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Minimum dimensional shrinkage in transverse direction (dx) by plastic injection moulding using RSM

Ravi Prakash Sharma[1], Deepak Kumar[2]

[1]M.Tech pursuing in Production Engineering, Poornima College of Engineering, Sitapura, Jaipur,India

ravidhacholia@yahoo.co.in

[2] Associate Professor, Department of Mechanical Engineering, Poornima College of Engineering, Sitapura, Jaipur,India

deepakme@poornima.org

Abstract

Now a day's demand of plastics product is very high because of their better quality, design, light in weight and appearance in comparison to other material product. The use of best operating parameters is required to produce better quality of plastics product. In the present research, the effect of injection moulding parameters on dimensional shrinkage has been investigated using response surface methodology (RSM). The dimensional Shrinkage is important defects in plastic parts produce by plastic injection moulding machine. The experimental work have been carried out on test polypropylene (H110MA) plastic material having the dimension of 100 mm diameter and 3.4 mm thickness. The mathematical model for dimensional Shrinkage has been developed in terms of melt temperature, injection pressure, cooling time, mould temperature using response surface methodology (RSM). The optimum values of melt temperature, injection pressure, cooling time, mould temperature have been found as 200 ^{0}C, 70 bar, 15 Sec and 30 ^{0}C respectively.

Keywords: Plastic injection moulding, Polypropylene, response surface methodology (RSM), dimensional shrinkage.

1. Introduction

In 1946 James Hendry built the first screw injection machine. This machine allowed material to be mixed before injection, which meant coloured plastic or recycled plastic could be added to the virgin material and mixed thoroughly before being injected. Today screw injection machines account for 95% of all injection machines. The industry has evolved over the years from producing combs and buttons to producing a vast array of products for many industries including automotive, medical, aerospace, consumer, toys, plumbing, packaging, and construction [1].

Plastic Injection moulding is one of the most important processes in the mass production of manufactured plastic parts with complex structures. The quality of the product of injection moulding depends on the material characteristics, the mould design and the process conditions [2]. Defects in the dimensional stability of the parts result in shrinkage and warpage. In order to minimize such defects in plastic injection moulding, design of experiment, the RSM and GA is applied. In experimental design, there are many variable factors that affect the functional characteristics of the product.

In order to find optimum levels, the central composite design matrix is used in Design expert software 8.0.4.1. In this way, an optimal set of process conditions can be obtained from very few experiments [3]. There are several researchers that have studied the effects of injection moulding process parameters on the shrinkage of moulding, for example [4] [5]. Since many process parameters affect the shrinkage, parameter optimization and experimental design are needed to produce high quality products.

1.1 Selection of injection moulding parameters

There are a few parameters that involved in injection moulding process. In the present research melt temperature, mould temperature, cooling time and injection pressure have been considered as injection moulding parameters.

2. Experimental Studies

2.1 Raw material

Polypropylene is used as the raw material. The Polypropylene (H110MA) used in this study was purchased from CIPET, Jaipur. The physical properties of the Polypropylene (H110MA) are listed in the Table 1.

Corresponding author: Ravi Prakash Sharma

Table 1: Physical properties of Polypropylene (H110MA) [6]

Property	Value	Unit
Melt flow rate	11-35	(g/10 min)
Density	0.90 – 0.91	g/cm^3
Tensile strength	25.1-36	(MPa)
Elongation at break	100 – 600	%
Young Modulus	1.5 – 2	(GPa)
Rockwell Hardness	82.6	-
Melting Temperature	190-210	^{o}C
Thermal conductivity at 23^{o}C	0.1 - 0.22	W/(m·K)

A number of experiments required, mainly depends on design of experiment. Thus, it is important to have a well designed scheme of the experiment, so that number of experiments required can be minimized. In this research, the design suggested by RSM based on face centered design (FCD) has been implemented to analyze the effect of independent process parameters on dimensional shrinkage. Tables 2show independent process parameters and their levels in producing product of polypropylene plastic. The complete design layouts with measurement results for experiments on polypropylene plastic are summarized in table 3. The design layout table shows total 30 experimental combinations of melt temperature, injection pressure, cooling time and mould temperature. The thirty set of experiments constitute 2^4factorial points, six centre points and eight star points.

Table 2 Process parameters and their levels for the produce part of polypropylene plastic

Factors	Symbol	Levels		
		-1	0	+1
Melt Temperature (^{0}C)	A	200	220	240
Injection Pressure (bar)	B	40	55	70
Cooling Time (Sec)	C	5	10	15
Mould Temperature (^{0}C)	D	30	45	60

Table 3 Experimental design layout with measurement results

Std	Run	A:Melt Temperature (^{0}c)	B:Injection Pressure (bar)	C:Cooling Time (sec)	D:Mould Temperature (^{0}c)	Dimensional Shrinkage(dx) (mm)
25	1	220	55	10	45	2.1
27	2	220	55	10	45	2.12
10	3	240	40	5	60	3.07
18	4	240	55	10	45	2.51

9	5	200	40	5	60	2.36
21	6	220	55	5	45	2.27
24	7	220	55	10	60	2.21
2	8	240	40	5	30	2.55
23	9	220	55	10	30	1.88
22	10	220	55	15	45	1.81
19	11	220	40	10	45	2.32
7	12	200	70	15	30	1
5	13	200	40	15	30	1.15
12	14	240	70	5	60	2.39
15	15	200	70	15	60	1.04
1	16	200	40	5	30	1.74
4	17	240	70	5	30	1.99
6	18	240	40	15	30	2.49
3	19	200	70	5	30	1.35
20	20	220	70	10	45	1.83
30	21	220	55	10	45	2.1
26	22	220	55	10	45	2.06
17	23	200	55	10	45	1.6
8	24	240	70	15	30	2.08
14	25	240	40	15	60	2.62
16	26	240	70	15	60	2.12
28	27	220	55	10	45	2.07
11	28	200	70	5	60	1.83
13	29	200	40	15	60	1.35
29	30	220	55	10	45	2.11

2.2 Product produced and test specimen

By using polypropylene plastic test specimen is produced. The test specimen produced show in fig. 1 is having 100mm diameter and 3 mm thickness.

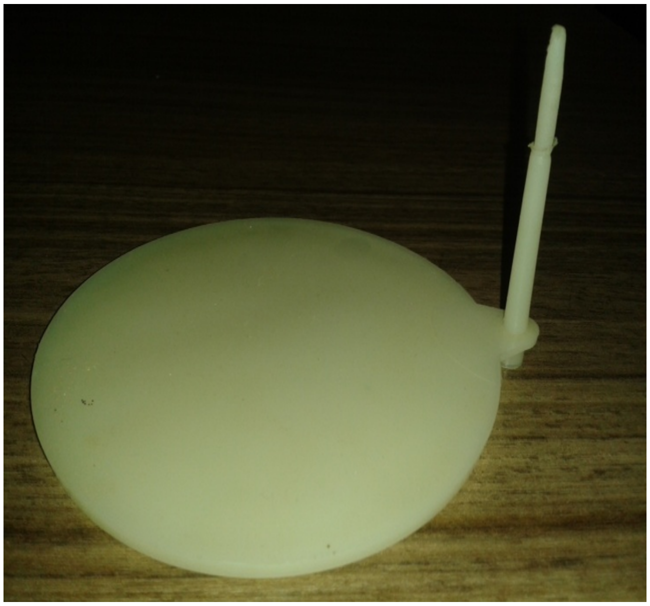

Fig. 1: Polypropylene test specimen

2.3 Calculation of dimensional shrinkage

Dimensional shrinkage can be calculate by using of this formula-

$S = (D_m - D_p)/D_m$

Here S- Dimensional Shrinkage in mm

D_m - Mould dimension in mm

D_P - Part dimension in mm.

3. Results and Discussion

3.1 Design of experiments

As an important subject in the statistical design of experiments, the Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [7]. The Response Surface Methodology (RSM) emerged in the 1950s [8][9] within the context of Chemical Engineering in an attempt to construct empirical models able to find useful statistical relationships between all the variables making up an industrial system. He has exhaustively reviewed the literature in the sense, describing the developments and applications of this methodology [10]. Very recently, RSM has been used even to validate new experimental methods [11].

3.2 Analysis for dimensional shrinkage in transverse direction (dx)

After the examination of Fit Summary, output revealed that the quadratic model is statistically significant for dimensional shrinkage and therefore it will be used for further analysis.

Mathematical model for dx

The final regression model for dimensional shrinkage in terms of coded factors is shown as follows:

$$Dimensional\ shrinkage\ dx = 2.09 + 0.47 * A - 0.22 * B - 0.22 * C + 0.15 * D - 0.048 * A * B + 0.13 * A * C - 0.016 * A * D + 0.049 * B * C - 0.032 * B * D - 0.10 * C * D - 0.040 * \mathrm{A}^2 - 0.055 * \mathrm{C}^2 - 0.050 * \mathrm{D}^2 \quad (1)$$

While, the final regression model for average surface roughness in terms of actual factors is shown as follows:

$$Dimensional\ shrinkage\ dx = -7.976 + 0.065 * Melt\ temperature + 0.020 * Injection\ pressure - 0.257 * Cooling\ time + 0.062 * Mould\ temperature - 1.604 * 10^{-4} * Melt\ temperature * Injection\ pressure + 1.281 * 10^{-3} * Melt\ temperature * Cooling\ time - 5.208 * 10^{-5} * Melt\ temperature * Mould\ temperature + 6.583 * 10^{-4} * Injection\ pressure * Cooling\ time - 1.416 * 10^{-4} * Injection\ pressure * Mould\ temperature - 1.341 * 10^{-3} * Cooling\ time * Mould\ temperature - 9.971 * 10^{-5} * Melt\ temperature^2 - 2.195 * 10^{-3} * Cooling\ time^2 - 2.217 * 10^{-4} * Mould\ temperature^2 \quad (2)$$

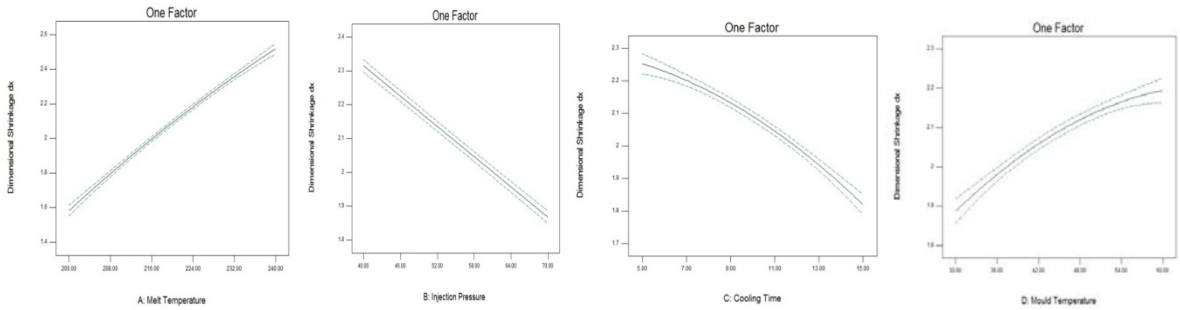

Fig.2 Effect of process parameters on dimensional shrinkage

The figure 2 shows the effect of process parameters on dimensional shrinkage.The 3D surface graph for dimensional shrinkage is shown in Fig.3 and the curves have curvilinear profile in accordance to the quadratic model fitted. According to the 3 D plot, the dimensional shrinkage is significantly minimized when the melt temperature and mould temperature is set to the low level 200 ^{0}C, 30 ^{0}C respectively and the dimensional shrinkage is significantly minimized when the cooling time and injection pressure at high level 15 Sec, 70 bar respectively.

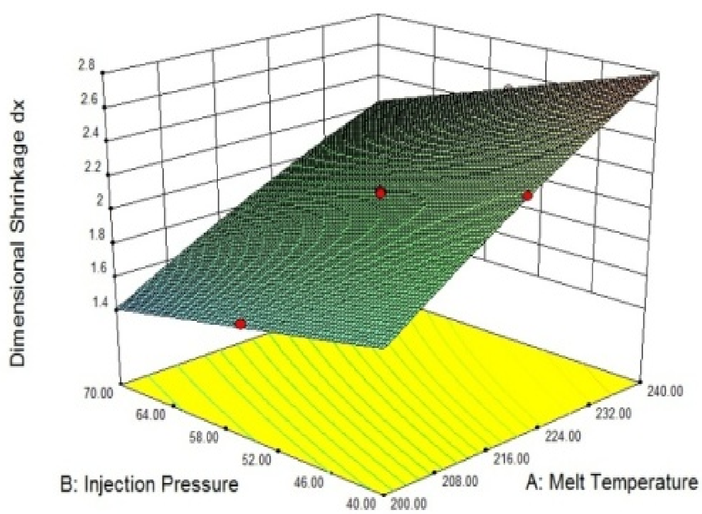

Fig.3. 3D surface graph for dimensional shrinkage

3.3 Optimization of process parameters

The table 4 shows the optimum results for dimensional shrinkage and table 5 shows the conformation experiments.

Table 4 Optimization results for dimensional shrinkage

No.	A:Melt Temperature	B:Injection Pressure	C:Cooling Time	D:Mould Temperature	Dimensional Shrinkage dx	Desirability	
1	200.03	70.00	14.98	30.03	0.9758	1	Selected
2	200.01	69.99	15.00	30.43	0.977128	1	Selected
3	200.00	67.06	15.00	30.50	0.996068	0.99471031	Selected

3.4 Conformation experiments

Table 5Plan of confirmation experiments and results for dimensional shrinkage

Sr. No.	Process Parameters				Experimental dimensional shrinkage	Predicted dimensional shrinkage	Error % (dx)
	A	B	C	D	dx	dx	
1	200.03	70.00	14.98	30.03	1.0071	0.9758	3.11
2	200.01	69.99	15.00	30.43	1.0087	0.977128	3.13
3	200.00	67.06	15.00	30.50	1.0091	0.996068	1.29

4. Conclusion

A three level four numeric factors response surface methodology based on the central composite face centered design technique has been used for the development of mathematical models to predict dimensional shrinkage.

The important conclusions drawn from the present work are summarized as follows:

1. Out of four parameters, cooling time seems to be the most significant and influential process parameter that affects the dimensional shrinkage followed by melt temperature, injection pressure and mould temperature.
2. The mathematical models developed clearly show that dimensional shrinkage increases with increase in the melt temperature, mould temperature but decreases with increase in the cooling time, injection pressure.
3. The results of confirmation runs verify that the developed mathematical models for dimensional shrinkage has excellent fit and provide predicted values of dimensional shrinkage close to the experimental values, with a 95 per cent confidence level.
4. The percentage error between the predicted and experimental values for dimensional shrinkage has been found within 5 per cent.

In this study, mathematical modeling and optimization has been attempted for dimensional shrinkage parameters. The work can be extended to consider more response variables like warpage, surface roughness, mechanical properties etc. Also, more process parameters such as injection velocity, packing pressure, etc can be introduced to have a better insight in to the process.

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