Synchronized Optimization of Injection Moulding Parameters for Higher Acceptance of Polypropylene Products

Bikash Bepari, Tanumoy Kolay, Kamal Nayan and Subham Mishra

Abstract The present exploration focuses on synchronized optimization of injection moulding parameters to adjudge the suitability of the polypropylene products in view of higher acceptance. A full factorial experimental layout was framed for the moulding parameters like injection temperature, pressure and speed, all at three levels. Before launching into the market, polypropylene products need to qualify the strength test (ASTM-D638-03), density test (ASTM-D 792), and Vicat Softening Point test (ASTM-D 1525). Grey Relational Analysis (GRA) was adopted to convert the multiple objectives into a single objective. Specimens were prepared at all the parametric combinations through injection moulding in compliance with ASTM-D 638-03-TYPE-I. The above mentioned tests have been carried for every specimen and the responses were obtained. It has been observed that products manufactured at 200 °C Injection Temperature, 70 bar Injection Pressure and 80 rpm Injection speed are poised with higher level of suitability from acceptance point of view. Grey analysis reveals injection temperature is the most dictating factor followed by injection velocity and injection pressure.

Keywords Polypropylene · Injection moulding · Optimization · Grey relational analysis

1 Introduction

Plastic is the material to drive the expansion of revolutionary innovations to convene society's major challenge. Currently, 58 % of the materials encountered are comprised of polymer. Unambiguously it is evident that the usage of plastic is ubiquitous in everybody's life. Since the utilization of plastic products is increasing over the sphere, the production techniques are also escalating side-by-side. Injection

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moulding technology being one of the techniques in plastic product manufacturing converts raw plastics into its functional counterpart. Survey reveals that, utilization of polypropylene goods are more compared to the useable counterparts. Polypropylene is a linear polymer composed of repeating units of isopropene. The main attractive features of PP are excellent flex life, commendable surface hardness, enhanced corrosion resistance and form stability at higher temperature. Before introduction of a polypropylene product in the market, it must undergo a series of qualifying tests, out of which tests as per (ASTM-D638-03), (ASTM-D 792) and (ASTM-D 1525) are the three mandatory tests. However, parametric optimization during moulding of polypropylene keeping in view of three above mentioned tests is unavailable in the literature as far as the knowledge of the authors are concerned.

Doong et al. (2000) optimized for injection moulding of reinforced polycarbonate composites by considering filling time, melt temperature, mould temperature and ram speed. CAE flow simulation software was employed to simulate the injection moulding process and to predict the probable fiber orientation. Recyclability of High Density Polyethylene (HDPE) was studied by Siddiquee et al. (2010). Objectives were attained by measuring the tensile, compressive and flexural strength which acted as the qualifying criteria subjected to the parameters like melt temperature, holding pressure, injection time and holding time (Kamaruddin and Mehat 2011) adopted Taguchi L_9 orthogonal array as DOE to improve mechanical properties of materials made from recycled plastics. They considered melt temperature, packing pressure, injection time and packing time as the parameters. They showed products produced at 1:3 (recycle to virgin ratio) exhibited enhanced flexural Strength (Ozcelik 2011) investigated the combined effect of mold parameters along with weld-lines. He considered injection temperature, packing pressure and injection pressure as the parameters while the responses were tensile load, elongation at break and impact strength and revealed that the injection pressure was the most influential parameter compared to melt temperature. Based on the literature survey, the objectives are primarily aimed (a) to optimize the process parameters for injection molding of polypropylene for the three factors; namely, injection pressure, temperature and speed to qualify the products made at all possible parametric combination so as to ensure all the tests pertinent to ASTM as mentioned in the abstract and (b) to determine the relative importance of the parameters.

2 Machining and Measuring Tabs

The experiments were conducted at Central Institute of Plastics Engineering and Technology. Figure 1 depicts the machining tab for injection molding. Figure 2a–c depict the measuring tabs to determine tensile strength, Vicat Softening Point and density respectively.

Fig. 1 The injection moulding machine

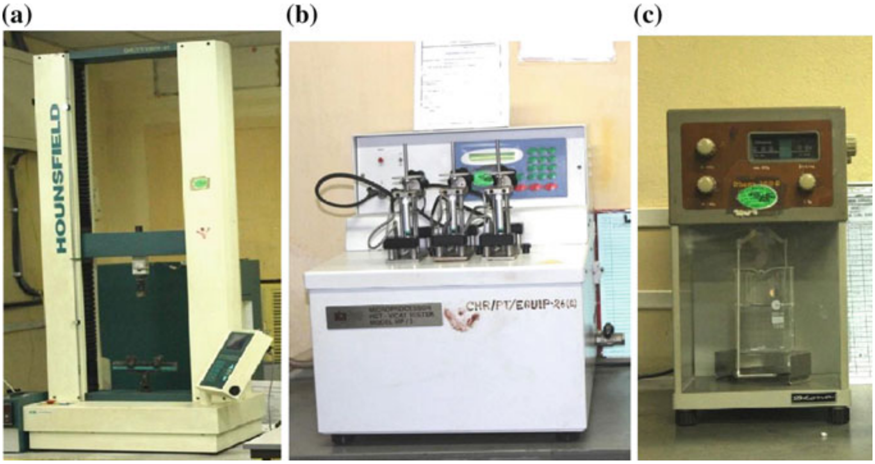

Fig. 2 The measuring tabs for different responses

3 Process Parameters and Responses

Injection pressure is the most important parameter during moulding of PP pertinent to dimensional accuracy when the mould temperature is held fixed (Rubin 1972). Higher injection pressure increases the density by increasing the compaction and to get rid of the shrinkage problem a higher holding time is essentially required. Moreover, higher pressure enhances rate of crystallinity. When higher tensile strength is expected from the molding upshots it is generally molded at moderately higher temperature and cooled gradually over a long period of time to avoid shrinkage and other imperfections. Higher temperature and pressure helps the molten material to propagate uniformly to the entire mold cavity instantaneously because of less viscosity. This phenomenon ultimately leads to fetch products with uniform density and higher abrasion resistive properties. It has been observed if the

Table 1 Notation of the parameters and their ranges during moulding

Parameter	Notation	Unit	Levels of factors		
			−1	0	+1
Injection temperature	IT	°C	190	200	210
Injection pressure	IP	Bar	50	60	70
Injection speed	IS	rpm	80	100	120

density is high then the quantum of mass for a considered volume is high and the porosity is less. Less porosity in other sense can be conferred as higher resistance to penetration and thus it increases the softening point. Therefore the authors found that temperature, pressure and speed of injection are the predominant parameters which have got significant importance on the objectives of the present experimental study. Table 1 shows the injection moulding parameters for the discrete range encapsulating their levels. The factors for the responses with regards to the present objective are higher tensile strength in yield, nominal density and higher VSP.

4 Grey Relational Analysis

Grey relational analysis (GRA) was introduced by Deng (1989), to judiciously approximate the relative suitability of a sequence based on grey relation grade. GRA has proven itself as a deft tool for multi objective optimization when it is subjected to inadequate information. The normalization of the original sequence is done in such a fashion so that the most preferred value reaches unity (White) and the least value becomes zero (Black). The intermediates are always lying in between them and therefore they are termed as grey entities.

In GRA, the discrete data is initially pre-processed through normalization to convert the original sequences into comparable sequence. Based on the orientation of the data sequence, different protocols for normalization were proposed by Fung and Kang (2005). When the target value is expected to be "the-higher-the-better", then it is normalized through:

$$x_i^*(k) = \frac{x_i^o(k) - \min x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \tag{1}$$

For cost attributes the orientation is "The-least-the-better" and then this is normalized as follows:

$$x_i^*(k) = \frac{\max x_i^o(k) - x_i^o(k)}{\max x_i^o(k) - \min x_i^o(k)} \tag{2}$$

When the expectancy is a value which is nominal (generally a targeted value is prescribed) then the original sequence is normalized by the following equation:

$$x_i^*(k) = 1 - \frac{\left|x_i^o(k) - x_i^o\right|}{\max x_i^o(k) - x_i^o} \tag{3}$$

where, $i \in m; k \in n$. 'm' is the experimental layout number, 'n' is the number of factors. $x_i^o(k)$ indicates the original set of data, $x_i^*(k)$ is the normalized data set, $\max x_i^o(k)$ and $\min x_i^o(k)$ are the highest and lowest value of $x_i^o(k)$ respectively; x_i^o is the nominal value for $x_i^o(k)$.

The Grey Relational Coefficient (GRC) for kth factor for ith layout is stated by:

$$\xi_i(k) = \frac{\Delta_{\min} + \zeta \cdot \Delta_{\max}}{\Delta_{oi}(k) + \zeta \cdot \Delta_{\max}} \tag{4}$$

$$\begin{aligned} \Delta_{oi}(k) &= \left|x_o^*(k) - x_i^*(k)\right|, \\ \Delta_{\max} &= 1.00, \Delta_{\min} = 0.00, \end{aligned} \tag{5}$$

where, $\Delta_{oi}(k)$ refers to the degree of separation measured from unity(1) for the normalized sequence. 'ζ' is a identification coefficient for fine tuning to compress the data set and to make the whole data to skew towards unity. 'ζ' is having a range of $0 < \zeta < 1$ and the value is generally selected based on the discretion of the subjective requirement during experimentation (Abhang and Hameedullah 2011). For the present investigation the authors took this value as 0.5.

After determining the GRCs, generally average function is employed to determine the grey relational grade (GRG). The grey relational grade is the adjudging entity which reveals the goodness or badness of the layouts (Mathew and Rajendrakumar 2011). For weighted averaging the GRGs are obtained following the proposition by Lin and Ho (2003) which is expressed as:

$$\gamma_i = \sum_{k=1}^{n} w_k \xi_i(k) \tag{6}$$

where, $\sum_{k=1}^{n} w_k = 1$ and w_k denotes the weights of the factors based on which the judgment is conferred. The weights of the responses were determined by Grey Entropy Method proposed by Wen and Chang (1998).

5 Results and Discussion

The DOE was based on a 3^3 full factorial layout with ternary parameter levels and the corresponding measurands along with GRCs and GRGs have been shown in Table 2. While calculating the Grey Relational Grades the weights for yield strength, density and Vicat softening point were considered as 0.33332, 0.33329 and 0.33337 respectively.

Table 2 Experimental layout, response values and grey relational coefficients and grades

Experiment no.	Process parameters			Original sequence (responses)			GRC			GRG
	Injection temperature (°C)	Injection pressure (Bar)	Injection velocity (RPM)	Yield strength in tensile (MPa) average	Density (g/cc)	VSP (°C)	Yield strength in tensile (MPa) average	Density (g/cc)	VSP (°C)	
1	190	50	80	32.44	0.9043	154.00	0.666	0.467	0.533	0.555
2	190	50	100	33.55	0.9045	154.20	0.957	0.429	0.615	0.667
3	190	50	120	32.82	0.9042	153.70	0.743	0.488	0.444	0.559
4	190	60	80	31.12	0.9042	153.80	0.489	0.488	0.471	0.483
5	190	60	100	32.36	0.9041	154.00	0.651	0.512	0.533	0.566
6	190	60	120	32.49	0.9043	153.50	0.675	0.467	0.400	0.514
7	190	70	80	31.97	0.9042	153.40	0.590	0.488	0.381	0.486
8	190	70	100	32.33	0.9044	153.60	0.646	0.447	0.421	0.505
9	190	70	120	32.06	0.9042	153.90	0.603	0.488	0.500	0.530
10	200	50	80	33.18	0.9036	153.50	0.835	0.677	0.400	0.637
11	200	50	100	32.8	0.9052	154.70	0.739	0.333	1.000	0.691
12	200	50	120	31.97	0.9041	153.70	0.590	0.512	0.444	0.515
13	200	60	80	33.38	0.9051	154.20	0.897	0.344	0.615	0.619
14	200	60	100	31.54	0.9032	153.80	0.534	0.913	0.471	0.639
15	200	60	120	31.94	0.9043	153.10	0.586	0.467	0.333	0.462
16	200	70	80	33.66	0.9034	153.40	1.000	0.778	0.381	0.720[a]
17	200	70	100	32.11	0.9043	153.50	0.611	0.467	0.400	0.492
18	200	70	120	32.7	0.9042	153.60	0.717	0.488	0.421	0.542
19	210	50	80	28.8	0.9043	153.40	0.333	0.467	0.381	0.394

(continued)

Table 2 (continued)

Experiment no.	Process parameters			Original sequence (responses)			GRC			GRG
	Injection temperature (°C)	Injection pressure (Bar)	Injection velocity (RPM)	Yield strength in tensile (MPa) average	Density (g/cc)	VSP (°C)	Yield strength in tensile (MPa) average	Density (g/cc)	VSP (°C)	
20	210	50	100	32.91	0.9042	153.60	0.764	0.488	0.421	0.558
21	210	50	120	33.44	0.9041	153.80	0.917	0.512	0.471	0.633
22	210	60	80	32.34	0.9043	153.70	0.648	0.467	0.444	0.520
23	210	60	100	31.61	0.9042	154.00	0.542	0.488	0.533	0.521
24	210	60	120	32.21	0.9041	153.60	0.626	0.512	0.421	0.520
25	210	70	80	33.17	0.904	153.80	0.832	0.538	0.471	0.614
26	210	70	100	32.01	0.9041	154.10	0.596	0.512	0.571	0.560
27	210	70	120	31.4	0.9042	153.20	0.518	0.488	0.348	0.451

[a]Highest value of GRG corresponds to optimal condition

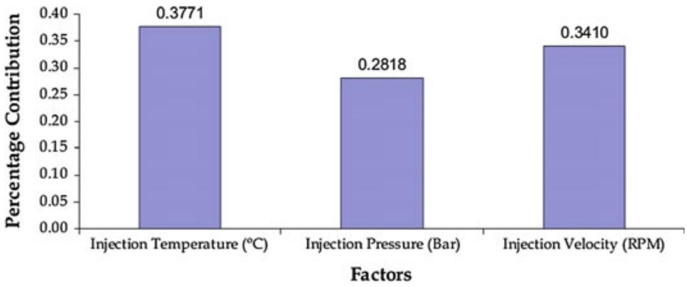

Fig. 3 Effect of injection parameters on multiple performance characteristics

After determining the GRGs, the Grey Response Analysis was accomplished. The Response Analysis considers the average of Grey Relational Grades for all the levels of all the process parameters and the difference in average GRGs for each parameter were determined to find out the importance of the parameters. This response analysis indicates that, for the present optimization problem; Injection temperature is the most influential parameter having a contribution of 37.71 % followed by Injection velocity and Injection pressure respectively having scores 34.10 and 28.18 % respectively. Figure 3 presents the graph for effect contribution of the control factors, which follows the descending order of feed rate, speed and depth of cut respectively. Furthermore it is evident that layout 16 fetches the highest GRG value which indicates parameter values as 200 °C Injection Temperature, 70 bar Injection Pressure and 80 rpm Injection velocity.

6 Conclusion

The present investigation was to find out a suitable combination of process parameters which would qualify polypropylene products pertinent to few mandatory tests as stated in ASTM guidelines. Owing to the previous survey of literature, experimentation and data interpretation the following conclusions are attained:

a. Polypropylene products produced at 200 °C Injection Temperature, 70 bar Injection Pressure and 80 rpm Injection speed are having higher level of probability to qualify the tensile strength test, density test and VSP test concurrently.
b. Injection temperature is the verbalizing parameter followed by injection velocity and injection pressure.
c. The present investigation considers full factorial layout considering three levels for each parameters and thus the suitability among the discrete combinations were adjudged within the problem space. Hence it leads to quasi-optimal solution instead of optimal solution and to mitigate the same in the next attempt evolutionary soft computing techniques will be attempted in the pursuit of optimality.

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