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OPTIMIZATION OF WORKING PARAMETERS TO IMPROVE THE QUALITY OF PLASTICS IN AN INJECTION MOLDING PROCESS

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Abstract: Improvement is required in any industry to increase the productivity by reducing the defects rate and remove the overall waste produced during manufacturing process. In this research paper, the working parameters are optimised that are responsible for process variation. A plastics manufacturing company, the major problems were flow marks and air bubbles appeared on the surface of mould part a car side mirror plastic cover. Because of these problems, the overall production of company was decreasing that resulted in customer dissatisfaction and company could not achieve its daily production target. The responsible working parameters for process variation are found to be injection pressure, melting temperature along with viscosity and flow rate of molten material during injection moulding process. The injection speed and screw speed are also considered. The analysis of variance (ANOVA) test was conducted to find most critical working parameters. It is identified that response surface methodology (RSM) can be used to optimise the working parameters to improve the quality of moulded part that will increase process efficiency by 50%. The data was collected from four machines to find which machine is causing more problems that is found to be Tederic 450 tone machine. This machine has more problems as compared to other machines. Acrylonitrile Butadiene Styrene (ABS) material is used for the production of car side mirror plastic cover. The Rejection of this moulded part was counted 35% of total rejection. After optimization, the rejection is reduced to 16% is recorded which is significant improvement.

Keywords: Working parameters, RSM, DOE, Injection moulding, injection pressure, flow rate, viscosity

I.INTRODUCTION

Quality is a serious concern not only in production area but also in-service area. Good quality products and services result in smooth business progress, customer loyalty, and low prices. The product with better quality increases the manufacturer's competency in the market and enhances customer demand to make human lives more comfortably. The working parameters are most significant in the production of good quality product in an injection moulding process. The values of working parameters depend upon the type of plastics, the dimensions of the product and dimensional tolerance etc. [1]–[3]. The working parameters such as injection pressure, melt temperature and flow rate are need to be optimised to produce good quality plastic parts [4]. Response surface methodology (RSM) is an eminent method that delivers a well-organised procedure for parametric optimisation [5]. RSM is generally used for the optimisation of the design of products and processes [6].

In an injection moulding process, the melt temperature contributes 16%, injection pressure 12%, flow rate 10% of the total rejection [7], [8]. The Cause and effect matrix and analysis of variance (ANOVA) are constructed to determine which working parameters are most critical and substantial [9]. Through the cause and effect and ANOVA, optimum working parameters could be predicted. The process development in a moulding process, design of experiment (DOE), is used to find the working parameter of the machine, which substantially influences the output of injection moulding operations [10]. The convenient injection moulding machine set-up depends upon the trial and error method or technician or operator's experience [11].

The trial-and-error method is considered a time consuming and non-cost-effective technique which is not acceptable in the plastics manufacturing industry. The problems and defects related to the quality of plastic products encountered in injection moulding operation include air bubbles, flow marks, flashes, short piece, burns and other surface marks [12], [13]. These defects in moulding operations result from various causes, which comprise the selection of injection moulding machine, pre-processing treatment of the plastic resin before moulding operation, and setting of working parameters of the machineas well as operators' training [14]. The plastic injection moulding process has a number of working parameters that affect the output variablesdirectly. Before the injection moulding process, raw material or plastics resin is passed through different stages, which include material storage and material handling [15].

During the injection moulding process, plastics resin is mixed with recycled or regrind material or master batch that also affects the quality of the product [16].The injection moulding machine maintenance and proper cleaning have a positive effect on the quality of the moulded parts. The plastic resin is dried for 2 to 3 hours before injection moulding [17]. The raw material passes through different temperature barrels, which melt the material and inject it into the mould cavity at a specific injection pressure [18]. The cooling is provided in the mould by circulating coolant, which allows the material to solidify to obtain the desired shape of the moulded part. This cooling also has a significant role in the moulded part shape [19].

Residual stresses from the moulding process are released; causing deformation creates hard fitting and shrinkage defects. Air bubbles or sink marks appear on the surface of moulded parts due to low material flow rate and injection pressure [20], [21]. The primary cause of flow marks and flashes on the surface of the moulded part is mould temperature. The black dots or colour lines appear when improper cleaning of the machine, lubrication leakage, burned material in the barrel, melting temperature and mixing of dust particles or other materials mix with the resin [22].The working parameters can be optimised to improve the quality of the moulded part through RSM.

The injection moulding process has mainly three phases: mould filling phase, cooling phase and ejection phase. The cooling phase has a significant influence on the quality of the product and productivity of the process [23], [24]. During manufacturing of plastics parts, the quality terms of part such as hard fitting, flow marks, flashes, sink marks, shrinkage, air bubbles, mould lines and other surface marks depend upon process working parameters that include melting temperature, injection pressure, mould temperature along with flow rate, viscosity and cooling time, screw speed, cooling temperature, packing pressure or holding pressure, packing duration, fillingtime or injection time, cycle time, injection speed [25].

Poor quality products not only affect the customer relationship but also influence the cost and lead times. Therefore, there is a need to recover the excellence of plastics products to enhance the lifetime of these products to make life more comfortable and save money and improve lead time [26] . In this work, the cover of a side mirror of a car is taken as a case study that encounters many quality defects like shrinkage or hard fitting, air bubbles or voids, flow marks, flashes, short piece, black dots, burns marks, weld lines, warpage, mould lines, sink marks. This moulded part has many complaints and poor feedback from customer that disturb thecustomer relationship with the company. So, this study focuses on improving the quality by optimising responsible working parameters such as injection pressure, viscosity, melt temperature, and flow rate. Flow marks and air bubbles on mould part surface reduce quality of part and lead to rejection from the side customer. Many complaints received from customer due appearance of air bubble and flow marks of the surface of moulded part [27].

Materials and methods

In this research study, response surface methodology (RSM) is applied to optimise the thermal working parameters. Response surface methodology (RSM) is a well-known method to optimise and model prediction. Through this methodology, the relationship between various process parameters and the responses would be calculated according to anticipated standards and the values of parameters.

Design of experiment (DOE)

In this research study, a full factorial design is selected with responsible working parameters of the injection moulding machine Tederic-450 tone. These four factors are melting temperature, injection pressure, flow rate and viscosity. Before applying this methodology, current performance was estimated and decided which moulded part is more defective and needed to improve its quality**.** Table 2 shows the current performance of the company and the percentage of defective parts. In these parts, car side mirror plastics cover has the highest percentage of rejection. Therefore, this part was taken as a case study to improve the quality of the injection moulding process.

Selection of Material

The plastics resin Acrylonitrile Butadiene Styrene (ABS) grade EA 707 is used to produce car side mirror plastic cover. This study basically focuses on process thermal working parameters that affect the superiority of the product. The ABS material is considered because this part is used to protect and plating necessity for automobile parts source and this substantial is measured to be having high influence strength as well as dimensional constancy.

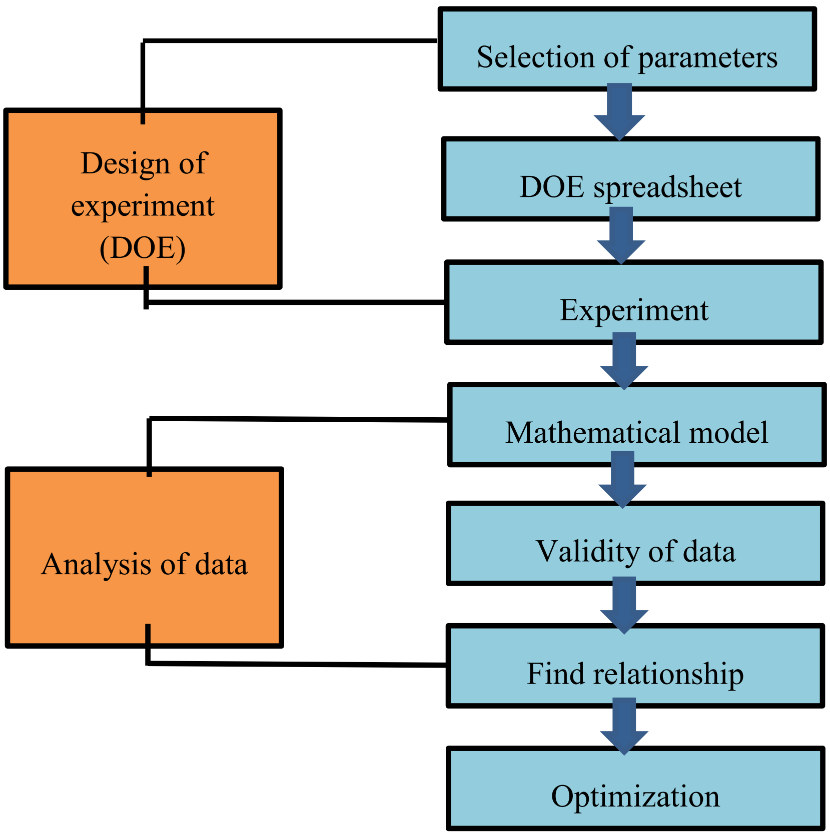

Figure 1: Steps involved in methodology

The elementary optimum parameters are taken from Design Expert software (7.0.0), and experiments are done considering those parameters without compromising the quality requirements. Table 1 shows the properties of material used for moulded part.

Table 1 Properties of material*[28]*

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Properties	**Test method**	**Value**
TensileStrength,3.2mm@yield	ASTM D638	450kg/cm²
Specific Gravity	ASTM D792	1.05
Melt Flow Rate@220C/10kg	ASTM D1238	18g/10Min
Tensile Elongation,3.2mm@Yield	ASTM D638	40%
Flexural Modulus,3.2MM	ASTM D790	25000Kg/cm²
Flexural strength,3.2MM	ASTMD790	760Kg/cm²
Moulding Shrinkage (Flow),3.2mm	ASTM D955	0.4- 0.7%

The injection moulding machine

The injection moulding machine that is used in this research study is Tederic-450 ton. This machine has a maximum injection pressure 180-244 MPa, the shot size is 300 grams.

Figure 2 Injection molding machine (Tederic-450 tone)

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Figure 3 Specimen

2.4 Identification of Current performance

Table 2: on-line rejection - total parts produced: 5000

Part name	**On-line rejection**	**On-line x 10^3**	**%age**	**Acc.**
Car side mirror cover	1650	1.650	33	33
Panel city	1052	1.052	21.04	54.04
Trim wheel	830	0.830	16.6	71
Others	238	0.238	4.76	75.76

Table 2 shows rejection data of injection moulding at 450-ton machines for the month of August2020. This rejection was the highest rejection in comparison to the rejection of the preceding month. In this rejection, car side mirror plastic cover has the highest rejection that is 1650 units, and this is 35% of total rejection. Figure 1 shows on-line rejection for a particular part. As car side mirror plastic cover has the highest rejection, it is taken as a research element.

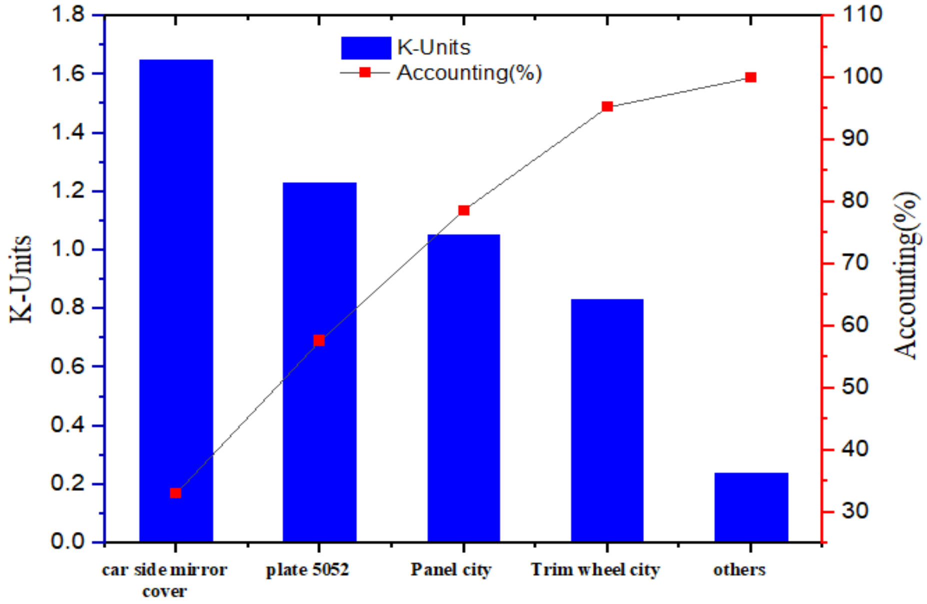

Figure 4: on-line rejection in August 2020

The parts are segregated on the basis of different defects from different injection moulding machines of 450-ton for various parts. These defects were analysed by the Fishbone diagram. The Fishbone diagram is shown in Fig. 5. On the basis of these defective parts, the injection moulding machine is also noted, which has more rejection rate than others. Injection moulding machine Tederic-450 has more rejection. Therefore, this machine is considered for analysis of working parameters. In table 3, major defects are black dots which contribute 35% of total defects, hard fitting contributes 20%, flow marks contribute 8.64%, and air bubbles 11% of total defects due to which parts are rejected. The comparison among machines defected data shows, hard fitting, air bubbles, flow marks, and black dots are still contributing the highest rejectionrate. Tederic-450 ton contributes black dots, air bubbles, flow marks, and hard fitting highest defects compared to other machines. Since Tederic-450 shows the highest rejection rate, its data is used to track down the root cause of hard fitting and black dots. This analysed data is used as a reference for other machines. In figure 5 fishbone diagram is shown that is used to track down the defects during the process.

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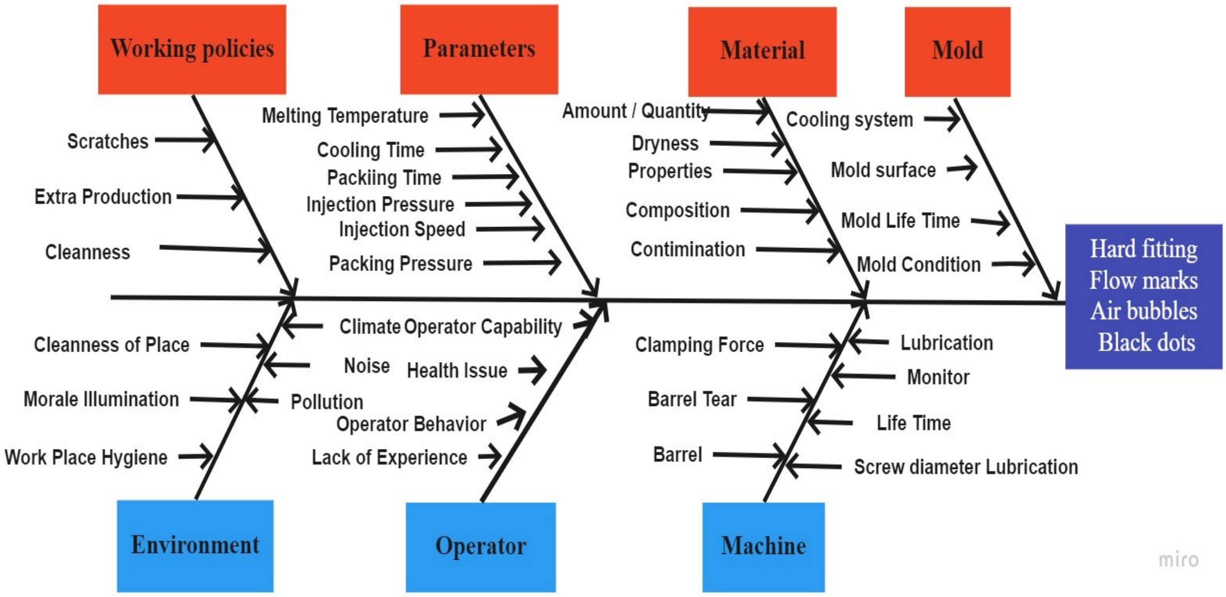

Figure 5: Fishbone diagram to identify the root cause of defects

Table 3: Rejection data based on types of defects

	Machine number						
Defects	**JSW**	**Tederic**	**Engel**	**Husky**	**Sub Total Defects**	**% age**	**Acc.**
Black dots	35	340	270	262	907	35.6	35.6
Hard fitting	2	142	122	266	532	20.9	56.5
Flow marks	0	102	98	20	220	8.6	65.2
Burn marks	15	23	97	0	135	5.3	70.5
Scratches	5	65	77	82	229	9.0	79.5
Short mold	3	62	8	5	78	3.1	82.6
oil/dirt	12	48	34	9	103	4.0	86.6
white marks	0	0	4	0	4	0.2	86.8
air bubbles	45	90	105	65	305	12.0	98.7
Parting bur	2	6	7	0	15	0.6	99.3
others	2	15	0	0	17	0.7	100.0
Total	**121**	**893**	**822**	**709**	**2545**		

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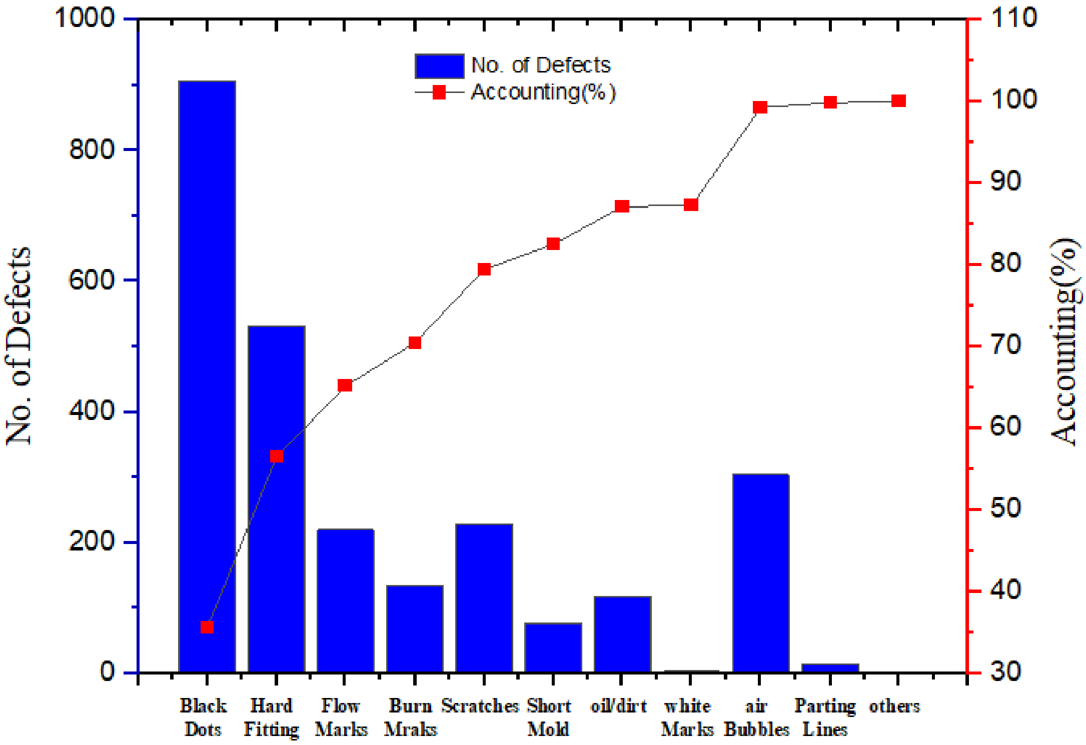

Figure 6: Rejection data based on types of defects

Selection of Process Working Parameters

Based on data analysis, there were four responsible working parameters for quality defects in the moulded part. They are melting temperature, injection pressure. The flow rate and viscosity of molten material are also considered with working parameters. Table 4 shows critical working parameters and their levels.

Table 4 Process Parameters with molten material properties

Parameters	**Level**	
	Minimum	**Maximum**
Melt Temperature	220℃	250℃
Injection Pressure Injection speed Screw speed	80 bars 20 m/s 18 rev/min	100 bars 26 m/s 24 rev/min
Flow rate	31.25 g/10 min	39.25 g/10min
Viscosity	1.8×10^{-3} Pa-s	2.33×10^{-3} Pa-s

A. Analysis of Variance (ANOVA)

The analysis of varianceis applied to find out the proportion of influencing parameters on the defects rate. Analysis of variance (ANOVA) calculates the measures including the degree of freedom (df), the sum of squares (S), degree F-statistic (F), Mean Square (MS) and percentage (P). These results are shown inTable 5.

Table 5 ANOVA results for working parameters

Source	DF	SS	Adjust MS	F	P value (%)
Melt temperature(°C)	4	0.049389	0.013724	5.26	20.45
Injection Pressure (Pa)	4	0.049232	0.0142011	4.99	15.6
Injection speed	4	0.00231	0.02712	19.40	13.89
Screw speed	4	0.01253	0.01527	21.25	11.3
Error	4	0.00967	0.002408		
Total	24	0.558412			

$\mathbf{R^2 = 97.28\% R^2(Adj) = 88.75\%}$

The analysis of variance (ANOVA) shows how a parameter significance and effect on the defect rate. In the ANOVA test, the percentage of affecting parameters on the defects rate is calculated. Table 6 shows ANOVA test one basis of second degrees mathematical model by using design expert software (7.0.0).We have obtained R-sq and R-sq Adjust for each of the model, Full Quadratic, Linear, Linear-Square and Linear-Interaction. Based on the R-sq and R-sq Adjust depends upon the least square method, the results are reported.The ANOVA results showed that the models on the y-axis are significant because prob>F has a value smaller than 0.05. In this study, backward elimination is chosen because it can remove insignificant terms in order to regulate the quadratic models for defects. In ANOVA results, the value of R^2 is also important to be observed. The quality of regression models is demonstrated by the determination of R^2. The value of R^2 near to 1, that is needed and reasonable concurrence with nearby R^2 is essential.

Table 6 ANOVA test on design expert

Removed	Estimate	Coeff=0	Prob>|t|	R-squared	MSE
AC	-0.62	-0.059	0.9545	0.7243	758.11
$\mathbf{A^2}$	0.84	0.12	0.9091	0.7238	664.67
$\mathbf{D^2}$	-0.98	-0.15	0.8866	0.7230	592.42
$\mathbf{C^2}$	1.73	0.28	0.7886	0.7207	537.70
C-Inj speed	-2.53	-0.40	0.6953	0.7161	496.76
BC	-6.87	-0.87	0.4016	0.6965	486.88
BD	-11.00	-0.91	0.3822	0.6757	480.25
B-Inj Pressure	-8.92	-8.97	0.3507	0.6523	478.09
AB	17.45	1.45	0.1683	0.5999	513.48
D-Screw speed	9.10	1.48	0.1584	0.5411	552.12
$\boldsymbol{B^2}$	8.70	1.44	0.4816	0.4816	586.99

Figure 7 shows defects on moulded parts that are selected to eliminate by optimising process parameters. These defects are mentioned as hard fitting, black dots, flow marks and air bubbles.

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Air Bubbles


Flow marks

Figure 7 Defects on the surface of parts

Table 7 ANOVA test for working parameters

Source	Sum of squares	df	Mean square	F-Value	Prob>F
Model	76376.86	14	5455.49	52.53	<0.0001
A-Melt temp	34.66	1	34.66	0.33	0.08845
B-Inj pressure	3339.43	1	3339.43	32.15	0.0713
C-Inj speed	7706.34	1	7706.34	74.20	0.0601
D-Screw speed	24.78	1	24.78	0.24	0.07425
AB	44.88	1	44.88	0.43	0.5353
AC	27.79	1	27.79	0.27	0.6234
AD	1233.33	1	1233.33	11.88	0.0137
BC	77.72	1	77.72	0.75	0.4202
BD	2.55	1	2.55	0.025	0.8806
CD	29.54	1	29.54	0.28	0.6130
A^2	156.56	1	156.56	1.51	0.2655
B^2	1514.57	1	1514.57	14.58	0.0088
C^2	14.08	1	14.08	0.14	0.7253
D^2	123.63	1	123.63	1.19	0.3171
Residual	623.14	6	103.86		
Cor total	77000.00	20			

The F =3.37 which is equal to 0.05 (or 95% confidence level) for a level of significant parameters. Melting temperature [F=8.845< F = 3.37], injection pressure [F=7.13>F=3.37] and Cooling temperature [F =2.35 < F = 3.37] has not given a significant effect process variation. The injection speed [F =7.45> F = 3.37], screw speed [F =6.1> F = 3.37] have given a significant consequence to the defects rate and meld temperature is giving the highest significant level.

The melting temperature contributes the most rate esteems that is 20.45% track by ambient temperature 11.17%, flow rate13.89%, injection pressure 15.6%, and viscosity 11.3% as the influence factor for defects. Cooling time only contributed 0.46%, and lastly, cooling temperature contributed 1.85%. The cooling temperature and cooling time have no significant effect on the process variation. These results ANOVA are tabulated in table 5.

Table 8 DOE to adjust working parameters

Sr.	Melt Temperature, X1	Injection Pressure, X2	Injection speed, X3	Screw speed, X23	Response (Y)
1	+1	-1	-1	+1	260
2	-1	-1	-1	+1	250
3	+1	+1	-1	-1	238
4	-1	+1	-1	+1	110
5	+1	-1	+1	-1	100
6	-1	-1	+1	-1	90
7	-1	+1	+1	+1	85
8	+1	+1	+1	+1	80
9	-1	-1	-1	+1	75
10	+1	-1	-1	+1	72
11	-1	+1	-1	-1	70
12	+1	+1	-1	-1	65
13	-1	-1	+1	-1	60
14	+1	-1	+1	-1	50
15	-1	+1	+1	+1	30
16	+1	+1	+1	+1	22

Second degree polynomial for optimisation

The RSM approaches the solution which is theoretical and practical methods arecombinedessentially to develop an acceptable functional relationship between the input parameter and the response y,Input parameters are symbolised by A, B, C……AC, BC,B^2, D^2, E^2. In this study, we have taken up statistical modelling to build similarity
between the response y and independent variables.

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_{12} D + \beta_{13} AC + \beta_{23} BC + \beta_{11} B^2 + \beta_{22} D^2 + \beta_{33} E^2 \quad (1)$$

$$Y = 0.32120\text{-}3.534696e^{-004}A\text{+}9.60220e^{-004}B\text{-}0.018898C\text{+}3.45567e^{-003}D\text{+}4.56277e^{005}AC$$

$$\text{+}5.38240e^{-005}BC\text{-}1.3027e^{-005}B^2\text{-}5.01132e^{-005}D^2 \quad (2)$$

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Where A is melting temperature (°C), B is injection pressure (MPa), C is injection speed (m/s), and D is screw speed (m/s). The common method used in RSM is the regression method. Design Expert (7.0.0) is used for the RSM analysis with the central composite design (Face centred) to determine which regression will suit our data.

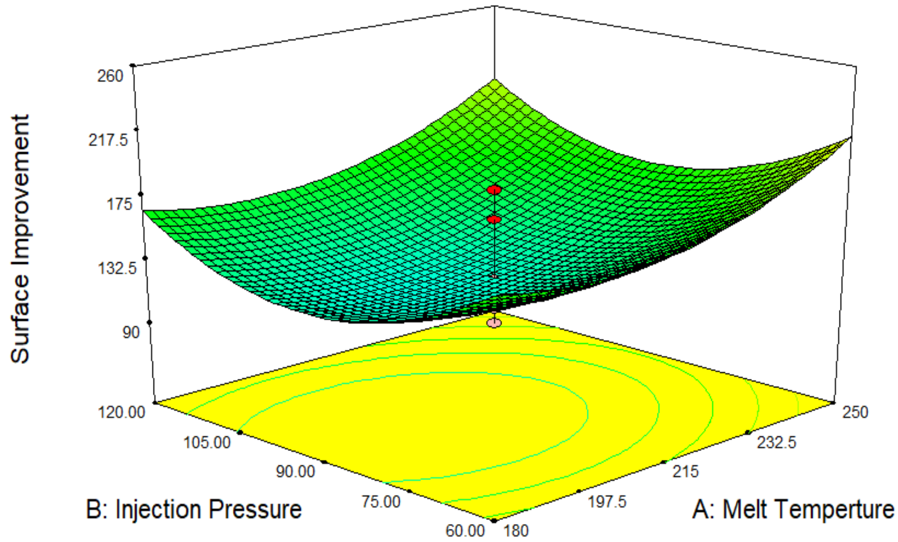

Figure 8: Contour plots between Injection Pressure and Melt temperature

In figure 8: Plot shows the relationship between viscosity and melt temperature. It is plotted between injection pressure, flow rate, melt temperature and viscosity of molten material. The above plotting is constructed by using Design Expert software.

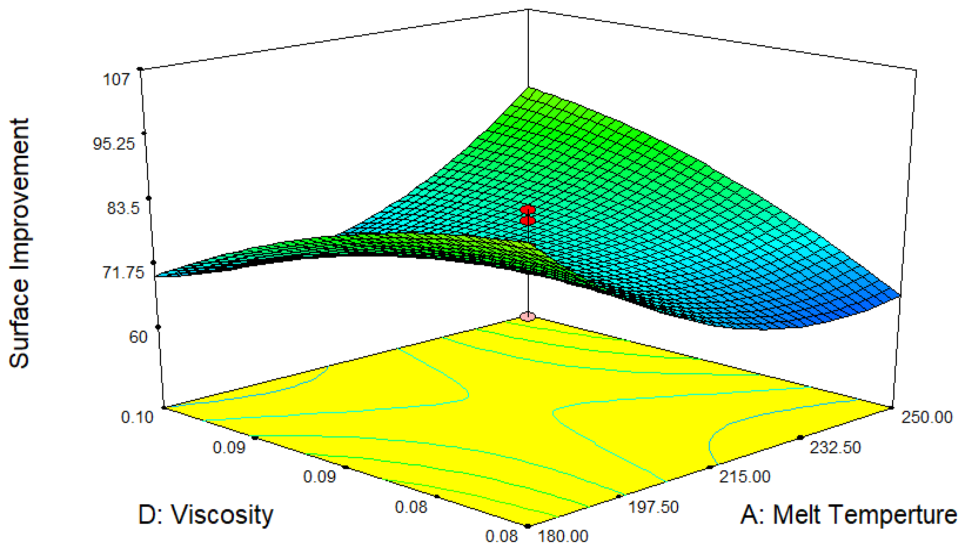

Figure 9: Contour plots between melt temperature and viscosity

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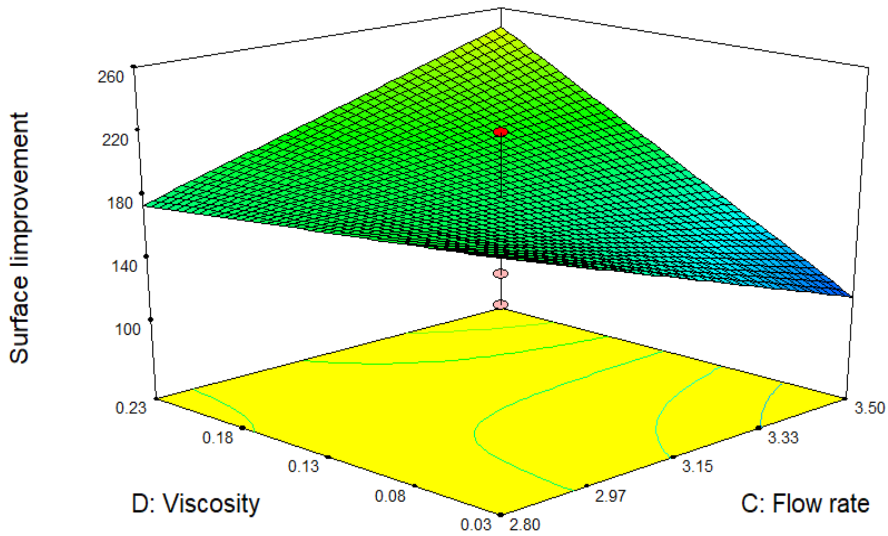

Figure 10 **Contour plots between flow rate and viscosity**

Results and analysis

Table 8 shows the factorial design in which four factors that are also known as parameters with two levels are selected. This matrix is constructed in design expert software (7.0.0). This factorial design shows parameters setting on which responses are obtained for each factor.

ANALYSIS OF BLACK DOTS, AIR BUBBLES AND FLOW MARKS

In the root cause of black dots, there are five significant factors that are responsible for black dots as following material, method, environment, operator and machine. The machine is one of the factors which must be responsible for black dots. Black dots that appear on moulded parts may be due to machine contribution. For example, improper working parameters setting causes carbonised screw. A damaged barrel or screw is also responsible for black dots. Flow marks appear on the surface of the moulded part due to mould temperature beyond the limit. Mould temperature beyond limit does not allow material to solidify in a given cycle time, leading to flow marks on the surface of the part. There should be proper cooling in the mould through cooling channels due to which molten material quickly in given cycle time. The air bubbles appear due to air trapped in the mould cavity when molten material is injected into the mould. The mass flow rate is also responsible for air bubbles in the moulded part. An improper flow rate of molten material causes air bubbles on the surface of plastics parts. Table 11 shows the S/N ratio for black dots, flow marks and air bubbles that are removed by optimising responsible parameters. These results are taken by using Minitab 2017.Table 12 shows recommended setting for optimum parameters.

Table 9 Summary of Results

Run	**1**	**2**	**3**	**Mean**	**MSD**	**S/N Ratio**
1	1.015	1.213	1.06	1.096	3.625	-0.822
2	0.939	1.137	0.984	1.02	3.144	-0.204
3	0.868	1.066	0.913	0.949	2.722	0.422
4	0.863	1.061	0.908	0.944	2.692	0.47

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5	0.882	1.08	0.927	0.963	2.801	0.298
6	0.872	1.07	0.917	0.953	2.748	0.381
7	0.808	1.006	0.853	0.889	2.393	0.983
8	0.895	1.093	0.94	0.976	2.879	0.178
9	0.808	1.006	0.853	0.889	2.391	0.985
10	0.94	1.138	0.985	1.021	3.148	-0.209
		Total Mean		**9.7**	**28.543**	**2.482**

Table 10 Recommended setting of factors

Factors	**Levels**	
	Minimum	**Maximum**
Melt Temperature(°C)	225	230
Injection Pressure (bars)	80	90
Injection speed (m/s)	35.3	39.25
Screw speed (rev/min)	24	32

CONFIRMATION EXPERIMENT

The confirmation experiments S/N ratio was calculatedusing the responsetable S/N ratio dependent upon following calculations:

$$Z = \bar{Z} + (B3 - Z) + (H3 - Z) + (G3 - Z) + (A3 - Z) + (C2 - Z) + (F3 - Z) + (E1 - Z) + (D1 - Z)$$

$$= 0.43 + 0.42 + 0.21 + 0.18 + 0.15 + 0.08 + 0.03 + 0.01 + 0.00$$
$$= 1.5$$

The injection moulding process has improved and reduced the 16.5% defects rate by using this optimum setting of factors, asshown in Table 13.

Table 11 Results of Confirmation

Run	**1**	**2**	**3**	**Mean**
1	0.63	0.83	0.68	0.71
2	0.62	0.84	0.66	0.71
3	0.64	0.82	0.65	0.70
			Total Mean	**0.71**

Table 12 Comparison after and before optimization

Factors	x-direction		y-direction		z-direction	
	Before	**After**	**Before**	**After**	**Before**	**After**
Melt Temperature (°C)	**220**	**230**	**220**	**230**	**220**	**240**
Injection Pressure (bar)	**80**	**100**	**80**	**90**	**80**	**95**
Injection speed	**20**	**25**	**20**	**25**	**20**	**25**
Screw speed	**16**	**18**	**18**	**20**	**22**	**24**
Flow rate (g/s)	**2.912**	**3.125**	**2.745**	**3.224**	**2.957**	**3.139**
Viscosity (Pa-s)	$1.8{\times}10^{-3}$	$2.3{\times}10^{-3}$	$1.9{\times}10^{-3}$	$2.02{\times}10^{-3}$	$1.8{\times}10^{-3}$	$2.48{\times}10^{-3}$

In Table 15, the comparison is made after and before improvement on the basis of data collection that shows significant development in the moulding process.

Table 13 Comparison of defective parts after and before improvement

Problem	**After**	**Before**
Hard Fitting	52	270
Flow marks	55	120
Black dots	48	122
Air bubbles	40	85
Flashes	13	85
Colour line	6	73

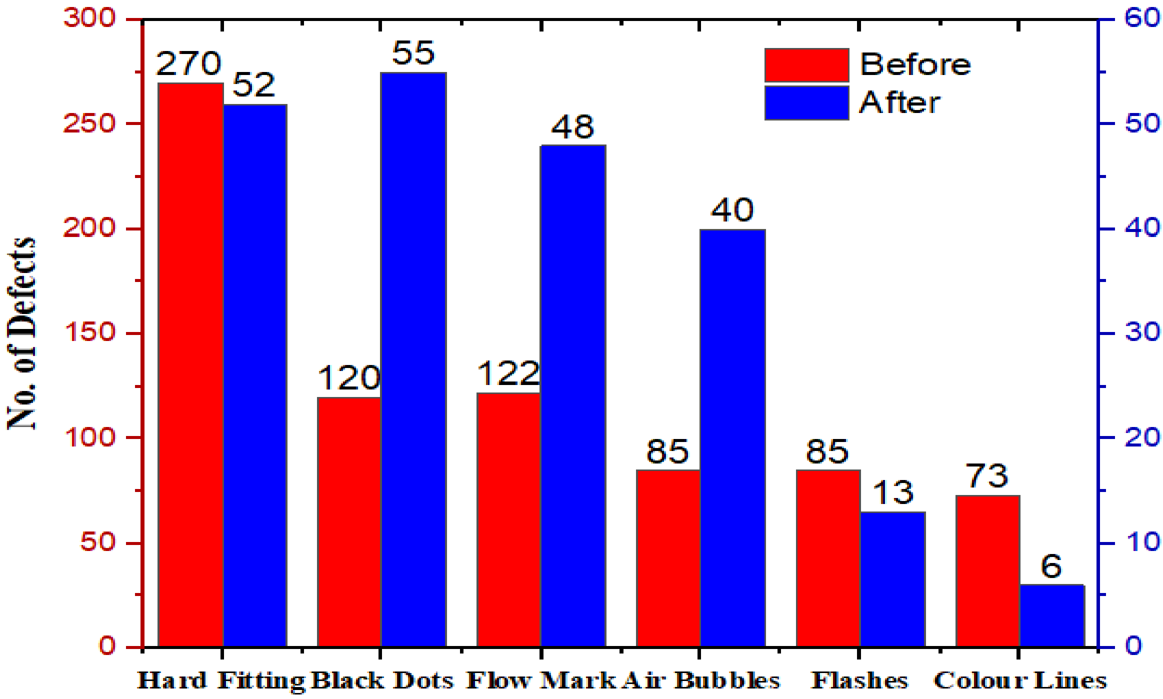

Figure 11: Defective parts after and before improvement

Conclusion

In this research study, the working parameters including melting temperature, injection pressure, injection speed and screw speed are optimised to improve the quality of the injection process using response surface methodology (RSM). The optimum working parameters are obtained by adjusting their values through which the quality of the car mirror plastic cover is improved significantly. The conclusion of this studyhas contribution of melting temperature 20.45%, injection pressure 15.6%, injection speed 13.89% and screw speed is 11.3 %. The optimum process parameters gained through response methodology (RSM) has improved. The process has16.5% improved, and the rejection rate has reduced 50% of total rejection. It will ensure the manufacturers to start production with a better starting data and also could decrease material production and time consume through this study. The selection of suitable range of parameters between each level is significant to give more effect in this study.Various manufactures producing same type of materials give a slight diverse value of consequence.The improvement that we made will be beneficial to the company, and it will enhance the profitability of the company. It will also increase the overall performance of the injection moulding process. In future, the quality of plastics parts can be improved by changing mould cooling channels and focusing on the material. This case study can be applied to all plastics manufacturers to enhance product quality and save company time.

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