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WARPAGE ANALYSIS ON FRONT PANEL HOUSING USING RESPONSE SURFACE METHODOLOGY (RSM)

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Abstract

The work reported herein is about a study to establish the best combination of injection moulding parameters in minimising warpage over a front panel housing using a simulation software. The warpage in x and y directions were analysed using Autodesk Moldflow Insight (AMI) software where specifications of injection moulding machine (Nessei NEX 1000) and P20 as a mould material were set in this analysis. On top of that, Acrylonitrile Butadiene Styrene (ABS) was adopted as the plastic material. Four process parameters were taken as variable factors which are mould temperature, melt temperature, packing pressure and packing time. Design Expert 7.0 software was used to optimise warpage obtained from AMI analysis. The mathematical model was obtained from Design of Experiment (DOE) integrated with Response Surface Methodology (RSM) along with Center Composite Design (CCD) method. Results showed that packing pressure and melt temperature is the most significant factor leading to warpage whilst mould temperature and packing time demonstrated the least significant in both directions.

Keywords: *Injection moulding, Response Surface Methodology, Design of Experiment.*

Introduction

Injection moulding is described among the most flexible and economical manufacturing processes to produce a high volume of plastic parts [1]. This manufacturing process demands appropriate settings of processing parameters to be able to manufacture top quality towards the moulded parts [1].

However, finish moulded parts will produce defects during the manufacturing process such as shrinkage, warpage, sink mark and weld line which can affect the quality of the product [2]. Defects such as warpage is a distortion of the part, where the surfaces of the moulded part do not follow the intended shape of the design [3]. The warpage defect is due to non-uniform temperature variation resulted differential shrinkage on the moulded parts [3]. The moulded part, front panel housing was selected for the simulation studies to minimise the warpage as shown in Figure 1, with dimension of 120 mm x 80 mm x 18.75 mm and 2.5 mm thickness and total volume of 27 663.64 mm3 with a curvature shape like a current trend of a product available in the market.

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The study of warpage on thin shell housing is important because the shape is close to current trends in the market and can provide useful data information for producing higher quality moulded parts such as reducing warpage defect as low as can.

Fig. 1. The specimen of front panel housing.

Previous researchers admitted that eliminating the warpage effect is a difficult task to do as there is a tendency of the plastic warp during the solidification process [3-6]. RSM method is widely used as a tool for model prediction and optimisation in various area [9-10]. It is a model to show the relationship between several of processing parameter towards moulded parts defects and find the significance of the process parameter to minimise the defects [11]. Many researchers investigated by simulation studies and experimental works in optimising the quality of moulded parts using optimisation methods, particularly Response RSM and those reported works proved that the RSM is an effective method to quickly analyse the best processing parameters in minimising the moulding defects such as shrinkage, warpage and maximising strength of the moulded parts produced [3-8].

From the research conducted by Chen et al. [4], it shows that warpage defect is possible to be minimised using optimisation methods. The work reported revealed on how an integrated optimisation system was proposed to investigate an optimal parameter setting of multi-input multi-output (MIMO) in plastic injection moulding process. The system was divided into two stages. In the first stage, the Taguchi method and Analysis of Variance (ANOVA) were employed to perform the experimental works, calculate the Signal-to-Noise (S/N) ratio, and determine the initial processing parameters. The Back-Propagation Neural Network (BPNN) was employed to construct the S/N ratio and a quality predictor. The S/N ratio predictor and Genetic Algorithms (GA) were integrated to search the first an optimal parameter combination. The materials PA-765 fire-proof plastic was used to mould specimens. Injection pressure, injection velocity, melt temperature, packing pressure, and packing time were selected as variable parameters. The results showed that the warpage had reduced 38.6 % (from 0.2202 mm to 0.1351 mm).

Another study was undertaken by Andrisano et al. [5] in 2011 who investigated the ability to optimise processing parameters to obtained the minimum warpage using Design of Simulation Experiments (DOSE) methodology. The specimens were moulded by Polyphenylsulfone (PPSU) material. The commercial Computer Aided Engineering (CAE) software Moldex3D was used for simulation analysis. The processing parameters were determined using Design of Experiment (DOE) through simulation studies. Melt temperature, mould temperature, packing time, packing pressure, injection time, maximum injection pressure and filling/pressure (F/P) switch over point were selected as variable parameters. The experimental plans were generated using Central Composite Design (CCD) in RSM. The result shows that the warpage was reduced 31.6 % (from 0.057 mm to 0.039 mm) after optimisation.

Not long after that, Mostafa et al. [6] continued exploring a RSM and Simulated Annealing Algorithm (SA) to reduce the shrinkage and warpage on the fuel filter. Autodesk Moldflow Insight (AMI) was used for simulation studies and ANOVA was used to analyse the results. The fuel filter specimens were moulded by Polyamide 66 (PA-66). Three variable parameters were considered in this study, which are mould temperature, melt temperature and injection pressure. The result showed that, the value of shrinkage was reduced from 3.757 mm to 3.573 mm (4.8%) and the warpage was reduced 3 % (from 2.303 mm to 2.232 mm) after optimisation.

Three years later Park and Nguyen [7] reported an investigation a car fender-based injection moulding process optimisation aiming to resolve the trade-off between energy consumption and product quality. AMI 2012 software was used for simulation studies and RSM was partnered with Nondominated Sorting Genetic Algorithm II (NSGA II) as an optimisation method in this study. The results showed that the clamping force reduced 12 % and the warpage was reduced 26.5 % (from 4.349 mm to 3.194 mm) after optimisation.

Dang [8] in the same year investigated a framework for the optimisation of the processing parameters in an injection moulding process using a hybrid optimisation approach. The specimens with the dimensions of 400 mm x 250 mm x 20 mm and 2.5 mm thickness were moulded using Polypropylene (PP) material. RSM and Radial Basis Function (RBF) were used in this study to optimise warpage. AMI software was used in the simulation studies to simulate the warpage occurred on the moulded parts. The results show that, the warpage was reduced 12.6 % (from 2.93 mm to 2.56 mm) using RSM method and the warpage was reduced 11.6 % (from 2.93 mm to 2.59 mm) using the RBF method.

This study attempts to address the effects of the processing parameters on the warpage of the moulded parts produced using Acrylonitrile Butadiene Styrene (ABS) material. Design of experiment (DOE) with full factorial design and RSM were applied to minimise the warpage on a front panel housing. The significant factors that contribute to warpage were identified from DOE analysis. AMI 2012 was used for simulation studies to obtain the warpage on the moulded parts.

Methodology

Simulation

An injection mould with the dimensions of 200 mm x 200 mm x 200 mm was designed to analyse the front panel housing (Figure 2) using Acrylonitrile Butadiene Styrene (ABS) material with a specification of 80 Tonnage injection moulding machine. Table 1 shows the technical specifications for the injection moulding Nissei, NEX1000 used in this study.

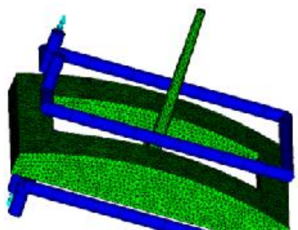

Fig. 2. Meshed model of front panel housing with the gating system and cooling channels.

Table 1. Technical configuration of Nissei NEX1000 [9].

Injection Unit	Screw diameter, mm	28
	Injection capacity, cm^3	69
	Plasticising capacity, kg/hr	28
	Injection pressure, MPa	243
	Packing pressure, MPa	205
Ejection Unit	Clamping force, tf	80
	Clamping stroke, mm	300
	Mould thickness, mm	200 – 385
	Ejector force, tf	2
	Ejector troke, mm	75
Other	Heating capacity,kW	8.36
	Machine dimensions (L x W x H), m	4.19 x 1.12 x 68
	Machine weight, tonne	3.7

Mould and Plastic Materials

In mould material P20 mould steel was used to simulate the analysis whilst mould insert was designed with meshes using 3D mesh and simulated with Cool (FEM) analysis in AMI 2012 software. ABS material, Toyolac manufactured by Toray was used as material for the front panel housing. The properties of plastic and mould materials are shown in Tables 2 and Table 3, respectively.

Table 2. Material properties of a plastic resin [9].

Plastic material	**ABS**
Trade name	Toyolac
Grade	700-314
Supplier	Toray
Mould shrinkage (ASTM D955)	0.4 – 0.6%
No flow melt temperature (^oC)	132
Minimum melt temperature (^oC)	220
Maximum melt temperature (^oC)	240
Minimum mould temperature (^oC)	40
Maximum mould temperature (^oC)	80

Table 3. Properties of P20 mould steel

Properties	**Value**
Mould density, (g/cm^3)	7.8
Mould specific heat (J/kgs)	460
Thermal conductivity, K (w/m^oC)	29
Elastic modulus, E (MPa)	2.0×10^5
Poisson's ratio, υ	0.33
Mould coefficient of thermal expansion (1/C)	1.2×10^{-5}

Design of Experiment

Two levels of full factorial design with four factors was selected as an experimental design in order to estimate the effects of the warpage on the moulded part using Design Expert 7.0 software. The factorial design was carried out to observe the curvature where the second order model was suggested if the curvature was significant. Mould temperature, melt temperature, packing pressure and packing time were four variable factors selected in this study. Table 4 shows the factors and levels for Design of Experiment (DOE).

Table 4. Factors and levels for DOE.

Factors	**Level**	
	Minimum	**Maximum**
Mould temperature, A (°C)	40	80
Melt temperature, B (°C)	220	240
Packing pressure, C (MPa)	30	70
Packing time, D (s)	3	10

Measuring warpage in simulation

Warpage on the front panel housing was measured by spotting on the pre-set coordinates. Table 5 shows the measuring point and coordinate in x and y directions to be measured in AMI 2012 analysis and while Figures 3 and 4 show the measuring points in graphical where warpage is measured from one end to one end. The distance between nodes are shown in Table 5 where shrinkage that lead to warpage was measured in AMI 2012. Inserting the value of nodes (615, 488, 603, 476, 726, 599, 1047, 1447, 867, 1267, 879, 1279) in AMI 2012, the value of shrinkage and warpage was compared after the optimisation method was used.

Table 5. Coordinates of the nodes where x and y direction at specified position on the front panel housing

Dimensions		**Measuring points**	
		From	**To**
Coordinate: x direction	**A**	Node 615 (-72.73, 115.65, -0.05)	Node 488 (47.87, 115.69, -0.05)
	B	Node 603 (-72.73, 77.81, -0.05)	Node 476 (47.87, 77.82, -0.05)
	C	Node 726 (-72.73, 38.65, -0.05)	Node 599 (47.87, 38.73, -0.05)
Coordinate: y direction	**D**	Node 1047 (-70.73, 117.57, -0.05)	Node 1447 (-70.73, 37.17, -0.05)
	E	Node 867 (-12.40, 117.57, -0.05)	Node 1267 (-12.42, 37.17, -0.05)
	F	Node 879 (45.98, 117.57, -0.05)	Node 1279 (45.98, 37.17, -0.05)

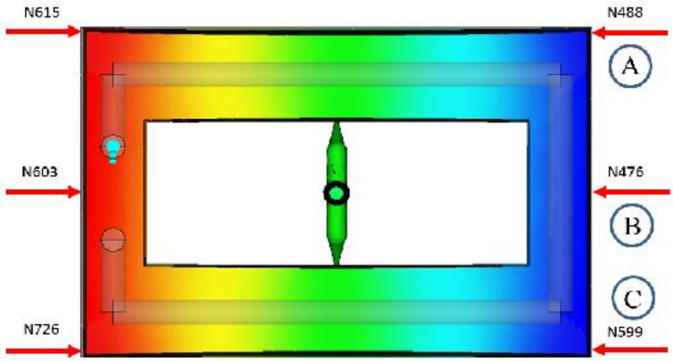

Fig. 3. Measuring points to measure warpage in x direction

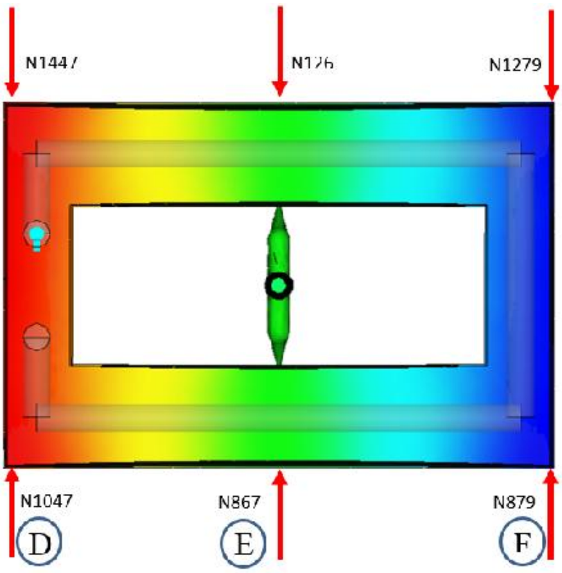

Fig. 4. Measuring points to measure warpage in y direction

Response Surface Methodology

In this study, the curvature has been found as significant, thus the factorial design was augmented to Centred Composite Design (CCD) with alpha, α value is 1 to acceptable quadratic model of the RSM. This type of design is commonly called as face centred CCD. The model is retrieved is based on quadratic model and response model information is gathered by simulation work process [9-13].

The full factorial design was used in CCD with combination of high and low level, which is (+1) for high and (-1) for low level and the midpoint between high and low is based on 8 axial point and 6 central points which is the midpoint between the high and low points. 30 trials of run are generated in this study that is referring to process parameter condition, according to CCD design in order to minimise shrinkage and warpage on the front panel housing. To obtain an optimum value of shrinkage and warpage on the front panel housing, the desired responses is seen as the smaller-the-better characteristic and influence each other relatively [14].

Results and Discussion

Based on Tables 6 and 7, a model "p-value" is very small which less than 0.05 indicated the model is significant effect on the response. As for "F value", it is calculated from the model mean square divided by a residual mean square. It is a test comparing model variance with a residual variance. If the ratio is close to one, the factor may have a significant effect on the response [15]. It can be seen that the simulation studies using DOE show that packing pressure is the main factor influencing to the warpage. The second factor that affected the warpage is melt temperature, follow by mould temperature and then packing time. This result is in line with Chen et al [4] and Berti and Monti [16] who found that the packing pressure have the most contribution that affecting warpage on the moulded parts. The results of warpage on the front panel housing in x and y directions are shown in Table 8.

Table 6. ANOVA of response surface model for x direction

Source	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Block	4.60E-05	4.60E-05			
Model	0.85	0.17	29.77	< 0.0001	significant
B-Melt T	2.22E-03	2.22E-03	0.39	0.5383	
C-PP	0.8	0.8	140.88	< 0.0001	
D-P Time	2.22E-03	2.22E-03	0.39	0.5383	
B^2	0.03	0.03	5.24	0.0316	
D^2	0.039	0.039	6.8	0.0157	
Residual	0.13	5.69E-03			
Lack of Fit	0.12	6.47E-03	3.24	0.1317	not significant
Pure Error	8.00E-03	2.00E-03			
Cor Total	0.98				

Table 7. ANOVA of response surface model for x direction

Source	Sum of Squares	Mean Square	F Value	p-value Prob > F	
Block	3.23E-04	3.23E-04			
Model	0.048	8.01E-03	21.58	< 0.0001	significant
A-Mould Temp	6.72E-04	6.72E-04	1.81	0.192	
B-Melt T	0.021	0.021	55.71	< 0.0001	
C-PP	5.69E-03	5.69E-03	15.33	0.0007	
D-P Time	6.81E-03	6.81E-03	18.34	0.0003	
AD	1.81E-03	1.81E-03	4.87	0.0381	
C^2	0.012	0.012	33.43	< 0.0001	
Residual	8.16E-03	3.71E-04			
Lack of Fit	7.84E-03	4.36E-04	5.45	0.0561	not significant
Pure Error	3.20E-04	8.00E-05			
Cor Total	0.057				

Table 8. Warpage values on the front panel housing from simulation

RUN	A (°C)	B (°C)	C (MPa)	D (s)	Coordinate X	Coordinate Y
1	80	220	30	10.0	0.12	0.35 35
2	60	230	50	6.5	0.11	0.45
3	40	220	70	10.0	0.29	0.34
4	80	220	70	10.0	0.30	0.34
5	40	240	70	3.0	0.37	0.45
6	40	220	30	3.0	0.15	0.42
7	80	240	30	3.0	0.30	0.51
8	60	230	50	6.5	0.15	0.46
9	80	220	30	3.0	0.15	0.41
10	80	240	70	10.0	0.36	0.39
11	40	240	30	3.0	0.02	0.42
12	80	220	70	3.0	0.32	0.40
13	80	240	70	3.0	0.35	0.66
14	40	240	70	10.0	0.33	0.40
15	40	220	30	10.0	0.40	0.37
16	40	220	70	3.0	0.32	0.38
17	60	230	50	6.5	0.15	0.46
18	60	230	50	6.5	0.20	0.46
19	40	240	30	10.0	0.20	0.46
20	80	240	30	10.0	0.10	0.46
21	40	230	50	6.5	0.11	0.44
22	80	230	50	6.5	0.16	0.44
23	60	220	50	6.5	0.10	0.38
24	60	240	50	6.5	0.15	0.48
25	60	230	30	6.5	0.20	0.41
26	60	230	70	6.5	0.33	0.36
27	60	230	50	6.5	0.14	0.48
28	60	230	50	10.0	0.16	0.44
29	60	230	50	6.5	0.15	0.44
30	60	230	50	6.5	0.20	0.44

From the analysis, the determination coefficients, R2 that is fitted to the model is 0.8662 in x direction and 0.8954 in y direction. The adjusted determination for x and y directions are 0.8371 and 0.8356 respectively, indicating that the model is significant with an adequate precision more than 4, which is 12.803 in x direction and 18.157 in y direction. The probability P-value obtained from ANOVA is less than 0.0001 suggesting that the model is significant for both directions. Therefore, from this result, the packing pressure and melt temperature seems to be the most significant factors affecting the warpage on the front panel housing. The polynomial regression model relating to the warpage to all input parameters which are mould temperature (A), melt temperature (B), packing pressure (C), and packing time (D) was established by Design Expert software and represented as Equation 1 in x direction and Equation 2 in y direction.

$$Warpage\ X = 0.40 - 0.011(B) - 0.21(C) + 0.011(D) + 0.093(B^2) - 0.11(D^2) \quad (1)$$

$$Warpage\ Y = 0.44 + 6.111E-003(A) + 0.034(B) - 0.018(C) - 0.019(D) + 8.125E-003(A)(B) - 0.011(A)(D) - 0.056(C^2) + 0.019(D^2) \quad (2)$$

A variable of parameter to be identified and optimised to improve the warpage on the moulded part through the simulation is needed. In this study, Design Expert 7.0 software is selected, utilise the Response Surface Methodology (RSM) technique in order to find the lowest value of warpage based on the polynomial model. This software will identify the significant process parameter that contributed to warpage defects to reduce the defect as low as can. The results of warpage on the front panel housing after optimisation are presented in Table 9.

Table 9. The results of warpage on the front panel housing after optimisation.

Factors		**Optimize parameter setting**
Mould temperature, A (°C)		78.59
Melt temperature, B (°C)		224.45
Packing pressure, C (MPa)		70
Packing time, D (s)		10
Warpage, (mm)	X direction	0.1290
	Y direction	0.3408

Conclusion

In conclusion, warpage can be effectively reduced using optimization tools particularly RSM. The results presented in this show that packing pressure and melt temperature are the two most significant factors affecting the warpage on the front panel housing while, whereas mould temperature and packing time were found to have the least significant in both x and y directions. The warpage on the front panel housing, improved 40.0 % and 23.7 % in x and y directions after the optimization took place.

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