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Optimization of Process Parameters on Injection Moulding Machine with LLDPE Reinforced Flyash using Taguchi

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***Abstract*—** *Injection Moulding (IM) is an important polymer process operation in the plastic industry. The Polymer Composite Material is injected into a mould cavity, during the process and solidifies to the shape of the mould. The demand for plastic product is very high because of a good set of their better quality, design and appearance in comparison to other material product in the present market. Operating parameters are needed to produce better quality of plastic products. Hence, the present paper deals with the parameter selection for injection moulding using Taguchi and ANOVA, since there are many critical factors involved in the process, the effect of Melting Temperature, Injection Pressure, Cooling Time and Injection Speed are considered in the present paper. A Plastic product from Linear Low Density Polyethylene (LLDPE) as Matrix Material and Flyash as Reinforcement Material (LLDPE + Flyash) Composites are taken for the experiment to obtain optimal injection moulding to find out Tensile Strength(IS) and Hardness in order to minimize defects and increase its strength, and toughness. The analysis of experimental work is performed on MINITAB-17 Statistical Software. The Design of Experiment (DOE) is used with an attempt to optimize input parameters and achieve good results using "Orthogonal Arrays" (OA) by Taguchi method. The output characteristics analysed and presented the optimal results.*

***Keywords*—** **ANOVA, DOE, Flyash, Hardness, Injection moulding, LLDPE, Taguchi, Tensile Strength.**

I. INTRODUCTION

Need for quality of the products with latest developments has made the industries to search for new methods for manufacturing or production of components with low cost. Among the Production Processes, Injection Moulding (IM) is a practical technique used in manufacturing industry for mass production of plastics parts quickly and inexpensive. Further, the plastic parts have become more popular and critical in modern engineering applications.

Injection moulding is generally used to produce thermoplastic polymers. It consists of heating of thermo plastic materials until it melts and then injecting into the steel mould, where it cools and solidifies to take its final shape. The plastic materials are usually received in the granular form. It is placed in the hopper of the moulding machine from which it is fed to a heated cylinder. Granules are heated in the cylinder to melt or plasticize. The melting temperature varies with the material. The mould is usually made-up of steel and water to cool. A plunger forces the molten plastics from the cylinder into the mould wherein, it cools and solidifies. The mould is opened and the moulded part as well as the attached runner is removed.

The present experimental work done to investigate and optimize the critical parameters in Injection Moulding (IM). The main factors include Melting Temperature, Injection Pressure, Cooling Time and Injection Speed with a formal application of DOE. The material used in this work is LLDE + Flyash. The material is choose because it has good strength, high impact-resistance, optical clarity and good electrical insulator. The property of LLDPE is to undergo large plastic deformations with-out cracking or breaking makes it different from most thermoplastics. Fig.1 shows Injection Moulding Machine Processing the mould.

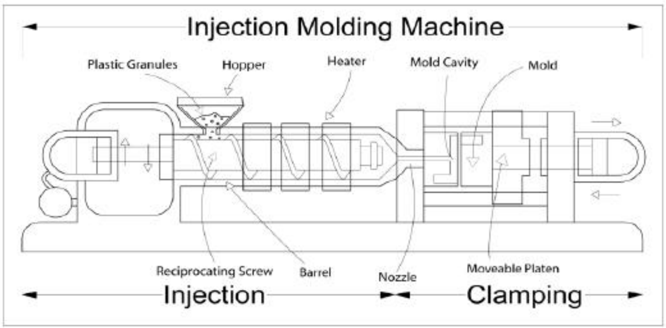

Fig. 1: Schematic view of Injection Moulding Machine.

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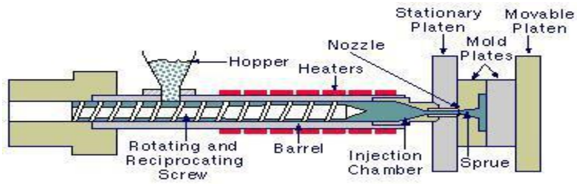

Fig. 2: Injection Moulding Machine in Operation

II. OBJECTIVE OF PRESENT WORK

So much of research is going on, out the usage of Flyash as reinforcement material with LLDPE Base material has not been exploited fully. Therefore, the study is carried-out in the present work.

III. PROPOSED METHODOLOGY

A. *Composite Material*

A composite material is a composed basic material with reinforcement of fibers, particles, flakes, and / or fillers and embedded in a matrix leading to polymer metals or ceramics. The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix.

B. *Constituents of PMCs*

The main constituents of PMCs are LLDPE as matrix material (base materials) and Flyash as reinforcement materials in the form of particles. This matrix material and reinforcement material are used to obtain in the different composite.

C. *Matrix Material - LLDPE*

Linear Low Density Polyethylene (LLDPE) has a significant number of short branches and hence it has shorter and more branches with chains. Therefore LLDPE higher tensile strength and higher impact and puncture resistance than the LDPE. It has a density of 0.91-0.94 g/cm^3. The LLDPE granules are shown in Figure-2 followed by the reinforcement material Flyash in Figure -3

Fig. 3: LLDPE Granules

D. *Reinforcement Material - Flyash*

Flyash is one of the residues generated in the combustion of coal. It is an industrial by-product recovered from the flue gas of coal burning electric power plants. Depending upon the source and makeup of the coal being burnt, the components of the fly ash produced vary considerably, but all fly ash includes substantial amounts of SiO_2, Lime, Al_2O_3.Therefore, larger application of fly ash is in the cement and concrete industries.

Fig.4: Flyash

IV. EXPERIMENTATION

A. *Preparation of PMC Samples*

In the present work, LLDPE Granules are considered as a Matrix Material and Flyash as a reinforcement Material to produce cylindrical rods, by mixing the LLDPE granules with Flyash. The mixture consisting of 90% of LLDPE and 10% of Flyash is shown in figure - 4. The parts those are going to be produced with 40 mm diameter and length of 70 mm are shown in figure-5 and with different combinations.

The polymer composite material is pushed forward from the feed hopper through the barrel towards the nozzle by a rotating screw (Refer Figure - 2)

The barrel is surrounding with band type electric heaters / heating coil to melt the polymer composite material with the temperatures varying between 100^{0}C to 175^{0}C. At the end of rotating screw the material converts into semisolid of viscous in nature and injected into mould cavity towards the nozzle by a rotating screw.

The material is injected into the mould cavity by the nozzle. The mould is closed and the nozzle of the extruder is pushed against the sprue bushing of the mould.

When the mould is completely filled, the screw remains stationary for some time to keep the plastic in the mould under pressure. This is called the hold time. During the hold time additional melt is injected into the mould to compensate for contraction due to cooling. For

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cooling the product, its takes for a period of time 10 to 16 sec. When the material in the mould has cooled sufficiently to obtain its shape, the mould opens and the parts are ejected from the mould. When the moulded part has been ejected, the mould closes and the cycle starts over again.

At the injection stage, the pressure developed 40 bar to 70 bar and injection speed is 20 rpm to 50 rpm.

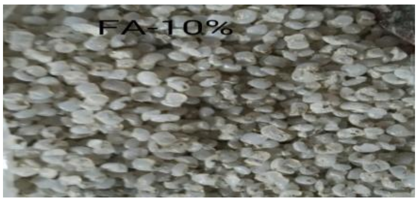

Fig. 5: The LLDPE - 90% + Flyash - 10% mixture.

Fig. 6: Ejected Components with different combinations

B. Taguchi Approach

Design of Experiments (DOE) is a popular method applied for inventing new processes, discovering more knowledge about the existing processes and finally achieves optimal solution. DOE usually has three processes as planning the given data, designing as per the array and analyzing the input values for conducting the experiment so that valid and objective conclusions can be achieved perfectly. As such the Taguchi approach is used in the present work.
The process consists of three stages:

- System Design: Selection of Objective Function.
- Parameter Design: Finalizing the levels of selected factors.
- Tolerance Design: Evaluating the final tolerance for each selected factor level.

Taguchi's specially designed method of Orthogonal Array (OA) is applied to select final design and conducted experiments. Taguchi's emphasis on minimizing deviation from target lead him to develop measures of the process output that incorporate both the location of the output as well as the variation. The measures are called signal to noise ratios. The Signal-to-Noise ratio provides a measure of the impact of noise factors on performance.

C. Influential Parameters

a) *Melting Temperature:* It is melting level of temperature to which the plastic material to be heated. This path begins when the material is transferred from the machine hopper into the heating cylinder of the injection unit. The material is injected into the mold where it travels along a runner system, through gates and into cavity. Hence, control of the melt temperature is essential all along that path.

b) *Injection Pressure:* It is the pressure applied on the injection screw when a material is being injected into the mold.

c) *Cooling Time:* It is a post injection, post holding pressure waiting period during which the tool remains closed so that the part may cool to an acceptable level, ideally the tool temperature. If cooling time is not sufficient, the part may come-out too hot and deform upon ejection; too long and not meeting the required size.

d) *Injection Speed:* It is directly affects the injection time and injection pressure and dictates how quickly the polymer is forced into the mould. If it is too slow the polymer may freeze before it has fully filled the mould, leading to an incomplete part; too high and it may result in polymer being forced into unwanted areas of the tool this is known as flashing.

Table 1: Selection of Influential Parameters and their levels

S. No.	Influential parameters	Level 1	Level 2	Level 3	Level 4
1	Melting Temperature, A (^{0}C)	100	125	150	175
2	Injection Pressure, B (Bar)	40	50	60	70
3	Cooling Time, D (Sec.)	10	12	14	16
4	Injection Speed, C (rpm)	20	30	40	50

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D. Selection of Orthogonal Array

Selection of best orthogonal array design, In an L16 (4^4) orthogonal array four levels of each factor are conducted where the selection of the array is done based on its suitability for four factors with four Levels as in Table-2, Table of L16 (4^4) (OA). The selection depends on the level of total degrees of freedom. The four different levels of selected factors are chosen based on the thermal properties of PMC's as shown in table 1 Levels and Control factors.

Table 2: Table of L16 (4^4) Orthogonal Array

Trial No.	Column No.			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

Table 3: Optimal Factor –level combinations of Experimental Trials

S. No.	Melting Temp. (^{0}C) A	Inj. Pr. (Bar) B	Cooling time (Sec) C	Inj. Speed (rpm) D
(1)	(2)	(3)	(4)	(5)
1	100	40	10	20
2	100	50	12	30
3	100	60	14	40
4	100	70	16	50
5	125	40	12	40
6	125	50	10	50
7	125	60	16	20
8	125	70	14	30
9	150	40	14	50
10	150	50	16	40
11	150	60	10	30
12	150	70	12	20
13	175	40	16	30
14	175	50	14	20
15	175	60	12	50
16	175	70	10	40

Determination of Optimal Factor-Level Combinations, The Control factor combination was arranged as per the orthogonal array design with 16 trials. Therefore, an L_{16} (4^4) orthogonal array with sixteen trials was applied. The design layout using the L_{16} OA is shown in Table 3 Optimal Factor-Level Combinations. Each single row represents an experiment having various combinations of factor levels.

Cumulative interpretation of experimental trials, Signal to noise (S/N) ratio is calculated on the values of Impact Strength, each test specimen was done according to design trials of OA, it is shown in Table 4. As Cumulative Experiment trial values.

S/N = -10 log (mean square of the inverse of the response)

$$\frac{S}{N} = -10\log_{10}\left[\frac{1}{n}\sum\frac{1}{y^2}\right]$$

MSD = Mean Square Deviation, y_i are the response observations and n is the number of trial. Hence, a Larger-the-better factor was selected for this experimental study.

The response values measured from the experiments and their corresponding S/N ratio values are tabulated in Table-6.1 Considering Table 4 the S.No. of the experimental is shown in column-1, Melting Temperature in column-2, injection Pressure in column-3, Cooling Time in column-4, Injection Speed in column-5 and Impact Strength (IS) in column-6 after experiment, the seventh column presents the S/N ratio for the Impact Strength for S/N ratio Column-7. By applying 'Larger-the-Better' type quality characteristic, the S/N Ratio response table for each level of the process parameters (Melting Temperature, Injection Pressure, Cooling Time and Injection Pressure) was created in the integrated manner and the results are given in the following stages.

Table-4: S/N Ratio Values for output Responses

S. No.	Melting Temp.	Inj. Pr.	Cool-ing Time	Inj. Speed	I S (N/m m^2)	S/N Ratio
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	100	40	10	20	1.725	4.736
2	100	50	12	30	1.975	5.911
3	100	60	14	40	1.775	4.983
4	100	70	16	50	1.825	5.225
5	125	40	12	40	1.8	5.105
6	125	50	10	50	1.875	5.460
7	125	60	16	20	1.925	5.688
8	125	70	14	30	1.95	5.800
9	150	40	14	50	1.9	5.575
10	150	50	16	40	1.825	5.225
11	150	60	10	30	1.825	5.225
12	150	70	12	20	1.875	5.460
13	175	40	16	30	1.85	5.343
14	175	50	14	20	1.825	5.225
15	175	60	12	50	1.66	4.402
16	175	70	10	40	1.85	5.343

V. RESULTS AND DISCUSSIONS

A. *Estimation of Optimal Levels of Parameters for Injection Moulding Responses Parameters*

Optimal levels for parameters various responses are estimated by S/N ratio analysis and the estimation are explained in the following.

Estimation of Optimal Levels of Parameters for Tensile strength

The Larger-the-Better quality characteristic is used to estimate the S/N ratio for Tensile Strength response of Injection Moulding parameters and the results are shown for Table-5. From the Table-5, it is observed that Melting Temperature is most influential parameter for Tensile Strength followed by Injection Pressure, Cooling Time and Injection speed. Hence, speed is the least influential parameter for Tensile Strength response. The performance characteristics for the S/N ratio are shown in Figure.7 from the graph it can be seen that the Tensile Strength, the optimal parameter levels are identified as 150^{0}C Melting Temperature, 50 Bar Injection Pressure, 12 Sec Cooling time and 30 rpm Injection speed.

Table-5: Mean S/N Response for Tensile Strength by Factor Levels

Level	Melting Temp. (^{0}C) A	Inj. Pr. (bar) B	Cooling Time (sec) C	Inj. Speed (RPM) D
(1)	(2)	(3)	(4)	(5)
1	14.88	14.35	17.87	16.97
2	15.24	18.36	18.24	18.23
3	19.97	17.61	16.84	17.49
4	18.78	18.55	15.93	16.18
Delta	5.08	4.2	2.31	2.05
Rank	1	2	3	4

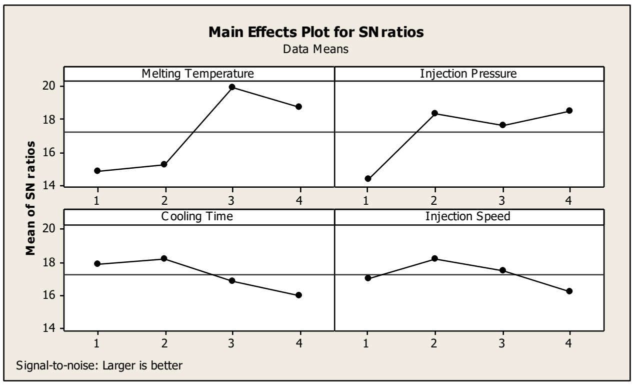

Fig. 7: Effect of the Injection Moulding Parameters on the Tensile Strength

Estimation of Optimal Levels of Parameters for Hardness Test

The Larger-the-Better quality characteristic is used to estimate the S/N ratio for Tensile Strength response of Injection Moulding parameters and the results are shown for Table-6. From the Table-6, it is observed that Injection Pressure is most influential parameter for Rockwell Hardness followed by Injection speed, Cooling Time and Melting Temperature. Hence, Melting Temperature is the least influential parameter for Rockwell Hardness Test response. The performance characteristics for the S/N ratio is shown in Figure.8, from the graph it can be seen that the Rockwell Hardness, the optimal parameter levels are identified as 125 ^{0}C

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Melting Temperature, 40 Bar Injection Pressure, 10 Sec Cooling time and 40 rpm Injection speed.

Table-6: Mean S/N Response Table for Hardness by Factor Levels

Level	Melting Temperature	Injection Pressure	Cooling Time	Injection Speed
(1)	**(2)**	**(3)**	**(4)**	**(5)**
1	38.66	38.9	38.79	38.59
2	38.77	38.55	38.7	38.71
3	38.74	38.6	38.55	38.88
4	38.55	38.66	38.67	38.53
Delta	0.22	0.35	0.23	0.35
Rank	4	1	3	2

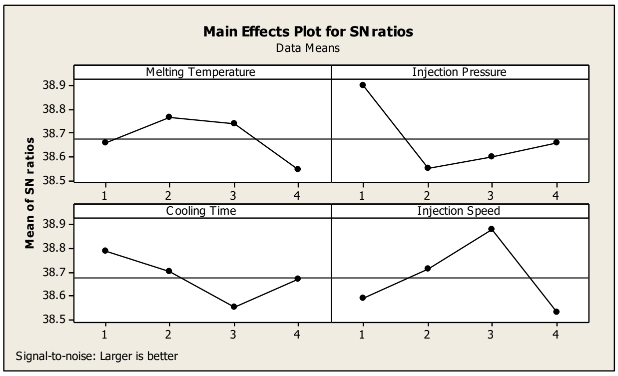

Fig. 8: Effect of the Injection Moulding Parameters on the Hardness

A. Analysis of Variance Approach

The percentage contributions of each injection moulding parameters on output response are estimated using ANOVA approach and the results are given in the following.

a) Estimation of Significant Parameters

The most effective factor affecting among the Responses was determined by performing Analysis of Variance (ANOVA). ANOVA for various Responses and significant parameters affecting the responses are discussed in the following.

b) Estimation of Significant Parameters of Tensile Strength

The percentage of contribution of Injection Moulding parameters on Tensile strength is depicted in ANOVA Table-7. That the Melting Temperature, Injection pressure, Cooling time and Injection speed have significant effects on the Tensile strength. It can be observed from Table-7, that the Melting Temperature, Injection Pressure, Cooling Time and Injection Speed are affecting the Tensile Strength by 50.706%, 30.024%, 8.568%, and 5.844% respectively.

Table 7: Results of the Analysis of Variance (ANOVA) for Tensile Strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Melting Temp	3	77.394	77.394	25.798	10.44	0.043	50.706
Inj. Pr.	3	45.826	45.826	15.275	6.18	0.084	30.024
Cooling Time	3	13.078	13.078	4.359	1.76	0.326	8.568
Inj. Speed	3	8.921	8.921	2.974	1.2	0.441	5.844
Residual Error	3	7.412	7.412	2.471			4.856
Total	15	152.631					100

c) Estimation of Significant Parameters of Hardness

The percentage of contribution of Injection Moulding parameters on Hardness is depicted in ANOVA Table-8. That the Melting temperature, Injection pressure, Cooling time and Injection speed have significant effects on the Hardness. It can be observed from Table-6.8, that the Melting Temperature, Injection Pressure, Cooling Time and Injection Speed are affecting the Hardness by 6.228%, 15.99%, 6.223%, and 15.420% respectively.

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Table 8: Results of the Analysis of variance (ANOVA) for Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of contribution
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Melting Temp	3	0.1133	0.1133	0.03777	0.11	0.948	6.228
Inj. Pr.	3	0.291	0.291	0.09699	0.28	0.835	15.99
Cooling Time	3	0.1132	0.1132	0.03773	0.11	0.948	6.223
Inj. Speed	3	0.2805	0.2805	0.09349	0.27	0.842	15.420
Residual Error	3	1.0211	1.0211	0.34036			56.135
Total	15	1.819					100

VI. CONCLUSION

The production of cylindrical rods are produced by Injection Moulding considering the 90% of Linear low density polyethylene (LLDPE) as matrix material and 10% of Fly Ash as reinforcement material. The Taguchi Method is considered for, S/N ratios was used for finding the optimal set of control parameters

The results show that, For Tensile strength the optimal parameter levels are identified as A3, B2, C2 and D2 i.e. Melting Temperature 150^{0}C, Injection Pressure 50 Bar, Cooling time 12 Sec and Injection speed 30 rpm. Melting temperature is the most significant parameter while injection speed is the insignificant parameter. The ANOVA shows contribution of parameters i.e. the Melting Temperature, Injection Pressure, Cooling Time and Injection Speed are affecting the Tensile Strength by 50.706%, 30.024%, 8.568%, and 5.844% respectively.

For Hardness the optimal parameter levels are identified as A2, B1, C1 and D3 i.e. Melting Temperature 125 ^{0}C, Injection Pressure 40 Bar, Cooling Time 10 Sec and Injection speed 40 rpm. Injection pressure is the most significant parameter while Melting temperature is the insignificant parameter. The ANOVA shows contribution of parameters i.e. the Melting Temperature, Injection Pressure, Cooling Time and Injection Speed are affecting the Hardness by 6.228%, 15.99%, 6.223%, and 15.420% *respectively.*

The influence of all factors has been identified and believed can be a key factor in helping mould designers in determining optimum process conditions injection molding parameters.

Scope for future work

The scope for further improvement, the following suggestions may prove useful for future work:

- HDPE and LDPE as matrix material
- Percentage of reinforcement material beyond the levels considered for this work.
- Aluminum oxide, and Boron carbide may be considered as reinforcement materials.
- Optimization can be performed by Grey Relation Analysis (GA), Fuzzy Logics and Neural Networks and Regression Analysis etc.,

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