. In the research of (Christopher Jocham, Thomas W. Schmid, Gunter Wuzella, 2012), the research showed that the electrical resistance led to the improvement of powder application. In addition, from (M. M. Banubakode et al., 2013), it showed that powder flow rate had great effect on orange peel and followed by blow air flow rate, powder and voltage. Orange peel is a type of quality characteristics which is the lower the better.

From (Kismet et al., 2021), the characterization of thermal properties was studied. The studies showed that the powder coated did not cure or harden between the range of 130 to 210 degrees Celsius. The uncured powder coated on the surface will caused lack of powder stick on the surface and the surface will be expose to the atmosphere.

2.2 Properties that influence orange peel

According to (Rowe, 2020), powder coating is one of the methods to paint metal parts that holds an electrical charge to spray on the metal surface by using coloured powder. The electrical charge helps to adhere to both powder and surface. The research on the factors of filler that affected the performance of the outcome of the coating surface was relatively less compared to the performance of powder coating. Filler plays an important role to fix the defects found on the surface. The mechanical properties such as hardness, thermal resistance and electrical resistance are taken into consideration.

Meanwhile,(Meng et al., 2009) had discussed the characterization of particle size during powder coating. The methodology mainly aimed to get the difference between coarse and ultrafine powder during the powder coating. This study discovered that the two-coating system had some discrete characteristics while the size evolution of the layer was the same.

From (Franco et al., 2019), the hardness increased after including fillers which result in a decrease in flexibility, toughness and ultimate elongation. Four types of resin systems which are epoxy, epoxy-polyester, polyurethane and polyester were used to investigate its performance in powder coatings.

As for now, there are still lack of research on the optimal parameters for powder coating. A proper experiment and analysis, can provide a guide for the industry to get the most cost-effective filler, thus bringing more profit to the industry. The experimental study on powder coated surface with polydur zinc-based filler is important to fill up the deficiencies of the research.

2.3 Response Selection

Several kinds of tests can be carried out to determine the effectiveness of the filler. To measure the surface flatness, optical flat can be used. Optical flat as shown in Figure 2.1, shows light band patterns when the optical flat is placed on a surface. It is a relatively simple and low-cost experiment on the market. However, it is limited to a shiny and flat surface as shown in which make it not suitable to use on sheet metal. (E et al., 2017)

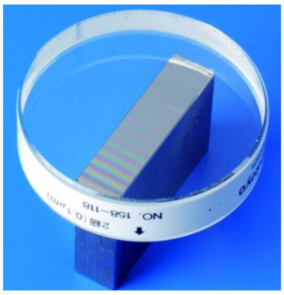

Figure 2.1 Optical Flat

Pencil Scratch Hardness test was used to determine the surface hardness. It was the simplest coating hardness test which uses pencils rating from 9H to 9B with a hardness scale as shown in Figure 2.2 to determine the hardness by scratching the coating surface. The experiment showed epoxy and polyurethane achieved 4H while epoxy-polyester and polyester only increased to 2H and H. Epoxy and polyurethane made filler have high hardness resistance that affected flexibility thus, epoxy-polyester and polyester increase filler flexibility.

Figure 2.2 Hardness Scale range from soft to hard (Tekra, 2013)

Due to the lack of research made on the title, and considering the availability of the machine, Mitutoyo Surface Roughness Tester is used. The tester can be able to read the roughness on the surface with high sensitivity of µm.

CHAPTER 3.0 METHODOLOGY

3.1 Scope of Research

The specimens are selected from two types of materials that are commonly used in the company which are aluminium steel and cold-rolled steel. Voltage, material thickness, heating duration and heat profile are manipulated to get the optimum parameter for powder coating. Lastly, the findings regarding the surface roughness of the steel after powder coating will be discussed and evaluated from the aspect of roughness.

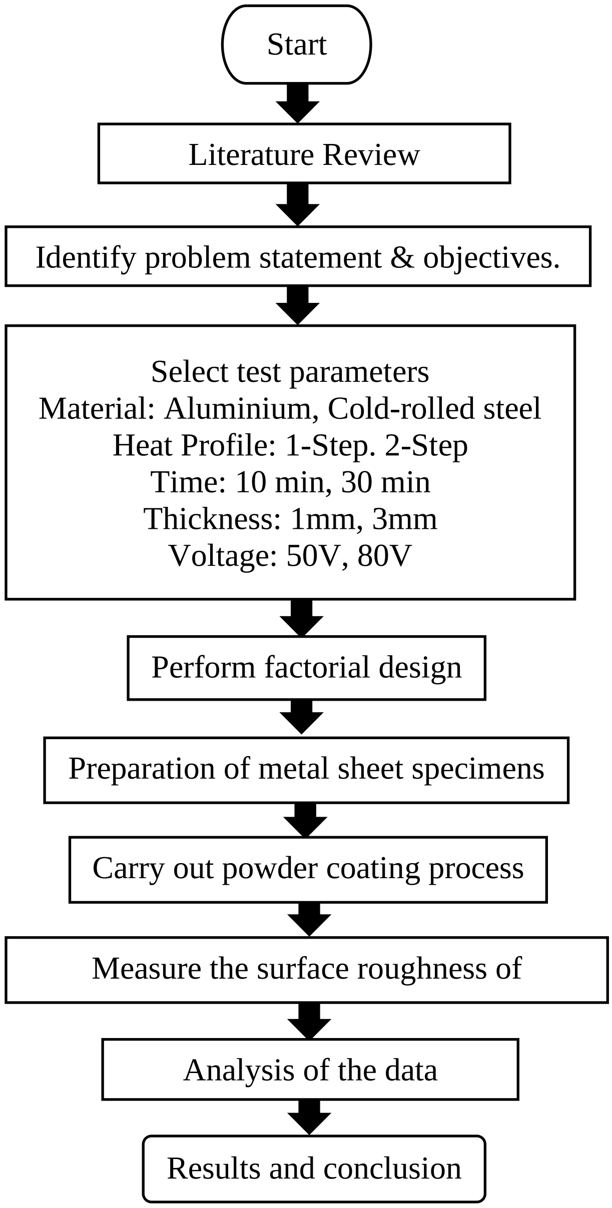

Figure 3.1 Flowchart of Research

3.2 Design of Experiment (DOE)

A surface roughness test was carried out to investigate the surface roughness of the specimens. As shown in the table below, there are five factors with 2 levels to be investigated. Materials of aluminium and cold-rolled steel are used as it is commonly used in the company.

Table 3.1 Parameters of Experiment

Factor	Level 1	Level 2
Material	Aluminium	Cold-rolled Steel
Thickness (mm)	1	3
Time (min)	10	30
Heat Profile	1-Step	2-Step
Voltage (V)	50	80

There are five factors which will need 32 runs which will need a high cost to carry out a full factorial experiment. Thus, fractional factorial designs can be used as some of the high-order interactions can be neglected and only collect information on the main effects and eliminate some of the insignificant combinations of parameters in the experiment. (Montgomery, 2013) From Table 1, the situation of interest in which five factors, each at two levels and the total run will be $2^5 = 32$ treatment combinations. However, the treatment of $2^{5-1}=2^4=16$ is only half of the full factorial. By putting the process parameter together, the table below shows the actual experimental levels of process parameters. While for the material 1 represents aluminium and -1 represent cold-rolled steel.

After experimenting, the data were extracted and used to construct the experiment model in DOE Pro XL. Each run was repeated three times as replication in experimental methods helps to check the reliability of the experiment.(Uyanık & Güler, 2013) The material, thickness, voltage, curing profile and time were the factors in the experiments while the surface roughness was the response to the parameters.

Table 3.2 Run Order with Actual Experimental Levels of Process Parameters

RunOrder	Material	Thickness	Heat Profile	Curing Time	Voltage
1	1	3	2-Step	30	80
2	1	3	2-Step	10	50
3	1	3	1-Step	30	50
4	1	3	1-Step	10	80
5	1	1	2-Step	30	50
6	1	1	2-Step	10	80
7	1	1	1-Step	10	50
8	1	1	1-Step	30	80
9	-1	1	2-Step	30	80
10	-1	1	2-Step	10	50
11	-1	1	1-Step	30	50
12	-1	1	1-Step	10	80
13	-1	3	2-Step	10	80
14	-1	3	2-Step	30	50
15	-1	3	1-Step	30	80
16	-1	3	1-Step	10	50

3.3 Preparation of Specimens

There are two types of materials, which are aluminium and cold-rolled steel as shown. The dimensions of the specimens are in the length of 150mm and width of 80mm while the thickness is 1mm and 3mm.

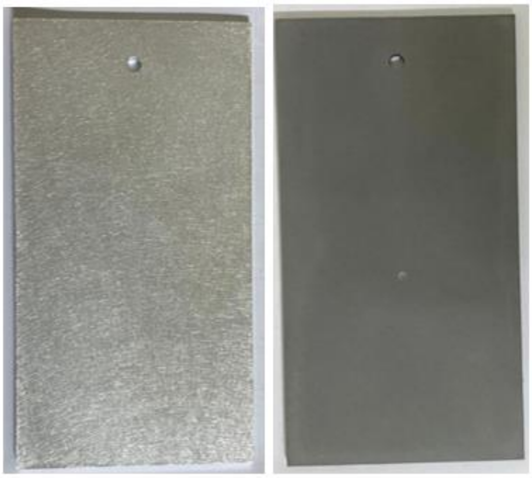

Figure 3.2 Aluminium (left) and Cold-Rolled Steel (right) specimens

3.4 Gardner Impact Tester 1115

To create a uniform unevenness on the surface of the specimens, a Gardner Impact Tester 1115 is used. The shaded part as shown in Figure *3.4* is the point where the 127mm diameter round-nosed end with the force of 12.7kg hit on the specimens.(Tester, n.d.)

Figure 3.3 Gardner Impact Tester 1115

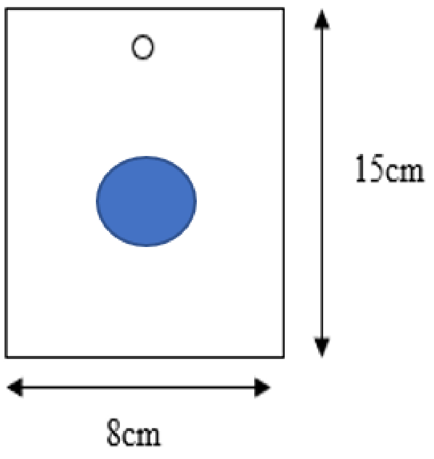

Figure 3.4 Shaded Part on Specimen

3.5 Roughness Specification

To determine the roughness that occurred on the surface of the specimens, the roughness was measured by using Mitutoyo S3000 Surface Roughness Tester. Ra which means average roughness is useful to be guideline of surface texture.(Sahay & Ghosh, 2018) It is the arithmetical mean deviation of the profile with the evaluation length of 2.0 mm. (Derler et al., 2005) From Figure 3.5, the values have been taken three times each on the dotted line on the surface of the specimen, and then the average values have been calculated.

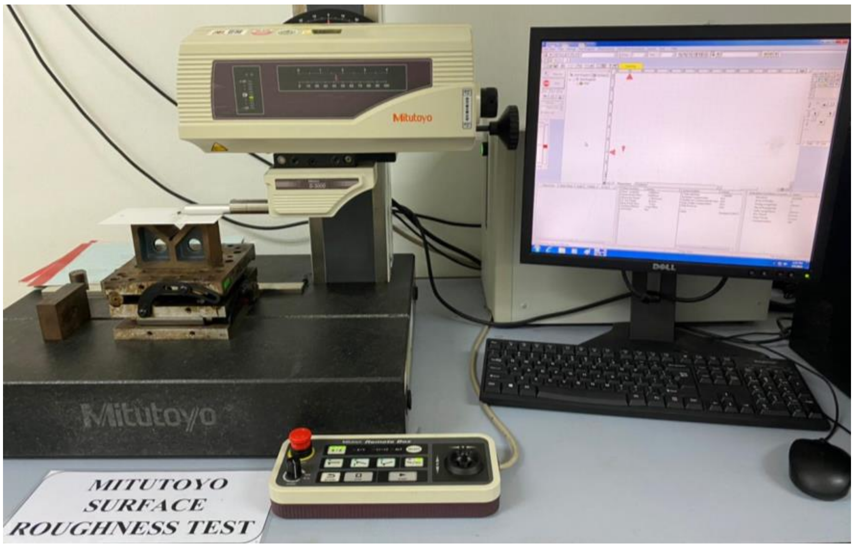

Figure 3.5 Mitutoyo S3000 Surface Roughness Tester

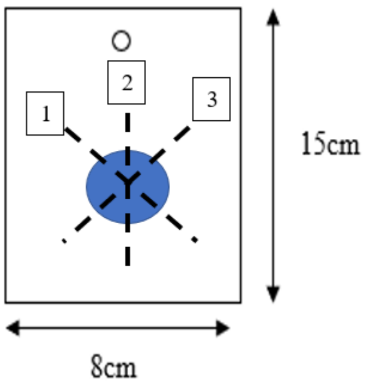

Figure 3.6 Filler Area and Lines Tested

3.6 Batch Oven for Powder Coating

In Surface Technology Solutions, there are two types of industrial ovens which are batch ovens and conveyor ovens. To control the curing steps and time required for the experiment, a batch oven is used for curing.

Figure 3.7 Batch Oven in Surface Technology Solutions

3.7 ANOVA

Analysis of Variance (ANOVA) is used to test whether there are statistically significant differences between the means among different combinations of parameters, or factors and levels, in the experiment (Vieira, 2011) (Durakovic, 2017). In this research, the statistical software DOE Pro XL employed to perform ANOVA based on the experimental data.

A p-value which is less than 0.05 is considered statistically significant and represent strong evidence against the null hypothesis. Hence, p-value of 0.05 normally used as the significance level to determine whether there is a relationship between the dependent variable and the independent variables. However, in this research, the results from the experiment only served as a rough estimation on the relationship between the variables studied. Regression table is able to obtain from DOE Pro and it will provide data to study the effect and correlation of input parameters on the output response.

3.8 Process for Powder Coating

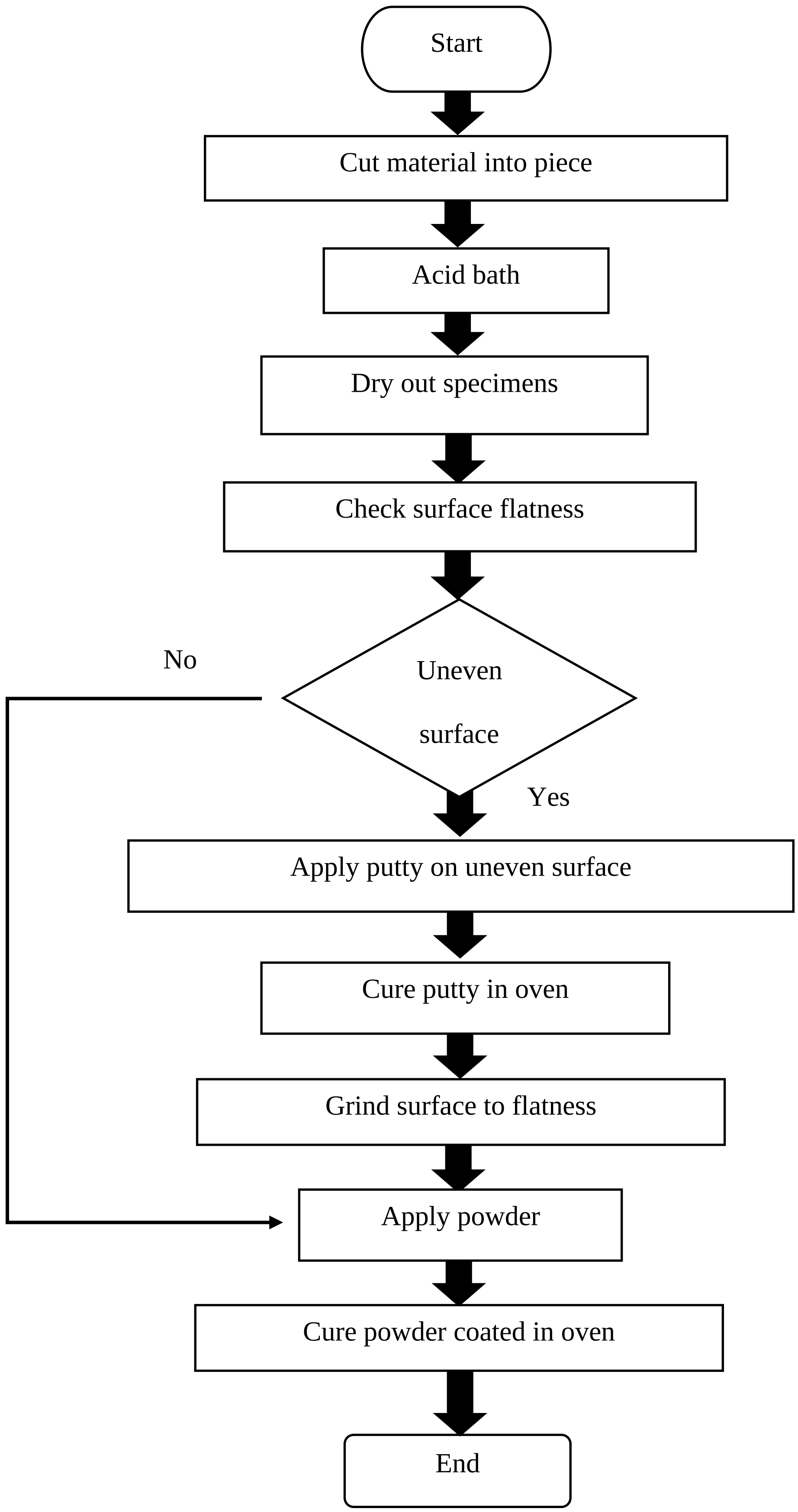

Figure 3.8 Process for Powder Coating

CHAPTER 4.0 RESULT AND DISCUSSION

4.1 Description of Surface

Data collections were done by carrying out a surface roughness test. The roughness of the surface visual defects such as orange peel, yellowish and pinhole effects were observed. The data were determined only on the area to which filler has been applied. The presences of visual defects were shown in Appendix while the table below was the details.

Table 4.1 Results

Sample	Dent diameter (mm)	Orange Peel	Yellowish	Pinhole
1(a)	3	Absent	Absent	Absent
(b)	3	Absent	Absent	Absent
(c)	3	Absent	Absent	Absent
2(a)	2	Absent	Absent	Absent
(b)	2	Absent	Absent	Absent
(c)	2	Absent	Absent	Absent
3(a)	10	Absent	Present	Absent
(b)	10	Present	Present	Absent
(c)	10	Absent	Present	Absent
4(a)	10	Present	Absent	Absent
(b)	10	Present	Absent	Absent
(c)	10	Absent	Absent	Present
5(a)	11	Present	Absent	Absent
(b)	11	Present	Absent	Absent
(c)	13	Present	Absent	Absent
6(a)	3	Absent	Present	Absent
(b)	3	Absent	Present	Absent
(c)	3	Absent	Present	Present

7(a)	3	Absent	Absent	Absent
(b)	3	Absent	Absent	Absent
(c)	3	Absent	Absent	Absent
8(a)	10	Present	Present	Absent
(b)	10	Present	Present	Present
(c)	10	Present	Present	Absent
9(a)	3	Absent	Present	Absent
(b)	3	Absent	Present	Absent
(c)	11	Absent	Present	Absent
10(a)	4	Absent	Absent	Absent
(b)	4	Absent	Absent	Absent
(c)	4	Absent	Absent	Absent
11(a)	11	Present	Absent	Present
(b)	11	Present	Absent	Present
(c)	11	Present	Absent	Present
12(a)	9	Present	Absent	Absent
(b)	10	Present	Absent	Absent
(c)	9	Present	Absent	Absent
13(a)	3	Absent	Absent	Absent
(b)	3	Absent	Absent	Absent
(c)	3	Absent	Absent	Absent
14(a)	3	Absent	Absent	Absent
(b)	3	Absent	Absent	Absent
(c)	3	Absent	Absent	Absent
15(a)	8	Absent	Present	Absent
(b)	8	Absent	Present	Absent
(c)	10	Present	Present	Absent
16(a)	12	Present	Absent	Present
(b)	13	Present	Absent	Present
(c)	12	Present	Absent	Present

4.2 Experimental Data

The software DOE Pro XL was used to generate the total runs needed for the experiment, the experimental model for the experiment parameters on regression tables, Pareto charts, marginal means plots, multiple plots of interactions, and a response optimizer. The experiment was carried out using half factorial experimentation with various parameter combinations.

While the table below were the results of the response which was the surface roughness after powder coating on the specimen. Mean shown in the table is the average value of the surface roughness from the three-run of the experiment for the same combination of parameters. A list of standard deviations for every combination of experiments before proceeding with running the data for regression analysis is in the table below.

Table 4.2 Data Collection Result

	Factors						Roughness					
No	Materia l	Thickne ss	Voltage	Heat Profile	Curing Time		Y1	Y2	Y3		Y bar	S
1	-1	1	50	1	30		9.0098	12.6672	7.5834		9.7535	2.6222
2	-1	1	50	2	10		1.3069	0.9711	1.4558		1.2446	0.2483
3	-1	1	80	1	10		14.3277	13.6769	10.01297		12.6725	2.3261
4	-1	1	80	2	30		4.3604	5.8618	5.248		5.1567	0.7549
5	-1	3	50	1	10		1.2309	3.3787	2.7016		2.4371	1.0981
6	-1	3	50	2	30		3.8191	1.6366	1.4941		2.3166	1.3031
7	-1	3	80	1	30		2.6267	2.6701	2.4801		2.5923	0.0996
8	-1	3	80	2	10		1.6666	1.4706	2.0946		1.7439	0.3191
9	1	1	50	1	10		8.2460	6.8552	11.3938		8.8317	2.3253
10	1	1	50	2	30		4.7652	5.964	7.3192		6.0161	1.2778
11	1	1	80	1	30		13.9378	14.8819	13.3897		14.0698	0.7548
12	1	1	80	2	10		12.6355	8.0369	10.48		10.3842	2.3008
13	1	3	50	1	30		2.0101	2.1593	2.3291		2.1662	0.1596
14	1	3	50	2	10		2.2884	1.3671	0.9959		1.5504	0.6655
15	1	3	80	1	10		4.1386	3.2501	3.7034		3.6974	0.4443
16	1	3	80	2	30		3.0069	2.3382	1.8881		2.4111	0.5629

4.3 Statistical Analysis on DOE Pro XL

Regression Model

First analysis:

In Table 4.3, the principal regression is shown, and it displays the initial results of the model's experimental runs. Regression analysis is a statistical approach used to estimate the relationship between variables. There are three types of font colours for 2 tailed P-value column which are blue, red and black. After generating the data, P-value numbers which are more than 0.05 are eliminated.

Table 4.3 First Regression Model

Factor	Name	Coeff	P(2 Tail)
Const		5.44	0.0000
A	Material	0.7006	0.0012
B	Thickness	-3.076	0.0000
C	Voltage	1.151	0.0000
D	Heat Profile	-1.587	0.0000
E	Curing Time	0.12003	0.5467
AB		-0.6087	0.0041
AC		0.34901	0.0860
AD		0.53689	0.0103
AE		-0.09509	0.6327
BC		-0.90393	0.0001
BD		1.228	0.0000
BE		-0.11286	0.5708
CD		-0.07972	0.6885
CE		-0.65354	0.0023
DE		0.00215	0.9914
	R^2	0.9333	
	F	29.8272	

Tables 4.4 show the finalized regression table after eliminating insignificant parameters. For the Y-hat model, the coefficient for each component is calculated. The observed key factors influencing the experiment's response are material, thickness, voltage, curing time and heat profile. The combination of BD, BC, CE, AB

and AD provide high interaction. While the factors B, D, C and A are also crucial in the acquired data, where A is material, B is thickness, C is voltage, D is heat profile, and E is curing time. The R^2 value assesses the robustness of the experimental model. The model's degree of prediction of the dependent variable was determined to be 0.9310, where R^2 should be more than 0.7 for a better match of percentage (Hulland, 1999). Thus, the data and factors are strong and indicate the goodness of fit in the model.

The adjusted R^2 value calculated is 0.9310 of the actual R^2 value which is ideal for the model. The closer the R^2 value is to 1, the stronger the model of the experiment, therefore we conclude that the experiment model is strong. The F-value in the experimental model is used to determine whether the factors are significant in the model. The F-value should ideally be more than 6 for the predictor variables to be significant and matched with the p-value. From the table above, the final regression model shows that the F-value is 49.8963 which is higher than the optimum value of more than 6, and a higher F-value indicates that the data acquired are not impacted by noise (Elarbe et al., 2022). The experiment factors are significant in the model.

Table 4.4 Final Regression Model

Factor	Name	Coeff	P(2 Tail)
Const		5.44	0.0000
A	Material	0.7006	0.0012
B	Thickness	-3.076	0.0000
C	Voltage	1.151	0.0000
D	Heat Profile	-1.587	0.0000
AB		-0.6087	0.0041
AC		0.34901	0.0860
AD		0.53689	0.0103
BC		-0.90393	0.0001
BD		1.228	0.0000
CE		-0.65354	0.0023
	R^2	0.9310	
	F	49.8963	

4.4 Graph Analysis

After eliminating the insignificance factors, the Pareto chart is plotted to indicate the significance of each parameter based on corresponding coefficients. For the Y-hat Pareto chart of obtained responding variable, which is the surface roughness after powder coating, it is shown that thickness (B) is the most significant factor that affects the surface roughness after powder coating, followed by the heat profile (D) and voltage (C). In addition, the significant level of combination of factors decreases with the order of BD, BC, CE, AB and AD. However, it cannot determine whether the parameters increase or decrease the response. It only indicates the standardized effect of the parameters on the surface roughness.

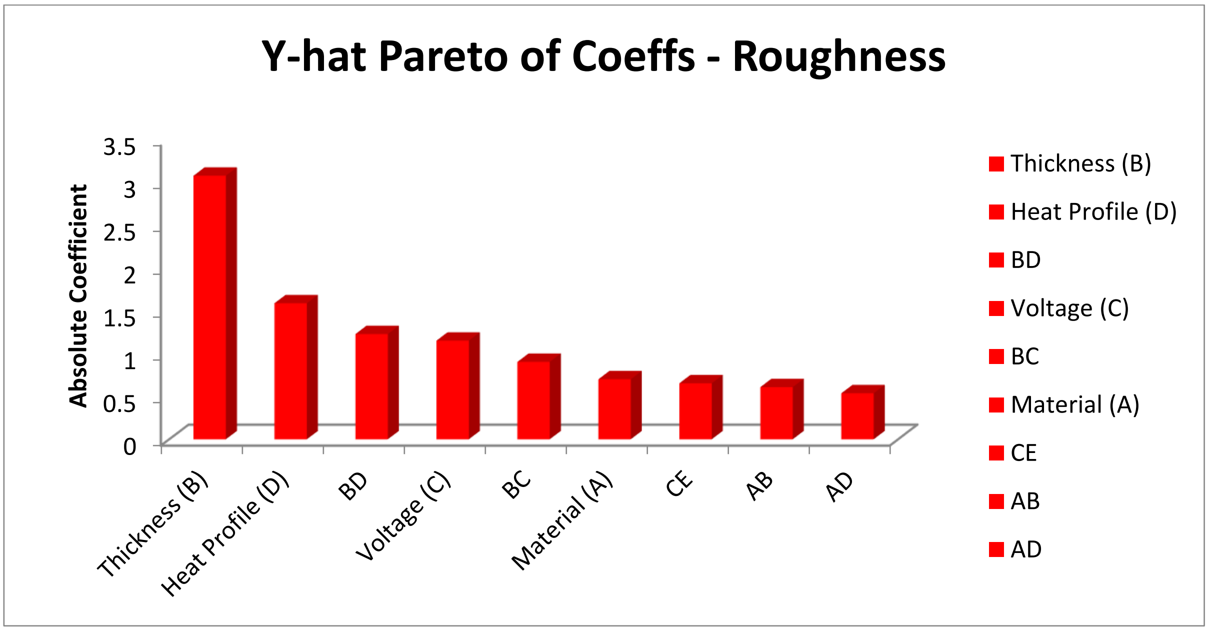

Figure 4.1 Y-hat Pareto of Coefficient Chart for Roughness

4.5 Analysis of Variance (ANOVA)

In the experimental model, an ANOVA table is generated to indicate the contribution of each component and the combination of factors. The experimental model's p-value indicates the level of significance of the relevant coefficients. The greater the significance level of the coefficient, the lower the p-value of the component. (Elarbe et al., 2022). It is shown that factors A, B, C, D, AB, AD, BC. BD and CE have p-values of $P < 0.05$, therefore the factors significantly affect the response variable in the design model. In addition, the 5 factors that have the lowest p-value contributed a total of 74.2%. The contribution is significantly higher than other factors. The error from the experiment is predicted to be 6.67%

Table 4.5 ANOVA Table

Source	F	P (2 Tail)	% Contrib
Material	12.641	0.001	2.64
Thickness	243.667	0.000	50.83
Voltage	34.104	0.000	7.11
Heat Profile	64.888	0.000	13.54
Curing Time	0.371	0.547	0.08
AB	9.542	0.004	1.99
AC	3.137	0.086	0.65
AD	7.424	0.010	1.55
AE	0.233	0.633	0.05
BC	21.044	0.000	4.39
BD	38.865	0.000	8.11
BE	0.328	0.571	0.07
CD	0.164	0.688	0.03
CE	11.000	0.002	2.29
DE	0.000	0.991	0.00
Error			6.67

4.6 Marginal Means Plot

The marginal means plot is a tool to visualize the effect levels on each factor. The steeper the value of the coefficient, the higher the significant level of the factor. From Figure 4.2 below, the speed of spray painting is shown to have higher effect levels compared to other factors. The result of the graph is shown to have the same characteristics as the Pareto chart of the coefficient and the regression table.

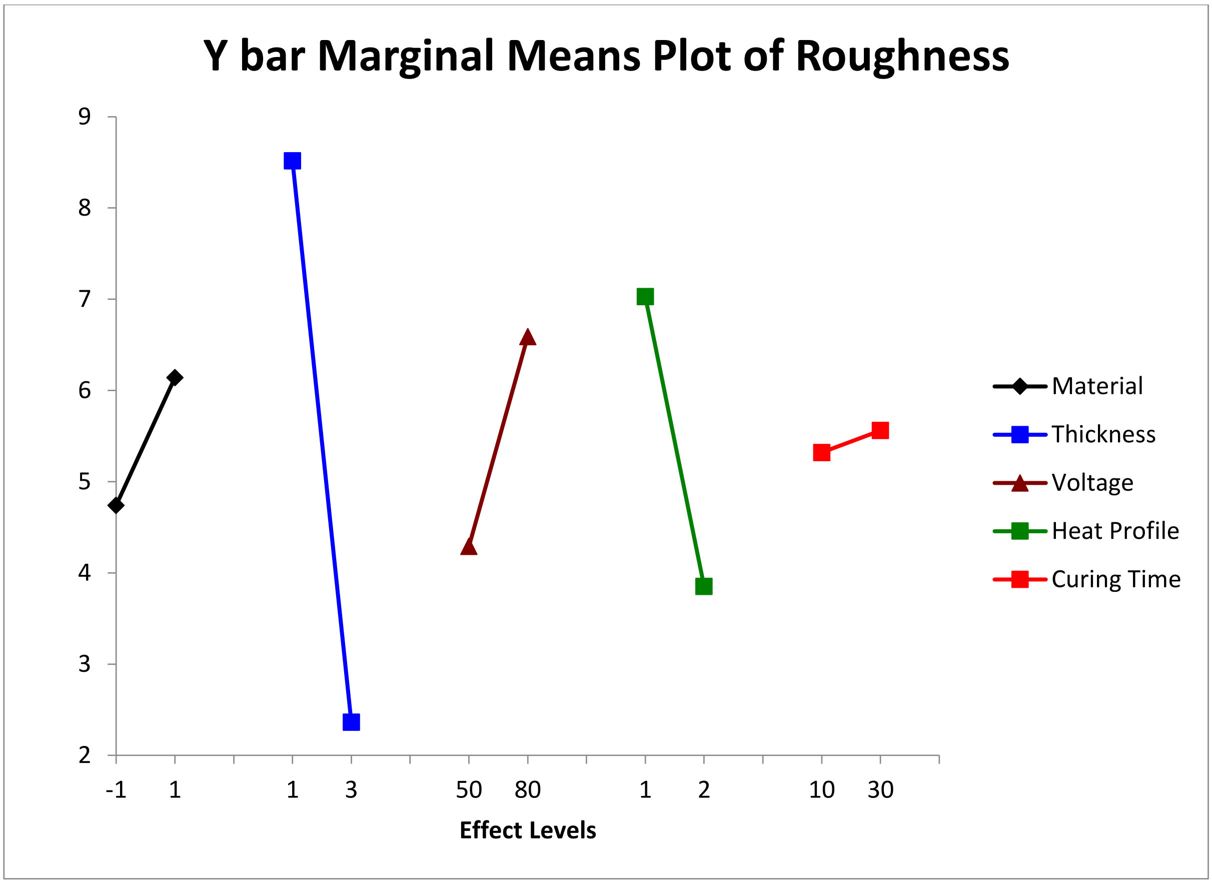

Figure 4.2 Y-bar Marginal Means Plot of Roughness

A multiple plot shows the effect of interactions between the parameters at a low and high level of another factor. The multiple plots are used to interpret the level of significance of interactions between the factors. Interaction is present when the response at a factor level depends on the level of other factors. As each factor magnify or diminish the effects of other factors, evaluating each interaction is vital for experiment modelling. The graph which has the 2 factors parallel to each other indicates that they have no relation to each other. From Figure 4.4, 4.5 and 4.6, the significant interactions between factors are voltage vs curing time, heat profile vs thickness and material vs thickness as the graphs are not parallel to each other. This means that the factors will have an interaction between them. The greater the departure of the lines from the parallel state, the higher the degree of interaction.