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RESEARCH ARTICLE

MINIMIZATION THE REJECTION RATE OF THE AUTOMOTIVE THERMOPLASTIC PARTS IN INJECTION MOULDING USING RESPONSE SURFACE METHODOLOGY

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Abstract

Plastic injection moulding is widely used for manufacturing due to variety of plastic product. In this study, plastic part defects such as air bubble and gas mark defect are commonly occurs in thermoplastic part, specifically acrylonitrile butadiene styrene (ABS). In order to optimize the process parameters of injection moulding, design of experiment (DOE) with Response Surface Methodology (RSM) model was used. Process parameters such as melt temperature, mould temperature and injection pressure were selected for the DOE development. The experiments were conducted with melt temperature range from 200 °C to 240 °C, mould temperature from 60 °C to 80 °C and injection pressure from 90 to 99%. The result indicates that, all the selected parameters were significantly influence the rejection rate of the automotive ABS part. The optimum melt temperature, mould temperature and injection pressure were 220 °C, 70 °C and 98% respectively, in obtaining minimum rejection rate.

1.0 INTRODUCTION

Plastic technology like injection moulding, vacuum forming and thermoforming are the methods that used to manufacture plastic. Among them, plastic injection moulding (PIM) is more suitable technique to manufacture mass produced plastic parts (Shen, Wang et al. 2007). In this process, hot polymer melt is forced into a cold empty cavity of a desired shape and then it is allowed to solidify under a high holding pressure. The entire injection moulding cycle can be divided into three phases: filling, post-filling and mould-opening (Galantucci and Spina 2003). However, defects such as warpage, shrinkage, sink mark, gas mark, bubble mark and residual stress are occurred for plastic product due to parameters such as mould temperature, melt temperature and injection pressure during the production process (Ozcelik and Erzurumlu 2005). These defects influence the quality and accuracy of the products.

PIM is a complex manufacturing processes due to the strong nonlinearities, even though numerous people regard it as a simple and common manufacturing process (Chen, Tai et al. 2008). This process includes four phases: plasticization, injection, packing, and cooling (Seaman, Desrochers et al. 1994). For the plasticization phase, the turning screw conveys the granulate from the feed hopper through the screw channels to the screw tip. During the injection phase plastic material, usually in the form of pellets, is loaded into a hopper on top of the injection unit. The pellets feed into a cylinder where they are heated until they reach molten form. Within the heating cylinder there is a motorised screw or ram that mixes the molten pellets and forces them to end of the cylinder. Once enough material has accumulated in front of the screw, the injection process begins. The molten plastic is inserted into the mould through a sprue (channel), while the pressure and speed are controlled by the screw. During packing phase additional plastic is injected into the cavity to compensate for the shrinkage that occurs in the plastic that was injected in the injection phase. This is a pressure and velocity controlled phase of cooling process involves the plastic inside the mould beginning to cool after it makes contact with the interior mould. As the plastic cools when it hardens it will take the desired shape. The part may defects slightly during cooling.

It is well known that, PIM is a very complex process in producing plastic, where parameters adjustment is required to produce high quality product. Quality of product depends upon the choice of material, mould and process parameters. Thus, optimum process parameters setting are crucial. In order to reduce the cost and time, optimization tool is needed for the investigation, where response surface methodology (RSM) is one of the popular adopted method (Islam et al., 2018; Ong et al., 2016; Ong et al., 2012). In this work, RSM has been selected to study the optimization of process parameters such as melt temperature, mould temperature and injection pressure in automotive acrylonitrile butadiene styrene (ABS) plastic part in one of the automotive plastic part manufacturer in Malaysia.

2.0 METHODOLOGY

2.1 Experiment design using RSM

Design of experiment (DOE) has been implemented to select many of manufacturing process parameters, due to the effectiveness to improve the quality of products (Ozcelik, 2006). Response surface methodology (RSM) is a technique for DOE which a combination of mathematical, statistical and optimization techniques for analyzing the problems and applying to create model and optimize designs (Mcdonald, 2007). In this work, Injection moulding independent process parameters such as melt temperature, mould temperature and injection pressure were selected for the investigation. The selected automotive ABS plastic part is car grille. The lower and upper limit setting was presented in Table 1. The ABS physico-mechanical properties was presented in Table 2.

Table 1 Show the parameters and range

Parameter	Lower limit	Upper limit
Mould temperature, °C	60	80
Melt temperature, °C	200	240
Injection pressure, %	90	99

Factorial experiment are conducted to analyze the main effects of factors and their interactions for the quality characteristic. In this study, the defects such as warpage, shrinkage, sink mark, gas mark, and bubble mark were considered. The full factorial design used was Box-Behnken design. Design expert software (version 7.0, Stat Easy Inc., Minneapolis, USA) was used for the design.

Table 2 Physico-mechanical properties of ABS

Properties	Value
Density	0.9 - 0.91 g/cm3
Coefficient of Linear Thermal Expansion	6 - 17 x 10-5 /°C
Elongation	150-600%
Tensile strength	20 – 40 Mpa
Yield strength	35 – 40 Mpa

2.2 Injection moulding plastic part

The experiment of the ABS plastic part was conducted in one of the automotive plastic manufacturer in Malaysia. The setting of the independent process parameters were followed the experiment run design by design expert software. The software will calculate in a statistical manner and the results will be verified with ANOVA.

2.3 Analysis of Variance (ANOVA)

The result of the quadratic model obtained from the optimization of the design expert will be verified by ANOVA to determine either the mathematical model was statistically significant or otherwise. In order to determine the significant factor that contribute to the rejection rate, the result have been analyzed using ANOVA. The ANOVA concept involving the relative percentage contribution among the factor is determined by comparing their relative variance. The ANOVA will compute the quantities such as degree of freedom (f), sum of squares (S), variance (V), F-ratio (F) and Percentage of contribution (P).

3.0 RESULTS AND DISCUSSION

3.1 Development of regression model equation

Plastic injection moulding experiments were carried out on a TOSHIBA IS550FA2 machine. The feasible space for the moulding parameters will be defined by varying the melt temperature (A) in the range of 200 °C – 240 °C, the mould temperature (cavity) (B) from 60 °C – 80 °C and injection pressure (C) from 90% - 99%. The plastic part selected for the experiment is grille upper. The specific material used for the part selected is ABS with industrial grade PA 727 and the part weight of each is 200 g. The drying temperature of ABS is 85 °C for 4 h of drying time. Each of the experiment run, 50 pieces of ABS plastic part was produced and the average rejection rate was recorded. The experimental results obtained for ABS part production rejection rate is presented in Table 3.

Table 3 Average rejection rate of ABS plastic part production

Run	Melt temperature, A (°C)	Mould temperature (cavity), B (°c)	Injection pressure, C (%)	Rejection rate, Y (%)
1	220	70	94.5	23.53
2	220	80	90	5.80
3	200	80	94.5	5.80
4	200	60	94.5	100
5	220	70	94.5	17.65
6	220	70	94.5	0
7	220	60	90	23.53
8	240	60	94.5	17.65
9	200	70	99	11.76
10	240	70	99	11.76
11	240	70	90	29
12	220	60	99	17.65
13	240	80	94.5	17.65
14	220	80	99	0
15	220	70	94.5	5.80
16	200	70	90	100
17	220	70	94.5	11.76

Table 4 Analysis of variance (ANOVA) for response surface quadratic model for rejection rate of ABS part

Source	Sum of Square	df	Mean Square	F Value	P -Value	
Model	12450.14	9	1383.35	5.15	0.0209	significant
A-Melt Temp	2502.78	1	2502.78	9.32	0.0185	
B-Mould Temp	2098.78	1	2098.87	7.82	0.0267	
C-Inj press	1715.81	1	1715.81	6.39	0.0393	
AB	2218.41	1	2218.41	8.26	0.0238	
AC	1260.25	1	1260.25	4.69	0.067	
BC	0.0016	1	0.0016	5.959E-006	0.9981	
A^2	2622.32	1	2622.32	9.77	0.0167	
B^2	8.6	1	8.6	0.032	0.863	
C^2	8.56	1	8.56	0.032	0.8633	
Residual	1879.35	7	268.48			
Lack of Fit	1532.31	3	510.77	5.89	0.0599	not significant
Pure Error	347.04	4	86.76			
Core Total	14329.49	16				

A polynomial regression equation was developed by using Box-Behnken design to analyze the factor interactions by identifying the significant factors contributing to the regression model. The complete design matrix together with the response values obtained from the experimental works are given in Table 3. The rejection rate of ABS part was found from 0% to 100%.

According to the sequential model sum of squares, the models were selected based on the highest order polynomials where the additional terms were significant and the models were not aliased. For rejection rate of ABS part, quadratic models was suggested by the software and selected due to higher order polynomial. The final empirical models in term of coded factors for rejection rate (Y) is shown in Eq. 1:

$$Y = 11.75 - 17.69A - 16.20B - 14.65C + 23.55AB + 17.75AC + 0.02\,BC + 24.96A^2 - 1.43B^2 + 1.43C^2 \quad (1)$$

Positive sign in front of the terms indicates synergistic effect, whereas negative sign indicates antagonistic effect. The quality of the model developed was evaluated based on the correlation coefficient value. The R_2 value for the equation was 0.8688. This indicated that 86.88% of the total variation in the rejection rate of ABS part. The closer the R_2 value to unity, the better the model will give predicted values which are closer to the actual values for the response. The R_2 of 0.8688 for Eq. 1 was considered relatively high, indicating that there was good agreement between the experimental and the predicted data from this model.

3.2 Statistical analysis

The result of the surface quadratic model in the from of analysis of variance (ANOVA) is presented in Table 4 for the rejection rate of ABS part. ANOVA is required to justify the significance and adequacy of the models. The mean squares were obtained by dividing the sum of the squares of each of the variation sources the model and the error variance, by the respective degrees of freedom. If the value of Prob>F less than 0.05, the model terms are considered as significant. From the Table 5, the model F-value is 5.15 and P-value is 0.0209 it implied that this model was significant. The significant of each coefficient can determined using P-value in Table 5. The P-value can be used as a tool to check the significance of each coefficient and the interaction strength between each independent variable. The corresponding variables would be more significant at greater F value and smaller P-value. In this case, melt temperature, mould temperature, injection pressure, AB and A^2 factors were significant model term where AC, BC, B^2 and C^2 were insignificant to the response. The lack of fit measures and the failure of the model is represented the data in the experimental domain at a point which are not included in the regression. As shown in Table 5, F-value and P-value of the lack of fit were 5.89 and 0.0599 respectively. It also implied that, it was not significant relatively to the pure error and indicated that model equation was adequate for predicting the minimization of air bubble defects under any combination of values of the variable.

From the statistical results shows that the above models were adequate to predict the rejection rate within the range of variables studied. Figure 1 shows the predicted value versus the experimental values for minimization of air bubble defects. The obtained predicted values are close to the experimental values, indicating that the models developed were satisfactory in capturing the correlation between operating parameter to the response.

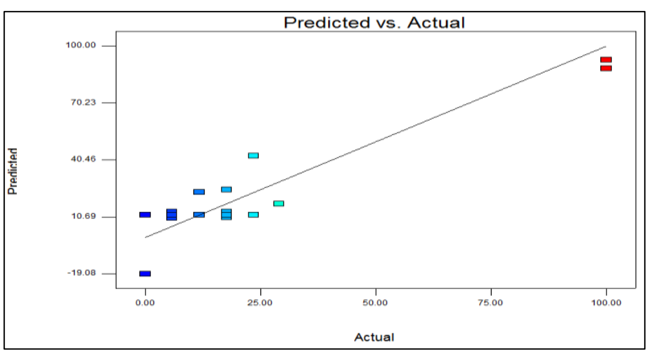

Figure 1 Predicted vs experimental of ABS part rejection rate

3.3 Interaction between parameter

Referring to Table 4, melt temperature showed the largest F-value 9.32 among the factors, indicating that this variable imposed the significant effect on the rejection rate. The effect of melt temperature was significant. Furthermore, mould temperature and injection pressure on the response was relatively significant. Figure 2 to 4 shows the interaction between parameter. By referred to Figure 2 and 3, there are interaction between melt temperature and mould temperature and melt temperature and injection pressure. The interaction occurs when the melt temperature is high in this setup. However, there was no interaction between mould temperature and injection pressure (Figure 4).

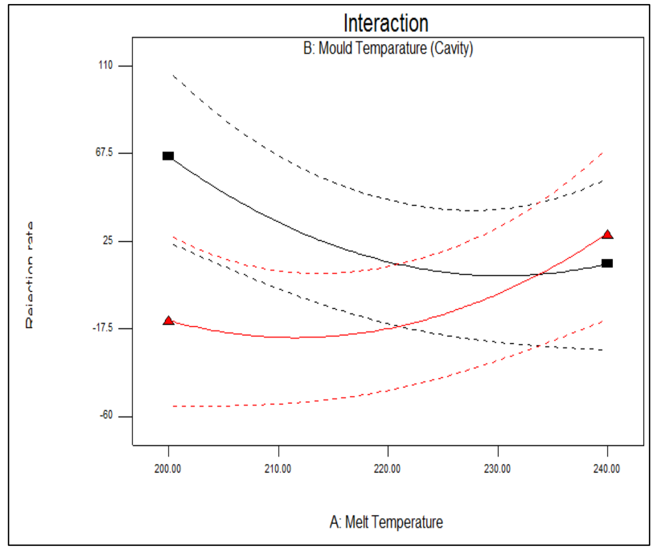

Figure 2 Interaction between melt temperature and mould temperature

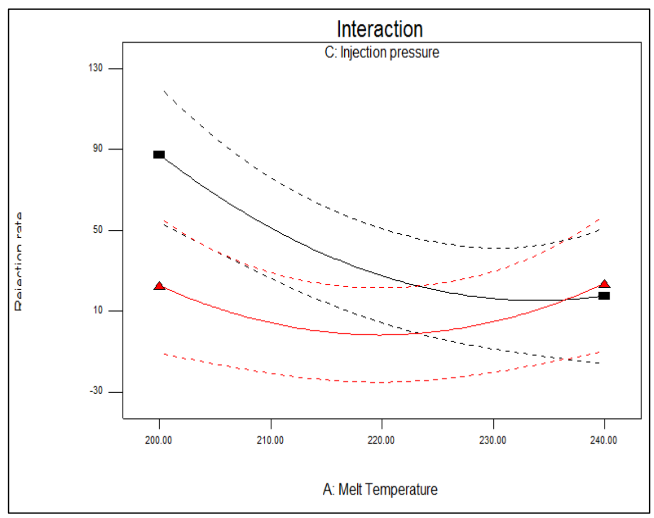

Figure 3 Interaction between melt temperature and injection pressure

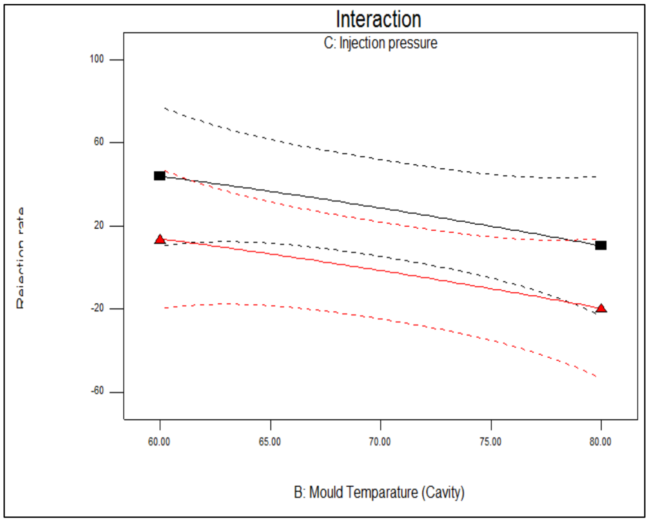

Figure 4 Interaction between mould temperature and injection pressure

3.4 Three dimensional analysis

The three dimensional parameter results shown in figure 5 to 7. It was found that to decrease with increasing mould temperature and injection pressure. The lowest response was obtained when mould temperature and injection pressure at the maximum point with melt temperature at the lowest point in this study. Meanwhile, there is less effect in Figure 7 between mould temperature and injection pressure.

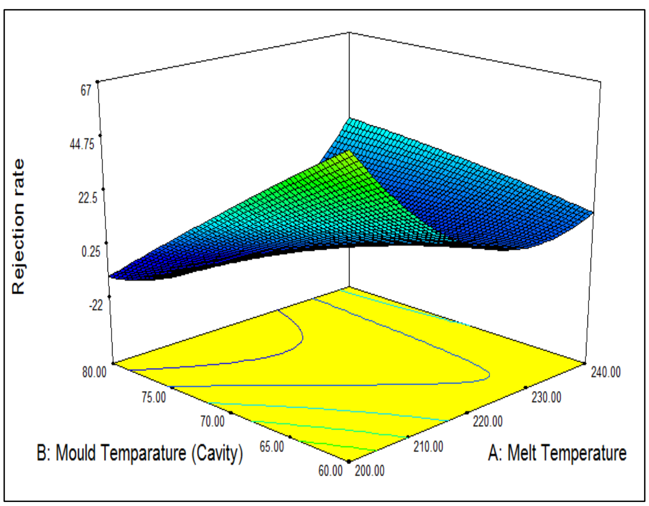

Figure 5 Shows response surface plot of melt temperature and mould temperature

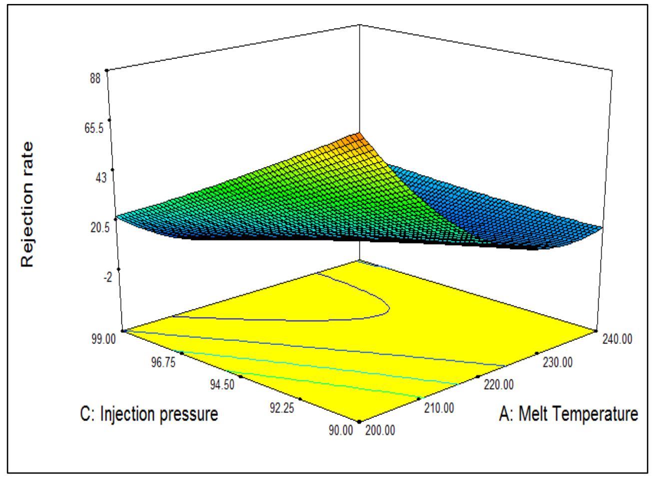

Figure 6 Shows response surface plot of melt temperature and injection pressure

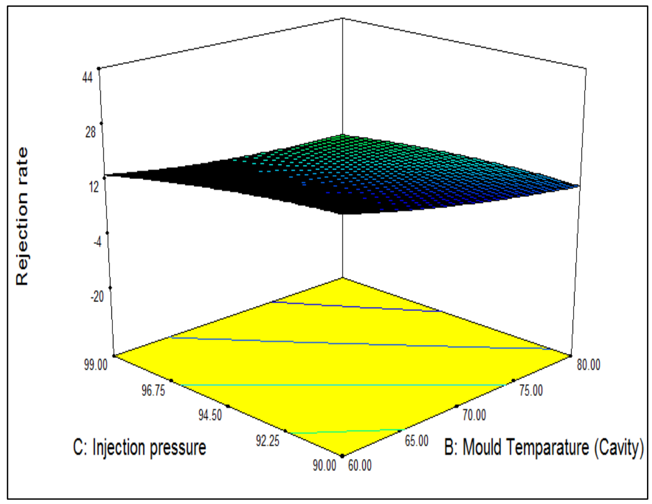

Figure 7 Shows response surface plot of mould temperature and injection pressure

3.5 Process optimization

Box-Behnken design has been used to optimize the parameters affecting the rejection rate response. In this optimization analysis, the target criteria was set as minimum values while the values for variables were set in the ranges being studied. The predicted and experimental results of rejection rate obtained at optimum conditions are shown in table 5. The optimum rejection rate of ABS part was obtained by using melt temperature, 220 °C, mould temperature, 70 °C and injection pressure, 98%. It was observed that the experimental values obtained were in good agreement with the value calculated from the models, with relatively small errors, which only 0%.

Table 5 Model validation

Melt temp (°C)	Mould temp (°C)	Inject pres (%)	Rejection (%)	Experim ent	Error (%)
220	70	98	0.00000036 8	0%	0%

4.0 CONCLUSION

The study on minimization the rejection rate of ABS part have been conducted by using Box-Behnken design. Through analysis of the response surface methodology, melt temperature and another parameter imposed the greater effect on the rejection rate. The optimum melt temperature, mould temperature and injection pressure were 220 °C, 70 °C and 98% respectively. After run the validation, it shown that experimental values obtained were in good agreement with the value calculated from the models. It is believe that, RSM is useful tool in optimizing the process parameter, which will help to reduce the cost and time of researcher and engineer.

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