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Effect of Injection Moulding Process Parameter on Tensile Strength Using Taguchi Method

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Abstract**—**The plastic industry plays very important role in the economy of any country. It is generally among the leading share of the economy of the country. Since metals and their alloys are very rarely available on the earth. Therefore, to produce plastic products and components, which finds application in many industrial as well as household consumer products is beneficial. Since 50% plastic products are manufactured by injection moulding process. For production of better quality product, we have to control quality characteristics and performance of the product. The process parameters plays a significant role in production of plastic, hence the control of process parameter is essential. In this paper the effect of the parameters selection on injection moulding process has been described. It is to define suitable parameters in producing plastic product. Selecting the process parameter by trial and error is neither desirable nor acceptable, as it is often tends to increase the cost and time. Hence, optimization of processing parameter of injection moulding process is essential. The experiments were designed with Taguchi's orthogonal array to achieve the result with least number of experiments. Plastic material polypropylene is studied. Tensile strength test of material is done on universal testing machine, which is produced by injection moulding machine. By using Taguchi technique with the help of MiniTab-14 software the best value of injection pressure, melt temperature, packing pressure and packing time is obtained. We found that process parameter packing pressure contribute more in production of good tensile plastic product.

Keywords**—**Injection moulding, tensile strength, Taguchi method, poly-propylene.

I. Introduction

THE plastic industry is the largest industry in the world and providing significantly effect to the nation's economy. This sector is the fastest growing sector in the Indian economy similar to globe. Nowadays injection moulding bears the responsibility of mass producing plastic components to meet the rapidly rising market demand as a multitude of different types of consumer products including medical, electronics and automobile. To sustain in the market it is required to produce quality products at least price. The effective process for mass production of plastic products is injection moulding. Injection moulding has high efficiency, largest yield and highest dimensional accuracy among all the processing methods. More than 1/3 of all thermoplastic materials are injection moulded and more than half of all polymer processing equipments are for injection moulding.

The process starts with a selected plastic compound which is normally supplied as pellets. These pellets are put into a hopper on the injection moulding machine and the pellets are then transferred to the electrically heated barrel. Inside the barrel, a screw is located and when the screw is rotating, the pellets are melted due to the heat generated by the friction between the barrel wall and the screw. The rotation of the screw feeds the partly molten pellets forward, and the screw is at the same time moved backwards by the accumulation of the melt in front of the screw tip. Up to 70% of the heat needed to melt the pellets is provided by this shear-induced heating, while the rest is provided by the heaters on the outside of the barrel. When the injection chamber is full with molten plastic, the rotation of the screw stops, and a valve is opened into the mild. The screw is pushed forward, and the melt flows through the nozzle, the sprue, and the runner system into the cavity. The cavity is the inverse of the desired shape of the part to be manufactured. The process parameters such as cycle time, fill time, cooling time, injection time, injection pressure, packing time, packing pressure, holding pressure, melting temperature, mould temperature and so on need to be optimized in order to produce finished plastic parts with good quality. Amongst these parameters melting temperature, injection pressure, packing pressure, packing time are paid attention by the researchers due to its significant influence on the tensile strength.

Since, experimenting by changing the parameter level one at a time leads to increase the number of experiment lengthy, simultaneously the cost. In this research Taguchi method is adopted to minimize the number the experiment as well as cost. It has been widely used for product design and quality optimization worldwide. This is the advantages of the design of experiment using Taguchi's technique, which includes simplification of experimental plan and feasibility of study of interaction between different parameters. It has been widely used by researchers to investigate the influence of process parameters on responses.

1) There are several studies have been conducted on optimization plastic manufacturing process. Reference [1] studies the effects of process parameters for injection moulding on surface quality of optical lenses. They consider warpage, waviness and other response on their research. Reference [4] studied effect of reprocessing cycle on shrinkage and mechanical properties of acrylonitrile-butadiene-styrene, they found that as reprocessing cycle increased, shrinkage decreased, and

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tensile and flexural ultimate strengths increased. So larger the tensile strength lesser will be the shrinkage in product. Reference [2] considers the tea plate of plastic product. On their analysis, they consider the tensile strength by taking process parameters melting temperature, injection pressure, cooling time and Polycarbonate as a material. They found that as the melt temperature increases tensile strength increases. Analysis of injection moulding considers the short shot defect by taking parameters injection pressure, mould closing speed mould pressure, back pressure [3]. Reference [5] studied the effects of processing parameters on the appearance of weldlines by Taguchi experimental design method. Weldlines are obtained by the right door of copy machine which is modelled with three gates. The pictures of moulding products are taken by digital camera. They consider the melt temperature, injection pressure, injection velocity as main factors which affect the strength of material polyproplylene. They showed that injection velocity is main factor for the visibility of weld lines. Reference [6] studied two processing parameters injection velocity and injection pressure effect on tensile strength of plastic moulded part. They did their analysis on polyethylene material of plastic. They showed that injection pressure has significant factor which affect tensile strength of material and injection velocity has no effect on tensile strength. In the study of processing parameters on injection moulding process [7], they consider injection pressure, melting temperature, Cooling time, injection speed, mould temperature, holding pressure, holding time on tensile strength of injection moulded part. They found that holding pressure and melt temperature significantly affect the tensile strength of material. In the study of processing parameters on injection moulding process [8], they consider injection speed, injection pressure and melt temperature on tensile strength of Polypropylene material of plastic part. They found that melt temperature, injection pressure and injection speed affect tensile strength significantly. Reference [9] studied on micro injection moulding process. They consider injection pressure, injection temperature, holding time factor effect on the tensile properties of polypropylene material. They found as injection pressure increases tensile strength increases but as injection time increases tensile strength increases first then it decreases. Reference [10] studied holding pressure factor effect on tensile strength of metal injection moulding material part. They found that as holding pressure increases tensile strength of metal injection moulded part increases. Reference [11] studied of temperature effect on ABS material composites. They found that as the melting temperature, mould temperature increases tensile strength of composite material increases. Reference [12] studied of factor melt temperature, injection pressure, cooling time on tensile strength of polycarbonate material. They found that as melt temperature increases tensile strength of material increases.

2) Although numerous efforts have been made to map injection moulding process with Taguchi technique and the influence of the processing parameters on various responses have been studied. However, use of Taguchi technique on modelling of tensile strength of plastic product by injection moulding is rare. Moreover the use of this model on polypropylene material which has wide range of application in the plastic industry, make it special, is rare.

The scope of this study is focusing on the simulation of tensile strength on the raw materials including determination of the effective parameters that contribute to the response, the selection of the orthogonal arrays (OAs) and determination of the optimum parameter. The selection of the orthogonal arrays (OAs) depends on the level and parameter involved thus the 3 levels and 4 parameters were chosen. The chosen parameters and level influenced the type of orthogonal arrays and the Taguchi L27 orthogonal arrays were used. Finally, the optimum parameters were determined by exploiting S/N ratio.

II. Methodology

A. Taguchi Method

Taguchi method was developed by Dr. Genichi Taguchi of Japan. The objective of the method is to produce high quality product at low cost to the manufacturer. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters that affect process and the levels. Orthogonal Arrays (often referred to Taguchi Methods) are often employed in industrial experiments to study the effect of several control factors.

B. Signal-to-Noise Ratio (S/N Ratio)

The experimental results are then transformed into a signal-to-noise (S/N) ratio. S/N ratio, which are ‘Log’ function of desired output serve as objective function for optimization, help in data analysis and prediction of optimal result. Taguchi recommends the use of S/N ratio to measure the quality characteristics deviating from the desired values. The S/N ratio for each level of process parameters is computed based on the S/N analysis. Generally, there are three categories of quality characteristic in the analysis of the S/N ratio, i.e. smaller-is-better, larger-is-better, and nominal-is-better. In the present experimental design, the higher-is-better type quality characteristics are used which is expressed as:

$$S/N = -10 \log_{10}(MSD) \quad (1)$$

For larger is better:

$$MSN = \frac{1}{n}\sum_{i=0}^{n}\frac{1}{y_i^2}$$

where; MSD = mean square deviation, y = observations, n= no. of tests in a trial.

Taguchi suggested a standard procedure for optimizing any process parameters. The steps involved are:

1. Determination of the quality characteristic to be optimized.
2. Identification of the noise factors and test conditions.
3. Identification of the control factors and their alternative levels.
4. Designing the matrix experiment and defining the data analysis procedure.
5. Conducting the matrix experiment.
6. Analysing the data and determining the optimum levels of control factors.
7. Predicting the performance at these levels.

III. Experimental Plan

A. Selection of Process Parameters and their Levels

For the present experimental work, the four process parameters each at three levels have been decided. It is desirable to have three minimum levels of process parameters to reflect the true behaviour of output parameters of study. The process parameters are renamed as factors and they are given in the adjacent column. The levels of the individual process parameters/factors are given in Table I:

TABLE I
Process Parameters and Their Levels

Parameter	Level 1	Level 2	Level 3
Melting Temperature (MT)	200	220	240
Injection Pressure (IP)	22	25	28
Packing Pressure (PP)	14	17	20
Packing Time (PT)	5	10	15

As per experimental design a set of three levels assigned to each process parameter has two degrees of freedom (DOF). This gives a total of 8 DOF for four process parameters selected in this work. The nearest three level orthogonal array available satisfying the criterion of selecting the OA is L_{27} having 8 DOF. For each trial in the L_{27} array, the levels of the process parameters are indicated in Table II.

IV. Experimental Setup

In this work polypropylene as a raw material is used to conduct the experiment. A series of experiments were conducted using a 150 tonne hydraulic Engel IMM in order to collect data which are shown in Fig. 1.

A. Material Properties of Polypropylene

Chemical composition and physical parameters of polypropylene is shown in Table III.

Polypropylene is processed by using different combinations of processing parameters. Different combinations of melt temperature, injection pressure, packing pressure and packing time have taken. After this, tensile test of the all specimen has done by using universal testing machine. An area of specimen of plastic is 12 $mm^2$is taken in the calculation of tensile strength.

Fig. 1 Injection moulding machine

TABLEII
Experimental Plan Using an L_{27} Orthogonal Array

1.	1	1	1	1
2.	1	1	1	1
3.	1	1	1	1
4.	1	2	2	2
5.	1	2	2	2
6.	1	2	2	2
7.	1	3	3	3
8.	1	3	3	3
9.	1	3	3	3
10.	2	1	2	3
11.	2	1	2	3
12.	2	1	2	3
13.	2	2	3	1
14.	2	2	3	1
15.	2	2	3	1
16.	2	3	1	2
17.	2	3	1	2
18.	2	3	1	2
19.	3	1	3	2
20.	3	1	3	2
21.	3	1	3	2
22.	3	2	1	3
23.	3	2	1	3
24.	3	2	1	3
25.	3	3	2	1
26.	3	3	2	1
27.	3	3	2	1

TABLE IV
Material Properties of Polypropylene

Chemical Composition Of Polypropylene	$(C_3H_6)_N$
Material Properties	Performance
Recommended Mould Temperature(^{0}c)	60
Recommended Melt Temperature (^{0}c)	240
Solid Density (G/M^3)	0.92889
Melt Density (G/M^3)	0.7751
Eject Temperature(^{0}c)	93
Maximum Shear Rate (S^{-1})	24000
Maximum Shear Stress (Mpa)	0.26
Thermal Conductivity(W/M^{0}c)	0.15
Elastic Modules(Mpa)	13.40
Poisson Ratio	0.392

V. Experimental Result and Discussion

Table IV shows the entire experimental result about the tensile loads at different experiment number. The value of tensile loads is found between 300 N and 372 N.

TABLE IV
Tensile Strength for Various Experiment Numbers

Parameter	Melting Temperature	Injection Pressure	Packing Pressure	Packing Time	Tensile Load	Tensile Strength
Unit	^{0}C	Mpa	Mpa	Sec.	Newton	Mpa
Symbol	MT	IP	PP	PT	P	S
1.	200	22	14	5	300	25
2.	200	22	14	5	312	26
3.	200	22	14	5	324	27
4.	200	22	17	10	336	28
5.	200	25	17	10	348	29
6.	200	25	20	15	360	30
7.	200	28	20	15	372	31
8.	200	28	20	15	300	25
9.	200	28	20	15	312	26
10.	220	22	17	15	324	27
11.	220	22	17	15	336	28
12.	220	22	17	15	348	29
13.	220	25	20	5	360	30
14.	220	25	20	5	372	31
15.	220	25	20	5	360	30
16.	220	28	14	10	312	26
17.	240	22	20	10	324	27
18.	240	22	20	10	336	28
19.	240	22	20	10	348	29
20.	240	22	20	10	360	30
21.	240	25	14	15	312	26
22.	240	25	14	15	324	27
23.	240	25	14	15	336	28
24.	240	25	14	15	348	29
25.	240	28	17	5	360	30
26.	240	28	17	5	372	31
27.	240	28	17	5	360	30

A. Response Effect for Signal-to-Noise Ratio of Tensile Strength

A greater value of S/N ratio is always considered for better performance irrespective of the category of the performance characteristics. The difference of maximum and minimum mean S/N ratio indicates the significance of process parameter, greater will be the difference, greater will be the significance. Table VI shows that packing pressure contributes more significantly towards tensile strength as the difference is highest, followed by injection pressure, packing time and melt temperature.

B. Effect on Tensile Strength

In order to see the effect of process parameter on tensile strength experiments were conducted using L_{27} orthogonal array (Table II).

TABLE V
Response Table for Signal to Noise Ratio

Level	MT	IP	PP	PT
1	28.93	28.81	28.45	29.19
2	28.96	29.30	29.19	28.89
3	29.16	28.85	29.22	28.97
Delta	.23	.49	.77	.29
Rank	4	2	1	3

The experimental data is given in Table V. The average values of tensile strength for each parameter at level 1, 2, and 3 for raw data and S/N data are plotted in Figs. 2 and 3, respectively.

The packing pressure is directly proportional to tensile strength in the range of 14 Mpa to 20Mpa. This is expected because as packing pressure increases the shear stress in the layers. Therefore, material does not flow as it comes from barrel. Besides, it is clearly evident that other factor does not influence as much as packing pressure.

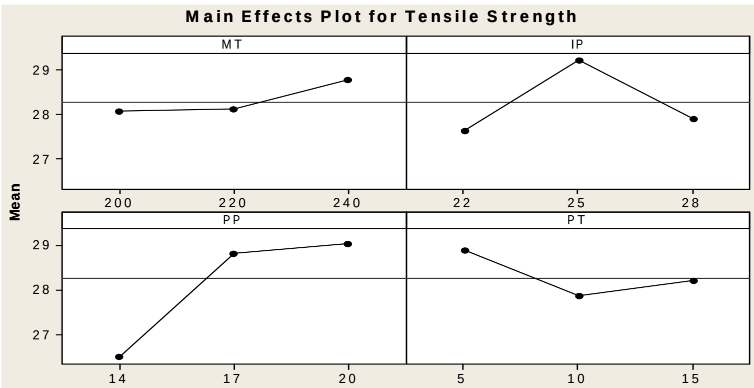

Fig. 2 Main effect plot for tensile strength

Four plots viz. normal probability plot, residuals vs fit, Histogram and residuals vs order. This layout is useful to determine whether the models meet the assumptions for analysis.

The residuals plots in the graph and interpretation of each residual plot indicate below:

1. Normal probability plot indicates the data are normally distributed and the variables are influencing the response.

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2. Residuals versus fitted values indicate the variance is constant and a nonlinear relationship exists as well as no outliers exist in the data.
3. Histogram proves the data are not skewed and not outliers exist.
4. Residuals versus order of the data indicate that there are systematic effects in the data due to time or data collection order.

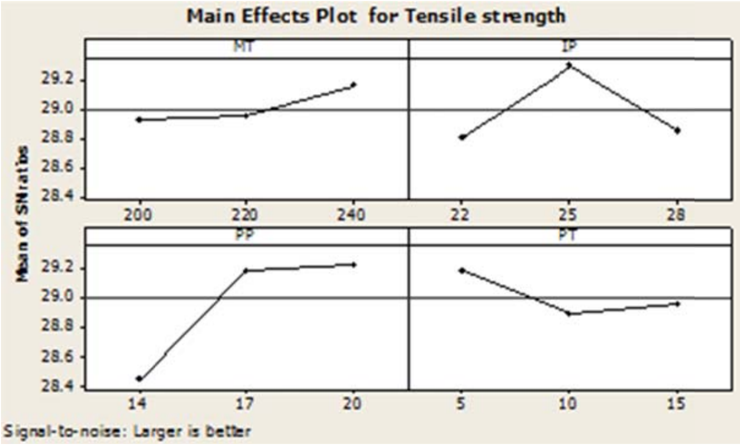

Fig. 3 Main Effect Plot for S/N ratio of Tensile strength

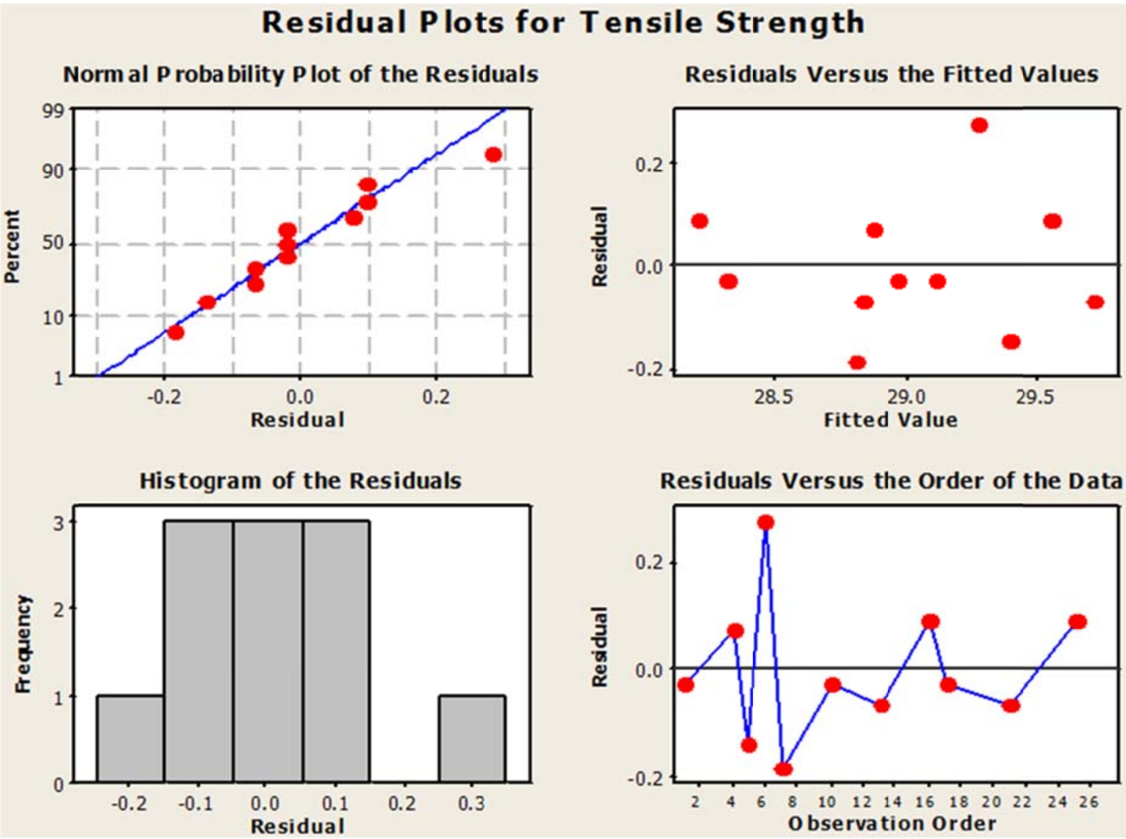

Fig. 4 Residual Plot of Tensile strength

C. Selection of Optimal Level

In order to selection of optimal levels of the process parameters towards Tensile strength, the response table was employed. The response tables (Table VI) show the average of each response characteristic (S/N data, means) for each level of each factor. The tables include ranks based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on delta values; rank 1 to the highest delta value, rank 2 to the second highest, and so on. The ranks indicate the relative importance of each factor to the response. The ranks and the delta values show that packing pressure have the greatest effect on Tensile strength, followed by injection pressure, packing time and melt temperature in that order.

As Tensile Strength is the 'Larger is better' type quality characteristic, it can be seen from Fig. 3 that the third level of Melt temperature (MT3), second level of injection pressure (IP2), third levelof packing pressure (PP3), and first level of packing time (PT1) provide maximum value of Tensile strength in injection moulding process.

TABLE VII
BEST COMBINATION OF PARAMETER

Factor	Values
Melting Temperature (MT)	240 ^{0}C
Injection Pressure (IP)	25Mpa
Packing Pressure (PP)	20Mpa
Packing Time (PT)	5 Sec

D. Regression Analysis of Tensile Strength

In this work the functional relationship between the process response (Tensile strength) and four processing parameters (Melt temperature, Injection pressure, Packing pressure and Packing time) is established using regression analysis. The linear functional relationship between the process response and different process parameters is predicted from the MINITAB 14 statistical software using the experimental data. The multiple linear regression equation for Tensile strength is given as,

$$\text{Tensile Strength} = 13.6 + 0.0315\ MT + 0.126\ IP + 0.327\ PP - 0.104\ PT$$

The developed mathematical models are checked for their adequacy using ANOVA and normal probability plot of residuals.

E. Model Analysis of Tensile Strength

The coefficients of model for Tensile strength are shown in Table VIII. The parameter R2 describes the amount of variation observed in MRR is explained by the input factors. R2= 36.9 % indicate that the model is able to predict the response with high accuracy. Adjusted R2 is a modified R2 that has been adjusted for the number of terms in the model. If unnecessary terms are included in the model, R2can be artificially high, but adjusted R2 (=25.4%.) may get smaller. The standard deviation of errors in the modeling, S=1.61750. Comparing the p-value to a commonly used α-level = 0.05, it is found that if the p-value is less than or equal to α, it can be concluded that the effect is significant (shown in bold), otherwise it is not significant.

TABLE VIII
ESTIMATED MODEL COEFFICIENTS FOR TENSILE STRENGTH

Predictor	Coef.	SE Coef.	T	P
Constant	13.598	5.590	2.43	.024
MT	0.3146	0.01819	1.73	.098
IP	0.1261	.1297	.97	.341
PP	0.3273	0.1255	2.61	.016
PT	-.10396	.07262	-1.43	.166
S=1.61750	R-Sq=36.9%			R-Sq(Adj)=25.4%

VI. CONCLUSION

Plastic injection moulding is a quite important field in manufacturing process. There are many plastic products that produced by the injection moulding process. The product that will produced will do experiment tensile strength. By using Taguchi method 27 trials have been run. The optimum parameter that can maximize the tensile strength are packing pressure etc. However, other factor are also have significant influence on the tensile strength.

REFERENCES

[1] Tsai, K. M., Hsieh, C. Y., & Lo, W. C. (2009). A study of the effects of process parameters for injection molding on surface quality of optical lenses. *journal of materials processing technology*, *209*(7), 3469-3477.

[2] Pareek, R., & Bhamniya, J. (2013). Optimization of Injection Moulding Process using Taguchi and ANOVA. *Journal of Scientific and Engineering Research*,*4*(1).

[3] Rathi, M. M., & Salunke, M. M. D. (2012, October). Analysis Of Injection Moulding Process Parameters. In *International Journal of Engineering Research and Technology* (Vol. 1, No. 8 (October-2012)). ESRSA Publications.

[4] Rahimi, M., Esfahanian, M., &Moradi, M. (2014). Effect of reprocessing on shrinkage and mechanical properties of ABS and investigating the proper blend of virgin and recycled ABS in injection molding. *Journal of Materials Processing Technology*, *214*(11), 2359-2365.

[5] Li, H., Guo, Z., & Li, D. (2007). Reducing the effects of weldlines on appearance of plastic products by Taguchi experimental method. *The International Journal of Advanced Manufacturing Technology*, *32*(9-10), 927-931.

[6] Raos, P., &Stojsic, J. (2014). Influence of Injection Moulding Parameters on Tensile Strength of Injection Moulded Part. *Manufacturing and Industrial Engineering*, *13*(3-4).

[7] Zhu, J., Chen, J. C., & Kirby, E. (2004). Tensile Strength and Optimization of Injection Molding Processing Parameters Using the Taguchi Method. *The International Journal of Modern Engineering, 4 (2).*

[8] Lin, Y. H., Deng, W. J., Huang, C. H., & Yang, Y. K. (2007). Optimization of injection molding process for tensile and wear properties of polypropylene components via Taguchi and design of experiments method. *Polymer-Plastics Technology and Engineering*, *47*(1), 96-105.

[9] Pal, R., Mukhopadhyay, S., & Das, D. (2012). Optimization of micro-injection molding process with respect to tensile properties of polypropylene. *Indian Journal of Fibre and Textile Research*, *37*(1), 11.

[10] Islam, A., Hansen, H. N., Esteves, N. M., & Rasmussen, T. T. (2013). Effects of holding pressure and process temperatures on the mechanical properties of moulded metallic parts. *ANTEC 2013*.

[11] Hashemi, S. (2008). Effect of temperature on tensile properties of injection moulded short glass fibre and glass bead filled ABS hybrids. *Express Polym. Lett*, *7*, 474.

[12] A. Riaz Ahamed, A. K. Shaik Dawood, R. Karthikeyan (2013). Designing and Optimizing the Parameters which affect the Molding Process using Design of Experiment. Volume 1, Issue 2, October-December 2013, pp.116-122.