Optimization for Injection Moulding process parameters towards Warpage and Shrinkage of HDPE-PBI composites

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Abstract. Injection moulding is a high-quality process that is preferred in modern manufacturing. Due to the defects in HDPE polymer composites the parameters had to be adjusted based on the necessity. Therefore, this study of parameters is to improve the quality characteristics of the injection moulding of HDPE-PBI composite samples. As the composition of HDPE composites varies, the quality aspects that must be controlled are shrinkage and warpage. The parameters that are considered as factors are Melting Temperature (°C), Injection pressure (MPa) and cooling time (sec). Using the Taguchi Optimization method of L9 Orthogonal array, the injection moulding process was performed and found that the injection pressure of 65 MPa and temperature of 180-185 °C showed better results. The influence of parameters was studied through this research using Analysis of Variance (ANOVA).

Keywords: HDPE Composite, Injection Moulding Machine, Optimization, ANOVA

1. Introduction
The automotive industry is working to improve gas mileage by replacing some metal parts with polymer composites. The injection moulding process has grown in popularity in the polymer processing industry. This method is used for mass production at a low cost and time [1]. The plastic HDPE-PBI composite pellets are put in the hopper of an injection moulding machine. The pellets are heated by four heating zone coils. A screw is provided inside the barrel to provide injection pressure and melting of plastics forced into the mould cavity. Warpage and shrinkage must be kept to a minimum because they affect the product's quality. To find the optimum condition of processing of the HDPE composites, to achieve desired properties, optimized processing conditions are necessary for the Injection moulding machines [2]. The warpage is caused by the shrinkage variation of plastic parts by the injection process. It is found that area shrinkage (due to packing pressure and crystallization variation), differential cooling (caused due to sectional shrinkage) and flow orientation (shrinkage caused due to the direction of plastic injection) [3-5]. The various factors that control these characteristics are packing pressure, injection pressure, melt temperature, screw speed, mould temperature, holding time and cooling time. The warpage problem was discussed by Ming-chih Huang et.al (1999) with the factors that affected the moulded parts. S.H. tang et al. (2006) have found that warpage is caused by some important parameters, like packing time and melt temperature, along with filling time and packing pressure. The method that is used for conducting multiple experiments is the Design of Experiments. DoE is used to reduce the number of experiments to obtain the optimal
parameters [6]. The Taguchi technique is a design of experiment (DOE) that uses a statistical method to optimize process parameters while minimizing variability and improving product quality. Nominal is the best of the Taguchi techniques in this study and is an appropriate application based on data characterization. It explains the techniques and steps used in DOE to determine the best quality parameter for a given quality characterization [7].

The major plastic material in use is the commodity polymer HDPE. From literature, we have found that the main reason for defects in the quality of plastic products is the setting up of process parameters in the injection moulding machine. This research investigation is about finding the influencing factors affecting shrinkage and warpage of HDPE composites.

2. Injection moulding machine

An injection moulding machine is one of the processes of melting plastic pellets and creating products of high quality and efficiency. The machine consists of four zones. Each zone is made up of heating coils that vary the temperature based on the plasticization. The front zone consists of a suck-back section, which is the nozzle of the machine. It is situated at the forefront of the barrel. There will be some internal pressure in the nozzle. The temperature had to be lower as compared to that of the plasticization area. This temperature setting is lower and not too low because it is to stop the flow of molten plastic under internal pressure [8]. Additional plasticization pressure is required to compensate for the flow of water back if the temperature is kept too low. The centre zone is the barrel middle zone. Here the temperature has to rise above the melting point of plastic and its sole purpose is to make the plastic into a molten state. The noticeable thing is the temperature should be too high as the decomposition of plastic material might happen. If the temperature is low in this zone, the plasticization process will not be proper and the torque has to be increased for the screw. The lower temperature zone is the rear zone, which is the feeding area near the hopper. The temperature set should be less than that of the centre zone, i.e., less than the melting temperature of the plastic pellets. This is also known as the pre-heating zone, where the temperature begins to rise towards the melting point. If the temperature is above the melting point, then the plastic starts to get melted and the process gets altered as the screw slippage occurs and, in the end, affects the quality of the material and the material delivered. If the pre-heating temperature is too low, there should be an increase in screw torque.

3. Data collection

The data for these studies is to calculate the existing mould dimensions and sample dimensions using a digital vernier caliper and a dial gauge. The shrinkage and warpage in an injection moulding process determine the quality of the product output. The specimens that are removed from the mould after the injection moulding process is completed must be cleared of flash before being measured.

\[
S = \frac{M_a - M_p}{M_a} \quad (1)
\]

The shrinkage can be calculated from equation 1.

\[
W = h - t_p \quad (2)
\]

The Warpage can be calculated from equation 2.

| Parameter | Description                    |
|-----------|--------------------------------|
| M_a       | Mould dimension (mm)           |
| M_p       | Specimen dimension taken from mould (mm) |
| W         | Warpage value (mm)             |
| h         | Maximum height of plate bend (mm) |
| t_p       | thickness of plate (mm)        |

4. Parameters selected and Experimental design

The taguchi method was opted to do this design of experiments; the three levels of parameters were selected for factors like Injection pressure, injection temperature, Packing pressure and cooling time.
The three values show the low, medium and high values which is significant factors in increasing the quality characteristics of the output product. The table shows the factors and levels of parameters taken for this research. The L9 Orthogonal array had been adopted for this work as it is having three levels and three factors. The table shows the L9 Orthogonal array, whereby A is for Injection pressure, B is for melting temperature, C is for cooling time [9-11].

### Table 1. Process parameters and levels

| No | Factors                        | Level 1 | Level 2 | Level 3 |
|----|--------------------------------|---------|---------|---------|
| 1  | Injection Pressure – A (MPa)   | 60      | 65      | 70      |
| 2  | Melting Temperature – B (°C)   | 180     | 190     | 200     |
| 3  | Cooling time – C (sec)         | 10      | 15      | 20      |

### Table 2. Warpage and Shrinkage value for HDPE composites by L9 Orthogonal Array

| Trial No. | A     | B     | C     | Shrinkage (mm) | Warpage (mm) |
|-----------|-------|-------|-------|----------------|--------------|
| 1         | 60    | 180   | 10    | 0.023          | 0.076        |
| 2         | 60    | 190   | 15    | 0.025          | 0.079        |
| 3         | 60    | 200   | 20    | 0.029          | 0.085        |
| 4         | 65    | 180   | 15    | 0.011          | 0.068        |
| 5         | 65    | 190   | 20    | 0.016          | 0.074        |
| 6         | 65    | 200   | 10    | 0.018          | 0.071        |
| 7         | 70    | 180   | 20    | 0.016          | 0.072        |
| 8         | 70    | 190   | 10    | 0.013          | 0.07         |
| 9         | 70    | 200   | 15    | 0.026          | 0.075        |

### Table 3. Analysis of Variance for Shrinkage

| Source            | DF | Seq SS     | Adj MS    | F cal | % of contribution |
|-------------------|----|------------|-----------|-------|------------------|
| Injection Pressure (MPa) | 2  | 0.000203   | 0.000101  | 25.33 | 74.6             |
| Temperature (C)   | 2  | 0.000053   | 0.000026  | 6.58  | 19.4             |
| Cooling Time (s)  | 2  | 0.000009   | 0.000004  | 1.08  | 3.33             |
From the table 3, we can infer the influence of parameters from the percentage of contribution in the shrinkage values. The higher being the injection pressure which contributes about 74.6%. The temperature has a percentage of 19.4 and it’s the 2nd influential contributor in the increase of shrinkage value. The cooling time parameter which is considered is not much influential comparatively to temperature and injection pressure. The R-square value obtained for shrinkage is 97.06 % from the ANNOVA.

| ERROR | 2   | 0.000008 | 0.000004 | 2.94 |
|-------|-----|----------|----------|------|
| TOTAL | 8   | 0.000272 |          | 100  |

**Figure 1. Main Effects plots for Shrinkage**

The fig 1 shown is the main effect plots of shrinkage of the HDPE-1% PBI samples. The highest shrinkage was seen at the Injection pressure of 60 MPa with a value of 0.0250 mm. the lowest shrinkage was obtained at the 65 MPa and at 70MPa the shrinkage increased slightly to 0.0163 mm. the decrease of shrinkage is about 45 % when the highest values and lowest values are compared with each other. From the temperature vs Shrinkage graph, the highest value is recorded at 200°C. The lowest shrinkage was seen at 180°C. The increase in the shrinkage values were noticed as the temperature profile increases. The temperature required being optimum and little above the melting temperature, so that minimum shrinkage can be obtained, if the temperature is too high the shrinkage will be more and also the materials get burned up and degrades. The cooling time didn’t have much of an impact when compared to Injection pressure (MPa) and Temperature (°C). There was a little increase while the cooling time was increased from 10 seconds to 20 seconds. This time was given after the machine cooling time, which is 50 seconds. The Packing pressure which was considered in other journals was not taken into account as the packing pressure was determined by some percentage pressure of Injection pressure. So it will directly equal to injection pressure shrinkage values, therefore the packing pressure was not taken into account in this study.
Figure 2. Main Effects plots for Warpage

The fig 2 shown is the main effect plots of warpage of the HDPE-1% PBI samples. The lowest warpage was seen at the Injection pressure of 65 MPa with a value of 0.080 mm. the highest warpage was obtained at the 60 MPa and the warpage increased slightly to 0.072 mm at 70 MPa. The warpage is a defect of bending due to variations in the temperature inside the mould. The side of sample that was near the injection sample is the hot area when compared with the side of the sample that was sticking on the base of die. This difference in the hot and cold region will cause the warpage effect in the injection moulded products [12]. The temperature vs warpage graph clearly states the temperature at which the warpage was high was the highest temperature of study. The graph was linear in nature and stating that, as the temperature increases, the difference of hot and cold region will be more and in turn the warpage defect will also be high. The warpage should be minimum for the proper output of products to be obtained [13].

The cooling time didn’t have much of an impact when compared to Injection pressure (MPa) and Temperature ( °C ). There was a little increase while the cooling time was increased from 10 seconds to 20 seconds. This time was given after the machine cooling time, which is 50 seconds.

Table 4. Analysis of Variance for Warpage

| Source                    | DF | Seq SS   | Adj MS    | F_cal | % of contribution |
|---------------------------|----|----------|-----------|-------|------------------|
| Injection Pressure (MPa)  | 2  | 0.000142 | 0.000071  | 91    | 66.3             |
| Temperature (°C)          | 2  | 0.000038 | 0.000019  | 24.14 | 17.75            |
| Cooling Time (s)          | 2  | 0.000034 | 0.000017  | 21.57 | 15.8             |
| ERROR                     | 2  | 0.000002 | 0.000001  | 0.93  |                  |
| TOTAL                     | 8  | 0.000214 |           |       | 100              |
From the table 4, the percentage of contribution of each parameters are shown, we can infer the influence of parameters from the percentage of contribution in the warpage defect. The warpage is due to the temperature difference while injecting the molten plastic into mould. The major contributor to this warpage is the Injection pressure (MPa) [14]. The temperature contributes about 17.75 % and the cooling time contributes 15.8 %. Both these parameters are nearly sharing equal contribution in the influence of Warpage. The R-square value obtained from the ANNOVA table is 99.27%.

![Contour Plot of Shrinkage (mm) vs Temperature (C), Injection Pressure (MPa)](image1)

**Figure 3.** Graph for Shrinkage vs Temperature and Injection pressure for HDPE composite

From the Contour plot graph, the darker regions shows the maximum effect of shrinkage, which is caused due to the reduction in injection pressure and increase in temperature [15]. The less shrinkage effect is seen at Injection pressure of 64-68 MPa and Temperature of 180-183°C.

![Contour Plot of Shrinkage (mm) vs Cooling Time (s), Injection Pressure (MPa)](image2)

**Figure 4.** Graph for Shrinkage vs Cooling time and Injection pressure for HDPE composite
From the Contour plot graph 4, the injection pressure of 64-67 MPa with Cooling time of 13-18 seconds had lesser attributes of shrinkage, as the pressure decreases the shrinkage value gets increased.

**Figure 5.** Graph for Warpage vs Temperature and Cooling time for HDPE composite

From the contour plot graph, the warpage is higher at the region of higher temperature and more cooling, time that is during the temperature is above 195-200 °C. The lower the temperature and more the cooling time, the warpage is very less. The 180 °C have the better quality parameter for reducing warpage.

**Figure 6.** Graph for Warpage vs Temperature and Injection pressure for HDPE composite
The contour plot for injection pressure and temperature vs warpage is shown in fig.6. It can be observed that at 180 °C, the warpage is minimum at 63 to 69 MPa. As the temperature is increased and pressure is decreased the warpage tends to increase higher. At 200 °C the warpage is maximum and at 180 °C the warpage is minimum at all pressures comparatively.

5. Conclusion
The HDPE composite specimens were prepared by the Injection moulding process. With the parameters set of are Melting Temperature (°C), Injection pressure (MPa) and cooling time (sec). The warpage and Shrinkage values were calculated using digital vernier caliper and dial gauge. From the readings the given below conclusions are drawn.

i. As the Temperature increases the warpage value and shrinkage value also got increased, it’s due to the temperature difference of the mould base and the side of plastic injection.

ii. The difference between the cold side and hot side inside the die is the main reason for causing warpage defect, and the study also shows similar effect of warpage. The injection parameters had to be controlled to avoid the development of defects in HDPE composite.

iii. The cooling time value didn’t do much influence as compared to temperature and Injection pressure parameters. The cooling time range is 15 -20 seconds at nominal pressure had better results.

iv. The Injection pressure of 63-68 MPa, the temperature range of 180- 185 °C gave better quality of specimens. The improvements in the quality will yield better results of the HDPE composite and the defects like warpage and shrinkage can be eliminated or reduced further to avoid wastage.

Further the work can be extended to find mechanical and metallurgical properties of the composites.

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