Optimization of Process Parameter for ABS, Nylon, Polypropylene Material in Injection Molding using Taguchi Method

V. V. Gaddamwar[1]*
*Department of Mechanical Engineering,
MIT Engineering, Aurangabad (M.S.), India.

Dr. S. P. Bhosle[2] **
** Department of Mechanical Engineering,
MIT Engineering, Aurangabad (M.S.),India.

***Abstract* :- The injection molding process itself is a complex mix of time, temperature and pressure variables with a multitude of manufacturing defects that can occur without the right combination of processing parameters and design components. Determining optimal initial process parameter settings critically influences productivity, quality, and costs of production in the plastic injection molding (PIM) industry. Most production engineers have used trial-and-error method to determine initial settings for a number of parameters, including melt temperature, injection pressure, injection velocity, injection time, packing pressure, packing time, cooling temperature, and cooling time which depend on the engineers' experience.**

The method for finding the optimized solution would involve use of Mini tab 17 software and for analysis Taguchi method is used. The use of this software would highlight the recommended values of the parameters for Injection Molding for the specified component design. Defect prevention coupled with minimum cycle time results in optimization of the process.

Keywords –Process parameter, PIM, orthogonal array; Analysis of variance; Taguchi method

I. INTRODUCTION

Injection molding is the most widely used polymeric fabrication process. It evolved from metal die casting, however, unlike molten metals; polymer melts have a high viscosity and cannot simply be poured into a mold. Instead a large force must be used to inject the polymer into the hollow mold cavity. More melt must also be packed into the mold during solidification to avoid shrinkage in the mold. The injection molding process is primarily a sequential operation that results in the transformation of plastic pellets into a molded part. Identical parts are produced through a cyclic process involving the melting of a pellet or powder resin followed by the injection of the polymer melt into the hollow mold cavity under high pressure.

The plastics injection molding process is integral to many of today's mainstream manufacturing processes. Industries such as telecommunications, consumer electronics, medical devices, computers and automotive all have large, constantly increasing demands for injection molded plastic parts. There are thousands of different grades of commercial of plastics materials with widely varying processing characteristics and complex part and mold designs are constantly pushing the limits of the process. The production of injection molded parts is a complex process where, without the right combination of material, part and mold design and processing parameters, a multitude of manufacturing defects can occur, thus incurring high costs. The injection molding process itself is a complex mix of time, temperature and pressure variables with a multitude of manufacturing defects that can occur without the right combination of processing parameters and design components. Determining optimal initial process parameter settings critically influences productivity, quality, and costs of production in the plastic injection molding (PIM) industry. Up to now, most production engineers have used trial-and-error method to determine initial settings for a number of parameters, including melt temperature, injection pressure, injection velocity, injection time, packing pressure, packing time, cooling temperature, and cooling time which depend on the engineers' experience and intuition to determine initial process parameter settings. However, the trial-and-error process is costly and time consuming.

Kamaruddin, Zahid A. Khan and S. H. Foong [1] has optimized the injection molding process parameters such as injection speed, injection pressure, holding pressure, melting temperature, holding time, cooling time using the Taguchi method. For improve the quality characteristic (shrinkage) of an injection molding product.

N.A.Shuaib, M.F. Ghazali, Z. Shay full, M.Z.M. Zain, and S.M. Nasir [2] has performed research to determine the factors that contribute to warpage for a thin shallow injection-molded part. The factors that been taking into considerations includes the mold

temperature, melt temperature, filling time, packing pressure and packing time. The process is performed by simulation and experimental method by Taguchi and ANOVA technique are employed. Packing time has been identified to be the most significant factors on affecting the warpage on thin shallow part.

Tao c. Chang and Ernest Faison [3] has applied the Taguchi method to systematically identify the significance of seven injection parameters and their effects on the appearance (width) of weld lines. The contributions of each factor to the quality and the optimum condition were identified. The optimal condition for weld line appearance was experimentally verified.

K. R. Jamaludina, N. Muhamad, M. N. Ab. Rahman, S. Y. M. Amin, Murtadhahadi, M. H. Ismail [4] has optimized injection molding parameters for the highest green strength of the metal powder mixture using Taguchi orthogonal array. Parameters optimized are the injection pressure, injection temperature, powder loading, mold temperature, holding pressure and injection rate.

Zhao Longzhi1, Chen Binghui1, Li Jianyun, Zhang Shangbing [5] has analyzed multi-molding process parameters by the combination of orthogonal experiments and Mold flow simulation tests.

Wen-Chin Chen, Gong-Loung Fu, Pei-Hao Tai, Wei- Jaw Deng, Yang-Chih [6] has used Taguchi's parameter design methods with back-propagation neural networks, genetic algorithms, and engineering optimization concepts, to optimize the initial process
settings of plastic injection molding equipment.

2. TAGUCHI TECHNIQUE

The Taguchi's method is a powerful method for designing high quality systems based on orthogonal array (OA) experiments that provide much reduced performance for the experiments with an optimum setting for process control parameters. This method achieves the integration of design of experiments (DOE) [7] with the parametric optimization of the process yielding the desired results. Design of experiment is one of the important and powerful statistical techniques to study the effect of multiple variables simultaneously and involves a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of process performance.

All designed experiments require a certain number of combinations of factors and levels be tested in order to observe the results of those test conditions. Taguchi approach relies on the assignment of factors in specific orthogonal arrays to determine those test conditions. The three phases are (1) the planning phase (2) the conducting phase and (3) the analysis phase. Planning phase is the most important phase of the experiment.

Analysis of the experimental setup results uses a signal to noise (S/N) ratio to aid in the determination of the best process designs which are logarithmic functions of desired output to serve as objective functions for optimization. The S/N ratio takes both the mean and the variability into account and is defined as the ratio of mean (Signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the product / process to be optimized. The three categories of S/N ratios are used: lower the better (LB), higher the better (HB), and nominal the best (NB). For the case of minimization of cycle time, LB characteristic needs to be used.

3.EXPERIMENTAL PROCEDURE

The experimentation will be carried out over a suitable molding machine based on the tonnage requirement for the subject components. The mold should be functional and the study should be carried out for current parts under production. Materials to be included in the study would be ABS, Nylon, PP materials. Document the data for research and analysis further using DOE. Taguchi optimization method will used to evaluate best possible combination of the injection molding process parameters like melt temperature, injection pressure, holding pressure, cooling time.

Table.1 Process with their values at three level parameters for ABS material

Level→	**Low**	**Medium**	**High**
Melting Temp(°c)	**80**	**85**	**90**
Injection Pressure(bar)	**35**	**45**	**55**
Cooling Time (Sec)	**12**	**14**	**16**
Holding Pressure(bar)	**25**	**30**	**35**
Code	**-1**	**0**	**+1**

Table.2 Process with their values at three level parameters for Nylon material

Level→	**Low**	**Medium**	**High**
Melting Temp(°c)	**180**	**190**	**200**
Injection Pressure(bar)	**30**	**40**	**50**
Cooling Time (Sec)	**22**	**24**	**26**
Holding Pressure(bar)	**20**	**25**	**30**
Code	**-1**	**0**	**+1**

Table.3 Process with their values at three level parameters for PP material.

Level→	**Low**	**Medium**	**High**
Melting Temp(°c)	**200**	**210**	**220**
Injection Pressure(bar)	**60**	**70**	**80**
Cooling Time (Sec)	**20**	**22**	**24**
Holding Pressure(bar)	**35**	**45**	**55**
Code	**-1**	**0**	**+1**

PLAN OFF EXPERIMENTS

Standard orthogonal array was used to conduct the experiments. The selection of the orthogonal array was based on the condition that the degrees of freedom for the orthogonal array should be greater than or equal to sum of those cycle time parameters. An L_{27} orthogonal array was chosen for the present experiments, which has 27 rows and 6 columns. The cycle time parameters chosen for the experiments were (1) Melting Temp (°c), (2) Injection Pressure (bar), (3) Cooling Time (Sec), (4) Holding Pressure (bar). The experiment consists of 27 tests (each row in the L27 orthogonal array) and the columns were assigned with parameters. For lower is the better performance objective, the response to be studied. ANOVA is performed to determine significant parameter.

4. RESULTS AND DISCUSSION

The tests were conducted with the aim of relating the influence of percentage of Melting Temp (°c), Injection Pressure (bar), Cooling Time (Sec), Holding Pressure (bar). On conducting the experiments as per orthogonal array, the cycle time results for various combinations of parameters were obtained and ANOVA results are shown in the Table 3.

4.1 *Analysis of variance*

The adequacy of the models is tested using the analysis of variance (ANOVA) technique. It is a statistical tool for testing null hypothesis for designed experimentation, where a number of different variables are being studied simultaneously. ANOVA issued to quickly analyze the variances present in the experiment with the help of fisher test (F test). This analysis was carried out for a level of significance of 5%, i.e. the level of confidence 95%. Table 3 shows the result of ANOVA analysis. One can observe from the ANOVA analysis that the value of P is less than 0.05 in all four parametric sources. Therefore it is clear that (1) Melting Temp (°c), (2) Injection Pressure (bar), (3) Cooling Time (Sec), (4) Holding Pressure (bar).has the influence on the cycle time of the injection molding component . The last column in Table 3 shows the percentage contribution of each factor on total variation indicating their degree of influence on the result.

Table 4: show ANOVA results For ABS

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Val ue**	**% Con trib utio n**	**Signific ant/Not Signific ant**
Melting Temp(°c)	2	272.3	136.1 5	28.06	0	54.3 5	Signific ant
Injection Pressure (bar)	2	52.52	26.25	5.41	0.01 4	10.4 8	Signific ant
Cooling Time (Sec)	2	36.96	18.48	3.81	0.04 2	7.37 7	Signific ant
Holding Pressure (bar)	2	51.85	25.92	5.34	0.01 5	10.3 5	Signific ant
Error	18	87.33	4.85				
Total	26	501					

For Nylon

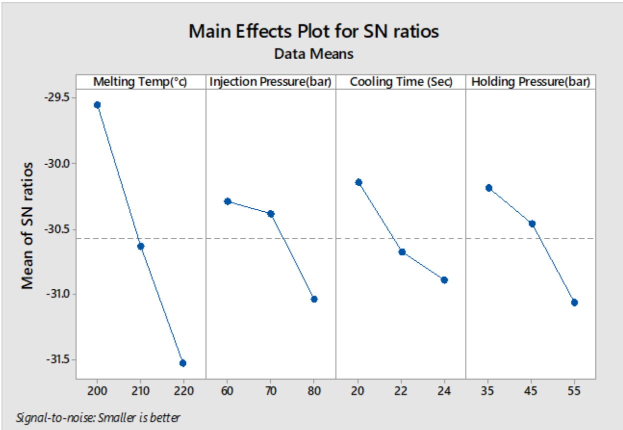
Source	**DF**	**Adj SS**	**Adj MS**	**F-Val ue**	**P-Val ue**	**% Con trib utio n**	**Signific ant/Not Signific ant**
Melting Temp(°c)	2	67.19	33.59	17.1 1	0.00 0	20.5 9	Significa nt
Injection Pressure (bar)	2	134.30	67.14	34.2 1	0.00 0	41.1 5	Significa nt
Cooling Time (Sec)	2	68.52	34.25	17.4 5	0.00 0	20.9 9	Significa nt
Holding Pressure (bar)	2	20.96	10.48	5.34	0.01 5	0.64	Significa nt
Error	18	35.33	1.96				
Total	26	326.30					

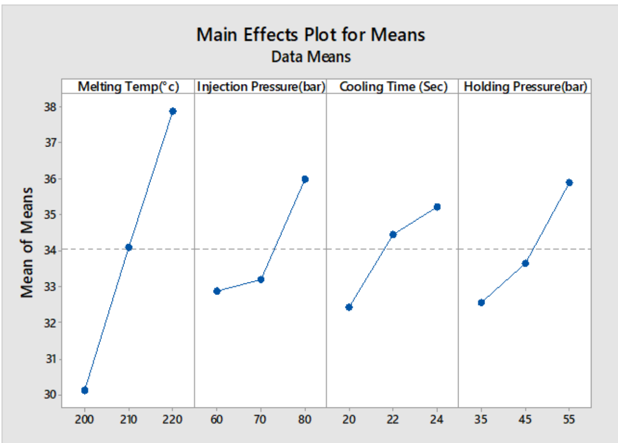
For PP

Source	**DF**	**Adj SS**	**Adj MS**	**F-Valu e**	**P-Valu e**	**% Contri bution**	**Significan t/Not Significan t**
Melting Temp(°c)	2	22.29 6	11.1 48	9.51	0.00 2	20.46	Significant
Injection Pressure (bar)	2	34.74 1	17.3 70	14.8 1	0.00 0	31.88	Significant
Cooling Time (Sec)	2	20.96 3	10.4 81	8.94	0.00 2	19.23	Significant
Holding Pressure (bar)	2	9.852	4.92 6	4.20	0.03 2	0.90	Significant
Error	18	21.11 1	1.17 3				
Total	26	108.9 63					

4.2 *Main effect plot*

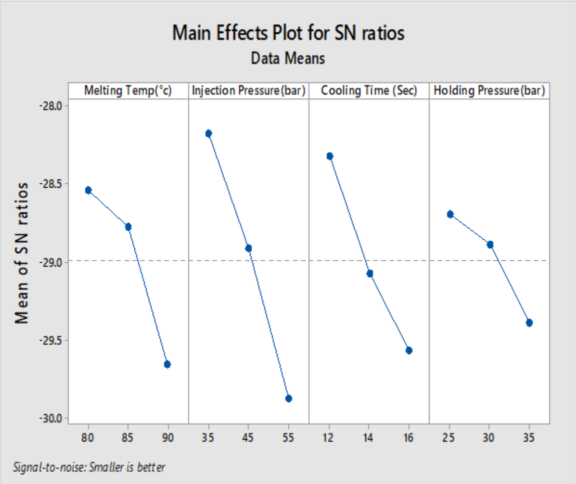
FOR ABS

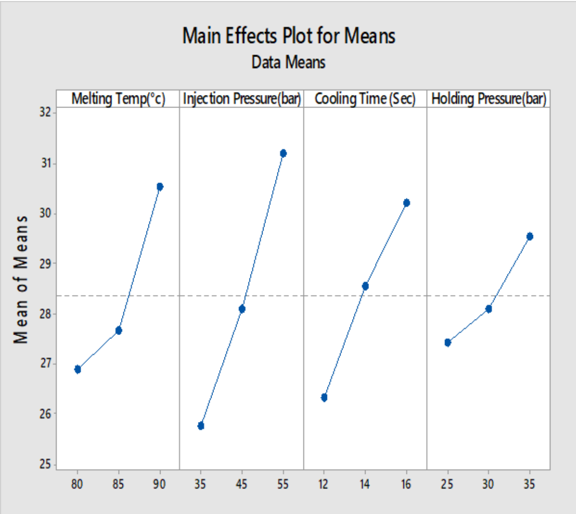




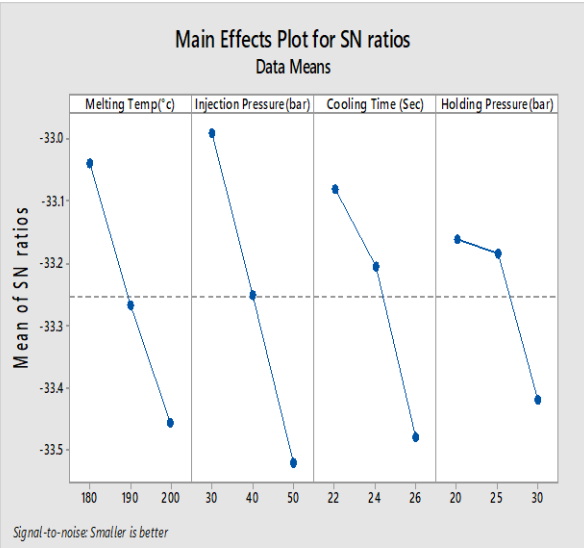
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 06, June-2019

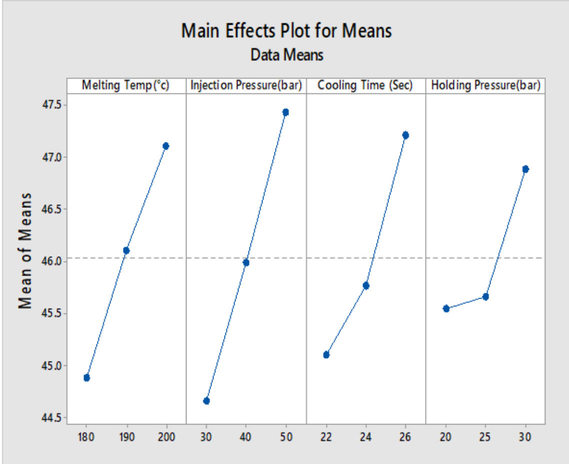
For nylon





For PP





The graph shows the Main Effect plot for S/N ratio. The level for a factor with the highest S/N ratio was the optimum level for response measured. From the plot, it is observed that the minimum cycle time was at the higher S/N values in the response graph. For ABS optimal cycle time parameter 200 °c Melting Temp, 60 bar Injection Pressure, 20 sec Cooling Time ,35 bar Holding Pressure .For Nylon optimal cycle time parameter 80 °c Melting Temp, 35 bar Injection Pressure, 12 sec Cooling Time ,25 bar Holding Pressure. For PP optimal cycle time parameter 180 °c Melting Temp, 20 bar Injection Pressure, 22 sec Cooling Time ,20 bar Holding Pressure Process parameter settings with highest ratio always give the optimum quality with minimum variance. The graph show the change of ratio when setting of the control factor was changed from one level to another.

4.3 *Multiple Linear Regression Models*

To establish the correlation between the cycle time parameters Melting Temp, Injection Pressure, Cooling Time , Holding Pressure , the cycle multiple linear regression model was obtained using statistical software "MINITAB 17".The terms that are statistically significant are included in the model. Final Equation obtained is as follows,

5. REGRESSION EQUATION

FOR ABS

Cycle time in sec = -81.3 + 0.3889 Melting Temp(°c)
+ 0.1556 Injection Pressure(bar)
+ 0.694 Cooling Time (Sec)
+ 0.1667 Holding Pressure(bar)………………….(1)

FOR NYLON

Cycle time in sec = -34.99 + 0.3667 Melting Temp(°c)
+ 0.2722 Injection Pressure(bar)
+ 0.972 Cooling Time (Sec)
+ 0.2111 Holding Pressure(bar)………………..(2)

FOR PP

Cycle time in sec = 3.37 + 0.1111 Melting Temp(°c)
+ 0.1389 Injection Pressure(bar)
+ 0.528 Cooling Time (Sec) + 0.1333 Holding Pressure (bar)……………………(3)

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 06, June-2019

Substituting the recorded values of the variables for the above equation (1),(2) and (3) cycle time of the abs nylon and pp material can be calculated. The positive value of the coefficient suggests that the cycle time of material increases with their associated variables. Whereas the negative value of the coefficient suggest that the cycle time of the material will decreases with the increase in associated variables. The magnitude of the variables indicates the weightage of each of these factors .It is observed from the Equation (1) that the melting temp has the more effect on cycle time of ABS material, which is followed by Injection pressure, Holding Pressure & Cooling time. from the Equation (2) that the Injection pressure has the more effect on cycle time of nylon material, which is followed by cooling time, melting temp,holding pressure for the tested range of variables. from the Equation (3) that the Injection pressure has the more effect on cycle time of pp material, which is followed by melting temp ,cooling time, ,holding pressure for the tested range of variables.

6. CONCLUSION

FOR ABS MATERIAL

Melting temperature is the cycle time factor that has the highest physical properties as well as statistical influence on the cycle time of the material (54.35%), Injection pressure (10.48%), Holding pressure (10.35%), and cooling time (7.377%) and for cycle time of ABS material, Injection pressure (10.48%),has moderate influence on the cycle time. Holding pressure (10.35%), and cooling time (7.377%) are the factor that has least influence on cycle time of ABS material.

FOR NYLON MATERIAL

Injection pressure is the cycle time factor that has the highest physical properties as well as statistical influence on the cycle time of the material (41.15%), cooling time (20.99%), melting temp (20.59%), and holding pressure (0.64%) and for cycle time of ABS material, the cooling time (20.99%), has moderate influence on the cycle time. melting temp (20.59%), and holding pressure (0.64%) are the factor that has least influence on cycle time of ABS material.

FOR NYLON MATERIAL

Injection pressure is the cycle time factor that has the highest physical properties as well as statistical influence on the cycle time of the material (31.88%), melting temp (20.46%), cooling time (19.23%), and holding pressure (0.90%) and for cycle time of ABS material, the melting temp (20.46%), has moderate influence on the cycle time. cooling time (19.23%), and holding pressure (0.90%) are the factor that has least influence on cycle time of ABS material.

REFERENCES:

[1] Optimization of Weld Line Quality in Injection Molding Using an Experimental Design Approach Taoc. Chang and Ernest Faison, Journal of Injection Moulding Technology, JUNE 1999, Vol. 3, No. 2 PP 61-66.
[2] Setting the Processing Parameters in Injection Molding Through Multiple-Criteria Optimization: A Case Study Velia Garc´ıa Loera, José M. Castro, Jesus Mireles Diaz, O´ scar L. Chaco´n Mondragon, , IEEE 2008 PP 710-715.
[3] Processing Parameter Optimization For Injection Moulding Products In Agricultural Equipment Based On Orthogonal Experiment And Analysis Yanwei1 Huyong IEEE 2011 PP 560-564.
[4] Warpage Factors Effectiveness of a Thin Shallow Injection-Molded Part using Taguchi Method N.A.Shuaib, M.F. Ghazali, Z. Shay full, M.Z.M. Zain,S.M. Nasir. International Journal of Engineering & Technology IJET-IJENS Vol: 11 No: 01 PP 182-187.
[5] Optimization of Plastics Injection Molding Processing Parameters Based on the Minimization of Sink Marks Zhao Longzhi1, Chen Binghui1, Li Jianyun, Zhang Shangbing IEEE 2010 PP 1-3
[6] Application of Taguchi Method in the Optimization of Injection Moulding Parameters for Manufacturing Products from Plastic Blends. "Kamaruddin , Zahid A. Khan and S. H. Foong." IACSIT International Journal of Engineering and Technology, Vol.2, No.6, December 2010 PP 574-580.
[7] Lim SC, Ashby MF. Acta Mater 1987;30:1.
[8] Ross, P. J., 1996. Taguchi Techniques for Quality Engineering, 2nd edn. McGraw – Hill, New York.