Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2016, 3(1): 5-11

Research Article ISSN: 2394 - 658X

An Experimental Study of Parameters on Plastic Product using Mold Flow Simulation-ANOVA Based Analysis

Amber Batwara[1] and Pankaj Sharma[2]

Department of Mechanical Engineering, Poornima Collage of Engineering, Jaipur, India
amberbatwara@gmail.com

ABSTRACT

This paper deals with the application computer aided engineering integrating with statistical technique to reduce the fill time variation depends on injection molding process parameters. Injection molding is one of the most exploited industrial processes in the production of plastic parts. Fill Time behavior of molded plastic part plays an important role in determining the final dimensions of part. Input parameters play an important role of quality of plastic parts. In this work input parameter melt temperature, mold temperature, injection speed and packing pressure to control fill time as response of injection molded parts to improve the quality of plastic part. In this study Mold Flow Advisor (MFA) is used to study & verify the effect to process parameters and optimize the fill time. Optimization of process parameters done using design of experiments (DOE) and analysis of variance (ANOVA) optimum combination of process parameter is governed by signals to noise (S/N) ratio and analysis of variance (ANOVA) and using the fuzzy logic approach .

Key words: Injection molding, DOE, ANOVA, model equation, fuzzy logic

INTRODUCTION

The injection molding is an important manufacturing process to polymers; it provided high dimensional products with low manufacturing cycles and low costs. The most widely used technique for fabricating thermoplastic materials is “Plastic Injection Molding” which is a rate production process and has great dimensional controls. The plastic injection molding process is cyclic process which consists of three stages. These stages are tilling and packing stage, cooling stage and ejection stage [1]. The process parameter like till time, packing parameter, injection speed, mold temperature etc. is the greatest importance because it significantly affects the productivity and the quality of final product. Plastic Injection Molding is one of the most important methods for forming thin-shell plastic products. It has many advantages such as short product cycle. High quality part surfaces good mechanical properties and light weight.

The process of PIM can be described:-

- Polymer materials heated up to melting temperature and melted polymer is injected into the cavity by a gate under high pressure.
- When filling is about to complete, the cavity is kept at a constant pressure for the packing pressure.
- In order to fill the remaining volume of the cavity and to reduce the shrinkage due to cooling the packing pressure is used extensively, the plastic is extruded from mold once the inner cavity is of stable case [2].

Recently computer aided engineering (CAE) has been successfully used in the simulation of the injection molding process it provided designers with visual and numerical feedback of the part behaviour and eliminates the traditional trial and error approach for optimization. MFA methodology is used to solve the problem is presented. This also covers step-by-step procedure adopted for developing a model of plastic specimen and other details of Mold Flow Adviser.

The simulation models of the plastic specimen were created with mesh geometry by MFA 2014 and run for the results. In this study a common material was selected for product making and selection was based on purely literature review and market research and material name was Polypropylene (PP). Trade name was Globalene.

Required material properties were Specific Heat (Cp) (3100 J/kg C), Elastic Modulus (1340 MPa), Poisson's Ratio (0.392), Shear Modulus (481.3 MPa), Melt Temperature (254.5), Density 0.899 g/cm3, Thermal Conductivity (0.17 W/m-c), Resin Identification Code 5, Energy Use Indicator 3.

In this study a product is used for analysis. Product is simple circular rod used in various areas shown in Fig. 1 and Fig. 2 show sprue location in product.

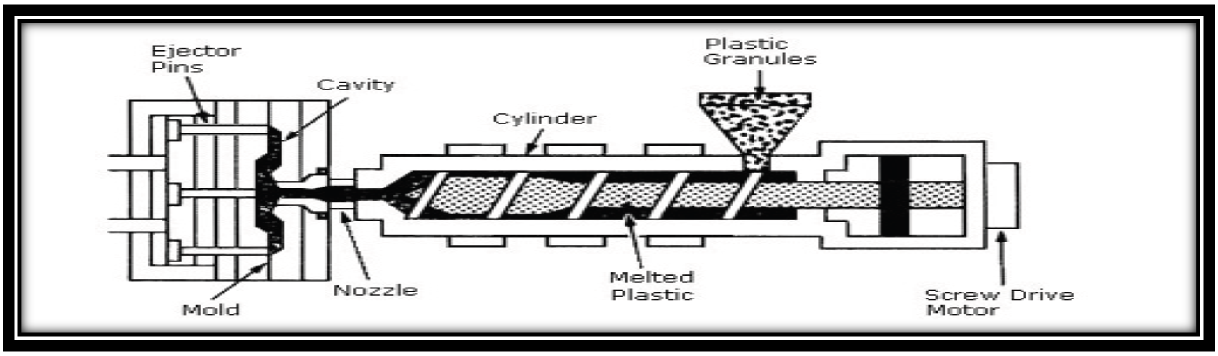

Fig. 1 Plastic Injection Molding Machine

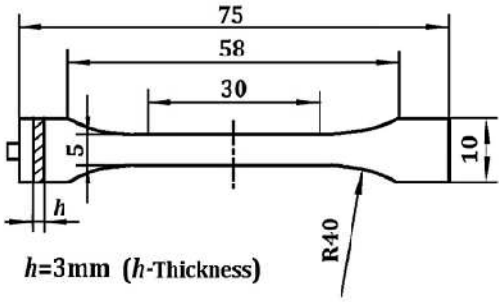

Fig. 2 Cross sectional area of casting product

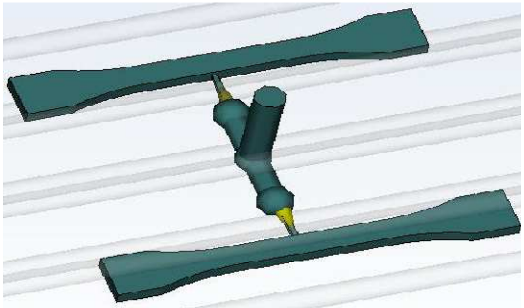

Fig. 3 Sprue Location in product

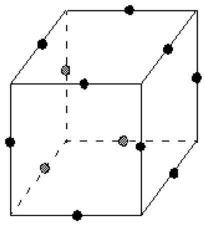

Fig. 4 Design methodology of Box Behnken methodology

DESIGN OF EXPERIMENT

It was R.A Fisher who at first introduced DOE in 1920 in England. It's a powerful statistical technique which assists in studying multiple variables and in maximization of learning using a minimum of resources. Redundant observations are eliminated and the time is reduced thus proving it to be a strong tool to design and analyze the experiments and a cost effective method as well. The analysis of experiments sorts out the queries like analysis of optimum condition, contribution of factors and quantity and expectancy regarding the results etc. It leads a series of tests with purposeful changes to observe and identify the reasons of changes in output. DOE highlights the important causes and variables with determination of main effects reducing the variation and cost reduction for the opening up the tolerance on unimportant variables [8].

Box-Behnken Design methodology is used for experiment generation using Minitab software. Box-Behnken designs have treatment combinations that are at the midpoints of the edges of the experimental space and require at least three factors. In this study four factors are suitably used for numerical simulation. The illustration below shows a four-factor Box-Behnken design. Points on the diagram represent the experimental runs that are performed. This design can also prove useful if user know the safe operating zone for its process. Box-Behnken designs do not have axial points, thus, user can be sure that all design points fall within its safe operating zone. Box-Behnken designs also ensure that all factors are never set at their high levels simultaneously. Table -1 shows their factors and low /medium/high limit for design of experiment

Factor and levels

This design process is done in Minitab software and summary of results are shown below. In table 2 all experiments are shown. [Factors: 4, Replicates: 1, Base runs: 27, Total runs: 27, Base blocks: 1, Total blocks: 1, Centre points: 3]

Table -1 Factor and Their Levels for Surface Response Design

level	A Melt Temperature	B Mold Temperature	C Injection Speed	D Packing Pressure
Low	310	115	65	40
Medium	320	125	75	45
High	330	135	85	50

Table -2 Box-Behnken Design Table

Std. Order	Run Order	Pt Type	Blocks	Melt Temperature	Mold Temperature	Injection Speed	Packing Pressure
14	1	2	1	320	135	65	45
9	2	2	1	310	125	75	40
21	3	2	1	320	115	75	40
22	4	2	1	320	135	75	40
16	5	2	1	320	135	85	45
3	6	2	1	310	135	75	45
2	7	2	1	330	115	75	45
5	8	2	1	320	125	65	40
12	9	2	1	330	125	75	50
6	10	2	1	320	125	85	40
27	11	0	1	320	125	75	45
26	12	0	1	320	125	75	45
7	13	2	1	320	125	65	50
4	14	2	1	330	135	75	45
23	15	2	1	320	115	75	50
24	16	2	1	320	135	75	50
10	17	2	1	330	125	75	40
18	18	2	1	330	125	65	45
13	19	2	1	320	115	65	45
15	20	2	1	320	115	85	45
20	21	2	1	330	125	85	45
17	22	2	1	310	125	65	45
8	23	2	1	320	125	85	50
19	24	2	1	310	125	85	45
11	25	2	1	310	125	75	50
1	26	2	1	310	115	75	45
25	27	0	1	320	125	75	45

Table -3 Response Results for All Design Points

Std. Order	Run Order	Pt Type	Blocks	Melt Temp.	Mold Temp.	Injection Speed	Packing Pressure	Fill Time
14	1	2	1	320	135	65	45	1.65015
9	2	2	1	310	125	75	40	1.72025
21	3	2	1	320	115	75	40	1.81065
22	4	2	1	320	135	75	40	1.51650
16	5	2	1	320	135	85	45	2.81000
3	6	2	1	310	135	75	45	1.57545
2	7	2	1	330	115	75	45	1.83226
5	8	2	1	320	125	65	40	1.88995
12	9	2	1	330	125	75	50	1.68445
6	10	2	1	320	125	85	40	1.52535
27	11	0	1	320	125	75	45	1.69385
26	12	0	1	320	125	75	45	1.68885
7	13	2	1	320	125	65	50	1.85635
4	14	2	1	330	135	75	45	1.65025
23	15	2	1	320	115	75	50	1.88105
24	16	2	1	320	135	75	50	1.48905
10	17	2	1	330	125	75	40	1.63005
18	18	2	1	330	125	65	45	1.85055
13	19	2	1	320	115	65	45	2.06015
15	20	2	1	320	115	85	45	1.70755
20	21	2	1	330	125	85	45	1.44295
17	22	2	1	310	125	65	45	1.99875
8	23	2	1	320	125	85	50	1.50775
19	24	2	1	310	125	85	45	1.59415
11	25	2	1	310	125	75	50	1.74765
1	26	2	1	310	115	75	45	1.96745
25	27	0	1	320	125	75	45	1.69985

MOLD FLOW ADVISER MODELLING

Mold Flow Advisor is software consisting of definitive tools to simulate, analyze, optimize and validate plastic parts and mold designs in plastics injection molding. According to Autodesk Simulation Mold flow (2014), MFA addresses the broadest range of manufacturing issues and design geometry types associated with plastics molding processes [6].

There are three stages of the simulation in MFA software. The first stage of a Finite Element (FE) method based simulation is called "pre-process". There are two ways of performing the pre process. The first method for performing this process is by using the simulation software itself and the second method being the usage of one of the Computer-Aided Design (CAD), computer programs such as Inventor, and Auto-cad. The geometric model is then meshed using triangular mesh elements (fixed). Then, the injection locations are set after the desired plastic polymer is selected. It is required to set the process conditions into the simulation software to finish the first stage. "Post-process" is the last stage of simulation. In this, the multiple colour contour results are studied and the most reliable and important information is extracted with the help of the experience of the analysis. Pre-process is very important for the efficiency of the simulation model. Hence, it must be thoroughly analyzed on the part geometry and its conditions as described in the following section.

In past when numerical approach was not available to solve these type problems, it was very difficult for engineers to analysis flow field conditions. Today with the help of MFA it is very easy to analysis complex plastic problems All input parameters were decided according to literature data. These input parameters are given at primary stage of simulation. A residual criterion for simulation is also important because it controls the errors in simulation. In most of the research papers steady state simulation has been done, however in this case unsteady state simulation has been done. In this section all experiments generated by DOE technique is numerically solved by MFA software and response fill time is solved numerical for all design points and are shown in table3.

RESULT AND DISCUSSION

All experiments were designed according to DOE technique (Box-Behnken design), which were presented in table 2 and MFA modelling results in term of fill time is presented in table 3.Main outcomes focused in this study are following: [ANOVA Analysis, Signal to noise ratios analysis, Model equations generation and fuzzy logic approach].

Signal to Noise Ratio

Signal to noise ratio is simple technique to predict the effect of changing of factors according to their levels to find effect on product quality. In this study "smaller is better" option is adopted as quality indicator for S/N ratio and means ratio. The response tables for S/N ratio and mean are presented in table 4 and table 5. Tables 4 & 5 show factors importance ranking and it is clear that mold temperature and injection speed is most important factor. Best and worst cases from experiment factors and their levels are also presented in this study and were calculated from Fig. 5 and Fig. 6.

Table -4 Response Table for Signal to Noise Ratio

level	A Melt Temperature	B Mold Temperature	C Injection Speed	D Packing Pressure
Low	-4.909	-5.451	-5.482	-4.488
Medium	-4.976	-4.588	-4.621	-5.143
High	-4.486	-4.783	-4.682	-4.544
Delta	0.490	0.863	0.861	0.656
Rank	**4**	**1**	**2**	**3**

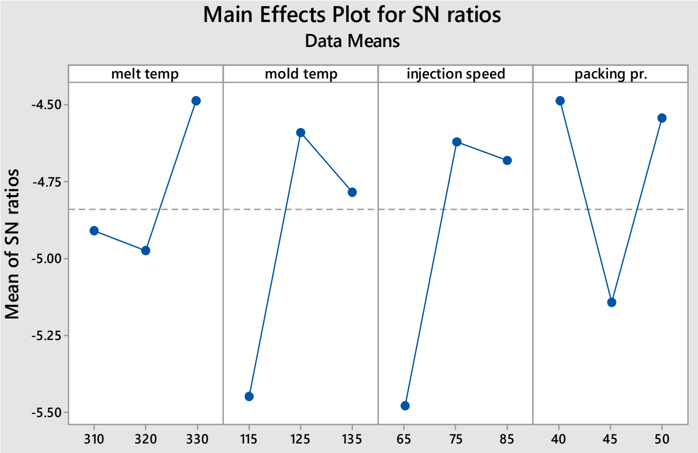

Fig. 5 Data Means for smaller is better for S/N Ratios
[Best Case: 330, 125, 75, 40 Worse Case: 320 115 65 45]

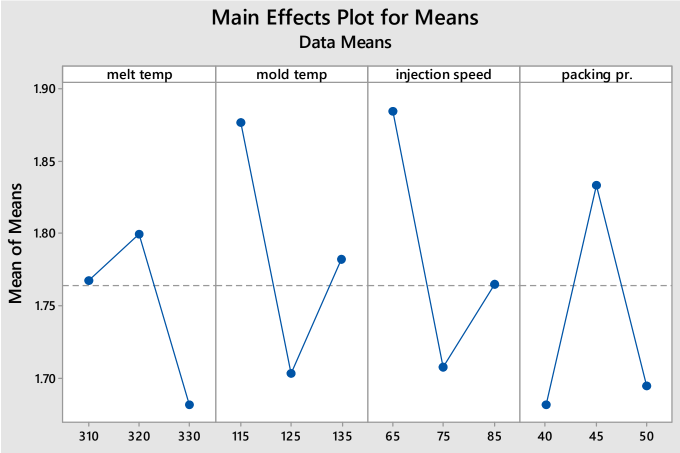

Fig. 6 Data Means for Mean Ratios
[Best case: 330, 125, 75, 40 Worse Case: 320 115 65 45]

Table -5 Response Table for Mean Ratio

level	A Melt Temperature	B Mold Temperature	C Injection Speed	D Packing Pressure
Low	1.767	1.877	1.884	1.682
Medium	1.800	1.703	1.708	1.833
High	1.682	1.782	1.765	1.694
Delta	0.118	0.173	0.177	0.151
Rank	**4**	**2**	**1**	**3**

ANOVA Analysis

The analysis of variance is calculated for this study and results are shown in table 6 respectively. In ANOVA analysis F-Test is 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.

ANOVA analysis is also tell that mold temperature and injection pressure has very low p value than other factor like melt temperature and packing pressure, All four factors in which only two factor have acceptable p value so it can concluded that fill time are affected by mainly two factor, this ANOVA analysis is linear single factor analysis, multi product ANOVA analysis can show more accurate results, which are presented in table 7, but not show good agreement for this study. Model equations for fill time are presented in below and ANOVA analysis with model equations.

Table -6 Analysis of Variance for Mass Fraction

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	0.09223	0.023058	0.29	0.880
Packing Pressure	1	0.00045	0.000451	0.01	0.940
Injection Speed	1	0.04298	0.042978	0.55	0.468
Mold Temperature	1	0.02686	0.026857	0.34	0.565
Melt Temperature	1	0.02195	0.021947	0.28	0.603
Error	22	1.73488	0.078858		
Lack of Fit	20	1.73481	0.086741	2859.59	0.000
Pure Error	2	0.00006	0.000030		
Total	26	1.82711			

Table-7 Different Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.11	2.94	1.40	0.176	
Packing Pressure	0.0012	0.0162	0.08	0.940	1.00
Injection Speed	-0.00598	0.00811	-0.74	0.468	1.00
Mold Temperature	-0.00473	0.00811	-0.58	0.0565	1.00
Melt Temperature	-0.00428	0.00811	-0.53	0.603	1.00

Model Equation -Regression Equation

Fill Time = 4.11 + 0.0012 packing pressure. - 0.00598 injection speed - 0.00473 mold temp. -0.00428 melt temp.

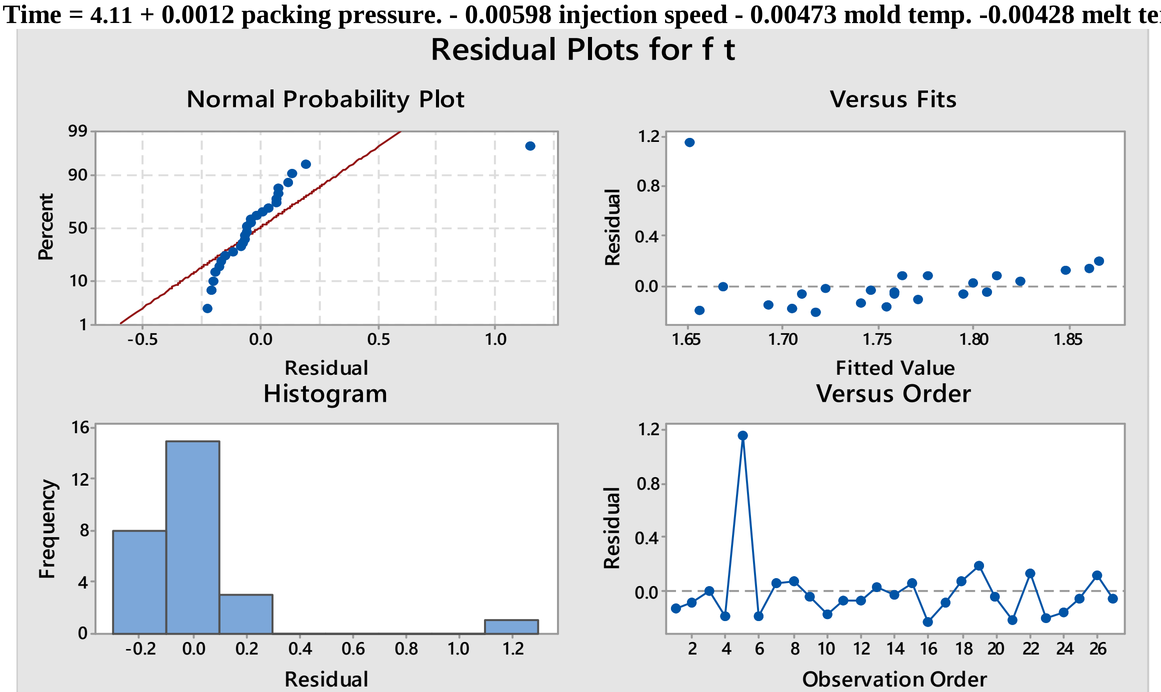

Fig.7 Normal probability for Fill Time

The adequacy of regression models shall be inspected to confirm that the all models have extracted all relevant information from all simulated cases. If regression equations results were adequate, than the distribution of residuals should be normal distribution.

For normality test, the Hypotheses are listed below -

- Null Hypothesis: the residual data should follow normal distribution
- Alternative Hypothesis: the residual data does not follow a normal distribution Normal probability for all responses were shown in Fig.7.

Fuzzy Logic Approach

Fuzzy logic is a standard of mapping classical sets and fuzzy sets to the functions. A fuzzy set is well-defined as a set with degree of memberships. Thus, it provides means to model the uncertainty and the lack of information. Fuzzy logic is applied as a suitable role in thinking a rule-based and linguistic control strategy of industrial process control. Fuzzy logic theory is adaptable and wide-spread used in Industrial Engineering.

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without a crisp, clearly defined boundary for input and output. It can contain elements with only a partial degree of membership. Fuzzy Inference System (FIS) of input and output set A membership function (MF) is a triangular that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the universe of discourse, a fancy name for a simple concept.

Membership function: nA membership function (MF) is a triangular that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the universe of discourse, a fancy name for a simple concept. The membership function of mold temperature shown in below:-

[Input1]
Name='melt_temp' Range=[305 335] NumMFs=3
MF1='low':'trimf',[305 310 315] MF2='medium':'trimf',[315 320 325] MF3='high':'trimf',[325 330 335]
[Input2]
Name='mold_temp' Range=[110 140] NumMFs=3
MF1='low':'trimf',[110 115 120] MF2='medium':'trimf',[120 125 130] MF3='high':'trimf',[130 135 140]
[Input3]
Name='injection speed' Range=[60 90] NumMFs=3
MF1='low':'trimf',[60 65 70] MF2='medium':'trimf',[70 75 80] MF3='high':'trimf',[80 85 90]
[Input4]
Name='packing pressure' Range=[35 55] NumMFs=3
MF1='low':'trimf',[35 40 45] MF2='medium':'trimf',[40 45 50] MF3='high':'trimf',[45 50 55]
[Output1]
Name='fill time' Range= [1.2 3.6] NumMFs=4
MF1='low':'trimf',[1.2 1.4 1.6] MF2='medium':'trimf',[1.6 1.7 1.8] MF3='high':'trimf',[1.8 1.9 2]
MF4='very_high':'trimf',[2 2.8 3.6]

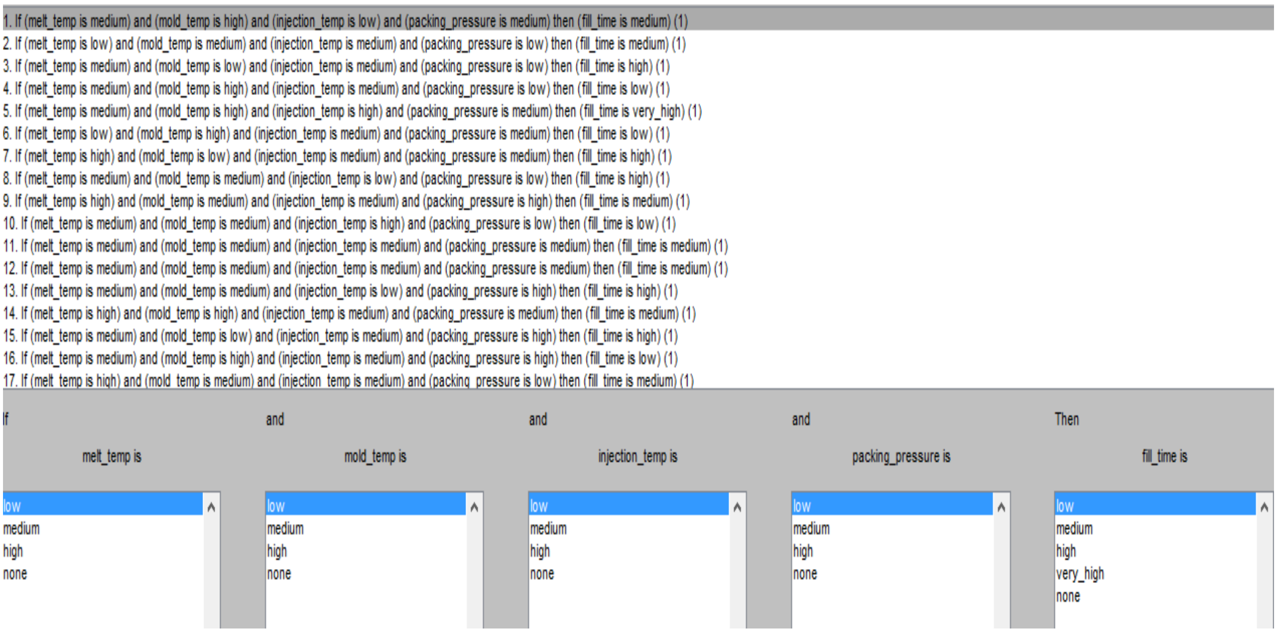

Fig.8. Fuzzy logic rules in FIS

Rule Viewer: To view the fuzzy inference diagram. Use this viewer as a diagnostic to see, for fill time, which rules are active individual membership function shapes influence the results.

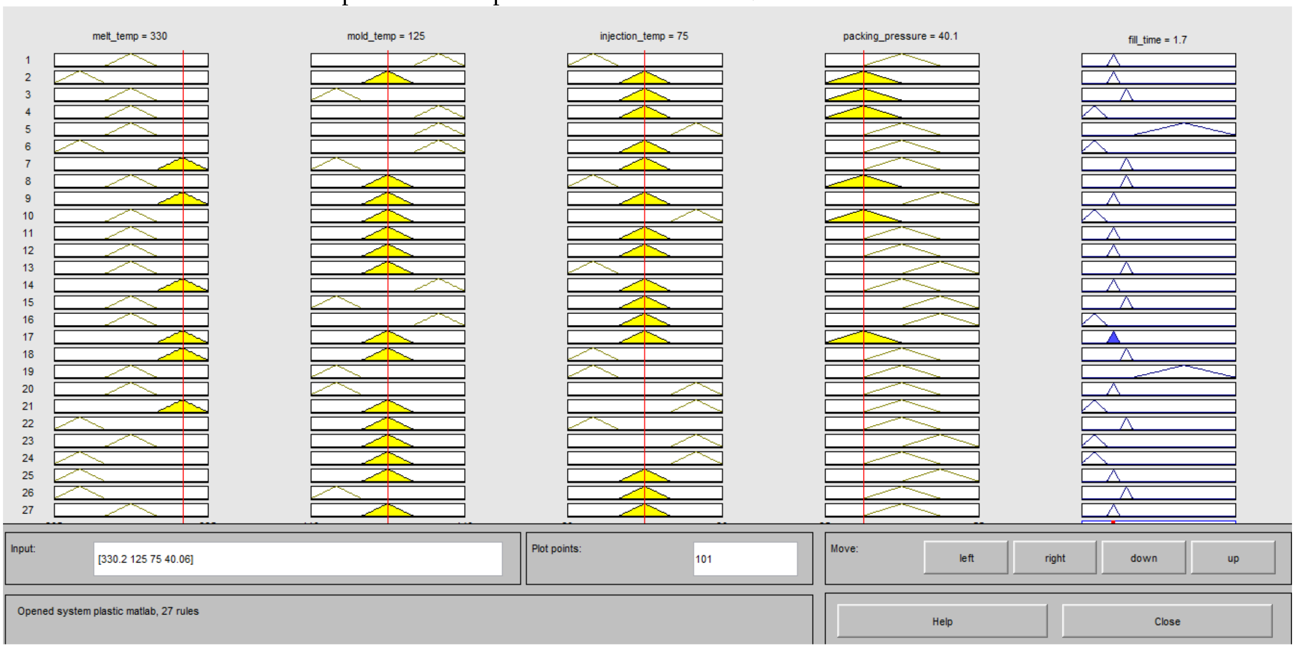

Fig.9. Fuzzy logic rules result

CONCLUSION

Plastic injection molding is numerically solved by MFA software. Design of experiment is used as tool in this study to find better results. Main outcome form this study is following

- Signal to noise ratio analysis is performed in this study and the final conclusion from this test is that injection speed and mold temperature play important role in fill time of melt material properly. Cooling rate is assumed constant in this study.
- Best and worst cases are solved in this study and presented with values in this section (Only S/N ratio based cases are presented) Best Case: 330, 125, 75, and 40 Worse Case: 320, 115, 65, and 45.

Using the fuzzy logic approach also we find the best case 330, 125, 75, 40.

- ANOVA analysis is performed in this study and with the help of regression modelling general modelling equation is generated for future application in casting industry which is working in this parameter range.

Model equation generated in this study is following -

Fill Time= 4.11 + 0.0012 packing pressure- 0.00598 injection speed - 0.00473 mold temp. -0.00428 melt temp.

REFERENCES

[1] Ching-Piao Chen, Ming-Tsan Chuang, Yun-Hsiang Hsiao, Yung-Kuang Yang and Chih-Hung Tsai, Simulation and Experimental Study in Determining Injection Molding Process Parameters for Thin-Shell Plastic Parts Via Design of Experiments Analysis, *Expert Systems with Applications* , **2009,** 36 , 10752–10759.

[2] MC Huang and CC Tai, The Effective Factors in the Warpage Problem of an Injection-Molded Part with a Thin Shell Feature, *Journal of Materials Processing Technology*, **2001,** 110, 1–9.

[3] MD Azaman, SM Sapuan, S Sulaiman, ES Zainudin and A Khalina, Shrinkages and Warpage in the Process Ability of Wood-Filled Polypropylene Composite Thin-Walled Parts Formed by Injection Molding, *Journal of Material and Design*, **2013**, 52, 1018-1026.

[4] PK Bharti and MI Khan, Recent Methods for Optimization of Plastic Injection Molding Process- A Retrospective and Literature Review, *International Journal of Engineering Science and Technology*, **2010,** 2, 4540-4554.

[5] Bozdana A Tolga and Eyercioglu Omer, Development of an Expert System for the Determination of Injection Moulding Parameters of Thermoplastic Materials: EX-PIMM, *Journal of Materials Processing Technology*, **2002,** 128, 113-122.

[6] B J Vikas and R Chandra Kumar, Influence of Feeding System in Injection Moulding for Lower Washer of a Bearing, *International Journal of Engineering And Technology*, **2013,** 2, 396-399.

[7] Chen Ching-Piao, Chuang Ming-Tsan, Hsiao Yun-Hsiang, Yang Yung-Kuang and Tsai Chih-Hung, Simulation and Experimental Study in Determining Injection Molding Process Parameters for Thin-Shell Plastic Parts Via Design Of Experiments Analysis, *Journal of Expert Systems with Applications*, **2009,** 36, 10752-10759.

[8] LM Galantucci and R Spina, Evaluation of Filling Conditions of Injection Moulding by Integrating Numerical Simulations and Experimental Tests, *Journal of Materials Processing Technology*, **2003,** 141, 260-275.

[9] Hamdy Hassan, Nicolas Regnier, Cyril Pujos, Eric Arquis and Guy Defaye, Modeling the Effect of Cooling System on the Shrinkage and Temperature of the Polymer by Injection Molding, *Applied Thermal Engineering*, **2010** , 30 ,1547-1557.