Minimizing Warpage on Injection molding through Response Surface Methodology (RSM)

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Abstract: Cosmetic defects can occur in injection molding. The aim of this study is avoidance of warpage on an injection molding parts. The selected parts is an aesthetics part in automotive industry. This study is conducted on moulded parts on the platting jigs, where warpage cannot be compensated through the fixing of parts on jigs entering platting baths where the temperature of the etching baths is around 65 deg. Analysis of variance is used to determine how inputs affect outputs. The inputs used are mould surface temperature, raw material melting temperature, filling pressure and filling time. These parameters are varied to get an optimal process parameters setting to avoid the warpage of the parts by using response surface methodology. It is very difficult to understand why the warpage on the parts happens. There is lots of factors which can contribute for warpage and to identify them is a huge task and this can be due to numerous things and to sequester the role of each parameters is an uphill task. One of the parameters is the holding pressure which decides how much the part is packed which, in turn, is the cause for the stress in the part. This induced stress when gets relieved over a period of time creates warpage in the part. Warpage can also be dependent on the sequence of filling the part with various gates. For example, if the part is filled from the centre & the end gates are opened last, it may cause over packing of the part at the end & cause more warpage only at the ends locally. However, usually parts are filled in this fashion only to avoid warpage in the centre.

Key words: Molding, Warpage, Parameters, Response surface methodology

1. INTRODUCTION

The use of injection moulding has grown a great deal due to its repeatability and suitability for bulk production and high quality and high accuracy parts with various design and contours can be manufactured. Plastic injection moulding involves 4 stages like refilling, injection, holding and cooling. These four parameters play a vital role in processing of the parts without warpage. Mould temperature determines the flow inside the mould is smooth and trouble free. The melting temperature of the resin improves the filling of the part, packing pressure and time plays a vital role in adding weight after injection and which determines warping of the parts. The packing time is determined based on the warping of the parts inside the mold. The Automotive exterior part which is taken for plating process is used for optimizing through RSM study.

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In this experiment we have considered a three-level full factorial experimental design which is conducted by Finite Element (FE) analysis to combine all these parameters. Result gained through FE investigation by Analysis of Variance(ANOVA) method is considered to be the most effective process variable which controls warpage. S Selvaraj, P. Venkataramaiah [1] had developed the submarine gate and baffle cooling to improve the efficiency of cooling and to avoid degating. The motive of the work carried out by Manoraj Mohan, M.N.M. Ansari & Robert A. Shanks[2] is to find out the strength of molding defects like warpage and shrinkage and to find out the relationship of molding parameters with molding defects based on polypropylene Wen-Chin Chen,Manh-Hung Nguyen, Wen-Hsin Chiu. Tzeng this paper proposes a methodical optimization method to process the processing parameters which are considered are Melt temperature, injection velocity, packing pressure and cooling time. They have considered S/N ratio and Anova to arrive at different process combinations. Mostafa et al. [4] used RSM with real time simulated annealing (SA) to identify the ideal parameters to lessen the warpage and also to reduce in injection molding process the shrinkage on a fuel filter. Li H, Guo Z, Li D (2007) [5] worked on Taguchi method and detailed his findings on the influence of weld lines which affects the strength as well as appearances here he has found melt temperature, injection velocity, and injection pressure are the chief aspects which contribute to weld lines. In 2015, M. Gupta et al. [6] studied RSM and PSO here we can see an approach to find out the actual cause of warpage on an optical mouse made of Acrylonitrile Butadiene Styrene which is analysed by Response Surface Methodology (RSM) and Particle Swarm Optimization (PSO) and identified moulding parameters which can cause the warpage and shrinkage on the final product they are packing pressure, packing time, melt temperature, mould temperature and cooling time and the result confirm that warpage was 0.0043% after the optimization process.

S.Taghizadeh [7] has used artificial neural network to predict the warpage and he has used various moulding parameters which he has varied to estimate the warpage of the parts and he has also utilized Moldflow to simulate the warpage. To save time and cost, the fractional factorial design of experiment is always meant for repeat experiments. This study deals with skill level required for mold making and molding machine control which contributes to rejection in molded parts. Taguchi experiments are used to regulate the optimal process parameters and it is shown that melt temperature is the contributor for warpage on molded part and filling time is not a factor on warpage. He has concluded with prime parameters where there is a chance of reduction of warpage on plastics parts.

Authors have worked adopted...
finite element (FE) based method which gives much more details about the study Kobayashi[9] has FE based backward tracing technique and designed a Pre-form in a shell housing. Joun and Hwang [9] they have worked on a FE based process optimization. S. Kamaruddin, Zahid A. Khan and S. H. Foong.[8] have used Taguchi Method and it is done on how to improve the shrinkage on molded plastic tray by blending PP and LDPE results which are analysed shows a sets of processing parameters which can improve the shrinkage on the molded part and it can influence the quality of the product. Here Taguchi method for design of experiment (DOE), other noteworthy effects such as collaboration among injection molding parameters are also analysed. Wen-Chin Chen [9] Here Taguchi method is used for experimentation and data analysis where the quality criteria are length and warpage. The parameters that are considered are melt temperature, injection velocity, packing pressure, packing time, and cooling time. Parameter combination are got through signal-to-noise (S/N) ratio and analysis of variance (ANOVA). Response surface Methodology is based on datas through experiments. Here the 4 predictors are shared with hybrid GA-PSO to get an optimal process parameters. The results shows a considerable constancy in the molding process in having good acceptable quality of length and warpage. N A Raimee1[10] Application of Response Surface Methodology (RSM) and Genetic Algorithm in Minimizing Warpage on Side Arm, this paper shows the moldflow simulation value along with RSM and GA method shows the minimization of the warpage on the part considered and the five variables such as mould temperature, melt temperature, packing pressure, packing time and cooling time have a effect in arresting the warpage on the part. Babur Ozcelik[11] has done the experiment for reduction of warpage using response surface methodology developing finite element analysis findings. RSM is checked with common boundary between genetic algorithm in order to get the best possible process parameter values. Kurt et al. [12] has used Taguchi orthogonal array experiments, S/N ratio values, analyses of variance (ANOVA), and regression models to seek the optimal parameters. Zhai and Xie [13], Moldflow software was used along with the Taguchi method in the molding to get the optimized process parameters. Öktem [14] has worked with the Moldflow software and also used taguchi and anova to categorize the process parameters which will play a role in avoiding the warpage of the product. Shi et al. [15] is using moldflow software to conduct experiments and to simulate the performance of the experimental values through backpropagation neural network (BPNN) along with Genetic algorithms (GA) here they have used Mold temperature, melt temperature, injection time and injection pressure as the controlling factor where the maximum shear stress is taken the quality representative. Davorin Kramarl1 and Djordje Cica[16] have worked on the mechanical properties of the molded component they have used fuzzy expert systems to predict the breaking force according against the experimental values and they have proved that the accuracy they have achieved is 97.8%. Wei Guo1,*, Lin Hua2, Huajie Mao1 and Zhenghua Meng[17] they have developed a model to predict the warpage through DOE AND CAE they have considered various process parameter which generally contribute to the warpage on the molded part. The findings of the experiment were compared to the practical experiments and deviations were found to be between -0.5203% and 0.8766%, and these experiments can also be taken to other major molding defects. Zeinab Hajiaabolhasani, Yousef Amer, Mehdi Moayyedian[18] here they have taken two distinct ways of Taguchi method, Acrylonitrile Butadiene Styrene (ABS) thin part has been taken to decrease warpage by orthogonal arrays of Taguchi and the Analysis of Variance (ANOVA). Injection pressure (A), packing time (B) and cooling time (C) are considered to be the influencing factors. Response Surface Methodology: Response surface methodology (RSM) is the optimization Tool used mostly between variable parameters which plays a major role in controlling the process in two or three dimensional surfaces. The second order polynomial regression is used to get the mathematical model. RSM is done based on accumulated simulation works which has been carried out.

**Experimental Procedure:**
CATIA software has been used to design the part of the component. The behavior of the part is verified by AUTODESK MOLDFLOW Insight 2012 software. LG MP 220 ABS material is used for this experiment. The part design with respect to runner, gate selection and location and sprue was based on the software and it is seen in Figure 1. The part has 2 cavities with LH/RH and also cooling lines are determined before going for mold making.
In this study, it is decided to analyze 4 process simulations. The first analysis is related to filling the parts which simulation is carried out with the investigation of the four stages goes with the simulation. The basic characteristics of the material used is tabulated in Table 1. Material filling analysis which involves melting temperatures (°C) of ABS MP220 and the surface temperature (°C) of the mold which gives filling time (s), shear rate (1/s) and screw position (mm). The second step is packing (Holding) analysis which also needs melt temperature (°C), mold temperature (°C) and refilling of the screw is also determined (mm) which gives the time for Holding pressure or packing pressure (Mpa). The third step is to analyse the cooling which needs melt temperature (°C), mold temperature (°C) and mold temperature controller which controls the cooling of the mold through water temperature (°C) which provides us the data for fixing of cooling time (s). Moldflow software 2012 has given us some inputs on parameter setting and warpage which is seen in Table 2 and Figure 2.

Table 1: Acrylic Butadiene Styrene LG MP 220

| Properties                  | Test Method | Value         |
|-----------------------------|-------------|---------------|
| Specific Gravity            | ASTM D792   | 1.05          |
| Tensile Strength,3.2mm@yield| ASTM D638   | 450kg/cm²     |
| Melt Rate@220°C/10kg        | ASTM D1238  | 18g/10Min     |
| Molding Shrinkage(Flow),3.2mm| ASTM D955  | 0.4-0.7%      |
| Flexural strength,3.2MM     | ASTM D790   | 760Kg/cm²     |
| Flexural Modulus,3.2MM      | ASTM D790   | 250000Kg/cm²  |
| Tensile Elongation,3.2mm@Yield | ASTM D638 | 40%           |

In reference to various research works being carried out on this subject, it is decided to have 5 variables for this study and which can have a significant effect on warpage of the molded component. The 5 variables are mold temperature (A), melt temperature (B), packing pressure (C), packing time (D) and cooling time (E). It is identified and fixed the ranges of individual factors by calculating with the results which have got by simulation and used through what have been analyzed by cooling time + Injection time + Holding time + warpage study to identify warpage. All these ranges are tabulated in Table 3.

Table 2: Parameter setting as per mold flow analysis

| Process Value | Parameter          |
|---------------|--------------------|
| Raw material Melting temperature (°C) | 220°C |
| Mould surface temperature (°C) | 40-60°C |
| Fill Time (s) | 1.2Sec |
| Injection Rate (mm) | 3.5Sec |
| Filling Time (s) | 2.7Sec |
| Filling Pressure (Mpa) | 164 MPa |
| (V/P) switch over (mm) | 1.773 –80% |
| Warpage in X-direction (mm) | 0.1935mm |
| Warpage in Y-direction (mm) | 0.63mm |
| Warpage in Z-direction (mm) | 0.437mm |

Table 3: Range of variable factors

| Raw material Melting temperature (°C) | 220-240°C |
| Mould surface temperature (°C) | 40-60°C |
| Filling Time (s) | 2.0 – 3.4Sec |
| Filling Pressure (Mpa) | 145 – 164Mpa |
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Cooling time + Injection time + Holding time + warpage study are got through Face centred central composite design (CCD) which is taken from facts of 50 levels of Response Surface Methodology (RSM). There have been significant studies on how warpage behaves and can be controlled by process parameters which will improve warpage. Response Surface Methodology: RSM is done to get the scientific typical function which shows link between the variable and response parameter. RSM also gives indepth knowledge of parameters which directly impact the warpage of the part and it also provides the various processing parameters where the process can be stable. Design Expert 7.0 software is taken for the RSM simulation which conducts 48 runs of experiment through Central composite design (CCD) and the results are shown in TABLE 4.

**TABLE 4: Warpage Results**

| Exp NO | Melt Temp | Mould surface Temp | Filling time | Filling pressure | Warpage in X direction | Warpage in Y direction | Warpage in Z direction |
|--------|-----------|--------------------|--------------|------------------|------------------------|------------------------|------------------------|
| 1      | 220       | 40                 | 2            | 145              | 0.228                  | 0.085                  | 0.352                  |
| 2      | 220       | 40                 | 2            | 164              | 0.228                  | 0.086                  | 0.3526                 |
| 3      | 220       | 40                 | 3.4          | 145              | 0.238                  | 0.098                  | 0.386                  |
| 4      | 220       | 40                 | 3.4          | 164              | 0.238                  | 0.098                  | 0.386                  |
| 5      | 240       | 40                 | 2            | 145              | 0.3107                 | 0.116                  | 0.54                   |
| 6      | 240       | 40                 | 2            | 164              | 0.3107                 | 0.116                  | 0.54                   |
| 7      | 240       | 40                 | 3.4          | 145              | 0.29                   | 0.105                  | 0.515                  |
| 8      | 240       | 40                 | 3.4          | 164              | 0.29                   | 0.105                  | 0.515                  |
| 9      | 220       | 50                 | 2            | 145              | 0.3106                 | 0.0907                 | 0.5345                 |
| 10     | 220       | 50                 | 2            | 164              | 0.3106                 | 0.0907                 | 0.5345                 |
| 11     | 220       | 50                 | 3.4          | 145              | 0.306                  | 0.0945                 | 0.53                   |
| 12     | 220       | 50                 | 3.4          | 164              | 0.306                  | 0.0945                 | 0.53                   |
| 13     | 240       | 50                 | 2            | 145              | 0.404                  | 0.13                   | 0.69                   |
| 14     | 240       | 50                 | 2            | 164              | 0.404                  | 0.13                   | 0.69                   |
| 15     | 240       | 50                 | 3.4          | 145              | 0.393                  | 0.127                  | 0.6753                 |
| 16     | 240       | 50                 | 3.4          | 164              | 0.393                  | 0.127                  | 0.6753                 |
| 17     | 230       | 60                 | 2.65         | 154              | 0.3009                 | 0.1068                 | 0.525                  |
| 18     | 230       | 60                 | 2.65         | 154              | 0.3009                 | 0.1068                 | 0.525                  |
| 19     | 230       | 60                 | 2.65         | 154              | 0.3009                 | 0.1068                 | 0.525                  |
| 20     | 230       | 60                 | 2.65         | 154              | 0.3009                 | 0.1068                 | 0.525                  |
| 21     | 230       | 60                 | 2.65         | 145              | 0.3009                 | 0.1068                 | 0.525                  |
| 22     | 230       | 60                 | 2.65         | 164              | 0.3009                 | 0.108                  | 0.525                  |
| 23     | 230       | 60                 | 2            | 154              | 0.3036                 | 0.1088                 | 0.541                  |
| 24     | 230       | 60                 | 3.4          | 154              | 0.3088                 | 0.101                  | 0.538                  |
| 25     | 220       | 60                 | 2.65         | 154              | 0.299                  | 0.1013                 | 0.48                   |
| 26     | 240       | 60                 | 2.65         | 154              | 0.33                   | 0.12                   | 0.59                   |
| 27     | 230       | 40                 | 2.65         | 154              | 0.29                   | 0.095                  | 0.46                   |
| 28     | 230       | 50                 | 2.65         | 154              | 0.365                  | 0.112                  | 0.63                   |
| 29     | 230       | 60                 | 2.65         | 154              | 0.3009                 | 0.1069                 | 0.526                  |
| 30     | 230       | 60                 | 2.65         | 154              | 0.3009                 | 0.1069                 | 0.526                  |
| 31     | 220       | 40                 | 2            | 145              | 0.228                  | 0.085                  | 0.352                  |
| 32     | 220       | 40                 | 2            | 164              | 0.228                  | 0.086                  | 0.3526                 |
| 33     | 220       | 40                 | 3.4          | 145              | 0.238                  | 0.098                  | 0.386                  |
| 34     | 220       | 40                 | 3.4          | 164              | 0.238                  | 0.098                  | 0.386                  |
| 35     | 240       | 40                 | 2            | 145              | 0.3107                 | 0.116                  | 0.54                   |
| 36     | 240       | 40                 | 2            | 164              | 0.3107                 | 0.116                  | 0.54                   |
| 37     | 240       | 40                 | 3.4          | 145              | 0.29                   | 0.105                  | 0.515                  |
Design Expert software which identified the 4 independent variables filling pressure, MPa (A), Filling time, second (B), MP220 melting temperature, ºC (C), mold surface temperature, ºC (D) Table 4 displays all input parameters for molding automotive parts which is used in Moldflow software to check the warpage (X,Y &Z-Direction).

As shown in Figs. 3 shows the normal residuals the warpage comes down when the packing time is more and the cooling time is kept constant, Figure 4 shows the Surface plot for warpage over the mold temperature and melt temperature which shows the mold temperature plays a major role in determining the warpage of the part. Figure 5 shows the warpage effect by having the optimized process parameters like packing time, packing pressure and cooling time against the melt temperature and mold temperature which will give us a better quality part. Figure 6 shows the warpage which was predicted by mold flow against the RSM where the RSM is seen as a better tool to minimize warpage in the parts produced.

II. RESULTS AND DISCUSSION:
Warpage = +0.93807 - 0.010798A - 0.058651B + 3.54962×10^-3×D + 6.17857×10^-4×AB - 4.45131×10^-5×AD + 4.23941×10^-5×A2

By using the above equation (1) warpage value can be forecasted by using the factors pondered by DOE.

| Direction | Variable Factors | Sum of Squares | Mean Square | F ratio | P value | R-Squared | Model F value |
|-----------|------------------|----------------|-------------|---------|---------|-----------|---------------|
| FP (MPa)  | FT (s)           | 1.203x10^-4    | 1.203x10^-4 | 1.31    | 0.2721  |           |               |
|           | MT (-C)          | 0.019          | 0.029       | 254.98  | < 0.0001|           |               |
|           | MST (-C)         | 0.032          | 0.033       | 354.99  | < 0.0001|           |               |
| y         | FT (s)           | 2.899x10^-7    | 2.899x10^-7 | 0.044   | 0.8344  | 0.9567    | 91.2          |

The equation (1) represents the Significant Factors in which A,B along with D are considered as factors
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The automotive part which is used has to be with lesser warpage so that the gaps is minimum between the mating part and plated part. The parameters are optimized to get the best results in molding. In this we have D-Expert software to get the right combination for processing of the above part and the results of RSM which can help in reducing warpage are tabulated in Table 6.

### Table 6. Optimised Process parameters through RSM

| Data set number | Filling pressure (MPa) | Filling time (s) | Melt temperature (°C) | Mould surface temperature (°C) | Warpage x (mm) | Warpage y (mm) | Warpage z (mm) |
|-----------------|-----------------------|------------------|-----------------------|-----------------------------|----------------|----------------|----------------|
| 1               | 154.2                 | 2.00             | 220                   | 40                          | 0.235467       | 0.08887        | 0.370893       |

### Table 7: Warpage before and After optimisation

|                      | Warpage directions |
|----------------------|--------------------|
|                      | X                  | Y                  | Z                  |
| Moldflow (mm)        | 0.1935             | 0.1667             | 0.437             |
| RSM (mm)             | 0.1840467          | 0.1388             | 0.348             |
| Results in(%)        | 4.88542            | 16.7366            | 20.366            |

Figure 6: Warpage Predicted Vs Actual
III. CONCLUSION:

Based on the studies done earlier most of the process parameters plays vital role in causing warpage. Earlier these parameters were set by virtue of the experience gained through various permutation and combination methods. With introduction of response surface methodology (RSM) setting has become accurate in resulting to less warpage. The warpage is most important quality criteria which will affect aesthetic of the car where it is being fitted after plating. The dimensions are considered for molded as well has the plated part. The motive of this experiment is to reduce the warpage by using parameters which are obtained by mold flow analysis and compared with RSM which gives a better result of 4.88%, 16.73% and 20.366% on X,Y and Z direction which is tabulated in Table7. RSM has given a better result for warpage the value which clearly shows that the experiments carried out will get a better quality for warpage and the process parameters are also identified which is shown in Figure6.

In this work, the study made on the automotive component to correlate the molding process settings parameters which have reduced the warpage of the molded part, where the melting temperature, mould surface temperature, filling Pressure and filling time are the process considerations. We have also used D-Expert software to optimize using Anova and RSM. After optimization the results gave us an Improvement, which is significant. It means that RSM is best suited to avoid warpage on this automotive component.

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