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# EFFECT OF FDM PROCESS PARAMETERS IN ABS PLASTIC MATERIAL

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***Abstract—*** The overarching aim of this work is to make an attempt to study the effect of FDM process parameters using ABS plastics. Numerous interactive parameters are involved in Fused Deposition Modeling (FDM) process where a small change in a single parameter or a combination of parameters may produce a considerable effect in both economical and technical factors. In the present study Acronitrile Butadiene Styrene is the material considered. The major FDM parameters such as Infill Density, Layer thickness, Shell thickness, Raster width, Air gap, Speed are considered for mechanical testing and dimensional accuracy of the printed specimens. The major parameters Layer thickness, Infill density etc have shown considerable effect over model building time, material consumption and mechanical properties of the material considered for study.

***Keywords*** — ABS Plastics , FDM , Rapid Prototyping , Infill Density , Layer Thickness,Model building time

## I. INTRODUCTION

The evolution and continuous growth of Rapid Prototyping (RP) techniques from the late 1980's have shown a propitious path for the product designers and manufacturing engineers in creating the prototypes or conceptual models for testing purposes.RP techniques are adopted to save time and cut costs at every stage of the product development process. Many RP techniques have been developed which are commercially available and each of them have potential application in the fields of Engineering ,Architecture and Medical due to their flexibility in building models at a faster rate with higher part quality.

Fused Deposition Modeling is one of the RP technique developed by Stratasys Inc, a leading 3D printer manufacturing firm headquartered at United States. In FDM , material is stored as a filament in a spool or catridge.Rollers then guide the filament to a liquefier where it is heated to a semi liquid state and extrude through a nozzle.FDM has become a widely used additive fabrication technologies. A plastic filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. The nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical directions. As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. the plastic cools and hardens immediately after being squirted from the nozzle and bonds to the layer below.The Fig 1 shows the schematic arrangement of FDM process.

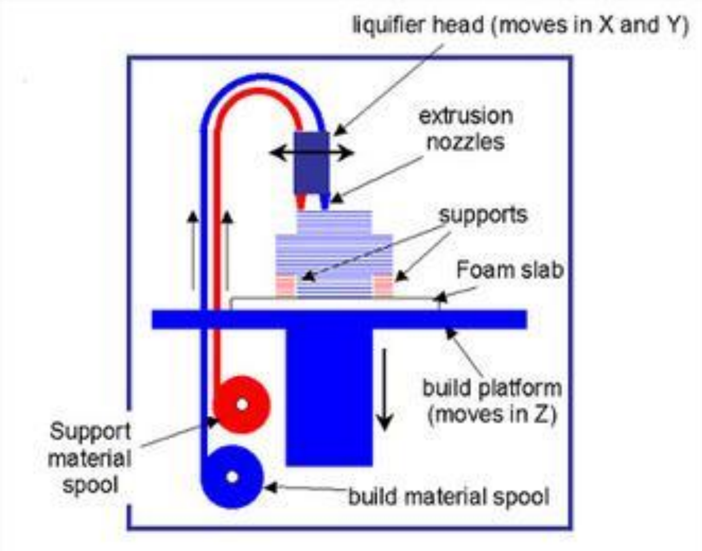


Fig. 1: Fused Deposition Modeling Process

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## II. FDM PROCESS PARAMETERS AND MATERIALS

A process parameter is one which has a strong connection with the properties and quality characteristics of the end product. More than 20 process parameters are involved in FDM process as reported by various researchers. The major FDM process parameters are discussed below.

1. **Layer Thickness (LT):**
Layer thickness is the measure of height of each successive addition of material. Increase in layer thickness generally reduces the part strength.
2. **Infill Density (ID):**
The amount of plastic inside the printed part. A higher infill density means more material is used and more time it takes to fill the part.
3. **Air Gap (AG):**
Air Gap is the space between two adjacent layers when they are printed. The air gap plays a vital role in the strength of the specimen.
4. **Raster Width (RW):**
It refers to the space between the beads of deposited FDM material .
5. **Speed (S) direction:**
The printing speed at which the material is deposited to create the complete model.
6. **Part Orientation (PO):**
It refers to the inclination of part in a build platform with respect to X,Y,Z axis.

Fused deposition modeling uses the thermoplastics PLA, ABS, ABSi, polyphenylsulfone (PPSF), polycarbonate (PC), PETG and Ultem 9085. In the present work ABS material is considered. ABS combines the strength and rigidity of acrylonitrile and styrene polymers with the toughness of polybutadiene rubber.It is considered superior for its hardness, gloss, toughness, and electrical insulation properties. It finds application in computer keyboard, power-tool housing, LEGO toys and automotive dashboards.It is available in variety of colors: White, blue, black, yellow, green and red.

## III. PREPARATION OF SPECIMEN

In the present work, ABS material in the form of a filament is converted into specimen in two ways. (a) Specimen for mechanical testing by varying five major FDM parameters. (b) A Gear component to check dimensional accuracy by varying three major FDM parameters as per $L_4$ Orthogonal array created by Minitab 17.0. The various properties of ABS material used in the present work are shown in Table 1

**Table 1 Properties of ABS Filament**

| S.No | Property | Value |
|---|---|---|
| 1 | Density (g/cm$^3$) | 1.04 |
| 2 | Tensile Strength (MPa) | 6.5 |
| 3 | Young's Modulus (MPa) | 1031 |
| 4 | Impact Strength (KJ/m$^2$) | 39.3 |
| 5 | Impact Energy (mJ) | 1500 |
| 6 | Flexural Modulus (MPa) | 1965.3 |

### *A. Specimen for Mechanical Testing*

In the preparation of Specimen for mechanical testing (Tensile,Bending,Impact) the specimens are modeled using CURA 15.04.06 software which has the feature of varying the major FDM parameters considered for mechanical testing. After creating the specimen model the software generates an appropriate G code to input the machine .The specimens are printed by using Maker Pi 2048 a Chinese made machine by following the IS1608:2005 standard followed by Scientific and Industrial Testing and Research Centre (SITARC) Promoted by SIEMA and CODISSIA,Coimbatore.

A total of 9 tensile, 3 bending, 6 impact specimens are prepared by different printing conditions. The specimens are prepared by three different infill densities (30% , 40 % , 50%) .The other major FDM parameters varied are Layer thickness(LT), Raster Width(RW), Shell Thickness (ST) , Air Gap (AG), Printing Speed (S).The variation in major process parameters are shown in Table 2.

**Table 2 Major FDM Parameters varied**

| S.No | Parameter | Low Value | Medium Value | High Value |
|---|---|---|---|---|
| 1 | Infill Density (%) | 30% | 40% | 50% |
| 2 | Layer Thickness (mm) | 0.2 | 0.25 | 0.3 |
| 3 | Raster width (mm) | 0.305 | 0.605 | 0.80 |
| 4 | Air Gap(mm) | 0 | 0.25 | 0.50 |
| 5 | Speed (mm/s) | 45 | 50 | 55 |

The various printing conditions for tensile , bending and impact testing are shown in Table 3,4,5.

**Table 3 Tensile Specimen printing conditions**

| S.NO | ID | PCN | LT | RW | ST | AG | S |
|---|---|---|---|---|---|---|---|
| 1 | 30 | 1 | 0.2 | 0.305 | 0.5 | 0 | 45 |
| 2 | 30 | 2 | 0.25 | 0.605 | 1 | 0.25 | 50 |
| 3 | 30 | 3 | 0.3 | 0.800 | 1.5 | 0.5 | 55 |
| 4 | 40 | 1 | 0.2 | 0.305 | 0.5 | 0 | 45 |
| 5 | 40 | 2 | 0.25 | 0.605 | 1 | 0.25 | 50 |
| 6 | 40 | 3 | 0.3 | 0.800 | 1.5 | 0.5 | 55 |
| 7 | 50 | 1 | 0.2 | 0.305 | 0.5 | 0 | 45 |
| 8 | 50 | 2 | 0.25 | 0.605 | 1 | 0.25 | 50 |
| 9 | 50 | 3 | 0.3 | 0.800 | 1.5 | 0.5 | 55 |

**Table 4 Bending Specimen printing conditions**

| S.NO | ID | PCN | LT | RW | ST | AG | S |
|---|---|---|---|---|---|---|---|
| 1 | 50 | 1 | 0.2 | 0.305 | 0.5 | 0 | 45 |
| 2 | 50 | 2 | 0.25 | 0.605 | 1 | 0.25 | 50 |
| 3 | 50 | 3 | 0.3 | 0.800 | 1.5 | 0.5 | 55 |

**Table 5 Impact specimen printing condtions**

| S.NO | ID | PCN | LT | RW | ST | AG | S |
|---|---|---|---|---|---|---|---|
| 1 | 30 | 1 | 0.2 | 0.305 | 0.5 | 0 | 45 |
| 2 | 30 | 2 | 0.25 | 0.605 | 1 | 0.25 | 50 |
| 3 | 30 | 3 | 0.3 | 0.800 | 1.5 | 0.5 | 55 |
| 4 | 50 | 1 | 0.2 | 0.305 | 0.5 | 0 | 45 |
| 5 | 50 | 2 | 0.25 | 0.605 | 1 | 0.25 | 50 |
| 6 | 50 | 3 | 0.3 | 0.800 | 1.5 | 0.5 | 55 |

The other machine parameters which are kept constant during the printing of specimens are listed in table 6

**Table 6 Printing Machine Parameters**

| S.No | Parameter | Value |
|---|---|---|
| 1 | Bed Size (mm) | 200*200*480 |
| 2 | Envelope size (mm) | 450*450*830 |
| 3 | Envelope Temp (C) | 180 -250 |
| 4 | Filament Thickness (mm) | 1.75 |
| 5 | Filament Color | Green |
| 6 | Part Orientation | Flat |
| 7 | Infill pattern | Honey comb |
| 8 | Printing cost | Rs 4 |

The Fig 2,3,4 shows the tensile, bending , impact specimens created using Makerpi machine for mechanical testing

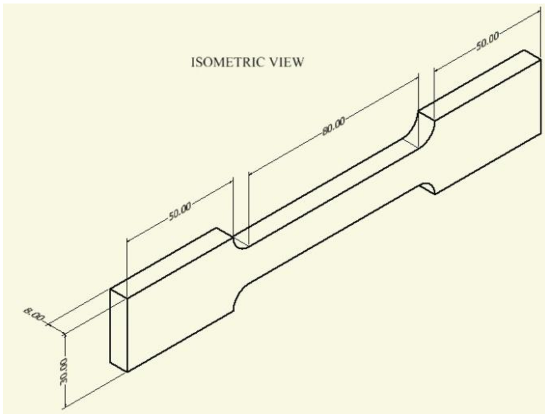


**Fig 2 Tensile Testing Specimen**

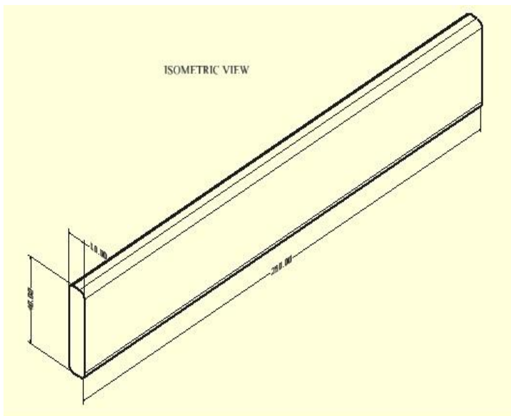


**Fig 3 Bending test specimen**

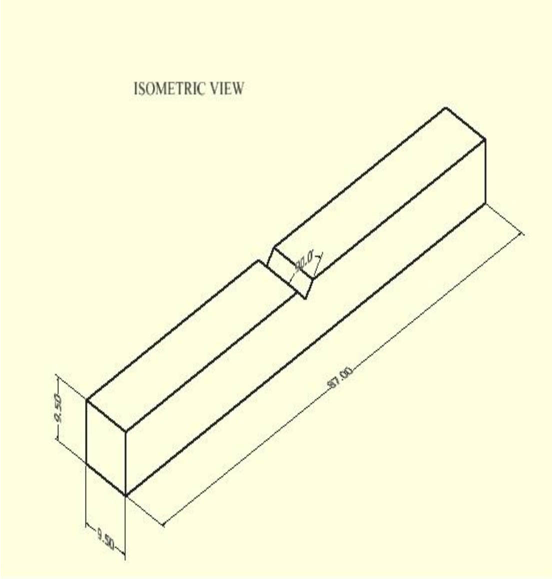


**Fig 4 Impact testing specimen**

The model prepared in the software is saved as a STL file and inputted to the FDM machine as a G code. The machine reads the G code and prints the specimen according to the instruction provided.

As the printing condition for tensile , bending and impact specimens vary with major FDM parameters, the economical factors like Model building time , Material Consumption and Cost of printing also gets affected due to the change in FDM process parameters.The table 6,7,8 shows the effect the of FDM parameters over the economical factors in printing ABS plastic material.

**Table 6A Economical factors for tensile specimen**

| S.No | ID | PCN | Time (Mins) | Material consumed (gms) | Cost (Rs) |
|---|---|---|---|---|---|
| 1 | 30 % | 1 | 83 | 20 | 332 |
| 2 | 30 % | 2 | 68 | 23 | 272 |
| 3 | 30 % | 3 | 66 | 27 | 264 |
| 4 | 40% | 1 | 82 | 23 | 328 |
| 5 | 40% | 2 | 75 | 26 | 300 |
| 6 | 40% | 3 | 71 | 29 | 284 |
| 7 | 50% | 1 | 89 | 27 | 356 |
| 8 | 50% | 2 | 79 | 29 | 316 |
| 9 | 50% | 3 | 73 | 32 | 292 |

The 9 different tensile specimen prepared by varying the major FDM parameters have shown different model building time due to the change in parameters. The increase in infill density generally increase the model building as more material need to be filled inside the part . The comparison of model building time at different infill densities with different print conditions are shown in fig 5

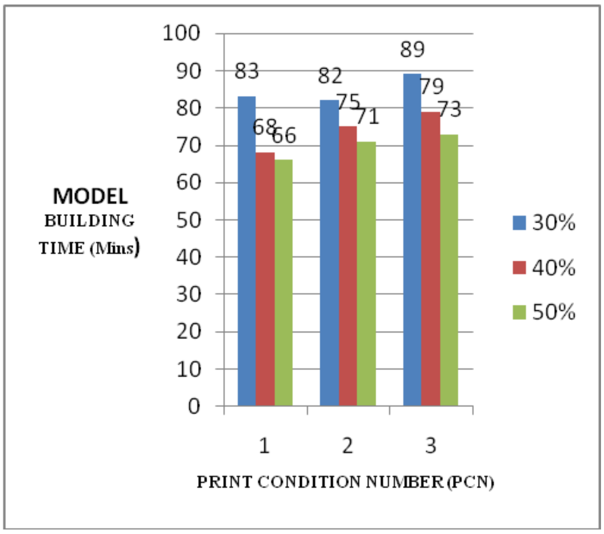


**Fig 5 Comparision of Model building time at different infill densities for tensile specimen**

Godfrey.C Et.al [11] have reported that the minimum layer thickness improves the part strength and it consumes more time for printing which would be costly. He also suggests that negative air gap significantly improves the tensile strength of the part produced.The increase in infill density generally increases the material consumption. A zero air gap makes the adjacent layers to be deposited one over the another.But a positive air gap generally creates a gap between two layers which ultimately reduces the material consumption. A negative air gap makes one layer to overlap over the another. In the present work shell thickness is provided with a positive increment which generally increases the material consumption as the shell area is always completely filled in the part.The comparision of material consumption at three different infill densities with different printing condition no are shown in Fig 6.

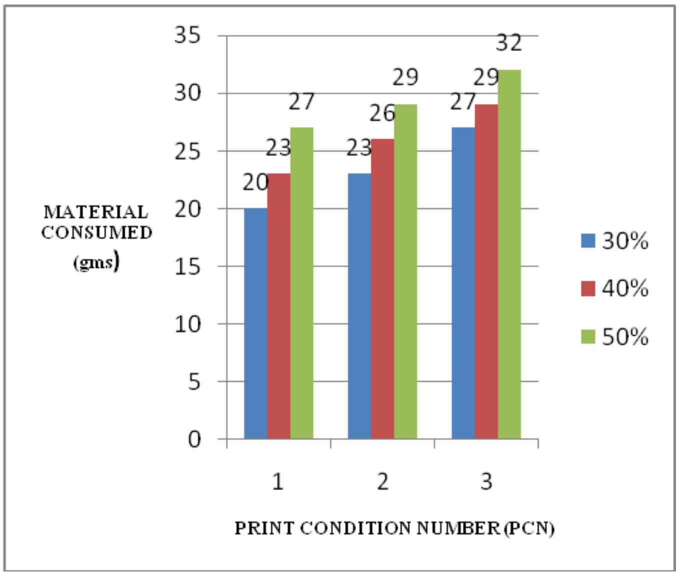


**Fig 6 Comparison of Material consumption at different infill densities for tensile specimen**

The economical factors for bending and impact specimen are shown in table 7,8

**Table 7 Economical factors for bending specimen**

| S.No | ID | PCN | Time (Mins) | Material Consumed (gms) | Cost (Rs) |
|---|---|---|---|---|---|
| 1 | 50% | 1 | 183 | 54 | 732 |
| 2 | 50% | 2 | 166 | 61 | 664 |
| 3 | 50% | 3 | 152 | 65 | 608 |

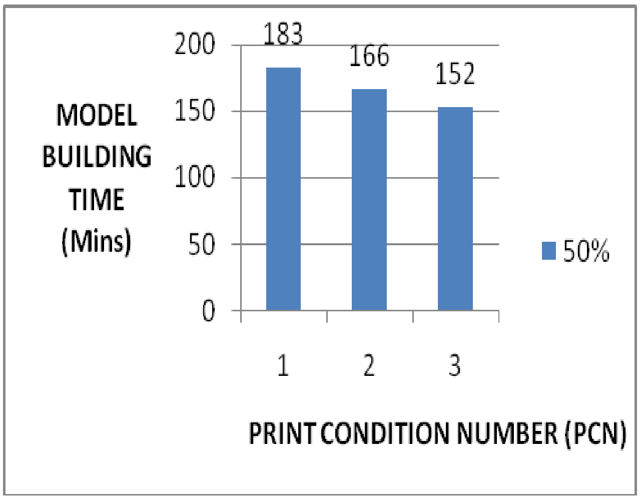


**Fig 7 Comparison of Model building time for Bending specimen**

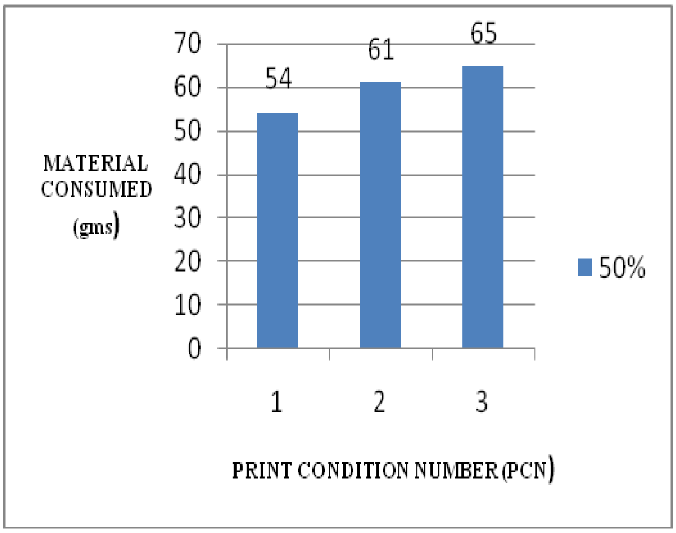


**Fig 8 Comparison of Material consumption for Bending specimen**

**Table 8 Economical factors for Impact specimen**

| S.No | ID | PCN | Time (Mins) | Material Consumed (gms) | Cost (Rs) |
|---|---|---|---|---|---|
| 1 | 30 % | 1 | 21 | 5 | 84 |
| 2 | 30 % | 2 | 16 | 6 | 64 |
| 3 | 30 % | 3 | 17 | 5 | 68 |
| 4 | 50% | 1 | 23 | 6 | 82 |
| 5 | 50% | 2 | 20 | 6 | 80 |
| 6 | 50% | 3 | 18 | 7 | 72 |

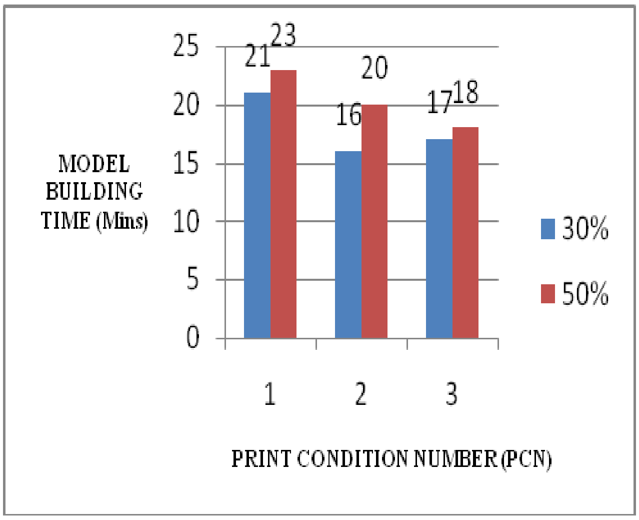


**Fig 9 Comparison of Model Building time for Impact specimen**

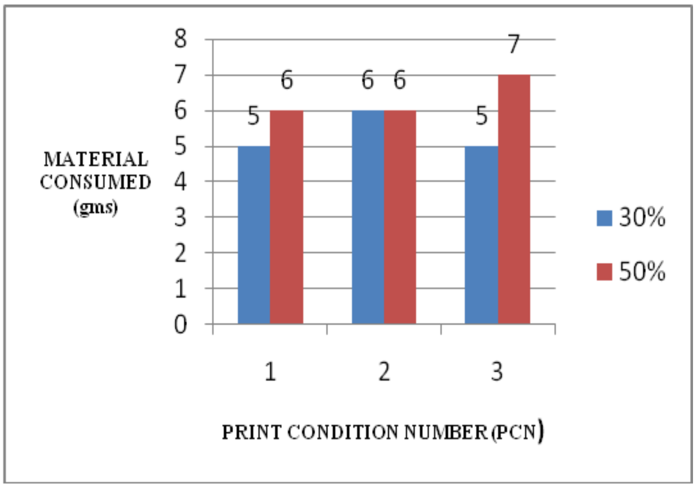


**Fig 10 Comparison of Material consumption for Impact specimen**

### *B. Gear Component for dimensional accuracy*

In the preparation of Gear component for checking the dimensional accuracy by changing the Layer Thickness (LT) , Raster width (RW) and Speed (S). The gear is printed by mixing the parameters as per $L_4$ Orthogonal array created using Minitab 17.0. The table 9 shows the parameters considered and varied for gear printing.Table10,11 shows the $L_4$ orthogonal array and the experimental conditions for printing the gears.

**Table 9 Varying Parameters for Gear printing**

| S.No | Parameter | Low Value | High Value |
|---|---|---|---|
| 1 | Layer Thickness (mm) | 0.2 | 0.3 |
| 2 | Raster width (mm) | 0.3 | 0.6 |
| 3 | Speed (mm/s) | 45 | 55 |

**Table 10 $L_4$ Orthogonal array**

| Exp No | A | B | C |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 |
| 3 | 2 | 1 | 2 |
| 4 | 2 | 2 | 1 |

**Table 11 Parameter settings for Printing Gear**

| Exp No | LT | RW | S |
|---|---|---|---|
| 1 | 0.2 | 0.3 | 45 |
| 2 | 0.2 | 0.6 | 55 |
| 3 | 0.3 | 0.3 | 55 |
| 4 | 0.3 | 0.6 | 45 |

The gear component used in lathe application is taken as reference for printing the gear with ABS material . The reference gear is a Spur gear made of Cast iron with 25mm bore dia , 15mm thickness , 50mm outer dia , addendum and dedendum values are 2mm and 4mm respectively. The gears are printed with 30% as infill density with zero air gap. The gears printed as per the Orthogonal array experiments are compared for model building time and material consumption.The table 12 shows the building time and material consumption for the gears printed suing ABS material.

**Table 12 Comparison of Model building time, Material Consumption and Cost for gear printing**

| Exp No | Time (Mins) | Material Cons (gm) | Cost (Rs) |
|---|---|---|---|
| 1 | 74 | 12 | 296 |
| 2 | 78 | 11 | 312 |
| 3 | 73 | 12 | 292 |
| 4 | 75 | 13 | 300 |

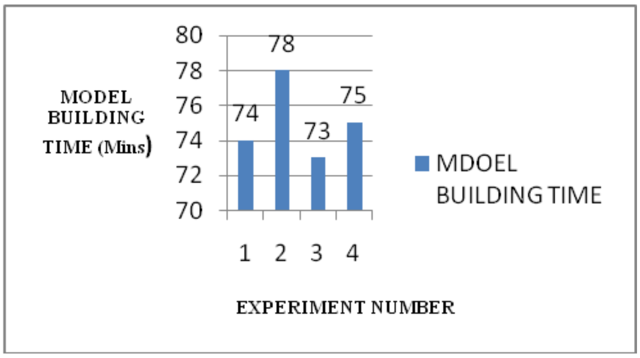


**Fig 11 Comparison of Model building time for printing gears**

## Experimental Work

### *A. Mechanical Testing*

The mechanical testing of various specimens are conducted as per the IS standard IS1608:2005 followed by SITARC Coimabtore. The tensile , bending and impact , hardness tests are carried out to study the influence of major FDM parameters over the mechanical properties of the ABS material processed by means of Fused deposition modeling.

#### *1) Tensile testing*

A total of 9 tensile specimens were prepared to conduct the tensile test. The specimens are prepared by varying three infill densities with different FDM parameters in combination. The dog bone shape specimen is fixed at one end of the Universal Testing Machine and the specimen is pulled continuously at a constant velocity until the specimen undergoes complete fracture. The load at which the specimen breaks is considered as the breaking load of the specimen and the values are tabulated. The table 13 shows the breaking load for various tensile specimens. Fig 12 and 13 shows the fractured specimens at 40% and 50% infill densities at Print conditions 1,2 & 3.


**Fig 12. Fractured specimens at 40% Infill density**

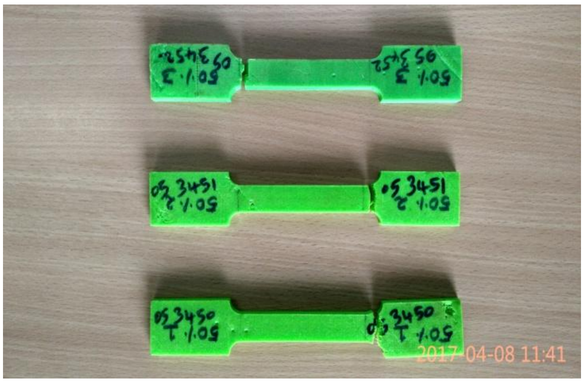


**Fig 13 Fractured specimens at 50% Infill density**

**Table 13 Breaking Load for Tensile Specimen**

| S.no | ID | PCN | Breaking Load (N) |
|---|---|---|---|
| 1 | 30 % | 1 | 480 |
| 2 | 30 % | 2 | 480 |
| 3 | 30 % | 3 | 470 |
| 4 | 40% | 1 | 500 |
| 5 | 40% | 2 | 510 |
| 6 | 40% | 3 | 490 |
| 7 | 50% | 1 | 530 |
| 8 | 50% | 2 | 550 |
| 9 | 50% | 3 | 525 |

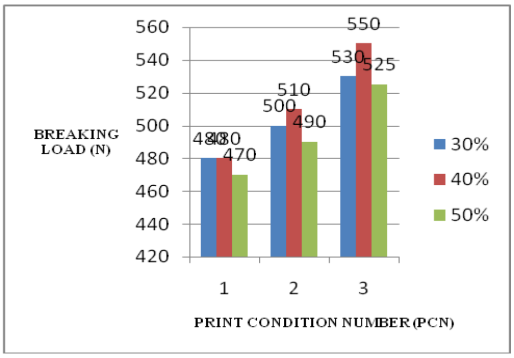


**Fig 14 Comparison of Breaking Load (N) for tensile specimens**

#### *2) Bending Test*

Three point bending test is conducted by providing supports at both the ends of the specimen and the load is applied at the centre. The specimen is loaded until the specimen undergoes complete fracture .The fig 15 (a) (b) (c) shows the specimen under initial stage of loading , Flexion in progress, breaking of specimen.

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**Fig 15 (a) Initial loading**

**Fig 15 (b) Flexion in progress**

**Fig 15 (c) Breaking of specimen**

**Table 14 Breaking load for Bending Specimen**

| S.no | Infill Density(%) | PCN | Breaking load (N) |
|---|---|---|---|
| 1 | 50% | 1 | 1760 |
| 2 | 50% | 2 | 640 |
| 3 | 50% | 3 | 2240 |

The table 14 shows the breaking load for bending test specimen at different printing conditions and Fig 16 shows the comparison of breaking load for bending specimens.

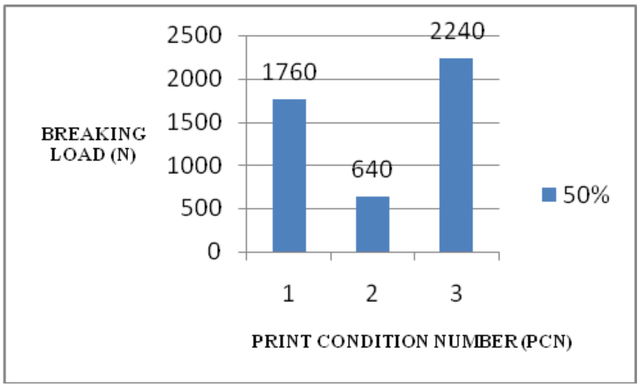


**Fig 16 Breaking load for bending specimen.**

***3) Impact testing***

The impact testing of the specimen is done according to Izod impact testing method. The experiment is conducted as per the standard procedure and the results observed are tabulated in Table 15.

**Table 15 Impact test results**

| S.no | Infill Density(%) | PCN | Impact Energy (J/mm$^2$) |
|---|---|---|---|
| 1 | 30 | 1 | 0.028 |
| 2 | 30 | 2 | 0.014 |
| 3 | 30 | 3 | 0.028 |
| 4 | 50 | 1 | 0.0561 |
| 5 | 50 | 2 | 0.0421 |
| 6 | 50 | 3 | 0.0421 |

The fig 17 (a) and 17 (b) shows the specimens broken after Izod impact test.

**Fig 17(a) 30% Infill Impacted Specimens**

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**Fig 17(b) 50% Infill Impacted Specimens**

### *B. Dimensional Accuracy*

The gear component printed as per Orthogonal array is need to be checked for the dimensional accuracy as the FDM process parameters are taken in combination for the printing of gears. The table 16 shows the values obtained for the four gears printed by taking the cast iron gear as reference. The deviation in dimension is observed and the error percentage is calculated with reference to the original dimension.

**Table 16 Deviation in Gear Dimensions**

| Parameter | Boredia (mm) | Thickness (mm) | Outer Dia (mm) | Addendum (mm) | Dedendum (mm) |
|---|---|---|---|---|---|
| original Value | 25 | 15 | 50 | 2 | 4 |
| Gear 1 | 24.5 | 15.2 | 51.5 | 2 | 4.131 |
| Error% | 2 | 1.33 | 3 | 0 | 3.2 |
| Gear 2 | 24.5 | 15.4 | 51 | 2 | 4.1 |
| Error% | 2 | 2.6 | 2 | 0 | 2.5 |
| Gear 3 | 24.7 | 15.3 | 50.6 | 2 | 4.124 |
| Error% | 1.2 | 2 | 1.2 | 0 | 3.1 |
| Gear 4 | 24.6 | 15.5 | 51.3 | 2 | 4.2 |
| Error% | 1.6 | 3.3 | 2.6 | 0 | 5 |

## IV. CONCLUSION

The following conclusions has been arrived after observing the results from mechanical testing of various specimens and Dimensional accuracy analysis of gears printed using ABS plastic material by varying the major FDM process parameters.

(a) The major FDM process parameters Layer Thickness(LT), Raster Width (RW), Shell Thickness(ST), Infill Density (ID), Air gap (AG) and printing speed (S) have shown highly considerable effect over the economical and technical factors.

(b) Increase in infill density have shown increase in model building time, material consumption and cost incurred in making the model. It also increases the part strength as more material is added to the part. The tradeoff between the printing cost and part strength may be concluded by selecting the right infill density.AndersonV.Et al have reported that the FDM parameters Air gap , Layer thickness , Raster width and road direction have shown considerable effect over the mechanical properties of the specimen printed.

(c) For the Print condition number 1 at all three infill densities the tensile test results have shown increase in breaking load this is due to the fact that the increase in infill density increase the part strength .

(d) In bending test at 50% infill density the print condition number have shown better results as the shell thickness is higher compared to the other printing conditions. As shell is a region in the printed where 100% infill is done.Ognan et al have conducted bending test experiments by varying the Layer thickness, Infill density and deposition angle and observed varying flexural force for PolyLactic Acid (PLA) filaments.

(e) In bending test the specimen prepared as per print condition number 2 have shown very less value compared to the other conditions. It is due to the fact the specimen have undergone warping effect during printing.

(f) In case of air gap , the positive air gap generally creates voids or gaps between the adjacent layers which weakens the part printed but it takes less time and less material for printing the part.

(g) In the tensile testing specimens for 30% infill density with PCN 1&2 have shown good results compared to PCN 3. The reason would be the presence of more positive air gap, high layer thickness. For both 40% & 50% infill density PCN 2 have shown better results.

(h) In case of the gears printed by using FDM process to check the dimensional accuracy. The deviation in dimension is less con siderable and the error percentage obtained is not more than 5 %.

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