Optimization of process parameters of PIM process using DOE technique Taguchi

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Abstract— This paper studies the effect of process parameters like melt temperature, mold temperature, injection pressure and packing pressure on product quality responses like fill time of cavity and volumetric shrinkage of indoor desert cooler fins. First part of this study is to develop a experimental methodology using design of experiment (DOE) technique, in this section taguchi methods are used for four factors having four levels. Second part is developing FEM simulation using MFA software provided by Autodesk Company. Main results are based on S/ N ratio and ANOVA analysis. It is found that most critical parameter in this study is melt temperature and less effective parameter is packing pressure. Model equations are also developed in this study.

Index Terms— MFA, DOE, taguchi methods, ANOVA, Model Equations.

I. INTRODUCTION

The substitute of materials in the assemblies of product has originated from improved performance, weight reduction; cost reduction, visual appeal etc. Plastic injection molding is a common process in most of the plastic parts while a plastic injection mold, whose design is an integral part of plastic injection molding, is a high precision tool for the mass production of plastic parts in the industries like electronics, automotive and medical sector and so on. However, costly tooling and machinery are needed in this manufacturing process. There are two main components that are required in plastic injection molding .The one is plastic injection-molding machine and another is injection mold. The plastic injection-molding machine allows the mold to be mounted on it and provides the mechanism for molten plastic transfer from the machine to the mold, clamping the mold by application of pressure and ejection of the formed plastic part. On the other hand, the injection mold is a tool for transforming the molten plastic into the final shape and dimensions of the plastic part. It's obvious from the present market condition that advanced technology has led to the production of new designs for the consumers but its creating a crisis for the supply of plastic parts for future generation .At present injection molds are designed, manufactured and tested based mainly on the experience level of the mold designers, machinists and other personnel. Although some form of standardization had been used in the mold making industries through the use of standardized components in the mold design, much of the design process is still considered an "art" that requires experience and thus the final design varies between mold designers. The plastic industry is growing faster replacing the several traditional materials in every industry which offers many advantages over traditional materials with higher production rates, complex geometries, high strength to weight ratio, flexibility in design, less wastage, recyclability etc. For example: Fiberglass structural components are being used more and more in the transportation industry, because of their tremendous strength-to-weight properties and impressive design flexibility to large extent. Due to its high strength, lightweight and its electrical insulating properties, plastic is used widely in appliances, tools and other machinery. Additionally, corrosion resistant plastic like glass fiber reinforced tanks and pipes offer extended service life over metals.

II. NUMERICAL SIMULATION

Autodesk Simulation Moldflow (2014), MFA is a complete suite of definitive tools for simulating, analyzing, optimizing and validating plastics part and mold designs in plastics injection molding. MFA address the broadest range of manufacturing issues and design geometry types associated with plastics molding processes. Thus, MFA can work to reduce or eliminate time delays, improve part quality, and deliver projects within budget constraints. With MFA analysis modules, filling, packing, and cooling stages of the plastic, the injection molding process can be simulated. MFA also predict post-molding phenomena such as shrinkage sink mark, air trap, weld line, and war page of the products. In addition, MFA offers an expanded material database, which includes over 9300 unique plastic materials for use in plastic injection molding process simulation software in order to ensure that users have access to the highest quality material data for plastic simulation.

A. Steps follow by software

Step 1: Import a CAD model, which was previously created in any design software. In this thesis Auto-desk Inventor 2014 was used for this step.

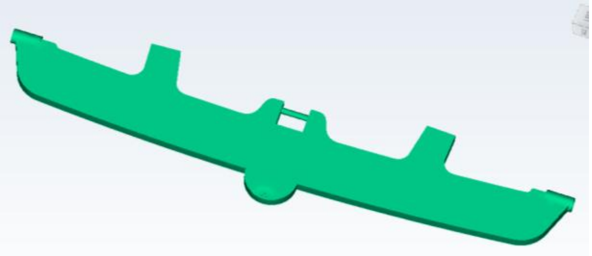

Fig. 1 Geometry made by Autodesk Inventor

Step 2: Mesh the CAD model.

MFA software is easy to mesh automatically using triangular elements to cover the model surface with least distortion. This is an important step.

Step 3: Material Selection: Genric PP

Step 4 Simulation type selections

Step 5 Process parameters selection

1. Melt Temperature

2. Mold Temperature

3. Injection Speed

4. Packing Pressure

5. Runner Type

Step 7 Results

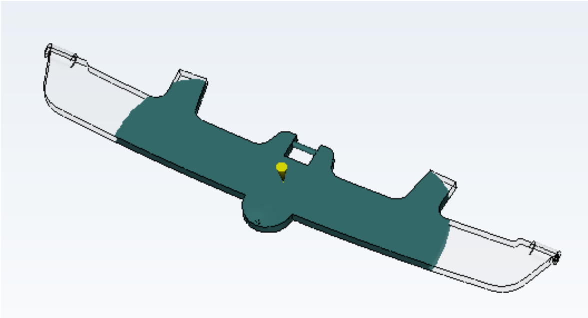

Fig. 2 Cavity Fill Time in Second

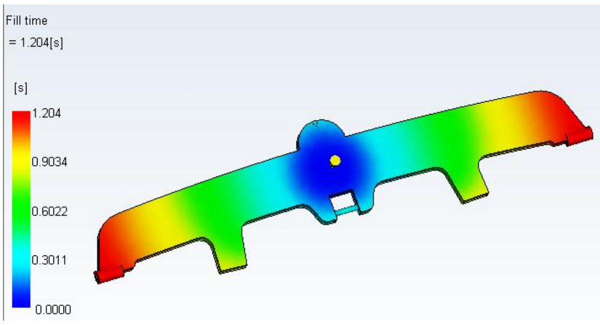

Fig. 3 Fill Time

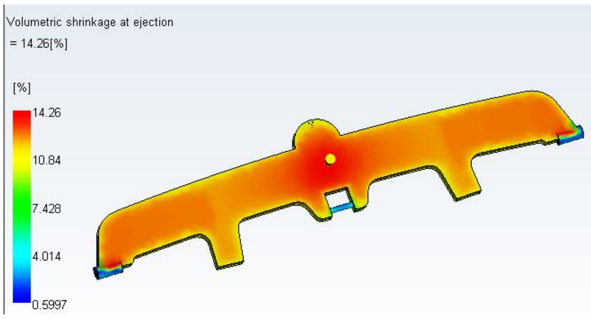

Fig. 4 Volumetric Shrinkage

III. PROBLEM DESCRIPTION

The problem focused in this study was to apply CAE methods in plastic injection molding process to improve productivity of thick plastic products. In this study four controlling factors named mold temperature, melt temperature, injection pressure, and packing pressure were used with four levels and taguchi tables were used for design of experiment.

IV. DESIGN OF EXPERIMENT METHODOLOGY

The product quality made from plastic injection molding process is always affected by its process parameters like injection pressure, injection speed, mold temperature, melt temperature, packing pressure, packing time, cooling time and many more. The effects of these parameters were studied by various researchers from last decades. It was very difficult to design, experiments for any type of research and here a scientific approach is helpful for researchers which is known as "DESIGN OF EXPERIMENT". This technique was adopted by researcher for this study. By use of DOE techniques any researcher can determine important factors which are responsible for output result variation of experiments. DOE can found optimum solution for particular experiments.

V. FACTORS AND LEVELS

Design of DOE table was only possible by selection of proper factors and their levels. In this study five factors were selected with three levels for each product and were shown in table 1.

Table 1: Summary table of Factors and Levels for used product

Levels	P1 (Mold Temp)	P2 (Melt Temp)	P3 Injection Pr	P4 (Packing Pr. MPa).
1	35	245	60	35
2	40	250	70	40
3	45	255	80	45
4	50	260	90	50

Outcome parameters for this study were fill time and volumetric shrinkage (%) shown in below table 2. After selection of factors and levels for current study it was important to select accurate orthogonal array and for this task MINITAB software was used for making of orthogonal array of factors and their levels.

VI. RESULT AND DISCUSSION

Single cavity plastic injection molding process was simulated in this study for desert cooler fins. Autodesk mold flow adviser ultimate FEM package was used for simulation purpose. All experiments were designed according to DOE technique (Taguchi orthogonal array table), which were discussed in table 2. Main outcomes focused in this were following:

Fill Time

Volumetric Shrinkage

Analysis of variance (ANOVA)

Signal to noise ratio was simple method to predict the effect of changing of factors according their levels to find effect on product quality. In this study "smaller is better" was adopted as quality indicator for S/N ratio.

The response tables for both design cases were shown in table 3 and table 4 respectively. S/N ratio gives best combination of input parameters for both cases.

Table 2: L16 orthogonal Array for used product

S. No.	**Mold Temp**	**Melt Temp**	**Injection Pr.**	**Packing Pr.**	**Shrinkage**	**Fill time**
1	35	245	60	35	14.26	1.204
2	35	250	70	40	14.49	1.206
3	35	255	80	45	14.98	1.088
4	35	260	90	50	14.96	1.089
5	40	245	70	45	14.41	1.204
6	40	250	60	50	14.94	1.206
7	40	255	90	35	15.05	1.087
8	40	260	80	40	15.03	1.089
9	45	245	80	50	14.54	1.204
10	45	250	90	45	14.8	1.206
11	45	255	60	40	15.4	1.208
12	45	260	70	35	15.13	1.089
13	50	245	90	40	14.71	1.324
14	50	250	80	35	14.85	1.206
15	50	255	70	50	14.99	1.207
16	50	260	60	45	15.11	1.211

From table 3 it is concluded that melt temperature is most important parameter whereas packing pressure is less important parameter. On the basis of mean ratio it is concluded that it also showed same results like S/N ratio.

Table 3 The response table for S/N ratio

Levels	(Mold Temp)	(Melt Temp)	(Inj. Pr.)	(Packing Pr.)
1.	-20.34	-20.24	-20.49	-20.43
2.	-20.45	-20.41	-20.39	-20.48
3.	-20.52	-20.60	-20.45	-20.44
4.	-20.49	-20.57	-20.47	-20.46
Delta	0.17	0.36	0.10	.05
Rank	2	1	3	4

Table 4 The response table for mean ratio

Levels	(Mold Temp)	(Melt Temp)	(Inj. Pr.)	(Packing Pr.)
1	7.910	7.857	8.067	7.985
2	8.002	7.988	7.966	8.057
3	8.072	8.126	7.998	8.001
4	8.076	8.088	8.028	8.017
Delta	**0.166**	**0.269**	**0.102**	**0.073**
Rank	**2**	**1**	**3**	**4**

Response table for plastic product were show that input Parameter melting temperature, was most critical responsible parameter for shrinkage and fill time outcomes. Rank was also show based on response table. Most critical parameter was melting temperature whereas less important parameter was packing pressure because level values were high and show no effect in product quality variation. Figure 3 and 4 show graphical presentation of S/N ration and also show best cases for all experiments.

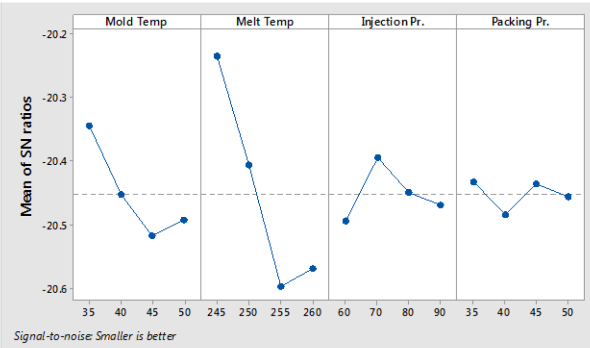

Fig. 5 S/N ratio

Although S/N ratio was good approach to find optimum combination of input parameters but for verification means based study was also show in this study and response figure based on means

Best Case: A1-B1-C2-D1 (S/N ratio)

Best Case: A4-B3-C1-D2 (mean ratio)

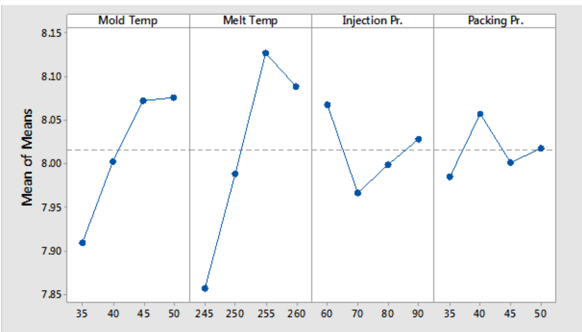

Fig. 6 mean ratio

VII. ANOVA ANALYSIS

The analysis of variance was calculated for plastic product and results were shown in table 5 to table 6 respectively. In ANOVA analysis F-Test was conduct to compare a model variance with a residual variance. F value was calculated from a model mean square divided by residual mean square value. If f value was approaching to one means both variances were same, according F value highest was best to find critical input parameter.

Table 5 ANOVA result for vol. shrinkage

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.99575	0.248936	7.38	0.004
Mold Temp	1	0.14028	0.140281	4.16	0.066
Melt Temp	1	0.85491	0.854911	25.33	0.000
Injection Pr.	1	0.00045	0.000451	0.01	0.910
Packing Pr.	1	0.00010	0.000101	0.00	0.957
Error	11	0.37120	0.033745		
Total	15	1.36694			

Table 6 ANOVA result for fill time

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.054150	0.013537	9.75	0.001
Mold Temp	1	0.018120	0.018120	13.05	0.004
Melt Temp	1	0.032321	0.032321	23.27	0.001
Injection Pr.	1	0.002977	0.002977	2.14	0.171
Packing Pr.	1	0.000732	0.000732	0.53	0.483
Error	11	0.015279	0.001389		
Total	15	0.069429			

From literature review various researchers found that if p value was very small (less than 0.05) then the terms in the regression model have a significant effect to the responses.

Table 5 to table 6 list out one important result that F value for regression models were very high (table 5 F value was7.38, and like table 9 f value was 9.7) than one and P value were very less (approx 0.0000) suggested that all cases were significant.

VIII. MODEL EQUATIONS:

Fill Time

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Regression Equation

Fill time = 2.991 + 0.00602 Mold Temp - 0.00804 Melt Temp - 0.001220 Injection Pr.
            + 0.00121 Packing Pr.
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Vol. Shrinkage

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Regression Equation

Skrinkage = 3.72 + 0.01675 Mold Temp + 0.04135 Melt Temp - 0.00047 Injection Pr.
            + 0.00045 Packing Pr.
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Normal Probability Graphs

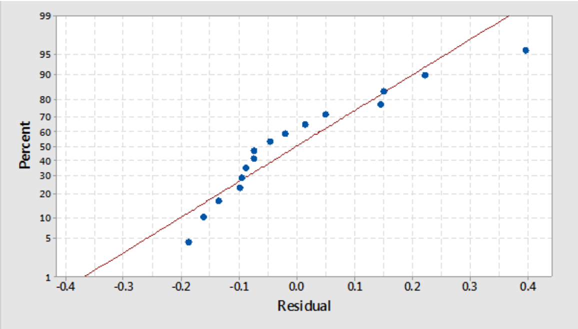

Fig. 7 Normal Probability Graphs for shrinkage

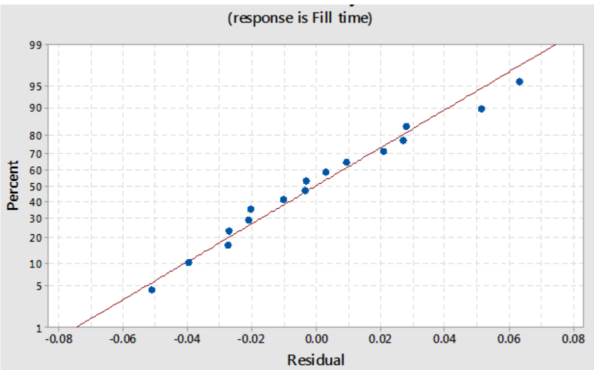

Fig. 8 Normal Probability Graphs for Fill time

IX. CONCLUSION

The aim of this study is to strike balance among response efficiency and FEM simulation results for mold flow plastic injection process. This study utilizes L16 orthogonal array for data analysis for plastic product. In this study Analysis of variance (ANOVA), and regression analysis was main key techniques to show response and factor relations strongly with each other. Main results are summarized as follows:

Best case for this study

Best Case: A1-B1-C2-D1 (S/N ratio)

Best Case: A4-B3-C1-D2 (mean ratio)

ANOVA results indicate that the injection pressure, melt temperature were most significant factors for volumetric shrinkage for product. Like that for fill time melt temperature and injection pressure were most critical factors for product. mold temperature and injection speed was most critical factors.

Model equations for fill time and shrinkage was predict accurately with Minitab software and show 90% good prediction for responses and can be used by any plastic injection molding process manufacturer.

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