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EFFECT OF FDM PROCESS PARAMETERS ON VIBRATION PROPERTIES OF PET-G AND ABS PLASTICS

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Abstract**—** The purpose of prototyping is to validate the material and geometrical shape of the design created for a product. The properties and quality of the prototype created plays a vital role in validating the design. The selection of an appropriate process parameters for making the prototype has more influence over the mechanical properties and quality characteristics of the finished prototype. In other words, the success and market life of a product entirely relies upon the prototyping results. Rapid prototyping techniques generally involve numerous process parameters which need to be optimized to build a prototype with superior performance. Fused deposition modeling is one of the familiar and fascinating RP technique which has gained interest in the field of prototyping products of Engineering, Architecture, Medical, Automotive and Aerospace due to its simplicity and flexibility in creating conceptual models and functional parts with desired quality. In the present work Impact Hammer testing of FDM processed PolyEthylene Terephthalate Glycol-modified(PET-G) and Acronitrile Butadiene Styrene (ABS) plastics is conducted to observe the influence of FDM process parameters. The major FDM parameters such as Infill Density (ID), Layer Thickness (LT) and Printing Speed (S) are considered to obtain Frequency Response Function (FRF) for PET-G and ABS plastics. The test results have shown considerable changes in vibration properties (Frequency and amplitude) in both the materials. A 2^3 (2 Levels, 3 Factors) design L_4 Orthogonal Array is created using Minitab 17.0 is used for conducting the experiments.

Keywords **—** ABS Plastics , FDM , Rapid Prototyping , PET-G , Layer Thickness, Printing Speed ,S/N ratio, Minitab 17.0

I. INTRODUCTION

Prototypes are very important for realization of concepts in design, manufacturing and analysis. Prototyping is an essential part of product development and manufacturing cycle required for assessing the form, fit and functionality of a design before a significant investment is made[6]. Rapid prototyping is used to quickly fabricate a prototype of a part using 3D computer aided data with the layer-bylayer addition of the material. Fused Deposition Modelling (FDM) comes under the solid based Rapid Prototyping systems. The current range of materials include Paper, Wax, Resins, Nylon, Plastics, Thermo-plsatics, Metals and Ceramics.[15].

Fused deposition modeling (FDM) is an additive manufacturing technology commonly used for modeling, prototyping, and production applications. It is one of the techniques used for 3D printing. The technology was developed by S. Scott Crump in the late 1980s and was commercialized in 1990 .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. Fused Deposition Modeling (FDM) is an additive manufacturing technology that builds parts up layer-by-layer by heating and extruding thermoplastic filament. Ideal for building durable components with complex geometries in nearly any shape and size, FDM is the only 3D printing process that uses materials like ABS, PC-ISO polycarbonate, and ULTEM 9085. This means FDM can create parts and prototypes with outstanding thermal and chemical resistance, and excellent strength-to-weight ratios FDM has become a widely used additive fabrication technologies..The Fig 1 shows the schematic arrangement of FDM process.

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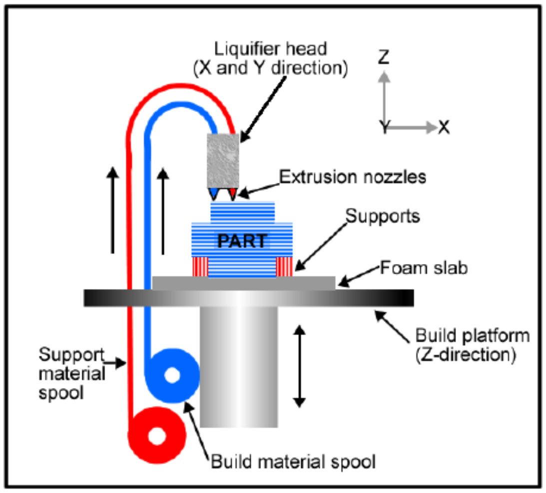

Fig. 1: Fused Deposition Modeling Process

FDM Process Parameters and Materials

In general the selection of appropriate process parameters for making a product or prototype truly plays a vital role in product design and manufacturing. An array of 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.

Fused deposition modeling uses the thermoplastics PLA, ABS, ABSi, polyphenylsulfone (PPSF), polycarbonate (PC), PETG and Ultem 9085. In the present work ABS and PET-G materials are 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.

PET-G is a clear amorphous thermoplastic available in the form of filament for FDM process. It is a plastic resin of the polyester family. It is used in fabrication of facemasks, burn management devices and check sockets.

Preparation of Specimen

In the present work, both the PET-G and ABS material available as 1.75mm thin wire filaments are converted into rectangular shaped specimens. The selected dimensions for printing the specimens are 150mm x 20mm x 6mm.The specimens are printed using Maker Pi 2048 a Chinese made machine and the machine receives instruction to print the specimens in the form of G codes prepared by CURA 15.04.06 software. The fig no 2 shows the specimen model and Fig 3 & 4 shows the printed PET-G and ABS specimens individually.

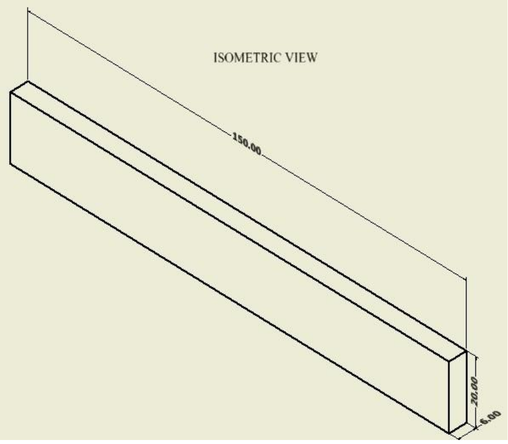

Fig 2 Rectangular Shaped Specimen

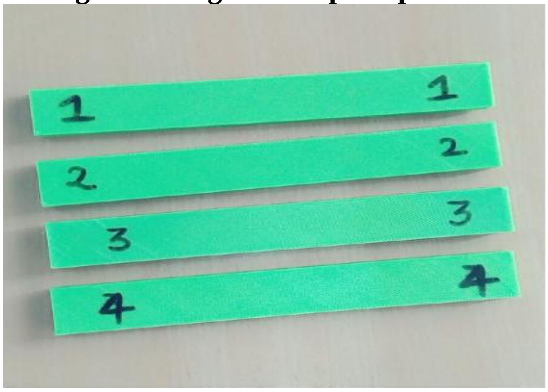

Fig 3 Rectangular Shaped PET-G Specimens

Fig 4 Rectangular Shaped ABS Specimens

The specimens are prepared by varying the major FDM process parameters such as Infill Density (ID), Layer Thickness (LT) and Printing Speed (S). A 2^3 (2 Levels , 3 Factors) L_4 Orthogonal array is created using Minitab 17.0. The table 1 shows the L_4 orthogonal array and table 3 shows the orthogonal array with the process parameters for printing the PET-G and ABS specimens.

Table 1 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

The major FDM parameters which are varied in printing the rectangular shaped specimen are shown in table 2.

Table 2 Major FDM Process parameters varied

S.No	Parameter	Low Value	High Value
1	Infill Density (%)	50%	100%
2	Layer Thickness (mm)	0.15	0.20
3	Speed (mm/s)	45	55

Table 3 Specimen Preparation Settings

Exp No	ID(%)	LT(mm)	S(mm/s)
1	50	0.15	45
2	50	0.20	55
3	100	0.15	55
4	100	0.20	45

In printing the specimens as per L_4 Orthogonal array by varying the major FDM process parameters both the materials have shown a considerable effect in model building time. The fig 5 & 6 shows the model building time for PET-G and ABS for various experimental conditions of L_4 Orthogonal array.

Table 4 Model building time for PET-G

Exp No	ID(%)	LT (mm)	S (mm/s)	Time (Mins)
1	50	0.15	45	78
2	50	0.20	55	62
3	100	0.15	55	147
4	100	0.20	45	114

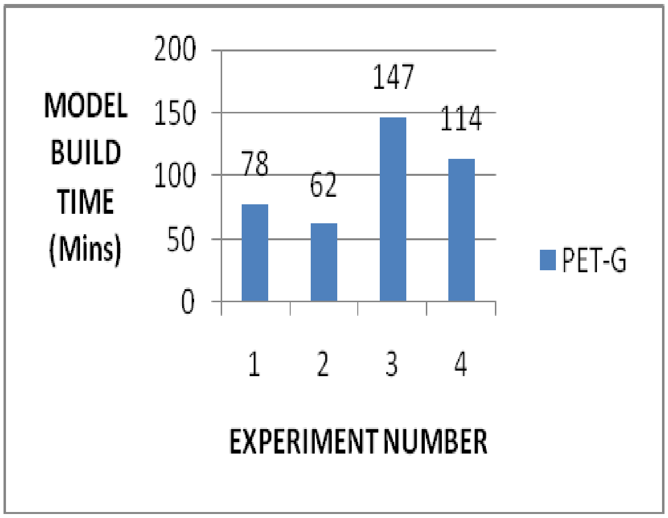

Fig 5 Comparison of Model building time for PET-G

Table 5 Model building time for ABS

Exp No	ID(%)	LT (mm)	S (mm/s)	Time (Mins)
1	50	0.15	45	69
2	50	0.20	55	61
3	100	0.15	55	137
4	100	0.20	45	118

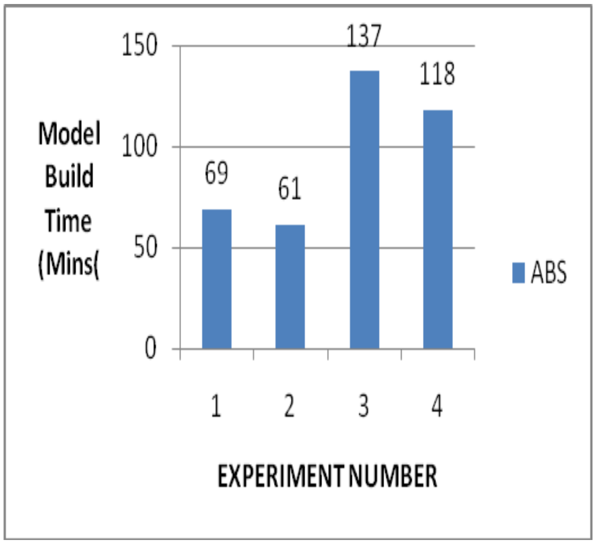

Fig 6 Comparison of Model building time for ABS

The cost for printing the specimen is directly related to the model building time. Increase in time generally increases the cost of the printed specimens.

Experimental Work

The main distinguishing feature of this work is that the materials considered for study. Most of the research papers on FDM have considered ABS, PLA and Polyimide as material for researching purposes, very less or only little paper have concentrated on PET-G material for study. In the present study the specimens printed under different experimental conditions as suggested by Taguchi's L_4 Orthogonal array is considered for Impact hammer testing. It is a method of testing that allows us to calculate the natural frequencies (modes), modal masses, modal damping ratios and mode shapes of a test structure.Vibration plays a vital role in the design of any component or product as it may create unexpected failure or malfunction of the entire system or component. Inorder to overcome such critical situation it is essential to optimize the process parameters for the manufacturing of different materials.

The experimental setup for impact hammer testing consists of the following components (a) Impact hammer (b) Accelerometer (c) Data Acquisition system. The Impact hammer is used to create an impact over the prototype. The accelerometer is used to convert the mechanical motion of thestructure into an electrical signal. The DAQ system is used to convert the analog signals into digital format. Software TEXT XPRESS 5A is used to execute signal processing and to analyses. The prototype is supported as a cantilever and hammering is done at the free end by using the Impact Hammer and the Accelerometer which is attached to the prototype to record the vibrations and the recorded vibrational signals are send to the Digital-To-Analog conversion unit. Then the analog signals are sent to analysis in TEXT XPRESS 5A.

The impact hammer testing conducted for all the four specimen samples of PET-G and ABS material printed as per the orthogonal array settings is observed for the frequency and amplitude. The specimens have shown varying frequency and amplitude for the varying experimental conditions.The fig 7 (a), (b), (c) and (d) shows the Frequency Response Function (FRF) graph for the PET-G specimens.A Frequency Response Function is used to identify the resonant frequencies, damping and mode shapes of a physical structure.

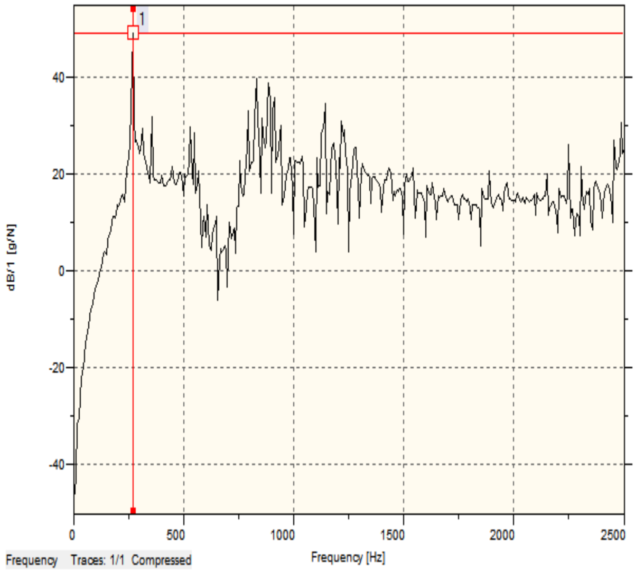

Fig 7 (a) FRF for PET-G Sample 1

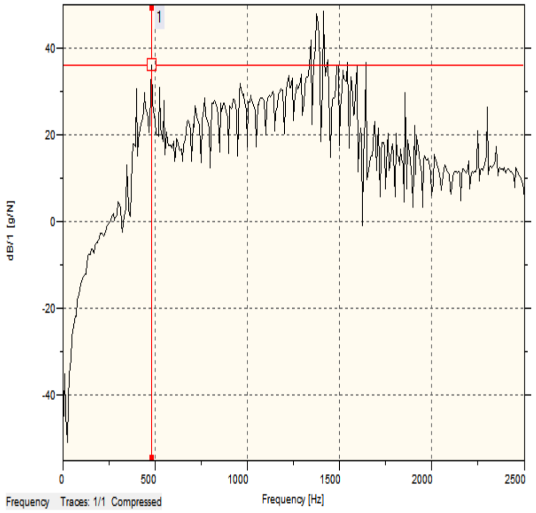

Fig 7 (b) FRF for PET-G Sample 2

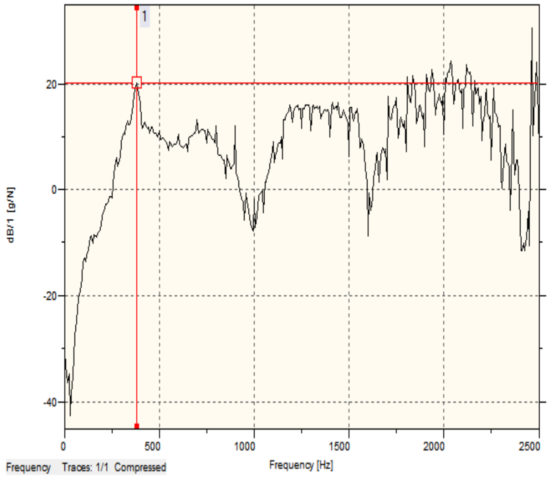

Fig 7 (c) FRF for PET-G Sample 3

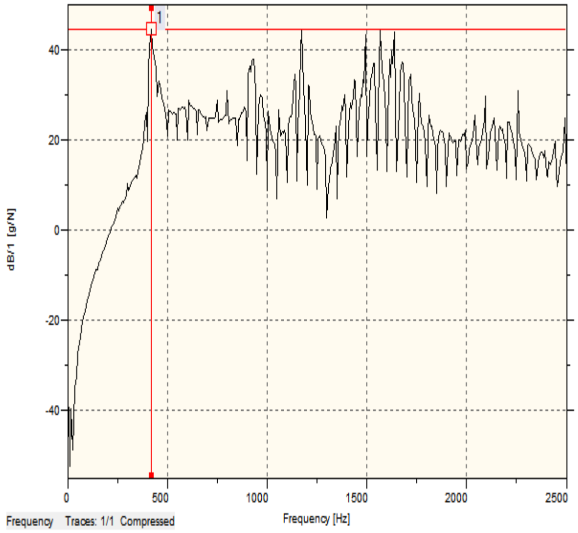

Fig 7 (d) FRF for PET-G Sample 4

The Frequency and Amplitude values obtained for the PET-G specimen are tabulated and shown in table 6. The specimen printed as per experiment number 1 have shown low frequency for PET-G and the Specimen printed as per experiment 2 have shown maximum frequency.In case of amplitude experiment number 1 have shown higher amplitude and experiment number 3 have shown lower amplitude values.

Table 6 Impact hammer testing results for PET-G

Exp No	Frequency (Hz)	Amplitude(g/N)
1	268.75	49.22
2	481.25	35.97
3	381.25	20.15
4	418.75	44.51

The fig 8 (a), (b), (c) and (d) shows the Frequency Response Function (FRF) graph for the ABS specimen samples

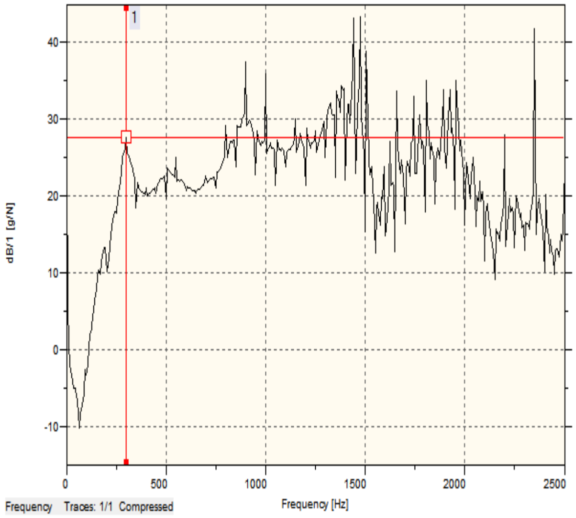

Fig 8 (a) FRF for ABS Sample 1

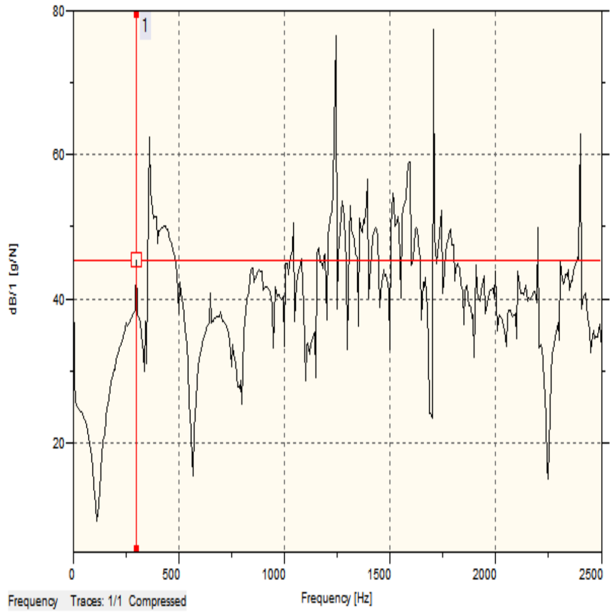

Fig 8 (b) FRF for ABS Sample 2

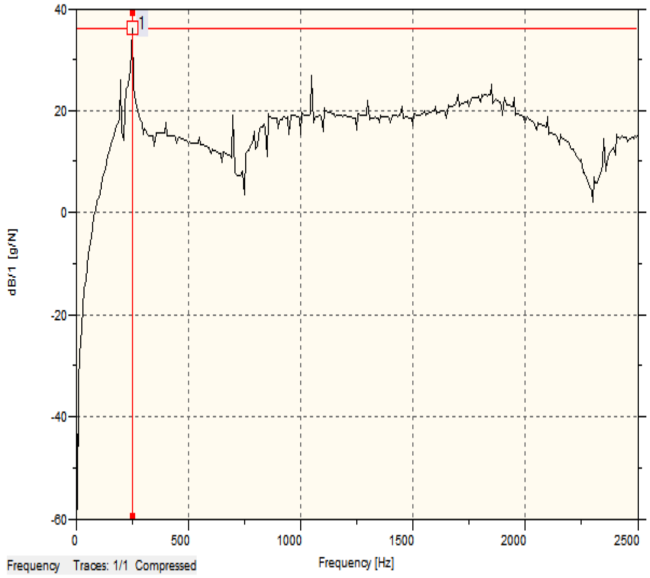

Fig 8 (c) FRF for ABS Sample 3

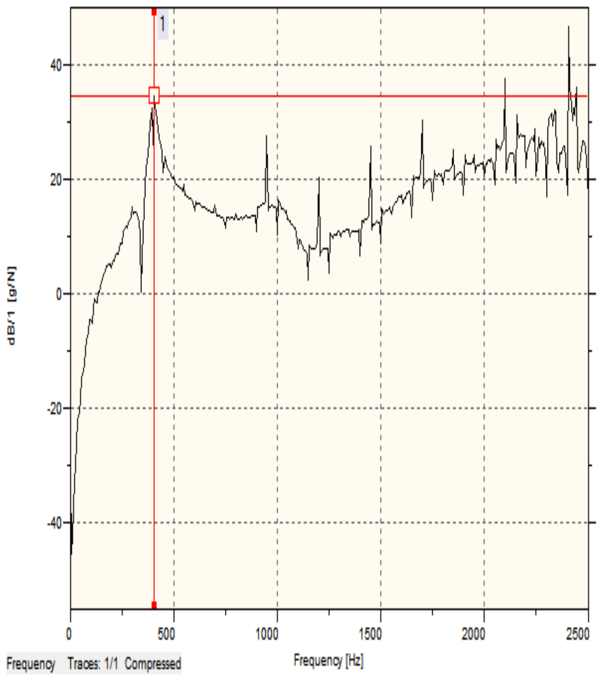

Fig 8 (d) FRF for ABS Sample 4

The Frequency and Amplitude values obtained for the ABS specimen are tabulated and shown in table 7. The specimen printed as per experiment number 3 have shown low frequency for ABS and the Specimen printed as per experiment 4 have shown maximum frequency.In case of amplitude experiment number 1 have shown lower amplitude and experiment number 2 have shown higher amplitude values.

Table 7 Impact hammer testing results for ABS

Exp No	Frequency (Hz)	Amplitude(g/N)
1	283.91	27.92
2	292.78	46.12
3	250	37.45
4	410.17	35.67

A comparison of Frequency and amplitude values obtained for both the materials are done to understand the influence of process parameters over the vibrational properties of the FDM processed PET-G and ABS plastics.The fig 9 shows the comparison of frequency for various experiments of both the materials.

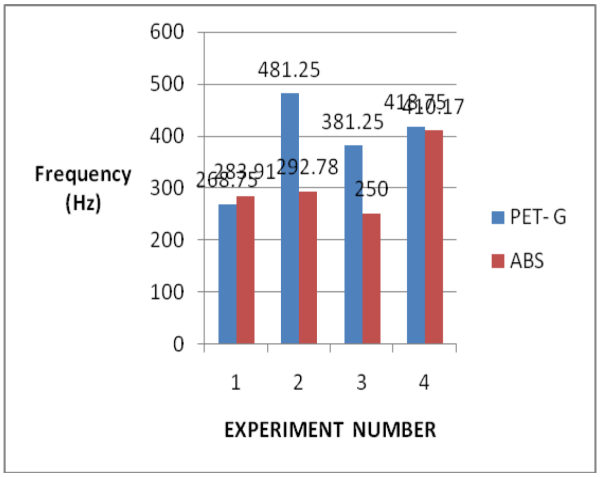

Fig 9 Comparison of Frequency for Various experiments

The fig 10 shows the comparison of amplitude for various experiments of both the materials.

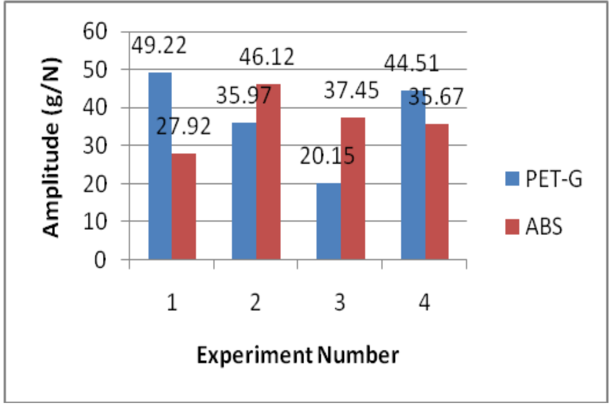

Fig 10 Comparison of Amplitude values for various experiments

II. MINITAB RESULTS AND ANALYSIS OF S/N RATIO

Minitab is a statistics package developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. It allows an user to create orthogonal arrays depending upon the number of factors and its levels. The software allows the user to calculate the signal – to - noise ratio.

Signal-to-noise ratio (abbreviated SNR or *S/N*) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. In the present work S/N ratio is calculated to find the more influencing process parameter of FDM over the vibrational properties of the PET-G and ABS material.S/N ratio can be found in three different ways by using Minitab 17.0. (a) Smaller is best (b) larger is best and (c) Nominal is best. The data obtained from impact hammer testing (Frequency and Amplitude) is inputted to the minitab software as response to the different experimental conditions of Taguchi's Orthogonal array and S/N ratios are calculated. The calculated values of S/N ratio by three different ways are tabulated to understand the effect of FDM process parameters over the desired properties of PET-G and ABS.

For PET-G material the response table for signal to noise ratio is calculated by three different ways

A. Smaller is best

Table 8 Smaller is best for PET-G

Level	Infill Density	Layer thickness	Speed
1	-48.19	-47.17	-47.60
2	-49.05	-50.07	-49.65
Delta	0.87	2.90	2.05
Rank	3	1	2

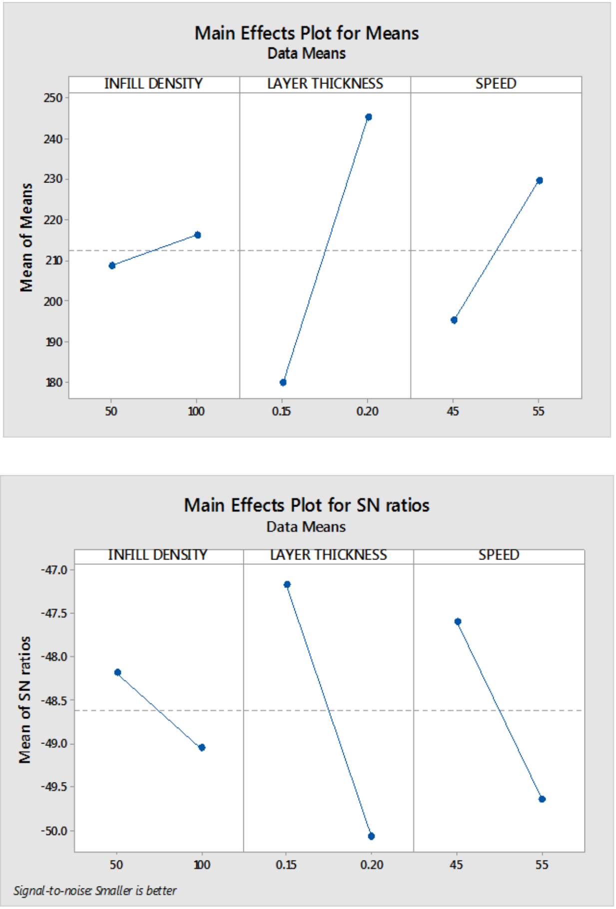

Fig 11 S/N effect of process parameters for PET-G Smaller is best

B. Larger is best

Table 9 Larger is best for PET-G

Level	Infill Density	Layer thickness	Speed
1	35.41	32.90	36.32
2	32.51	35.02	31.59
Delta	2.90	2.12	4.73
Rank	2	3	1

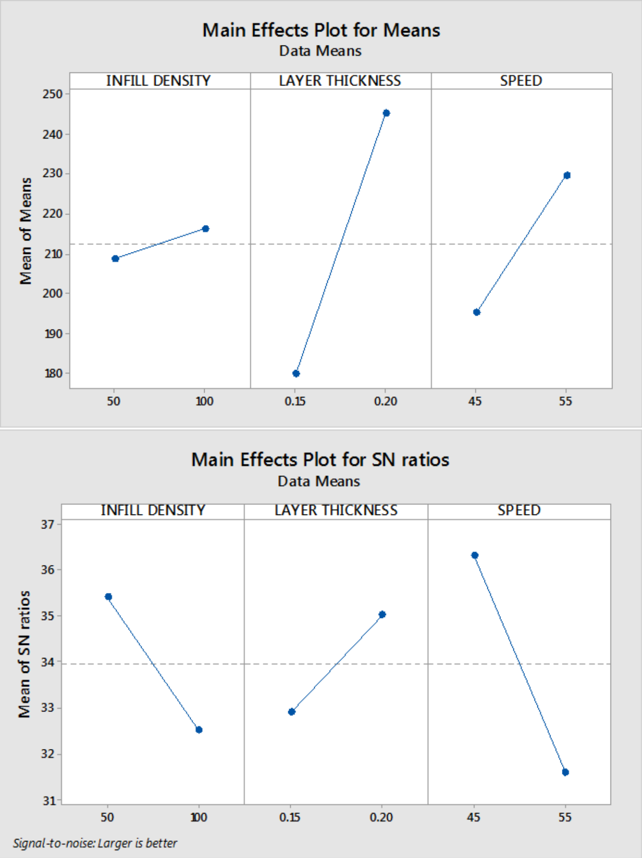

Fig 12 S/N effect of process parameters for PET-G Larger is best

C. Nominal is best

Table 10 Nominal is best for PET-G

Level	Infill Density	Layer thickness	Speed
1	-0.7503	-0.9416	-0.4740
2	-1.6244	-1.4331	-1.9007
Delta	0.8740	0.4916	1.4267
Rank	2	3	1

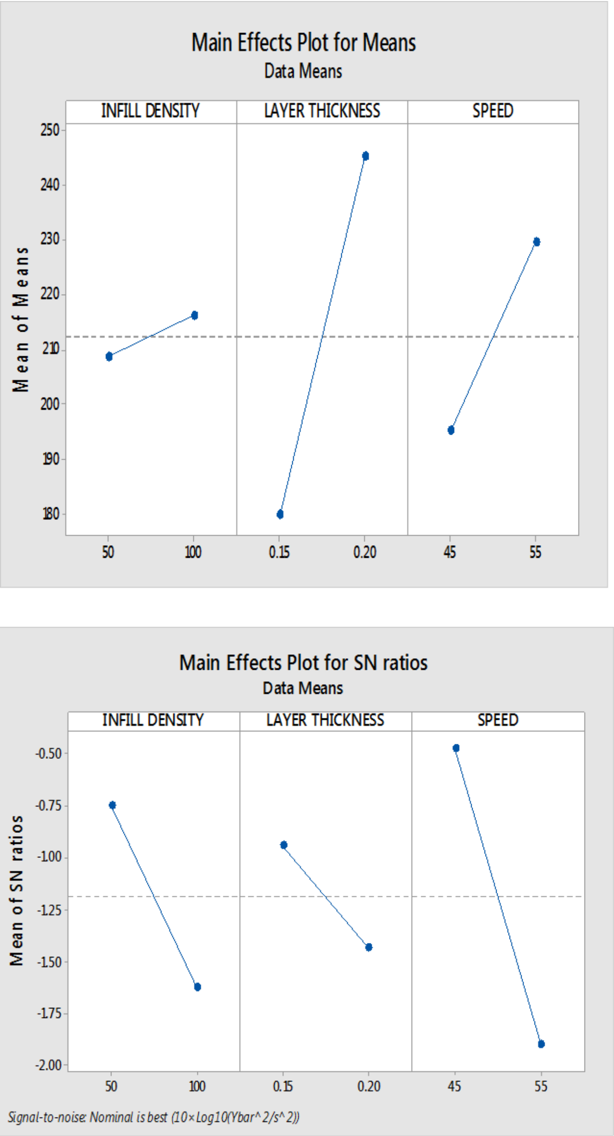

Fig 13 S/N effect of process parameters for PET-G Nominal is best

For ABS material the response table for signal to noise ratio is calculated by three different ways

A. Smaller is best

Table 11 Smaller is best for ABS

Level	Infill Density	Layer thickness	Speed
1	-46.26	-45.57	-47.69
2	-47.16	-47.85	-45.74
Delta	0.90	2.28	1.96
Rank	3	1	2

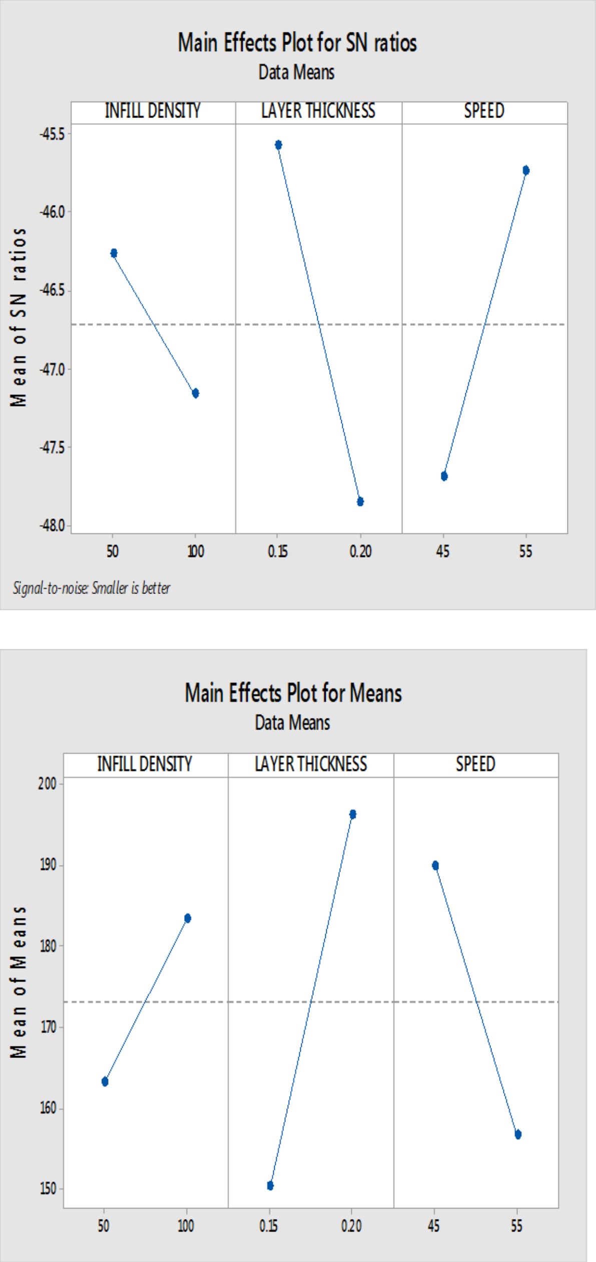

Fig 14 S/N effect of process parameters for ABS Smaller is best

B. Larger is best

Table 12 Larger is best for ABS

Level	Infill Density	Layer thickness	Speed
1	34.33	33.43	33.25
2	34.20	35.10	35.28
Delta	0.13	1.67	2.03
Rank	3	2	1

Fig 15 S/N effect of process parameters for ABS Larger is best

C. Nominal is best

Table 13 Nominal is best for ABS

Level	Infill Density	Layer thickness	Speed
1	-44.96	-44.31	-46.77
2	-46.00	-46.65	-44.19
Delta	1.04	2.33	2.59
Rank	3	2	1

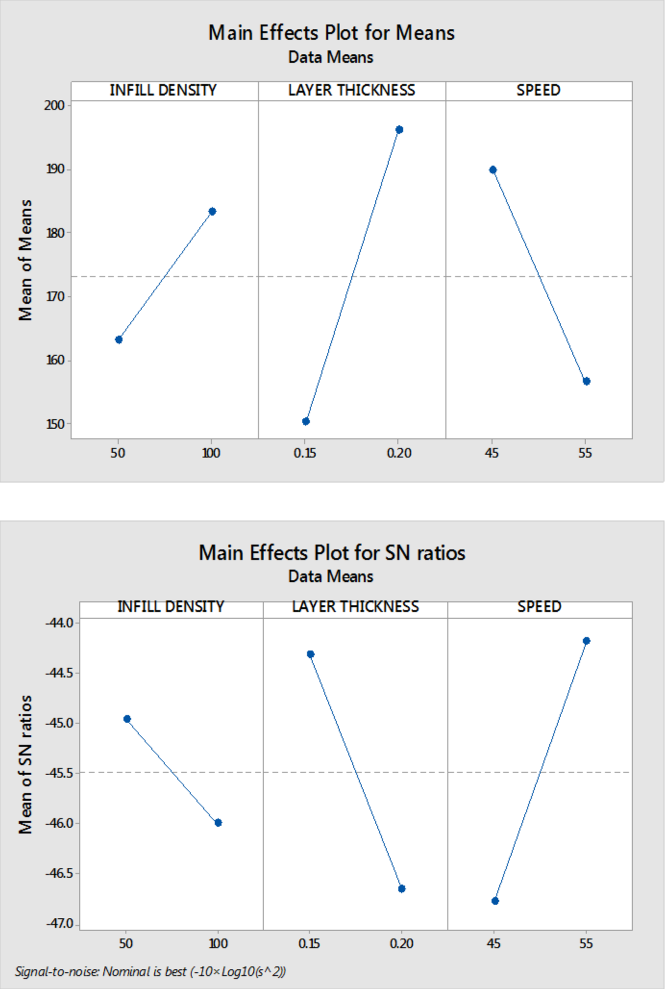

Fig 16 S/N effect of process parameters for ABS Nominal is best

III. CONCLUSION :

The following conclusion have been drawn from the experimental results and S/N ratios calculated using Minitab software .

1. The samples of ABS and PET-G printed as per the orthogonal array created using Minitab 17.0 has shown increase and decrease in Model building time as the layer thickness,Infill density and Printing speed varies with the experiments conducted . The increase in infill density increases the model building time and increase in layer thickness generally reduces the model building time drastically.Fahraz ali et.al have reported that the change in FDM process parameters may affect the model building time.
2. The impact hammer testing of both PET-G and ABS specimen have shown considerable changes in both frequency and amplitude.
3. Harish Yadav Et.al have reported that the change in part orientation and part thickness have created changes in the vibration properties of the models selected for study
4. In case of Frequency, low frequency levels are generally expected. For ABS the specimen printed according to experiment number 3 has shown low frequency values where the infill density is 100% . But for PET-G the specimen printed according to experiment number 1 have shown low frequency values where the infill density is only 50%.
5. In case of Amplitude ,For ABS experiment number 1 have shown low amplitude values and for PET-G experiment number 3 have shown low amplitude values.
6. In case of High frequency values , for ABS experiment no 4 is considered. For PET-G experiment no 2 is considered.
7. For higher amplitude values PET-G specimen printed as per experiment number 1 and experiment 2 has shown higher amplitude values for ABS material.
8. From the calculation of S/N ratio by different methods the effect of process parameter over the vibration properties of both the materials can be understood. For PET-G material 50% Infill density , Layer thickness 0.15mm and Speed 45mm/s are the optimized values from the levels selected inorder to get low frequency . The results are in common to all the three different ways of calculating S/N ratio.
9. The major influencing parameter for both PET-G and ABS is layer thickness according to the method Smaller is best. But the other two methods Larger is best and Nominal is best have given the top rank for printing speed as the major influencing parameter over the vibrational properties of both the materials.
10. For ABS material 50% Infill density , Layer thickness 0.15mm and Speed 55mm/s are the optimized values from the levels selected inorder to get low frequency .
11. For low amplitude values of PET-G, the optimized values are 100% Infill density, 0.20mm layer thickness and 55mm/s printing speed may be considered.
12. For amplitude values of ABS, the optimized values are varying according to the type of S/N ratio method adopted for calculation

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