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

Sreedharan.J, C.Manimaran, V.Velumani, Thirumalai Muthusamy

***Abstract:** Cosmetic defects can occur in injection molding. The aim of this study is avoidance of warpage on an injection moulding parts. The selected parts is an aesthetics part in automotive industry This study is conducted on moulded parts on the plating jigs, where warpage cannot be compensated through the fixing of parts on jigs entering plating baths where the temperature of the etching baths is around 65deg.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*

I. 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.

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* Correspondence Author

Sreedharan.J*, Department of Manufacturing Engineering, School of Mechanical Engineering, VIT University, Vellore – 632 014, India.

C.Manimaran, Associate Professor, Department of mechanical Engineering, IFET College of Engineering, Villupuram -605108,India

V.Velumani, Assistant Professor, Department of mechanical Engineering, Sri Nandhanam college of Engineering and Technology, Tirupattur -635601, India.

Thirumalai Muthusamy, Department of Manufacturing Engineering, School of Mechanical Engineering, VIT University, Vellore – 632 014, India.

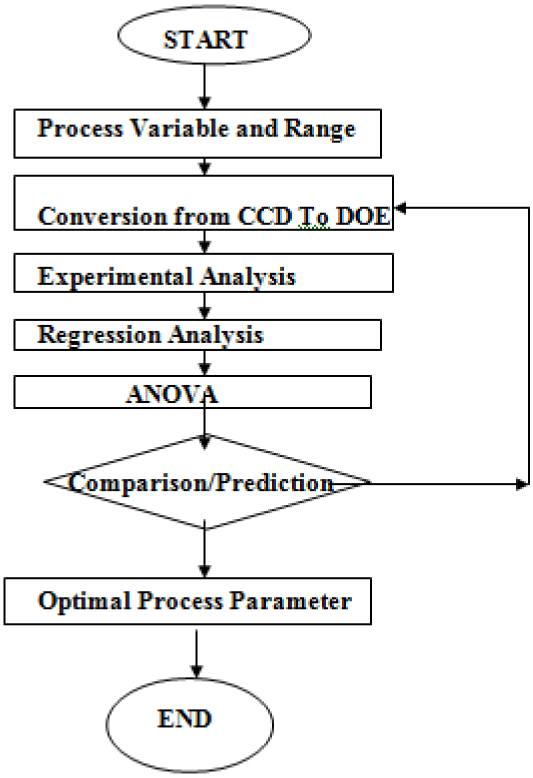
The Automotive exterior part which is taken for plating process is used for optimizing through RSM study. In this experiment we have considered a three-level full factorial experimental design which is conducted by Finite Element (FE) analysis to combine all these parameters.

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 warapage and shrinkage and to find out the relationship of molding paramaters 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 molding 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 molding 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 accepatable 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 alongwith 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 Ozcelik1[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 alonwith 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) alongwith 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 Kramar1 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 achieved against the experimental values and they have proved that the accuaracy 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 Hajiabolhasani,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.

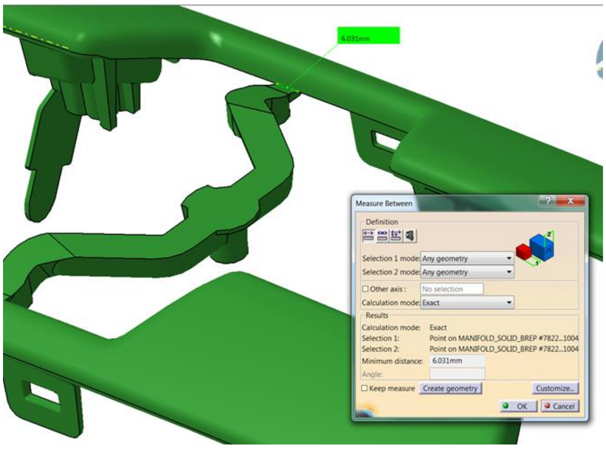


Figure 1. Automotive part with gates

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 (^{0}C) of ABS MP220 and the surface temperature (^{0}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 (^{0}C), mold temperature (^{0}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 (^{0}C), mold temperature (^{0}C) and mold temperature controller which controls the cooling of the mold through water temperature (^{0}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.

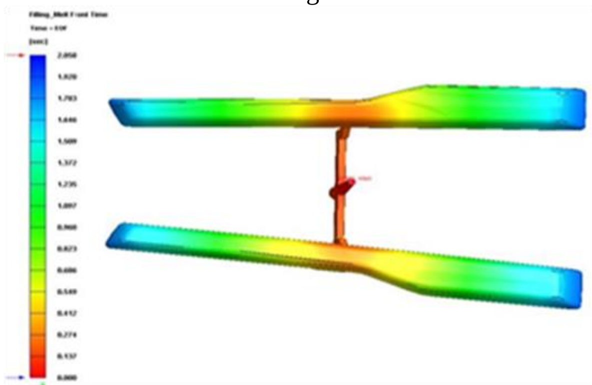


Figure 2 : Warpage y direction from mold flow

TABLE1: 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 Flow Rate@220C/10kg	ASTM D1238	18g/10Min
Molding Shrinkage(Flow),3.2mm	ASTM D955	0.4- 0.7%
Flexural strength,3.2MM	ASTMD790	760Kg/cm²
Flexural Modulus,3.2MM	ASTM D790	25000Kg/cm²
Tensile Elongation,3.2mm@Yield	ASTM D638	40%

TABLE 2. Parameter setting as per mold flow analysis

Process Parameter	**Value**
Raw material Melting temperature (°C)	220°C
Mould Surface temperature (°C)	50°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

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 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

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 48runs of experiment through Central composite design (CCD) and the results are shown in TABLE4

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

38	240	40	3.4	164	0.29	0.105	0.515
39	220	50	2	145	0.3106	0.0907	0.5345
40	220	50	2	164	0.3106	0.0907	0.5345
41	220	50	3.4	145	0.306	0.0945	0.53
42	220	50	3.4	164	0.306	0.0945	0.53
43	240	50	2	145	0.404	0.13	0.69
44	240	50	2	164	0.404	0.13	0.69
45	240	50	3.4	145	0.393	0.127	0.6753
46	240	50	3.4	164	0.393	0.127	0.6753
47	230	60	2.65	154	0.3009	0.1068	0.525
48	230	60	2.65	154	0.3009	0.1068	0.525
49	230	60	2.65	154	0.3009	0.1068	0.525
50	230	60	2.65	154	0.3009	0.1068	0.525

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.

ANOVA table and AMI software are found to be good to analyse the results of warpage. The ANOVA normally preferred to condense the output of warpage the result of Automotive component is shown in Table 5. "Prob. >F" value higher than 0.05 is not considered so significant in respect to warpage and shall be deleted[3]. To this model Backward elimination process is used to figure out the non important parameters and can be adjusted with the quadratic model for warpage.In this situation, C, D, E, AC, BE, DE are significant model terms. These are considered to be important significant model terms. These dynamics are significant and which has affected the warpage of the automotive component. In this study, an resourceful optimization methodology using RSM was familiarized to minimize warpage produced by injection molding.In this we have used Automotive component was used in order to reduce the warpage on the injection molded part which is being carried on for chrome plating where the final part has to be assembled to the vehicle where the aesthetic is much more important.

The equation (1) represents the Significant Factors in which A,B along with D are considered as factors

II. RESULTS AND DISCUSSION:

$$Warpage = +0.93807 - 0.010798A - 0.058651B + 3.54962 \times 103 \times D + 6.17857 \times 104 \times AB - 4.45131 \times 105 \times AD + 4.23941 \times 105 \times A2$$

s------ 1

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

TABLE 5: Warpage Results by Anova

Direction	Variable Factors	Sum of Squares	Mean square	F ratio	P value	R-Squared	Model F value
x	FP (MPa)	Reject				0.9564	104.85
	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	FP (MPa)	Reject				0.9567	91.2
	FT (s)	2.899x10 -7	2.899x10 -7	0.044	0.8344		

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	MT (◦C)	3.088x10-3	3.088x10-3	466.95	< 0.0001		
	MST (◦C)	4.674x10 -4	4.674x10 -4	71.94	< 0.0001		
	FP (MPa)	Reject					
	FT (s)	6.440x10 -5	6.440x10 -5	0.65	0.4402		
	MT (◦C)	0.11	0.11	1000.92	< 0.0001		
z	MST (◦C)	0.11	0.11	1149	< 0.0001	0.979	540.966

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 o (C)	Mould surface Temperature o (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

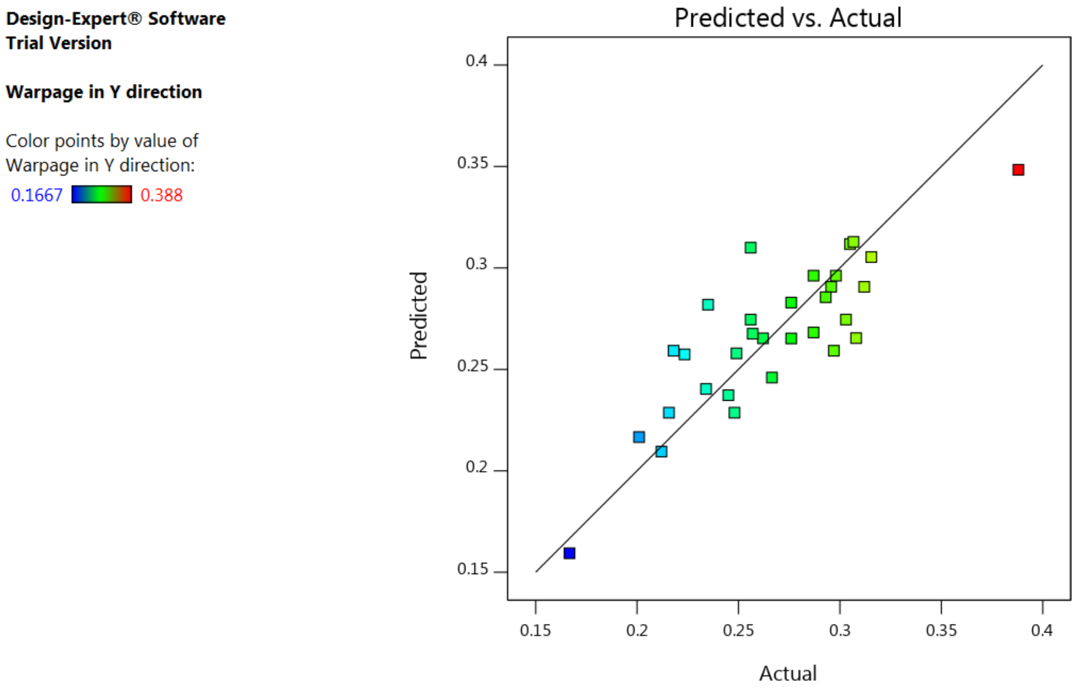

Figure 6:Warpage Predicted Vs Actual

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 aesthique 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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