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Investigation and Optimization of Process Parameters for Warpage in Injection Molded Gear

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***ABSTRACT*—** In injection molded part uneven cooling causes uneven distribution of stresses. These stresses affect dimensional accuracy and warpage is set up in the part. The lack of injection molding machine control leads to this defect in plastic parts. Accurate prediction of optimum process parameters is important to minimize warpage. To find optimum process parameter values Finite Element analysis software, Moldflow Plastic Insight, and different optimization techniques are used.The optimum combination of process parameters which minimizes warpage is found out. Melt temperature is the pivotal factor participating to warpage in this problem. After optimization warpage value is reduced by 5.3% with optimum proces setting. On the basis of finite element simulation data Neural network model is formulated which gives results with acceptable accuracy. It is used alternative as it is cheap and less time consuming comparable to finite element simulation process**.**

KEYWORDS— Warpage, Optimum, Finite element simulation.

I. Introduction

Plastics industry is one of the world's fastest growing industries.Plastic materials have played an important role in the development of this modern civilization. Injection molding is one of the most versatile, efficient, and widely used manufacturing processes to manufacture plastic parts. Defects such as flash,air traps,sink marks,warpage etc. may occur during injection molding process. The defects are occur due to improper process parameter settings, design of mold, and geometry of part as well as plastic material used to manufacture the part. Warpage is the result of uneven distribution of stresses among these defects.

Using Taguchi method Hakimian and Sulong (2012) discussed about warpage and shrinkage properties of injection molded micro gears polymer composites. Reduction of sink mark and warpage of molded part in rapid heat cycle molding process studied by Wang et al. (2013).To investigate the effect of processing parameters on warpage they used design of experiments via Taguchi methods. Chen et al. (2009) used Design Of Experiments (DOE) approach to determine optimal process parameter settings. For the results of simulation and experiment ANOVA and regression models were also created. For warpage prediction and optimization of plastic products Fei Yin et al.(2011) used back propagation neural network model. Taghizadeh et al. discussed the warpage in plastic injection molded part using Artificial Neural Network (ANN). Deng et al. (2010) proposed hybrid optimization method which combines Mode-Pursuing Sampling (MS) method and the genetic algorithm to minimize warpage in injection molded plastic parts. According to problem under study different researchers found various process parameters as most significant.

II. EXPERIMENTAL PROCEDURE

Gear Model- A bevel gear (shown in Figure 1) having diameter of 16.4 mm, gear thickness of 3.5 mm, and number of teeth 20, is used for this study. The gear is made up of Nylon 66 polymer and its material properties are given in the Table 1. These values are taken from Moldflow Plastic Insight (MPI) material database. An 8-cavity mold layout is used in this study and 3D type of mesh is used for meshing the model. It is created in Moldflow Plastics Insight software which is based on hybrid finite element method for solving pressure, flow, and temperature problems. Figure 2 shows FE model with feeding system and cooling channels.

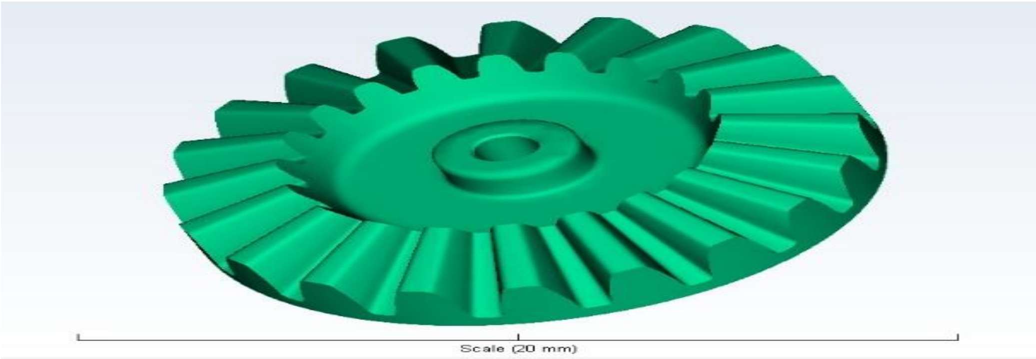

Fig.1 Bevel gear model

Parameters used for study-Melt temperature, mold temperature, packing pressure, injection time, and cooling time are used as parameters for this study. These are represented by the letters P1, P2, P3, P4 and P5, respectively. Three levels of these parameters are selected taking reference from material database available in MPI and are given in Table 2. Taguchi L27 (35) orthogonal array are selected for the experimental design.

Table 1 Properties of Nylon 66

Properties	***Values***
Trade Name	*Unitika Nylon 66 A125*
Ejection Temperature (°C)	*158*
Elastic Modulus (MPa)	*2690*
Recommended Mold Surface Temperature(°C)	*90*
Recommended Melt Temperature(°C)	*290*

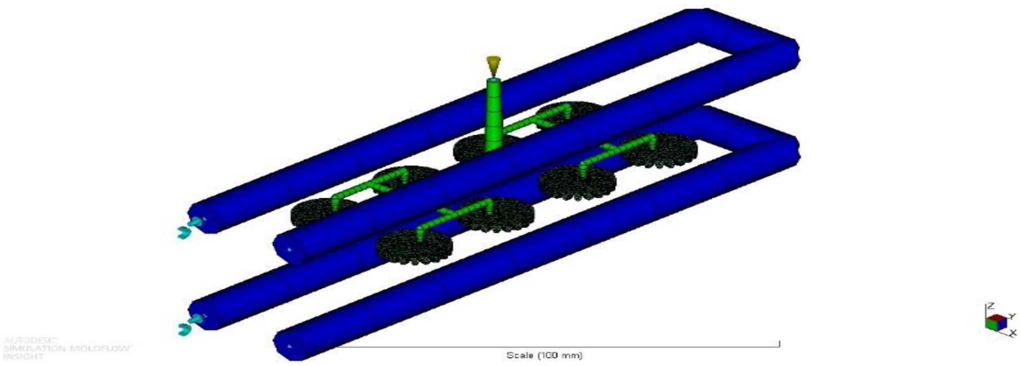

Fig.2 Complete finite element model

The FE analysis of this system is performed for all the 27 sets of process settings in Moldflow Plastics Insight and is given in Table 3 with their warpage values. "Fill + Pack + Warp" analysis sequence used in this case. The packing time is kept constant at 6 seconds for all the cases. Other machine and process parameters are kept as default. Figure 3 shows warpage analysis result of one analysis. The maximum and minimum warpage value of the part and its location can be seen directly from the figure 3.

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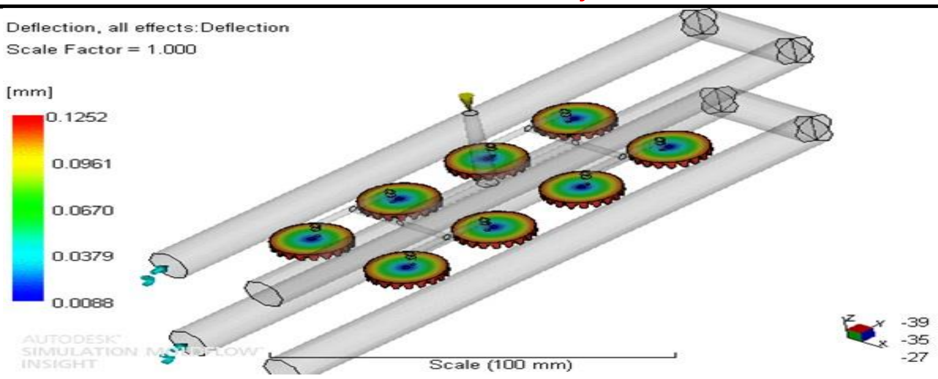

Fig.3 Warpage analysis result of one of the simulation

Table 2 Setting of the processing parameters

Level	*Experimental factors*				
	P1: Melt temperature (°C)	*P2: Mold temperature (°C)*	*P3: Packing pressure (MPa)*	*P4: Injection time (s)*	*P5: Cooling time (s)*
1	*280*	*80*	*30*	*0.5*	*15*
2	*290*	*90*	*40*	*1*	*20*
3	*300*	*100*	*50*	*1.5*	*25*

Table 3 Process settings with their warpage values obtained by FE simulation.

Test no	*Process setting*					*Simulated warpage value(mm)*	*S/N ratio*
	P1	*P2*	*P3*	*P4*	*P5*		
1	*280*	*75*	*30*	*0.5*	*15*	*0.1252*	*18.04*
2	*280*	*75*	*30*	*0.5*	*20*	*0.1252*	*18.04*
3	*280*	*75*	*30*	*0.5*	*25*	*0.1252*	*18.04*
4	*280*	*85*	*40*	*1*	*15*	*0.1248*	*18.07*
5	*280*	*85*	*40*	*1*	*20*	*0.1251*	*18.05*
6	*280*	*85*	*40*	*1*	*25*	*0.1244*	*18.10*
7	*280*	*95*	*50*	*1.5*	*15*	*0.1255*	*18.03*
8	*280*	*95*	*50*	*1.5*	*20*	*0.1255*	*18.03*
9	*280*	*95*	*50*	*1.5*	*25*	*0.1255*	*18.03*
10	*290*	*75*	*40*	*1.5*	*15*	*0.1272*	*17.91*
11	*290*	*75*	*40*	*1.5*	*20*	*0.1272*	*17.91*
12	*290*	*75*	*40*	*1.5*	*25*	*0.1272*	*17.91*
13	*290*	*85*	*50*	*0.5*	*15*	*0.1285*	*17.82*
14	*290*	*85*	*50*	*0.5*	*20*	*0.1285*	*17.82*
15	*290*	*85*	*50*	*0.5*	*25*	*0.1289*	*17.79*
16	*290*	*95*	*30*	*1*	*15*	*0.1325*	*17.55*
17	*290*	*95*	*30*	*1*	*20*	*0.1322*	*17.57*
18	*290*	*95*	*30*	*1*	*25*	*0.1318*	*17.60*
19	*300*	*75*	*50*	*1*	*15*	*0.1318*	*17.60*
20	*300*	*75*	*50*	*1*	*20*	*0.1305*	*17.68*
21	*300*	*75*	*50*	*1*	*25*	*0.1318*	*17.60*
22	*300*	*85*	*30*	*1.5*	*15*	*0.1352*	*17.38*
23	*300*	*85*	*30*	*1.5*	*20*	*0.1352*	*17.38*
24	*300*	*85*	*30*	*1.5*	*25*	*0.1352*	*17.38*
25	*300*	*95*	*40*	*0.5*	*15*	*0.1343*	*17.44*
26	*300*	*95*	*40*	*0.5*	*20*	*0.1344*	*17.43*
27	*300*	*95*	*40*	*0.5*	*25*	*0.1344*	*17.43*

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The aim of this study is to minimize the warpage to the greatest extent possible. Also develop a predictive model for warpage so as to reduce the time and cost involved in repetitive FE analyses. Hence, a neural network model is developed for which MATLAB neural network toolbox is used.

III. RESULTS AND DISCUSSION

Taguchi method -The Taguchi method is applied to design the experiment and to determine the effect of process parameters on warpage. Table 3 shows warpage values and their corresponding S/N ratios. The S/N ratio is used to evaluate the effect of altering a particular parameter value on the desired output.

Table 4 The response table of S/N ratios

LEVEL	*P1*	*P2*	*P3*	*P4*	*P5*
LEVEL1	*18.05*	*17.86*	*17.66*	*17.76*	*17.76*
LEVEL2	*17.76*	*17.75*	*17.80*	*17.77*	*17.77*
LEVEL3	*17.48*	*17.68*	*17.82*	*17.76*	*17.76*
DIFFERENCE	*0.57*	*0.18*	*0.16*	*0.01*	*0.01*

Table 5 The ANOVA table for part warpage

FACTOR	*SS*	*Df*	*MS*	*F*	*P*	*PC(%)*
MELT TEMPERATURE	*0.0003243*	*2*	*0.0001622*	*1569.20*	*0.000*	*83.07*
MOLD TEMPERATURE	*0.0000345*	*2*	*0.0000172*	*166.91*	*0.000*	*8.83*
PACKING PRESSURE	*0.0000298*	*2*	*0.0000149*	*144.33*	*0.000*	*7.63*
INJECTION TIME	*0.0000001*	*2*	*0.0000000*	*0.42*	*0.664*	*0.02*
COOLING TIME	*0.0000001*	*2*	*0.0000000*	*0.39*	*0.685*	*0.02*
ERROR	*0.0000017*	*16*	*0.0000001*			*0.43*
TOTAL	*0.0003904*	*26*				*100*

“The smaller, the better” quality characteristic is selected while calculating the S/N ratios as the goal of this study is to minimize the warpage of the part. Table 4 shows response values of S/N ratios. The S/N response graphs are plotted using the data given in Table 4 and are shown in Figure 4. The optimum combination of process parameters can be determined by selecting the level with highest value for each factor. Hence, the best combination of process parameters for this study is P1(1), P1(1), P3(3), P4(3), and P5(1). Due to negligible difference between S/N ratios of two levels, we have selected P5(1) instead of P5(2) because selection of P5(1) causes reduction of cooling time from 20 s to 15 s. Thus, the cycle time of the process gets reduced by large amount without compromising the quality of the part. The difference values in Table 4 shows the most significant process parameters for warpage. Melt temperature was found to be most significant process parameter followed by melt temperature and packing pressure. Injection time and cooling time had least effect on warpage of the bevel gear.

Table 6 Comparison of warpage before and after optimization

	P1	*P2*	*P3*	*P4*	*P5*	*Simulated Warpage*	*ANN*
MOldflow recommended process setting	*290*	*90*	*40*	*1*	*20*	*0.1311*	*0.1311*
Process setting after optimization	*280*	*75*	*50*	*1.5*	*15*	*0.1216*	*0.1203*
Change rate(%)						*-7.24*	*-8.24*

The optimum combination of process parameters is not included in the 27 FE analysis test runs given in Table 3. Therefore, a confirmation test is conducted to validate the results obtained by Taguchi method. The corresponding S/N ratio is 18.30 dB, which is higher than those obtained in orthogonal array design of experiment. It shows that the results obtained are better and warpage value is optimized.

ANOVA-The ANOVA is conducted on the data obtained from the FE analysis results using MINITAB V14 software and the results are shown in Table 6. The confidence interval is set as 95% and significance level as 5% for the ANOVA analysis. If "P value" for any parameter is lessthan 0.05, then the parameter has significant effect on the result. From the "P value" column of Table 5, it is clearly seen that melt temperature, mold temperature, and packing pressure have significant effect on the warpage values. The percentage contribution of each parameter is calculated using the following equation:

$(PC)_A = SS_A/SS_{Total}$……………………………………(1)

where $(PC)_A$ = percentage contribution of factor A; SS_A = sum of squares of factor A; and SS_{Total}= sum of squares of all factors. Percentage contributions for other factors are calculated using the same method and are given in the last column of Table 5.

Neural network model -A neural network has one or more hidden layers placed between the input and output layers. The layers have processing units called neurons. These neurons are connected by variable weights. All the neurons in the preceding layer give total input to each neuron in the succeedinglayer. In this study, neural network is used to predict the warpage values corresponding to optimal process setting determined by Taguchi method and Moldflow recommended process setting. MATLAB neural network toolbox is used for this study. A 5–10–10–1 feed-forward backpropogation neural network model is created and trained. The value of warpage by Moldflow recommended process setting and process setting after optimization are found out using this network. Comparison of the predicted and FE simulation values of warpage for the optimal setting and Moldflow recommended setting are given in Table 6.

IV. CONCLUSIONS

Optimal settings of process parameters for the bevel gear made up of Nylon 66 are determined for the optimization of warpage. The optimal combination of process parameters for minimization of warpage is 280°C melt temperature, 75°C mold temperature, 50 MPa packing pressure, 1.5 s injection time and 15 s cooling time. Melt temperature is the most significant process parameter and contributes 83% to warpage. Mold temperature and packing pressure are the other significant process parameters while injection time and cooling time have least effect on warpage. The warpage value obtained in the Moldflow recommended process setting is reduced by 5.3% after optimization. A neural network is formulated using MATLAB neural network toolbox to predict the warpage values directly. The model predicts warpage values with good accuracy. The optimization methodology used in this study can be employed to minimize the time and cost associated with repetitive FE analyses.

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