Experimentation and Optimization of injection moulding process parameter through Taguchi method and Mould flow analysis

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Abstract— *Injection moulding is a manufacturing process in which the molten plastic is inserted into a cavity called as mould. Material for the part is fed through hopper into a heated barrel, mixed, and forced into a mould cavity, where it cools and hardens to the configuration of the cavity. In this project Taguchi method is used for Optimization of Injection moulding process parameter. The experiments conducted by using Injection moulding De-Tech100 machine with material Kaiffa PBT 302 G0 used. S/N ratio is used to find the optimum combination of process parameters and importance of each parameter is known by performing ANOVA analysis. The last important aim was to find the effect of Injection pressure, Injection speed, screw speed and cooling time on injection moulding process. The injection moulding process parameters are also optimized using Mould flow analysis using mould flow advisor Autodesk. The main conclusion drawn from this project is that most of rejections are due to short filling which can be minimized by setting the all these parameters at high level.*

Keywords: *Plastic Injection moulding, Taguchi method, S/N ratio, ANOVA, Creo 2.0, Mould flow analysis.*

I. INTRODUCTION

Injection moulding is a manufacturing operation in which molten plastic is inserted into a cavity called as mould. The molten plastic is injected into a mould bodily cavity to form the desirable shape. The different shaped plastic parts can be manufactured using injection moulding process. The plastic material is fed through hopper which flows from heated barrel and forced into mould cavity where it solidifies and gains shape of mould cavity. The different moulds are made by the design engineers according to the product design the mould are made by toolmakers from metal, mostly made from steel or aluminium. The mould may be of single or multiple cavities. Injection moulding can be achieved with large numbers of materials, like metals, elastomers thermoplastics and thermosetting plastics.

Injection moulding machine is mainly formed with two basic parts Injection unit and clamping unit. Injection unit melts the plastic and Inserts into mould cavity. Clamping unit clams the mould together which opens and closes it automatically and ejects the finished part.

II. PROBLEM STATEMENT

Industries using injection moulding process for production of plastic components are facing difficulty related to complete shape filling that is mould filling.

It is expected that the optimization of process parameters reduce shape filling problem. The various process variables considered for present study are injection pressure, injection speed, holding pressure, screw speed, nozzle temperature, cooling time.

III. LITERATURE SURVEY

The literature review shows the use of methods and parameters for Injection moulding process parameter optimization. [1] Nik mizamzul mehal & shahrul kamaruddin[2011] investigated the effect of injection moulding process parameters on mechanical properties of lrecycled plastic component and performed an experiment using mouldflow plastic insight integrated method with L 18 Taguchi [OA]. By adopting L9 Taguchi OA the parts is manufactured using from recycled plastics were produced by injection moulding and they found that the most significant factor is melt temperature. [2] Nik Mizamzul Mehat and shahrul kamaruddin [2011] Determined the optimal processing parameters using combination of single response through Taguchi approach and this study uses the S/N ratio approach to mortal the experimental results in individual effect. Bigger the better quality characteristic is adopted, for the flexural modulus and flexural strength. ANOVA is conducted to investigate the parameter affecting quality characteristics.[3]Manoraj Mohan, M.N.M. Ansari & Robert A. shanks[2016] studied the shrinkage and warpage phenomena which is associated with the temperature and pressure and reviewed the influential processing parameters on the post-molded strengths, shrinkage and warpage of injection moulded parts using L8 OA Taguchi approach and S/N ratio and concluded mould temperature and packing pressure are most significant for shrinkage and warpage, cooling time and packing time are less significant, melt temperature and injection pressure are secondary.[4]Yiyo kuo, Taho Yang and Guan-wei huang[2008] used grey based Taguchi method for simulation optimization to solve a multi-response simulation-optimization problem.[5] Shi W. Lee & Seokyoung Ahn[2011] In these paper Taguchi method is applied effectively to study the difference and similarities among plastic injection moulding, metal injection moulding and ceramic injection moulding.[6] M. Packianathera, F. Chan[2013]presented the optimization of micro injection moulding process through DoE and Taguchi method. The DoE was used to identify the factors that were active and significant to study and fractional factorial experiment with Taguchi quality concepts has been conducted. And hence optimal setting found for the MIM process. [7] Daniele Annicchiarico & Jeffrey R. Alcock (2014) In this paper author reviwed the factors affecting shrinkage of moulded parts in injection moulding. He used selective screening of 10 papers published in last 10 years and organized it according to material, parameter, mould, specific Design, and found the critical processing parameters were temperature, packing pressure, cooling time, injection speed, temperature and packing pressure resulted critical factors at microscale. [8] B. KC, O. Faruk, J.A.M. Agnelli [2015] Presented an application of Taguchi method to optimize injection moulding process parameters of sigal/glass fiber hybrid composites. For experimentatin, L18 orthogonal array with a mixed-level design and signal-to-noise (S/N) of smaller-the-better was used. Optimal combination IM parameters were determined and the significant variables were identified using ANOVA. [9] Gurjeet Singh ,Ajay Verma [2017] Reviewed a brief information on injection moulding manufacturing processes and the different methodology's used for various parameters.[10] M.H. Othman, S. Hasan & S.Z. Khamis (2017) controlled the quality characteristics like shrinkage and warpage and selected parameters were packing pressure, barrel temperature, screw speed and filling time. The process was performed based on the orthogonal array from Taguchi optimization method resulted in reduction in rejection due to warpage and shrinkage.

IV. METHODOLOGY

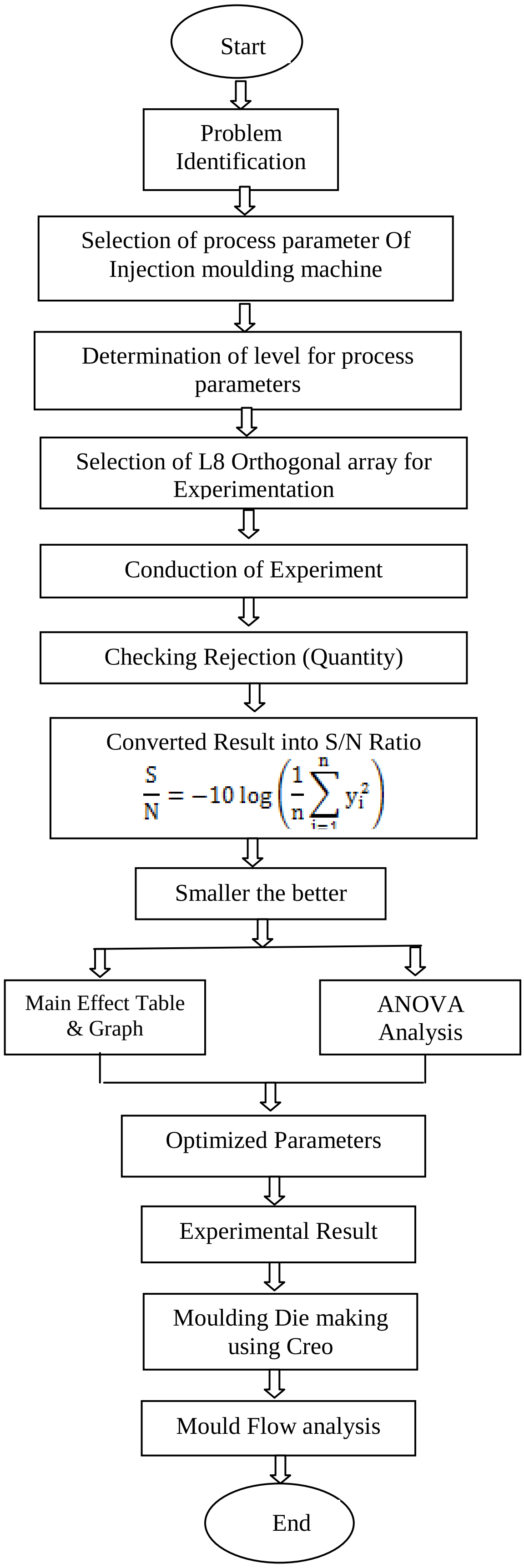

Fig.1 Methodology Flow chart

V. TAGUCHI APROACH

The Taguchi methods are statistical tool defined by Genichi Taguchi to better the quality of manufacturing goods. It is utilised to optimise the process parameters and better the quality of components that are factory-made. The Taguchi method can be well explained using block diagram. Taguchi realized that the first possibility to rid of variation of the last outcome quality is through the product design stage and its manufacturing procedure. He established a plan of action for quality technology that can be utilised in both settings. The activity levels as follows 1) System design, 2) Parameter (standard) design, and 3) Tolerance design. System design is theoretical level, connecting creativeness and innovation. Parameter design: When the concept is accepted, the nominal values of the different measurements and design parameters appeal to be set, the detail design phase of conventional engineering. Taguchi method is important representation which gives perfect choice of variables needful is under-specified by the operation need of that system. In many condition, this allows the factor to be chosen so as to decrease the effects on performance originate from fluctuation in industry, surroundings and cumulative damage. This is also called as robustification. Factor can show controllable and intense noise variant; they desire to feat relation between optimize settings that decrease the effects of the noise variables. Tolerance design with a with success complected factor design and an apprehension of the outcome that the diverse factor have on performance, resources can be focussed on reduction and dominant fluctuation in the critical few dimensions.

A. SIGNAL-TO-NOISES (S/N) RATIO:

Taguchi tool uses the signal-to-noise (S/N) ratio. The S/N ratio show normal and change of the quality characteristics .The S/N ratio is a standard of demonstration intention at processing good and processes unreactive to noise factors. The standard S/N ratio used in three ways: Nominal is best (NB), lower the better (LB) and higher the better (HB). The lower value of short moulding behavior is predictable in this study. Characteristics used in S/N ratio is smaller-is-better functional in the analysis which is shown in table IX and can be calculated by using,

Smaller-is-the-better (minimize)

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$$

VI. EXPERIMENTAL CONDITION AND PLANNING OF EXPERIMENT:

The Experimental work is carried out with the help of De-Tech100 Injection moulding machine as shown in the figure 2 and the technical specifications for the machine are shown in Table 1

Fig.2: Experimental Setup

Table I

Technical Specification of Injection Moulding

Sr. No.	Description	Unit	D-100
INJECTION UNIT			
1	Screw Diameter	mm	35
2	Plasticising Capacity	Kg/Hr	90
3	Shot Volume	cm3	145
4	Shot Wight (PS)	Gram	90
5	Injection Pressure	Kg/cm2	2000
6	Injection Stroke	mm	150
7	Injection Rate	cm3/sec.	75
8	Screw Revolution	Rpm	150
9	Nozzle Stroke	mm	250
10	Nozzle Holding Force	Ton	5
11	Heating Zones	Nos.	5
12	Screw L/D Ratio	-	1:20
CLAMPING UNIT			
13	Mould Clamping force	Ton	100
14	Mould Opening Stroke	mm	400
15	Min. Mould	mm	250

	Height		
16	Max. Mould Height	mm	550
17	Max. Day Light	mm	550
18	Distance Between	mm	400*400
19	Mould Platen Size h x w	mm	405*405
20	Ejector Stroke	mm	200
21	Ejector Force (hyd.)	Ton	2.5
ELECTRIC DEVICES			
22	Pump Motor	kw/hp	33
23	Heater	kw/hp	1.5 kw into 4 zone
24	Total Electrical Power	kw/hp	50 kw
GENERAL			
26	Machine Weight	Ton	100
27	Machine Size (LxWxH)	Mtr.	1200*2400*1500

A. Product Information

Name of Product: capacitor box
Raw material used: Kaiffa PBT 302 G0 BLU
Mould ID:- Capacitor box
Application of Capacitor box:- 1) This product is used in electronic circuits. 2) Tape recorders, 3) Mother Board 4) Printers 5) Scanners 6) Televisions.
Manufacturing method of product:- Injection moulding.

B. Material Used In Experimentation

The material used for the experimentation is Kaiffa PBT 302 G0 BLU and following are the properties of the given material.

Table II
Properties of material Kaiffa PBT 302:

Sr. No.	Physical Properties	Metric
1	Density	1.40 g/cc
2	Water Absorption	0.001
3	Linear Mold Shrinkage	0.014 - 0.020 cm/cm
	Mechanical Properties	Metric
4	Tensile Strength at Break	45.0 MPa
5	Flexural Strength	80.0 MPa
6	Flexural Modulus	2.50 GPa
7	Izod Impact, Notched	0.280 J/cm
8	Charpy Impact Unnotched	2.50 J/cm²
9	Charpy Impact, Notched	0.300 J/cm²
	Electrical Properties	Metric
10	Volume Resistivity	1.00e+16 ohm-cm
11	Dielectric Constant	Frequency 1e Ohm-cm
12	Dielectric Strength	20.0 kV/mm
13	Dissipation Factor	0.02

D. Selection of process parameter and their levels

According to literature review and Injection moulding machine the Identified process parameters are as follows: Injection pressure, Injection speed, Holding time, holding pressure, screw speed, Nozzle temperature, cooling time etc.

Table III
Process parameter Identified are as follows

NO.	Process parameter	Symbol
1	Injection pressure	A
2	Injection speed	B
3	Holding time	C
4	Holding pressure	D
5	Screw speed	E
6	Nozzle temperature	F
7	Cooling time	G

C. Computer Aided (Creo) Model:

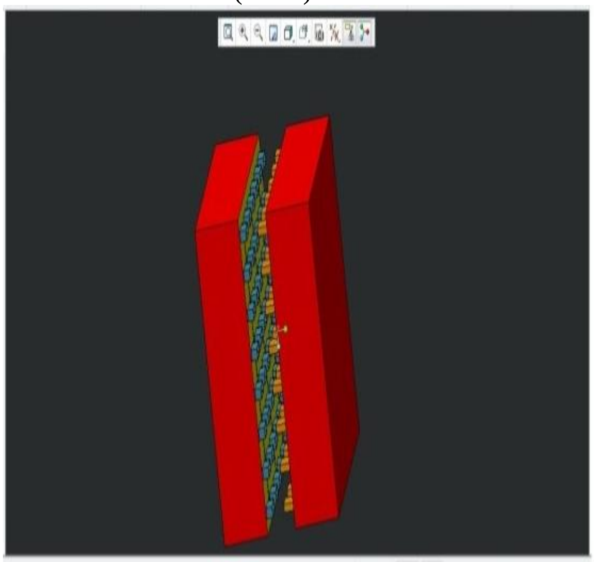

Fig.3 assembly showing core and cavity of die and capacitor box

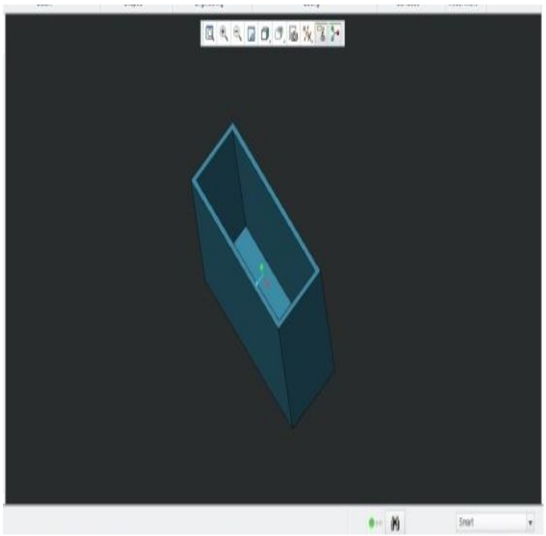

Fig.4 Capacitor Box (creo) model

Fig.3 and Fig.4 showing the creo model of injection moulding die assembly with gating for material injection which is used for mould flow analysis.

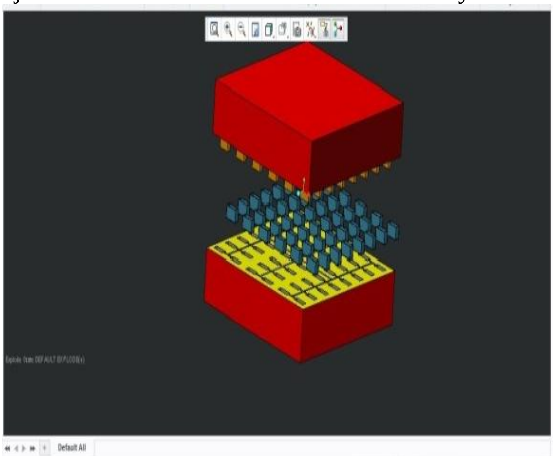

Fig. 5 Exploded view of mould and plastic part

E. P-B Design for Experimentation:

The screening designs elaborated by R. L. Plackett and J. P. Burman. And hence the name Plackett-Burman (P-B) designs. The P-B designs are based on Hadmard matrices in which the number of experimental runs or trials is multiple of four. I.e. N=4, 8, 12…, etc.

Table IV
8 Run Geometric P-B Design for the Experiment.

Sr.No.	A	B	C	D	E	F	G
1	+1	-1	-1	+1	-1	+1	+1
2	+1	+1	-1	-1	+1	-1	+1
3	+1	+1	+1	-1	-1	+1	-1
4	-1	+1	+1	+1	-1	-1	+1
5	+1	-1	+1	+1	+1	-1	-1
6	-1	+1	-1	+1	+1	1	-1
7	-1	-1	+1	-1	+1	+1	+1
8	-1	-1	-1	-1	-1	-1	-1

Table V
Process parameters and their levels for Experimentation

No.	Processing parameters	Unit	Levels	
			LOW(-1)	HIGH(+1)
1	Injection pressure	Bar	960	1000
2	Injection speed	cm3/sec	53	60
3	Holding time	sec	0.1	0.4
4	Holding pressure	Bar	50	400
5	Screw speed	rpm	25	35
6	Nozzle temperature	0C	255	275
7	Cooling time	sec	3	5

Table VI
Experimental Result 8 Run Geometric P-B Design

No	A	B	C	D	E	F	G	R1	R2
1	1000	53	0.10	400	25	275	5	185	99
2	1000	60	0.10	50	35	255	5	410	410
3	1000	60	0.40	50	25	275	3	410	410
4	960	60	0.40	400	25	255	5	2	0
5	1000	53	0.40	400	35	255	3	0	0
6	960	60	0.10	400	35	275	3	62	49
7	960	53	0.4	50	35	275	5	410	410
8	960	53	0.10	50	25	255	3	395	369
Note:- 41 components are produced in one stroke									

(Where R1-Trial-1 Rejection In 10 strokes,R2-Trial-2 rejection In 10 strokes, R-means- (R1+R2)/2) Experimental Result of 8 run geometric P-B Design shows that the parameters which are most influential on shape filling problem are Injection pressure(A), Injection speed(B), screw speed(C), cooling time(D).

VII. EXPERIMENTAL DESIGN USING TAGUCHI METHOD:

Table VII
An Orthogonal array [OA] L 8[23] for experiment.

NO.	A	B	C	D
1	960	53	25	3
2	960	53	35	5
3	960	60	25	5
4	960	60	35	3
5	1000	53	25	5
6	1000	53	35	3
7	1000	60	25	3
8	1000	60	35	5

Where A-Injection pressure (bar), B-Injection Speed (cm3/sec), C-Screw speed (rpm),D-Cooling Time (sec)

A. EXPERIMENTAL RESULT FOR ORTHOGONAL ARRAY

Table VIII
Taguchi L8 Experimental Orthogonal Array

No.	A	B	C	D	R1	R2	R Means
1	960	53	25	3	4	7	6
2	960	53	35	5	4	2	3
3	960	60	25	5	2	2	2
4	960	60	35	3	2	2	2
5	1000	53	25	5	2	2	2
6	1000	53	35	3	1	1	1
7	1000	60	25	3	4	2	3
8	1000	60	35	5	1	0	1

(Where R1-Trial-1 Rejection In 10 strokes,R2-Trial-2 rejection In 10 strokes, R-means- (R1+R2)/2)

VIII. MOULD FLOW ANALYSIS.

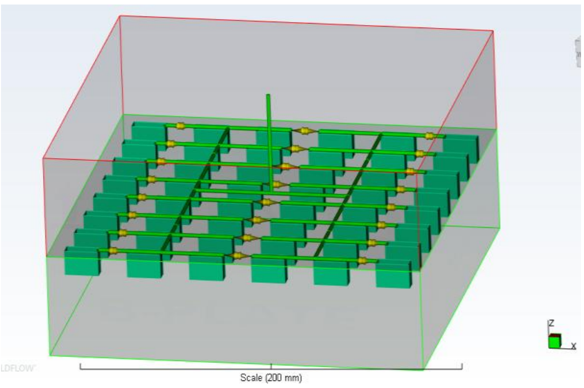

Fig 6 Die and Component in Mould flow analysis

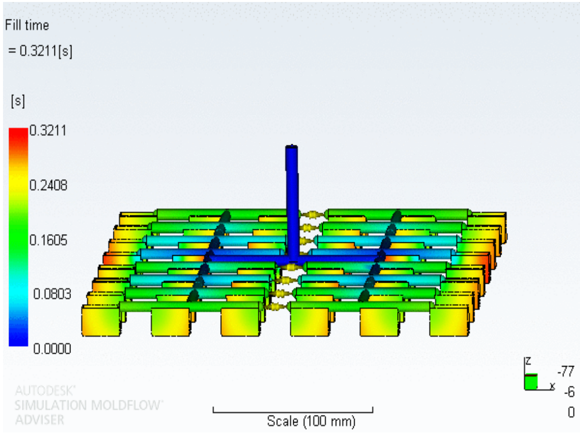

Fig. 7 Filling time required in Injection moulding

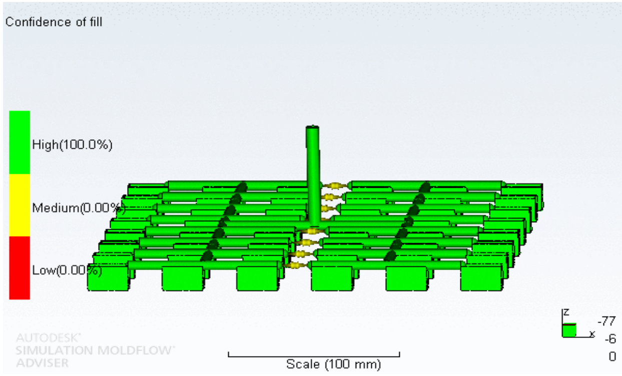

Fig.8 Confidence Of fill

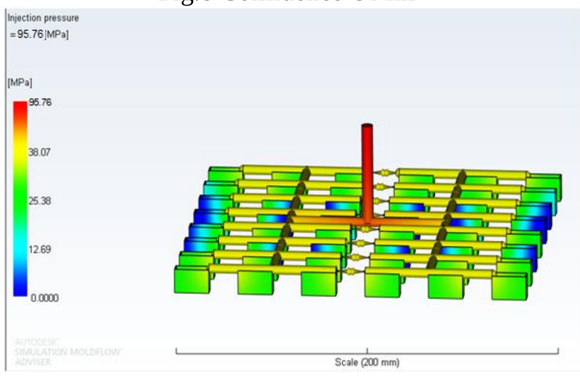

FIG. 9 INJECTION PRESSURE

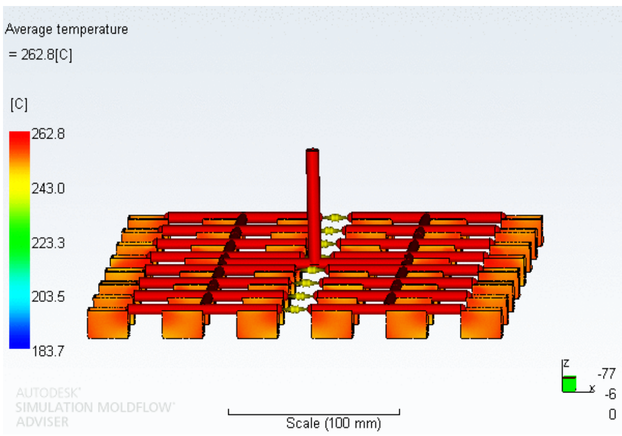

Fig. 10 Average Temperature in flow

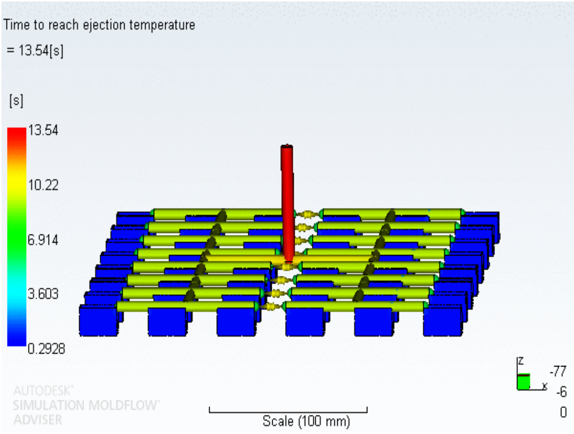

FIG. 11 TIME TO REACH EJECTION TEMPERATURE

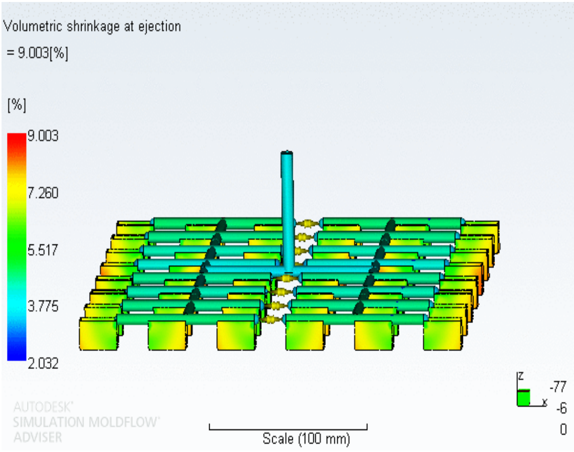

FIG 12 VOLUMETRIC SHRINKAGE AT EJECTION

IX. RESULT AND DISCUSSION:

Using Taguchi method Rejection is minimized during Plastic Injection Moulding Process by setting the parameters to high level.

Table IX
Signal to Noise ratio for Mean rejection

Sr. No.	A	B	C	D	Means	S/N ratio
1	960	53	25	3	6	-14.8073
2	960	53	35	5	3	-9.54243
3	960	60	25	5	2	-6.0206
4	960	60	35	3	2	-6.0206
5	1000	53	25	5	2	-6.0206
6	1000	53	35	3	2	-6.0206
7	1000	60	25	3	3	-9.54243
8	1000	60	35	5	1	6.0206

Table X
S/N Response Table for Rejection Means

	A	B	C	D
Level	(Bar)	(cm3/SEC)	(SEC)	3.000
1	3.250	3.000	3.000	2.000
2	1.750	2.000	2.000	1.000
Delta	1.500	1.000	1.500	1.000

From Table IX and Table X it shows that Injection speed and cooling time is most Influencing parameter for Rejection and Injection pressure and screw speed are less Influencing parameters for rejection. Fig. 4 shows the main effect plot for mean Rejection.

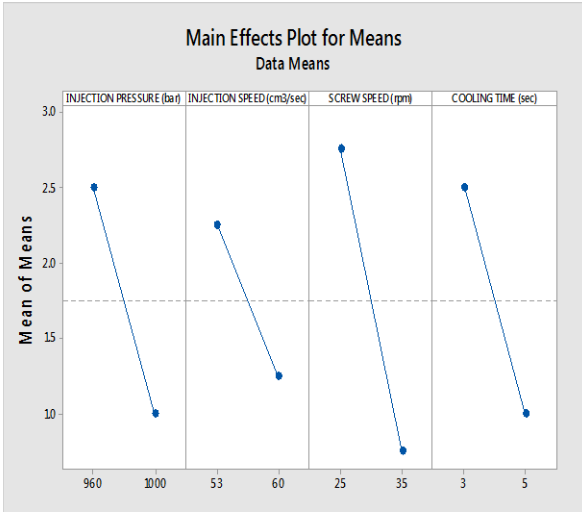

Fig.13: Main effects plot for means rejection

Table XI
ANOVA Result

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
INJECTION PRESSURE (bar)	1	4.500	4.500	2.7	0.199
INJECTION SPEED (cm3/sec)	1	2.000	2.000	1.200	0.353
SCREW SPEED (rpm)	1	4.500	4.500	2.700	0.199
COOLING TIME (sec)	1	2.000	2.000	1.200	0.353
Residential Error	3	5.000	1.667		
Total	7	18.00			

From the mean effects plot for Rejection means it is clearly observed that Injection pressure, Injection speed, screw speed, cooling time should be set to high levels to reduce the rejection for short filling. Figur 7 shows the main effects plot for Mean Rejection and Table 11 shows ANOVA result.

Table XII
Results obtained by Mould flow analysis.

Actual filling time	0.32 (s)
Actual injection pressure	50.777 (MPa)
Clamp force area	137.8701 (cm^2)
Max. clamp force during filling	49.757 (tonne)
Velocity/pressure switch-over at % volume	98.29 (%)
Velocity/pressure switch-over at time	0.29 (s)
Total part weight at the end of filling	24.696 (g)
Shot volume	48.1078 (cm^3)
Cavity volume	16.2720 (cm^3)
Runner system volume	31.8358 (cm^3)

X. CONFIRMATORY TEST:

As the Optimum level of the design parameters selected, the last footstep is to predict and confirm the betterment of the quality characteristics using the optimal level of the design parameters. The estimated S/N ratio using the optimal level of the design parameter S/N ratio using the optimal level of design parameters can be calculated as [10]:

$$\hat{\eta} = \eta_m + \sum_{i=1}^{0} (\overline{\eta}_i - \eta_m)$$

ηprediction =ηm + (A2- ηm) + (B2-ηm)+ (E2-ηm)+ (G2- ηm)
ηm= 14/8 = 1.75
ηprediction =1.75 + (1- 1.75) + (1.25- 1.75)+ (0.75-1.75)+ (1- 1.75)
ηprediction = 1.75- 0.75- 0.5 -1-0.75
ηprediction = -1.25≈ 0
Thus ηprediction shows that when all four parameters are set at high level there is approximately zero rejection due to short filling.
Based on the mean effect plot the optimum setting found is as follows:

Table XIII
Final Optimum setting

Sr. No.	Experimental Setting	Predicted Settings	Level
1	A2	A2	1000
2	B2	B2	60
3	E2	E2	35
4	G2	G2	5

Table XIV
Confirmation test for final Optimum setting

A2	B2	C2	D2	Rejection R1(10 strokes)	Rejection R2(10 strokes)	Rejection R3(10 strokes)
1000	60	35	5	0	0	1

Table XV
Confirmation test for Final Optimum setting for 1-shift

A2	B2	C2	D2	Rejection in 1shift(Before)	Rejection in 1-shift(After)
1000	60	35	5	431	239

After the optimization the optimum settings are set in the machine for 1-shift and the rejection are counted before setting and after setting. The table 14 shows the Rejection count before and after setting.

XI. CONCLUSION

This paper represents an application of the Taguchi method in the optimization of Injection moulding process parameter. The conclusions drawn based on the Experimental result of this study are as mentioned below:
1) Taguchi’s [OA] design method is appropriate to examine the Injection moulding process parameter and their levels.
2) Taguchi method give simplex, organized and efficient methodology for the optimization of the Injection moulding process parameter.
3) The experimental results shows that high level Injection pressure (bar), high level Injection speed (cm3/sec), high level screw speed (rpm), high level cooling time (sec)i.e. A2B2C2D2 are recommended to reduce rejection in injection moulding.
4) The Injection moulding parameters can be confirmed using mould flow analysis.
5) The shape filling problem can be minimized by using taguchi method and mould flow analysis.
6)Mould flow analysis also shows Cycle time, best Gating pattern for filling by Iterative methods.

XII. ACKNOWLEDGMENT

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