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Comparative Analysis of Polypropylene Component manufactured by FDM and Injection Molding Technology

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Abstract: FDM or 3D printing is a process of produce components by adding one layer to another layer with the ability to create or makes complex parts from thermoplastics. Injection molding is a process for manufacturing parts from thermosetting and thermoplastic materials. The quality of 3D printed and injection molding parts depends upon their process parameters. The work focuses on the experimental analysis of polypropylene (PP) material by 3D printing and injection molding process. This works provides the dependence of Hardness and Tensile strength on input process parameters. This paper shows Optimization of Hardness value and Tensile strength of Polypropylene (PP) material by injection molding and FDM technology.
Keywords: FDM, Injection molding, Polypropylene (PP), Tensile strength, Hardness

I. INTRODUCTION

FDM or 3D printing is a process of produce or manufacturing component by adding one layer upon another layer with computer-controlled methods. A 3D printer can produce any complex shapes designed. Producing the part of the complex shape required a predefined file format.STL format. There are many types of 3D printing processes that are available are fused deposition modeling (FDM), selective laser sintering (SLS), Stereolithography (SLS). In this work, FDM 3D printing technology was used.

Injection molding is a process of produce or manufacturing component with a given mold by injecting raw material in the mold cavity with the help of a screw. The process of injection molding is costly due to the mold costing, as compared to the 3D printing process injection molding is a very expensive process. In the injection molding process for producing any shape of the component mold or Die is required and the cost of mold or Die is very high.

In this paper, the work shows a comparative study of Polypropylene (PP) material by FDM and injection molding technology. A Taguchi Optimization method is used for study the impact of input parameters on hardness and tensile strength of specimen.

II. METHODOLOGY

In this study, for optimization of input process parameters MINITAB 17 software is used. The software gives an optimum set of input process parameters with the Analysis of variance (ANOVA) and Design of Experiment (DOE). The Design of Experiment (DOE) gives the number of set of process parameters and Analysis of variance (ANOVA) is gives the optimum set of input process parameters with response variables and graphs in the form of signal to noise ratio and residual plots and is also gives the percentage of contribution of process parameters with Regression equation of that process parameters.

For the optimization, I have selected two process parameters three levels, and two response variables. The process parameters are Temperature and Speed and Response variables are Tensile Strength and Hardness. I have selected the two process parameters because the range of temperature and speed same in the FDM and injection molding techniques.

To study the impact of selected input process parameters on given response variables. The experiments are performed by the Design of the Experiment (DOE) and its analysis is done by regression or analysis of variance (ANOVA).

A Design of Experiment (DOE)

The Design of Experiment (DOE) is a powerful optimization tool that was introduced by Genichi Taguchi. It is also known as the Taguchi method. This method is used in industries to produces better optimize products with better quality, minimizes variation, and stable the quality of a product. It helps to produce optimized products by reducing the no. of an experiment. The selected parameters and its levels as shown in Table 1.

Table 1 Process Parameters with its levels

Process Parameters	Level 1	Level 2	Level 3
Temperature (°C)	210	220	230
Speed (mm/s)	40	45	50

1) *Orthogonal Array:* The orthogonal array is a matrix that is used to determine all possible combinations of factors and its levels. Orthogonal array gives the information about several experiments that are to be performed, based on several input parameters and their level selected. In this study, the L9 orthogonal array is designed for two parameters and three levels. The orthogonal array for Design of Experiment as shown in Table 2

Table 2 Orthogonal array

Experiment No	Temperature (°C)	Speed (mm/s)
1	210	40
2	210	45
3	210	50
4	220	40
5	220	45
6	220	50
7	230	40
8	230	45
9	230	50

B Tensile Test

The tensile test was performed as per the American society for testing and materials (ASTM) D638 Standard. All the test specimens of Injection molding and 3D printing are made by ASTM D638 standard. Samples are tested on MCS 5 tonne universal testing machine. The tensile test specimen dimension as shown in Fig. 1

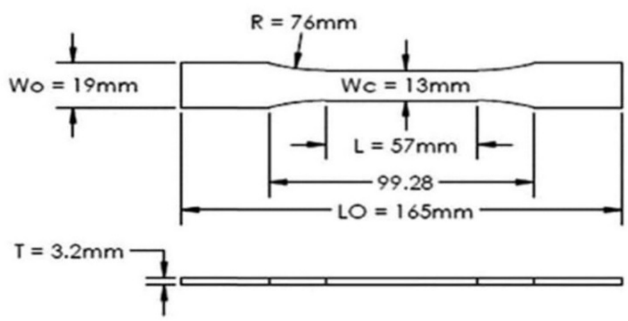

Fig. 1 Tensile test specimen dimension

1) *3D printed Specimen Testing:* The 3D printed hardness testing and the tensile testing specimen are designed with the CATIA V5 software and this CAD file is converted into the Standard Tessellation Language (.STL) file and for the slicing the (.STL) file it is imported into the CURA software. The 3D printed test specimen is made as per the orthogonal array as shown in Table 2. The test specimen material is Polypropylene (PP). Fig. 2 shows the test specimen mounting in Universal Testing Machine (UTM). Fig. 3 shows 3D printed test specimen before testing and Fig. 4 shows 3D printed test specimen after testing

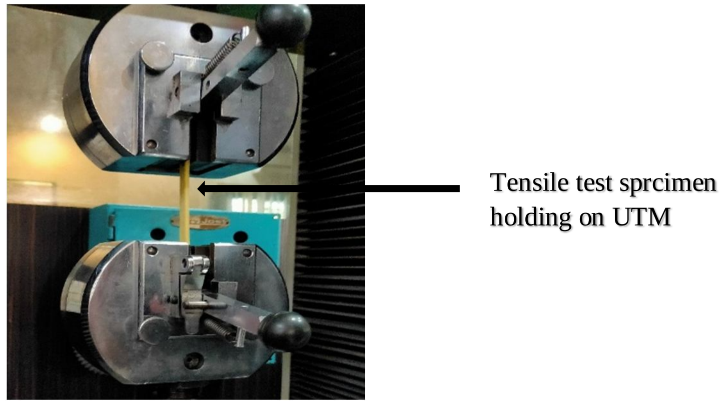

Fig. 2 Tensile testing specimen

Fig. 3 3D printed specimen before testing

Fig. 4 3D printed specimen after testing

2) *Injection Molding Specimen:* The injection molding test specimen is made by the ASTM D 638 standard. All 9 specimen are made by the orthogonal array as shown in Table 2. The specimen material of injection molding is Polypropylene (PP). The specimen is manufacture on JIT 80 injection molding machine. Fig. 5 shows the injection molding test specimen before testing and Fig. 6 shows the injection molding test specimen after testing.

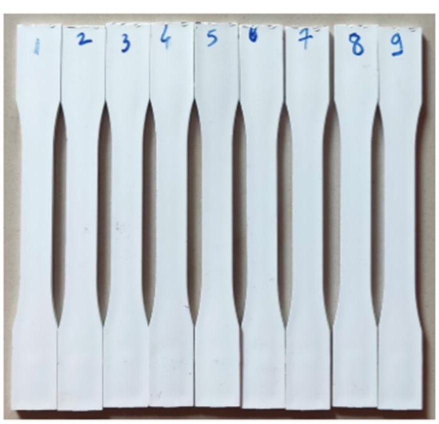

Fig. 5 Injection molding specimen before testing

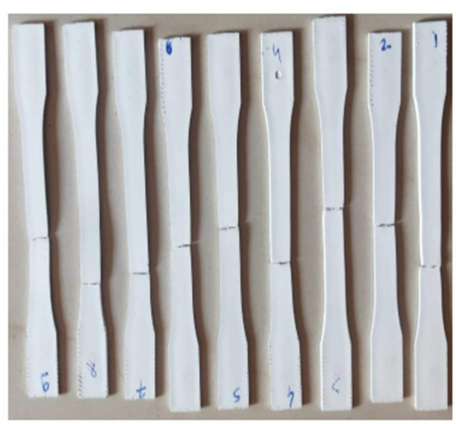

Fig. 6 Injection molding test specimen after testing

C Hardness Test

The hardness test was performed as per the American society for testing and materials (ASTM) D2240 Standard. All the test specimens of Injection molding and 3D printing are made by ASTM D2240 standard. As per the ASTM D2240, the thickness of the specimen required 6.4 mm, and no problem with the size and shape of the specimen may be in a square or circular form. The Shore D hardness was performed by a hardness tester. The indenter is press on the specimen up to the limit. Fig. 7 shows the Shore D hardness performed on 3D printed and injection molding

Fig. 7 Shore D hardness tester

The 3D printed hardness test specimen and Injection molding hardness test specimen are made as per the orthogonal array. The material of the hardness test specimen was Polypropylene (PP). The thickness of the specimen is 6.4 mm as per the ASTM D2240 standard. The 3D printed hardness test specimen as shown in Fig. 8 and the Injection molding hardness test specimen as shown in Fig. 9

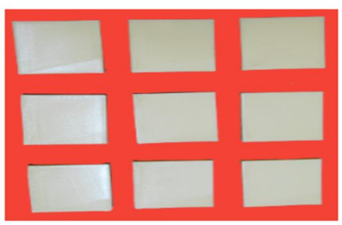

Fig. 8 3D printed test specimen

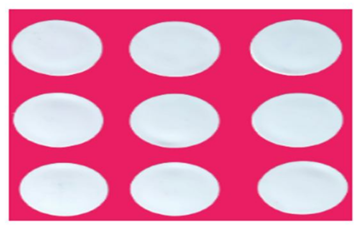

Fig. 9 Injection molding test specimen

III. RESULT AND DISCUSSION

The tensile test is carried out on MCS universal testing machine as per the ASTM D638 standard and hardness test carried out by shore D hardness tester by ASTM D2240 and optimization is performed by MINITAB 17 software. Table 3 shows the selected process parameters with their response variables according to the experimental run.

Table 3 Experimental Data for 3D printed specimen testing

Experiment No	Temperature (°C)	Speed (mm/s)	Tensile Strength (MPa)	Hardness value (Shore D)
1	210	40	26.51	70
2	210	45	29.41	74
3	210	50	29.71	75
4	220	40	30.78	73
5	220	45	29.37	76
6	220	50	33.35	72
7	230	40	30.53	75
8	230	45	30.62	76
9	230	50	32.53	77

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A. 3D printed specimen testing

All tensile tests and hardness test specimen are made as per the ASTM D638 and ASTM D2240 standard respectively.

1) *Optimization:* By the Taguchi optimization method optimization of input process parameters was carried out. The Response Table for Signal to Noise Ratios as shown in Table 4 and Response table for means as shown in Table 5.

Table 4 Response Table for Signal to Noise Ratios

Level	Temperature (°C)	Speed (mm/s)
1	31.49	31.67
2	32.15	31.86
3	32.22	32.34
Delta	0.73	0.67
Rank	1	2

Table 5 Response Table for means

Level	Temperature (°C)	Speed (mm/s)
1	50.77	50.97
2	52.25	52.40
3	53.31	53.27
Delta	2.84	2.30
Rank	1	2

From the table, it was found that the highest SN ratio for temperature is 32.22 for the 3rd level, highest SN ratio for speed is 32.34 for the 3rd level. Hence, optimized parameters to maximize the hardness and tensile strength were obtained from the response table. The maximum hardness and tensile strength were obtained at 230°C temperature and 50 mm/s speed. Fig. 10 shows the graph of SN ratio and Fig. 11 shows a graph of means

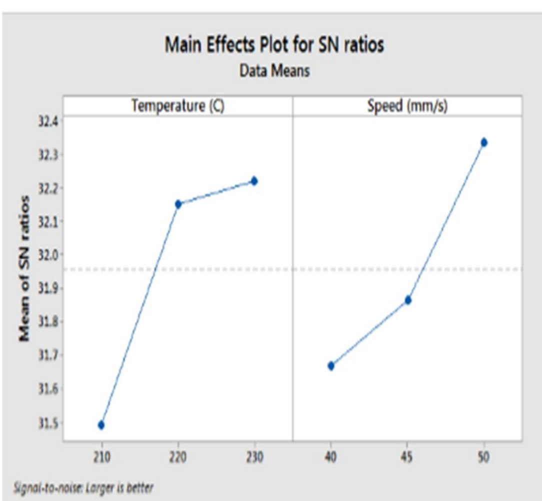

Fig. 10 Main effect plot for SN ratios

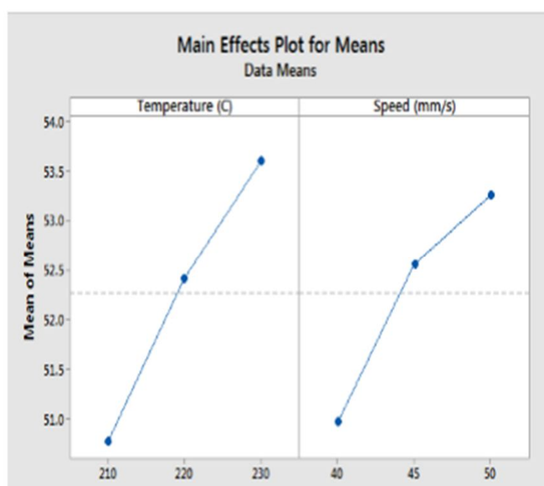

Fig. 11 Main effect plot for Means

2) *Analysis of variance (ANOVA):* ANOVA is a process of evaluating quantitative contribution of controlled input parameter on the response variable, thus it gives information about how the impact of each controlled input process parameter on the result of response variables. For the optimized parameter, the ANOVA method is perform and checked the *p*-value as shown in Table 6. The *p*-value of the input process parameter less than 0.05, the significance of that corresponding term is established. *P*-value should be greater than 0.05. Table 6 shows the results of ANOVA.

Table 6 ANOVA result of tensile strength vs process parameter

Source	Degree of freedom (DF)	Adj sum of square	Adj mean of square	F-value	*p*-value
Temperature	2	14.086	7.043	4.94	0.083
speed	2	11.243	5.621	3.94	0.113
Error	4	5.700	1.425		
Total	8	31.029			

Regression Equation

Tensile Strength = 30.312 - 1.769 Temperature (C)_210 + 0.854 Temperature (C)_220 + 0.914 Temperature (C)_230
1.039 Speed (mm/s)_40- 0.512 Speed (mm/s)_45 + 1.551 Speed (mm/s)_50 (1)

Table 7 ANOVA result of Hardness vs process parameter

Source	Degree of freedom (DF)	Adj sum of square	Adj mean of square	F-value	*p*- value
Temperature	2	16.222	8.111	2.92	0.165
speed	2	9.556	4.778	1.72	0.289
Error	4	11.111	2.778		
Total	8	36.889			

Regression Equation

Hardness = 74.111 - 1.111 Temperature (C)_210 - 0.778 Temperature (C)_220 + 1.889 Temperature (C)_230 -
1.444 Speed (mm/s)_40 + 0.889 Speed (mm/s)_45+ 0.556 Speed (mm/s)_50 (2)

The percentage of contribution is 53% temperature and 47% speed as shown in Fig. 12 and Fig. 13 shows the graph of tensile strength and Hardness normal probability plot.

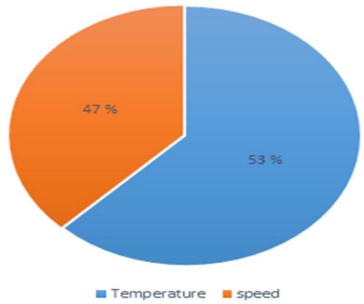

Fig. 12 Percentage contribution of Process parameters

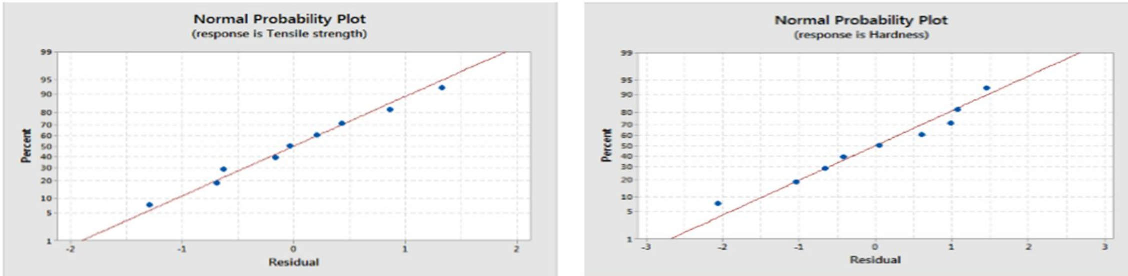

Fig. 13 Normal probability graph of tensile and hardness

By the ANOVA results, it is found that when the input process parameters values increase then the response variables hardness value and tensile strength are also increased. The SN ratio graph shows the hardness and tensile strength is maximum at 230°C temperature and 50 mm/s speed. ANOVA gives a relationship between process parameters and response variables.

B. Injection Molding Specimen Testing

All the injection-molded tensile and hardness test specimen are made by the ASTM D638 and ASTM D2240 standard respectively. The material of both test specimens is Polypropylene (PP). all test specimen is made by design orthogonal array by MINITAB 17 software as shown in Table 2 and experimental data for an optimization process as shown in Table 8.

Table 8 Experimental Data for Injection molding specimen testing

Experiment No	Temperature (°C)	Speed (mm/s)	Tensile Strength (MPa)	Hardness value (Shore D)
1	210	40	20.23	70
2	210	45	17.61	69
3	210	50	21.98	72
4	220	40	17.61	74
5	220	45	19.48	73
6	220	50	17.63	75
7	230	40	23.48	72
8	230	45	18.10	74
9	230	50	22.85	76

1) *Optimization:* By the Taguchi optimization method optimization of input process parameters was carried out. Response Table for Signal to Noise Ratios as shown in Table 9 and response table for means as shown in Table 10.

Table 9 Response Table for Signal to Noise Ratios

Level	Temperature (°C)	Speed (mm/s)
1	28.63	28.82
2	27.96	28.02
3	29.23	28.99
Delta	1.27	0.97
Rank	1	2

Table 10 Response Table for means

Level	Temperature (°C)	Speed (mm/s)
1	45.14	46.22
2	46.12	45.20
3	47.57	47.41
Delta	2.43	2.21
Rank	1	2

From the table, it was found that the highest SN ratio for temperature is 29.23 for the 3rd level, highest SN ratio for speed is 28.99 for the 3rd level. Hence, optimized parameters to maximize the hardness and tensile strength were obtained from the response table. The maximum hardness and tensile strength were obtained at 230°C temperature and 50 mm/s speed. Fig. 14 shows the graph of SN ratio and Fig. 15 shows a graph of means

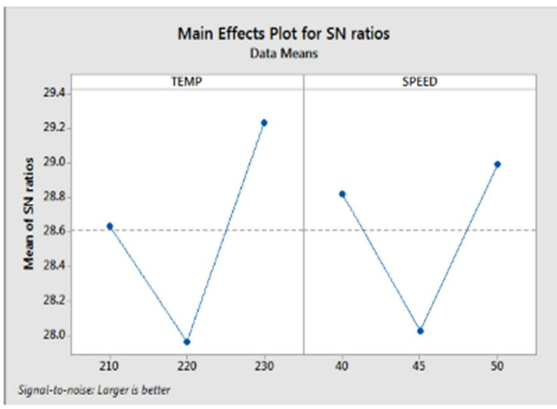

Fig. 14 Main effect plot for SN ratios

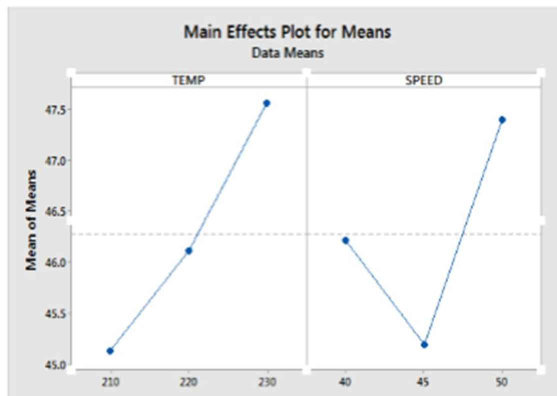

Fig. 15 Main effect plot for Means

2) *Analysis of variance (ANOVA):* The result of tensile testing vs input process parameters as shown in Table 11 and the result of hardness vs input process parameters as shown in Table 12

Table 11 ANOVA result of tensile strength vs process parameter

Source	Degree of freedom (DF)	Adj sum of square	Adj mean of square	F-value	*p*-value
Temperature	2	15.73	7.864	1.65	0.301
speed	2	10.19	5.096	1.07	0.425
Error	4	19.09	4.773		
Total	8	45.01			

Regression Equation

Tensile strength = 19.886 + 0.05 Temp_210 - 1.65 Temp_220 + 1.59 Temp_230 + 0.55 speed_40 - 1.49 speed_45 + 0.93 speed_50 (3)

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Table 11 ANOVA result of hardness vs process parameter

Source	Degree of freedom (DF)	Adj sum of square	Adj mean of square	F-value	*p*- value
Temperature	2	26.899	13.4444	14.24	0.015
speed	2	10.889	5.4444	5.76	0.066
Error	4	3.778	0.9444		
Total	8	41.556			

Regression Equation

Hardness = 72.778 - 2.444 Temp_210 + 1.222 Temp_220 + 1.222 Temp_230 - 0.778 speed_40 - 0.778 speed_45 + 1.556 speed_50 (4)

The percentage of contribution is 54% temperature and 46% speed as shown in Fig. 16 and Fig. 17shows the graph of tensile strength and Hardness normal probability plot

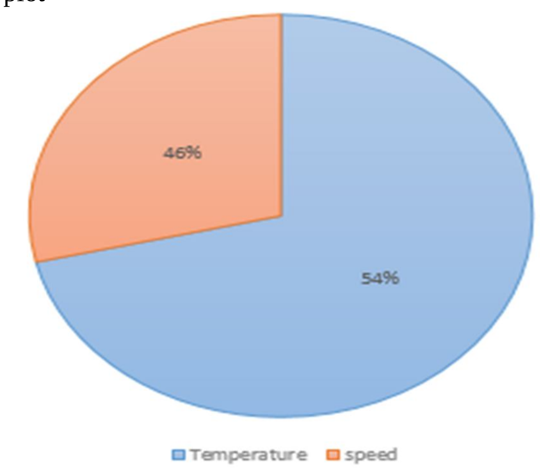

Fig. 16 Percentage contribution of Process parameter

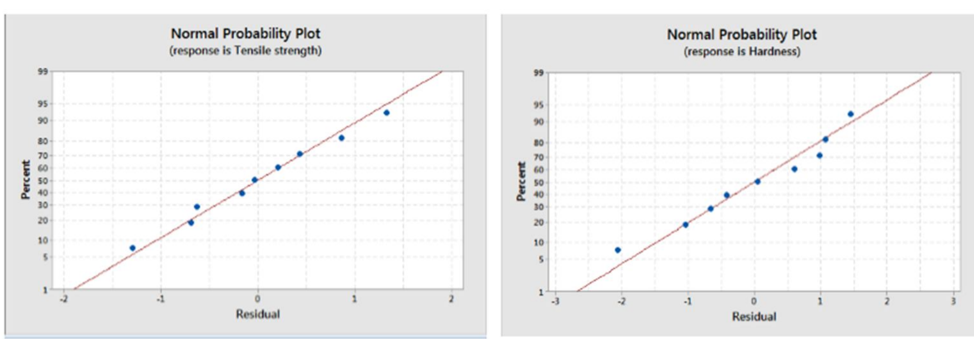

Fig. 17 Normal probability graph of tensile and hardness

According to the ANOVA results, it is found that when the process parameters values increase then the response variables hardness value and tensile strength are also increased. The SN ratio graph shows the hardness and tensile strength are maximum at 230°C temperature and 50 mm/s speed. ANOVA gives a relation between response variables and input process parameters.

IV. CONCLUSIONS

A. In the present work, an attempt has been a comparison of polypropylene (PP) material by FDM and injection molding technology. The comparison was done by optimizing of process parameters of both processes.

B. In this study impact of input process parameters of injection molding technique on the mechanical properties like hardness and tensile strength of polypropylene (PP) material is analyzed.

C. From the result of the 3D printed test was observed that maximum tensile strength 32.53 MPa and hardness 77 of polypropylene (PP) material was achieved for temperature 230°C and speed 50 mm/s.

D. From the result of the injection molding test was observed that maximum tensile strength 22.85 MPa and hardness 76 of polypropylene (PP) material achieved for temperature 230°C and speed 50 mm/s.

E. When we compared the FDM and injection molding technology, from the results hardness and tensile strength of 3D printing technology is better as compared to injection molding technology i.e tensile strength is 32.53 MPa and hardness is 77 for temperature 230°C and speed 50 mm/s

F. Hence by the results, the hardness and tensile strength of 3D printed Polypropylene (PP) material are better as compared to injection molded Polypropylene (PP) material.

V. ACKNOWLEDGMENT

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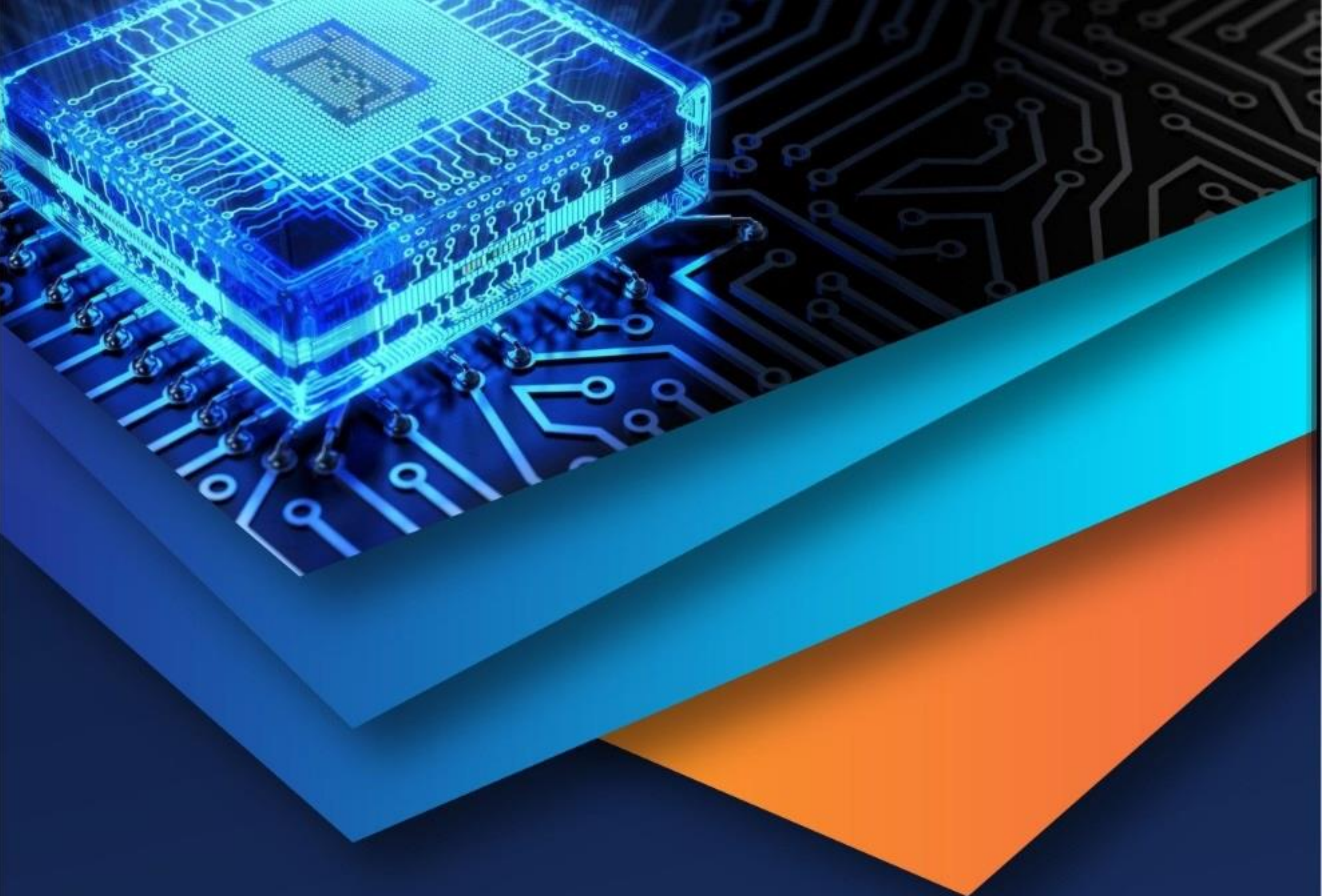

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