AN OPTIMIZATION OF SPRAY COATING PROCESS TO MINIMIZE COATING MATERIAL CONSUMPTION

Nitchakan Somboonwiwat
Suksan Prombanpong
Department of Production Engineering,
King Mongkut's University of Technology Thonburi (KMUTT), Bangkok 10140 Thailand
E-mail: nonpang24@hotmail.com, suksan.pro@gmail.com

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ABSTRACT

In cookware industry, interior spray coating process is an important process to protect the cookware product from the corrosion. In this process, the coating material "TEFLON" is used to spray to cover all the part's surface. If a pot or pan is not too deep, one spray gun is enough to spray to cover all the interior surface. However, for the high side-wall pot, two spray guns must be used to spray at two different areas. The first area is at the bottom and its corner. The second area is around the top rim of the pot or pan. Note that the spray pattern is of fan-type. Thus, the sprayed area will be covered by the mentioned two spray guns. Consequently, the large amount of coating material is consumed to meet the dry film thickness (DFT) requirement. In this paper, the optimization of spray coating process is studied aiming to minimize the material usage. The experimental design technique is applied to determine the optimal spray coating parameters. The parameters used in this study include angle, spray time, fan pattern, and air pressure. The relationship models of coating material volume and DFT are presented in this research. The optimal parameters of the two spray guns are presented.

INTRODUCTION

The cookware production comprises many processes starting from blanking to packing. The coating process is an important step before assembly. It makes the products strong, long lasting, beautiful and protects the surfaces. In the coating process, the spray gun is normally used to spray the coating material to a target surface. Basically, the coating process consist of triple-layer coatings: primer, middle, and top layer. The primer is the first layer of coating that is applied to the substrate for interfacing between the surface of the part and the middle layer. The main purpose of the primer layer is a preparation of the coating surface to ensure smoothness and good adherent of coating material to the part surface. The middle layer is the layer on the primer layer. The coating material of the middle layer is an actual coating material whose function is to increase corrosive resistant of a part. Finally, the top layer will be applied make a part look shinny and increase the efficiency of the coating material in the middle layer. Considering all three layers of the coating process, the middle layer is the most important which affects the durability of the cookware product. As a consequence, it increases the service life of products, while the primer is the substrate of coating and the top layer is the decoration purpose. Therefore, this research will focus on the middle layer coating.

In the spray coating process, a coating material waste due to an overspray and bounch of the coating material are the main issue. Thus, the objective of this research is to determine optimal spray parameters to minimize the coating material consumption due to DFT specification. (Winnicki et al. 2014 and From et al. 2011) study the optimal parameters of spray coating process to meet DFT but not the coating material consumption. There are few researchers studied the optimal parameters affecting both the coating material consumption and DFT research (Song et al. 2008 and S. Hong et al. 2014). (Luangkularb and Prombanpong 2014) present the optimal parameters concerning both of the coating material consumption and DFT for the single spray gun. However, this paper demonstrates a determination of optimal parameters considering both of material consumption and DFT for the two spray guns. The 26 cm in diameter of a pan is the specimen in this study. The spraying area is divided two positions i.e. bottom and corner, and top rim of a pan. Thus, the first gun sprays to cover the bottom area of the part whereas the second spray gun aims to cover the side wall and rim of the pan.

METHODOLOGY

The experimental design technique is applied to obtain the optimal spray parameters to minimize the coating material consumption and to attain DFT. The concerned parameters include gun angle, spray time, fan pattern and air pressure. The two levels used for the experiment is presented in Table 1. Thus, at each spray gun, the

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experiment is designed with regard to the 2^4 factorial design with two replications. Thus, a total of 16 experiments will be performed for each spray gun. The material consumption and DFT are measured as the response and the gun angle, spray time, fan pattern and air pressure are recorded as the independent variables. The data obtained from the experiment will be then analyzed using the analysis of variance (ANOVA) technique to determine the effect of these four independent variables on material consumption and DFT. The required DFT is in a range of 7.5-12.5 µm. The predictive relationship model for these two responses is then constructed to find the optimal parameters for the spray coating process.

Table 1: Data Used in the Experiment

Factor	First spray gun		Second spray gun	
	min	max	min	Max
Gun Angle (degree)	60	70	35	40
Spray time (sec)	1.2	1.4	1.2	1.4
Fan pattern (rev.)	315	360	315	360
Air pressure (bar)	2.5	3.0	2.5	3.0

RESULTS AND DISCUSSION

The result obtained from the experiment will be analyzed using MINITAB software. The normality, constant variance and randomization tests are performed. The analysis of variance (ANOVA) is subsequently conducted to determine the effect of variables on the coating material consumption (MC) and average dry film thickness (DFT). In addition, the process optimization is performed to minimize material consumption and also yield the DFT ranging in the specification. The results of statistical analysis of first spray gun and second one are as follows.

Coating Process of First Spray Gun

- **Statistical Analysis**

The model adequacy checking of the material consumption data shows that the p-value for the normality probability test, equal variance and randomization test equal to 0.722 0.487 and 0.153 respectively. For the DFT data, the p-value of the normality probability test, equal variance, and randomization test are equal to 0.437, 0.637 and 0.249 respectively (Table 2). The result indicates that the MC and DFT data are in the normal distribution and there is no deviation in a variance of each test. ANOVA is conducted and the results are obtained for MC and DFT responses as shown in Table 3 and 4. The p-value which is less than 0.05 is used as the criterion to determine the significance of the response.

Table 2: P-value of Model Adequacy

Model adequacy checking	P-Value	
	Material consumption	Dry film thickness
Normal distribution	0.722	0.437
Equal variance	0.487	0.637
Randomization	0.153	0.249

Table 3: Result of ANOVA Material Consumption for First Spray Gun

Term	P-Value
Gun angle	0.002
Spray time	0.000
Fan pattern	0.000
Air pressure	0.000
Gun angle*Fan pattern	0.004
Spray time* Fan pattern	0.020
Spray time*Air pressure	0.000
Fan pattern*Air pressure	0.003
S = 0.547875 PRESS = 12.8071	
R-Sq = 86.84% R-Sq(pred) = 76.61% R-Sq(adj) = 83.00%	

Table 4: Result of ANOVA Dry Film Thickness for First Spray Gun

Term	P-Value
Gun angle	0.033
Spray time	0.000
Fan pattern	0.001
Air pressure	0.000
Gun angle*Fan pattern	0.007
Spray time*Air pressure	0.023
Fan pattern*Air pressure	0.000
S = 0.547875 PRESS = 12.8071	
R-Sq = 86.84% R-Sq(pred) = 76.61% R-Sq(adj) = 83.00%	

- **Effect of Spray Condition Analysis**

The effects of gun angle, spray time, fan pattern and air pressure on the material consumption and dry film thickness are shown in Figure 1 and 2. The results indicate that the increment of gun angle, fan pattern and air pressure will decrease the material consumption and dry film thickness. However, the decrement in the spray time will decrease the material consumption and dry film thickness.

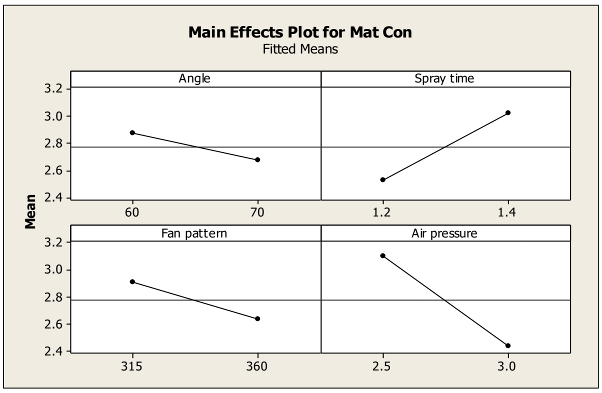

Figure 1: Main Effect Plot of Variable on Average Material Consumption for First Spray Gun

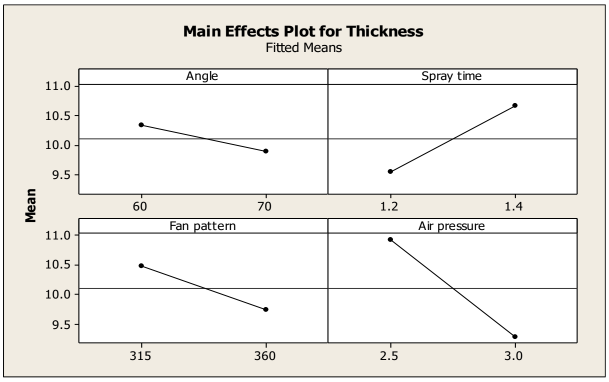

Figure 2: Main Effect Plots of Variables on Average Dry Film Thickness for First Spray Gun

- **Process Optimization and Modeling**

The regression model is constructed to present the relationship between response, coating material consumption and DFT, with the variables, angle, spray, fan pattern and air pressure as shown in (1) and (2). The optimal condition is the gun angle at 60 degree, spray time at 1.2 sec., fan pattern at 315 revolution (rev.) and air pressure at 2.7 bar. The material consumption and DFT equal to 2.8 g. and 10.45 µm which is in the specification. Table 5 shows the optimal results.

Parameters (Indepentdent Variables):

X_1 angle (degree)
X_2 spray time (sec)
X_3 fan pattern (rev)
X_4 air pressure (bar)

Responses (Dependent Variables):

MC_1 material consumption of inside area for first spray gun (gram)
DFT_1 dry film thickness (µm.)

The Relationship Models:

$$MC_1 = -25.8725-0.300469X_1+29.2672X_2+0.0296319X_3 +11.8631X_4+0.000830556X_1X_3-0.0328472X_2X_3 -5.71250X_2X_4-0.0171111X_3X_4 \quad (1)$$

$$DFT_1 = -26.0625-0.89325X_1+31.5X_2+0.0211944X_3 +33.6625X_4+0.00251667X_1X_3-9.425X_2X_4 -0.07322X_3X_4 \quad (2)$$

Table 5: Optimal Conditions, MC_1 and DFT_1

Variable	Optimal value
Angle (degree)	60
Spray time (sec.)	1.2
Fan pattern (rev.)	315
Air pressure (bar)	2.7
MC_1(g.)	2.8
DFT_1(µm.)	10.45

Coating Process of Second Spray Gun

- **Statistical Analysis**

The model adequacy checking of the material consumption data shows that the p-value for the normality probability test, equal variance, and randomization test equal to 0.699 0.427 and 0.198 respectively. For the DFT, the p-value of the normality probability test, equal variance, and randomization test are equal to 0.522, 0.571 and 0.369 respectively as shown in Table 6. The result indicates that the MC and DFT data are in the normal distribution and there is no deviation in variance of each test. The analysis of variance is conducted and the result is summarized in Table 7 and 8. The p-value which is less than 0.05 is used as the criterion to determine the significance of the response.

Table 6: P-value of Model Adequacy

Model Adequacy Checking	P-Value	
	Material Consumption	Dry film thickness
Normal Distribution	0.699	0.522
Equal variance	0.427	0.571
Randomization	0.198	0.369

Table 7: Result of ANOVA Material Consumption for Second Spray Gun

Term	P-Value
Angle	0.000
Spray time	0.005
Fan pattern	0.000
Air pressure	0.000
Angle*Fan pattern	0.003
Spray time*Fan pattern	0.029
Spray time*Air pressure	0.000
Fan pattern*Air pressure	0.005
S = 0.308862 PRESS = 4.44022	
R-Sq = 96.87% R-Sq(pred) = 93.37% R-Sq(adj) = 95.59%	

Table 8: Result of ANOVA Dry Film Thickness for Second Spray Gun

Term	P-Value
Angle	0.000
Spray time	0.000
Fan pattern	0.000
Air pressure	0.000
Angle*Spray time	0.000
Angle*Fan pattern	0.003
Spray time*Fan pattern	0.005
Spray time*Air pressure	0.000
Fan pattern*Air pressure	0.000
S = 0.547875 PRESS = 12.8071	
R-Sq = 86.84% R-Sq(pred) = 76.61% R-Sq(adj) = 83.00%	

- **Effect of Spray Condition Analysis**

The effects of gun angle, spray time, fan pattern and air pressure on the material consumption and dry film thickness are shown in Figure 3 and 4. The results indicate that the increment of gun angle, fan pattern, and air pressure decreases the material consumption and dry film thickness. However, the idecrement in the spray time decreases the material consumption and dry film thickness.

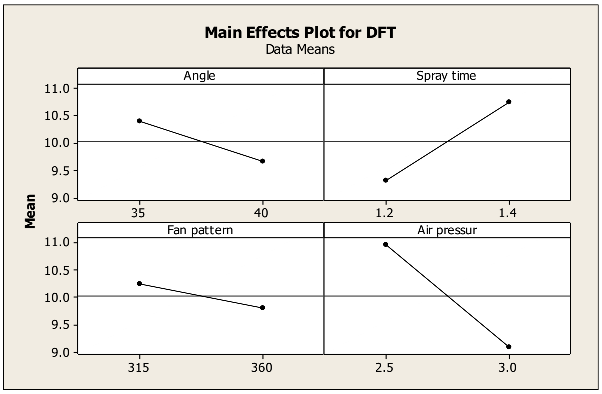

Figure 3: Main Effect Plot of Variable on Average Material Consumption for Second Spray Gun

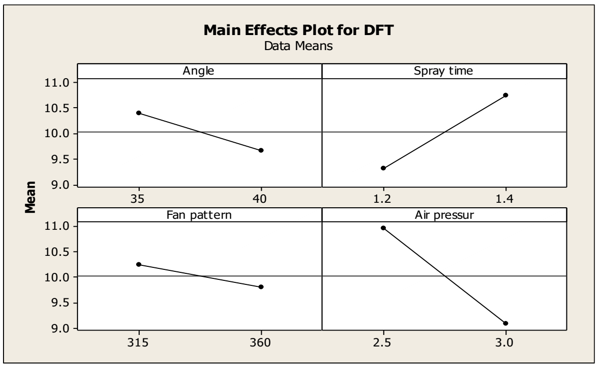

Figure 4: Main Effect Plots of Variables on Average Dry Film Thickness for Second Spray Gun

- **Process Optimization and Modeling**

The optimization of the spray coating process is performed to minimize the material consumption which the dry film thickness is in the range between 7.5-12.5 µm. The regression model is constructed to present the relationship between response, coating material consumption, and DFT as shown in (3) and (4). The optimal condition is the gun angle at 60 degrees, spray time at 1.2 sec., fan pattern at 315 rev. and air pressure at 2.7 bar. The material consumption and DFT is equal to 2.8 g. and 10.45 µm which is in the specification. Table 9 shows the optimal results.

Parameters (Indepentdent Variables):

X_1 angle (degree)
X_2 spray time (sec.)
X_3 fan pattern (rev.)
X_4 air pressure (bar)

Responses (Dependent Variables):

MC_2 material consumption of outside area for second spray gun (gram)
DFT_2 dry film thickness of outer radius for second spray gun (µm.)

The Relationship Models:

$$MC_2 = -21.6531-0.655187X_1+30.3516X_2+0.0113264X_3 +12.0244X_4+0.00183333X_1X_3-0.0327083X_2X_3 -6.10000X_2X_4-0.0159444X_3X_4 \quad (3)$$

$$DFT_2 = -86.5812-2.12275X_1+63.2062X_2+0.279889X_3 +38.6075X_4+0.745X_1X_2+0.00298889X_1X_3 -0.146389X_2X_3-12.60X_2X_4-0.077X_3X_4 \quad (4)$$

Table 9: Optimal Conditions, MC_2 and DFT_2

Variable	Optimal value
Angle (degree)	35
Spray time (sec)	1.23
Fan pattern (rev)	360
Air pressure (bar)	2.5
MC_2 (g.)	2.3
DFT_2 (µm.)	10.85

CONCLUSION

This study attempts to find the optimal solution for two spray gun process in order to minimize the coating material consumption while meeting the dry film thickness specification of 7.5-12.5 µm. The results also show that the significant parameters suchas gun angle, spray time, fan pattern, and air pressure to material consumption and DFT are in the same manner.

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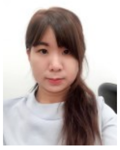

NITCHAKAN SOMBOONWIWAT is a graduate student in Industrial and Manufacturing System Engineering program at the Department of Production Engineering, King Mongkut's University of Technology Thonburi, Thailand. She received her bachelor's degree in Tool and Material Engineering from the same university. Her research interests are applied statistics and operations management. Her e-mail address is : nonpang24@hotmail.com.

Prof. Dr. SUKSAN PROMBANPONG is an Associaate Professor in the Industrial Management section, Department of Production Engineering Faculty of Engineering, King Mongkut's University of Technology Thonburi, (KMUTT) Thailand. He received Fulbright scholarship to pursue his master and doctoral degree at The Ohio State University (OSU) U.S.A. After graduation he worked at National University of Singapore for three years. Now he is a lecturer in the department of Industrial Engineering at KMUTT. He also holds a position of DEPUTY DIRECTOR for the Institute for Scientific and Technological Research and Services and a head of Continuing Education Center at KMUTT. His research interest is in the area of manufacturing applications, production planning and control, optimization, logistic and supply chain and green industrial. His e-mail address is : suksan.pro@gmail.com.