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Analysing the Effect of Polylactic Acid Plastic Using FDM Process through Vibration Testing

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Abstract—*A* prototype *is an early model or sample of a product built to test a concept. The purpose of prototyping is to validate the geometrical shape of the design and the percentage of the material used in the inner and outer layers of the product. For validating the design, the properties and quality characteristics of the prototype is most important. Additive manufacturing (AM) is the layer by layer process to join materials for building 3D products or prototypes. Fused Deposition Modelling based 3D printers have become very popular in Additive manufacturing because of its low cost and simplicity, due to this it is used in the various field for prototyping like Engineering, Medical, Automotive, Architecture, and Aerospace. In this paper, vibration testing using a laser sensor of FDM processed Polylactic Acid (PLA) is conducted to observe the effect of FDM process parameters. The role of printing parameters such as layer size (LS), nozzle temperature (NT) and printing speed (S) is considered to obtain natural frequency for PLA plastic. The test results show considerable changes in vibration properties. Taguchi L9 array for 3 variables has been used to study these parameters.*

Keywords: *Fused Filament Fabrication (FFF), Polylactic acid (PLA), Fused Deposition Modelling (FDM), Natural Frequency.*

1. INTRODUCTION

Polylactic acid (PLA) is a thermoplastic aliphatic polyester and also a biodegradable polymer and it is developed from plant starch such as cassava, sugarcane, and corn. PLA has interesting mechanical, thermal and optical properties and PLA is best suitable for a wide range of applications such as biomedical, food packaging and PLA based products that are increasing rapidly in the market[1]. Additive manufacturing (AM) is the layer by layer process to print the materials for creating 3D objects or prototypes[3]. 3D printing is a type of Additive manufacturing process, which is used to make a 3D objects or prototype of any shape from a CAD modal converted by stereolithography (STL) file designed in CAD software [4-5].

FDM based 3D printing process is cheap and most commonly used the process as compared to other 3D printing processes, which was developed by S. Scott Crump in 1980s and it was commercialized in 1990. Fused filament fabrication (FFF) is a 3D printing technique used in Fused that uses a continuous filament of a PLA thermoplastic material which can be fed from a large coil, through a moving heated extruder head. The molten material is forced out of the nozzle through the extruder and gets deposited on the heated bed layer by layer one over other thus forming the required 3D shape. And where support is needed, the 3D printer deposits a removable material (in dual nozzle system) that acts as a supporting structure. As compared to other 3D printing methods FDM is a relatively slow printing process technique. After the process, the support material breaks away or dissolves it in detergent or water.

Parameters affecting the 3D Print:

- **Infill** - decides to make the object complete solid or hollow(100%-solid)
- **Layer size** - thickness of each layer that the object needs to get sliced in.
- **Print speed** - the speed at which the printing head moves while extruding.
- **Nozzle Temperature** - Temperature at which the extruder of printer needs to be while printing.
- **Movement Speed** - Speed while traveling is at which printing head moves while not extruding filament.
- **Shell size** - is a value that sets the number of outlines printed on each layer of the object.
- **Raster angle** - Angle at which infill takes place.

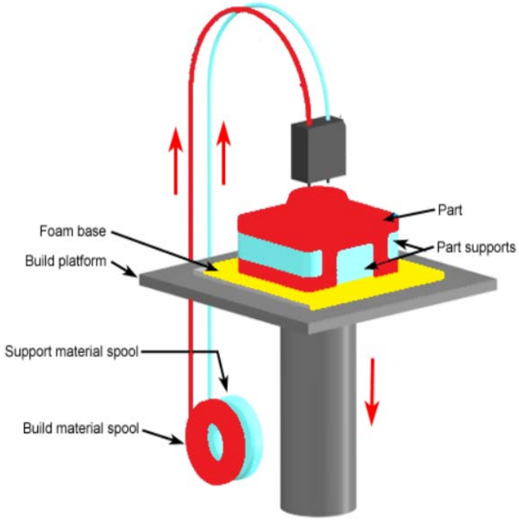

Figure 1. Fused Deposition Modelling Process

2. PREPARATION OF SAMPLE

PLA material available as 1.75mm thin wire filaments is converted into rectangular shaped samples. The dimensions selected for printing the samples are 100mm x 10mm x 2mm. The samples are printed on the FDM machine which was fabricated by us in the lab. A sample of rectangular is designed by CAD software CREO 2.0 and converted into a standard triangular language (STL) format (.stl format). Then the .stl file imported into Repetier-Host for G-codes conversion using the appropriate settings.

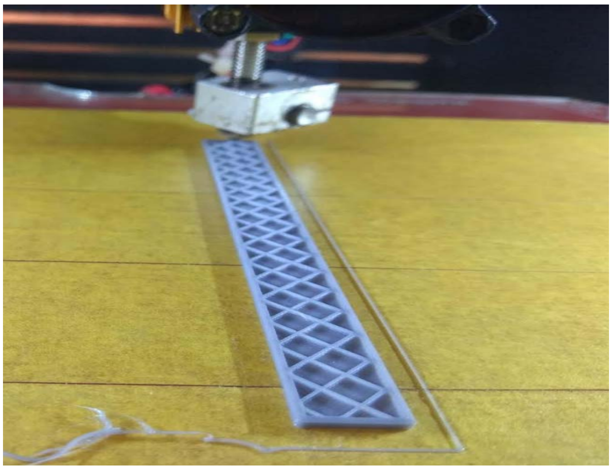

Figure 2. PLA sample printing process

Figure 3 shows the samples of PLA plastic printed by the FDM process and figure 2 shows how PLA samples are fabricated. The samples are prepared by varying the FDM process parameters such as Nozzle Temperature (NT), Layer Thickness (LT) and Printing Speed (S).

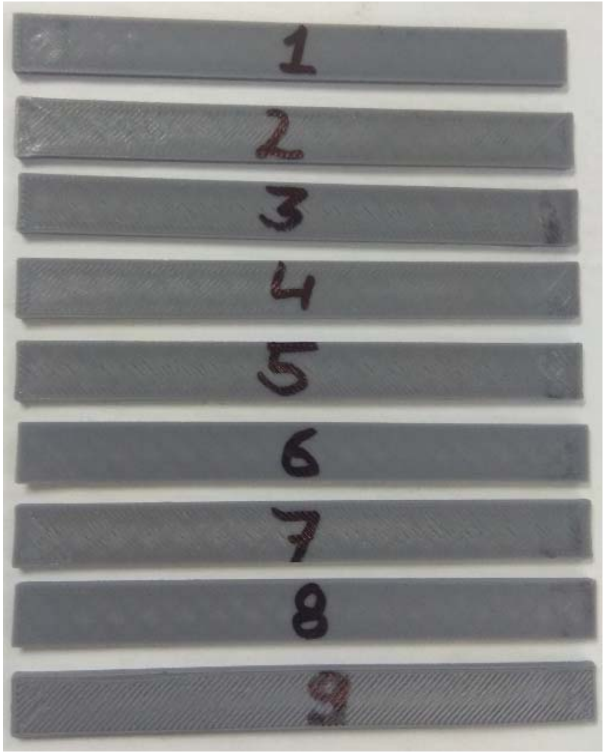

Figure 3. Rectangular shaped PLA samples

3. EXPERIMENT

A direct extruder-based 3D printer was used for experimentation for analysis of the effect on vibration properties of polylactic acid plastic by using different parameters.

Specification of the 3D printer taken for conducting experiment are as following:

Extruder Type: Direct with MK8 gearing;

Type: Cartesian

Parameters	Description
Nozzle diameter	0.4 mm
Bed temperature	50^0C
Shell thickness	1.0 mm
Raster angle	45^0C
Infill	20%
Material	1.75mm PLA (Gray Color)

A safe level of design taken from Pilot Experiments are Print Speed: 40mm/s, 50mm/s, 60mm-/s

Nozzle Temp: 215^0C, 220^0C, 225^0C

Layer Size: 0.1mm, 0.2mm, 0.3mm

The above parameters are adopted from a research paper for conducting an experiment within a safe range[2]. Taguchi L9 array for 3 variables has been used to study these parameters which are shown in Table 1.

Table 1. Taguchi L9 array for 3 variables

Run	Columns		
	1	2	3
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

4. DESIGN OF EXPERIMENT

For the design of experiment, Taguchi L9 array is taken from the past research works and papers [2] for analyzing the effect on vibration properties of polylactic acid plastic by using different parameters. To plot the natural frequency vs print speed and nozzle temp at various layer size from the model obtained after analyzing in Mini-Tab software.

Table 2. Design of Experiment (L9)

Samples	Printing Speed (mm/s)	Nozzle Temp. (^{0}C)	Layer Size (mm)	Natural Frequency (Hz)
1	40	215	0.1	64.54
2	40	220	0.2	52.32
3	40	225	0.3	59.95
4	50	215	0.3	60.11
5	50	220	0.1	61.07
6	50	225	0.2	62.60
7	60	215	0.2	61.30
8	60	220	0.3	60.59
9	60	225	0.1	56.6

5. RESULT AND DISCUSSION

From the above table 2, we can see that natural frequency for every sample is different even when the samples of material and geometry are the same. We know that the young modulus (E) is directly proportional to the square of the natural frequency (ω).

$E \, \alpha \, \omega^2$

And also young modulus (E) is directly proportional to tensile strength (σ).

$E \, \alpha \, \sigma$

Now from the above two relations we can say that the natural frequency is directly proportional to tensile strength.

$\omega^2 \, \alpha \, \sigma$

Results have been obtained on the basis of input parameters which are shown in table 2. Plotted graphs are discussed ahead:

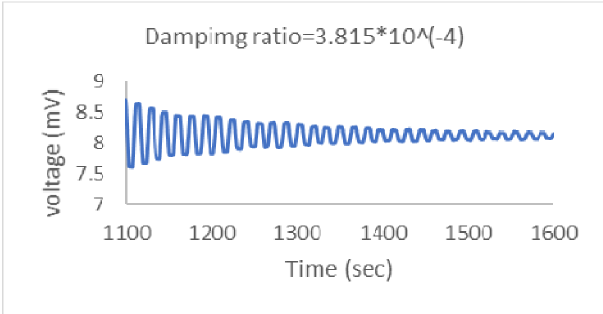

Figure 4. Showing the variation of natural frequency for sample 1 with respect to time and voltage.

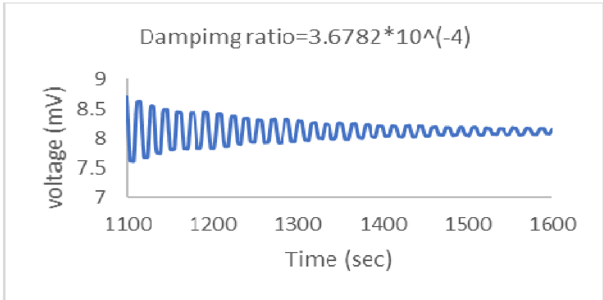

Figure 5. Showing the variation of natural frequency for sample 2 with respect to time and voltage.

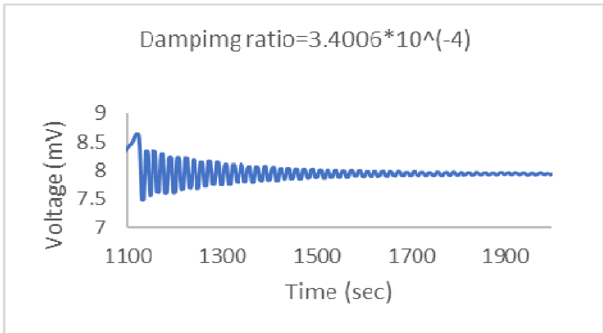

Figure 6. Showing the variation of natural frequency for sample 3 with respect to time and voltage.

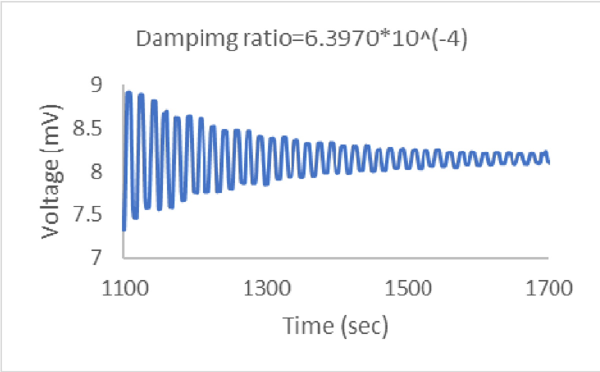

Figure 7. Showing the variation of natural frequency for sample 4 with respect to time and voltage.

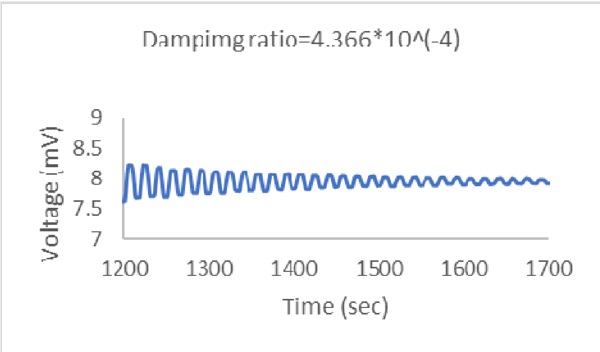

Figure 8. Showing the variation of natural frequency for sample 5 with respect to time and voltage.

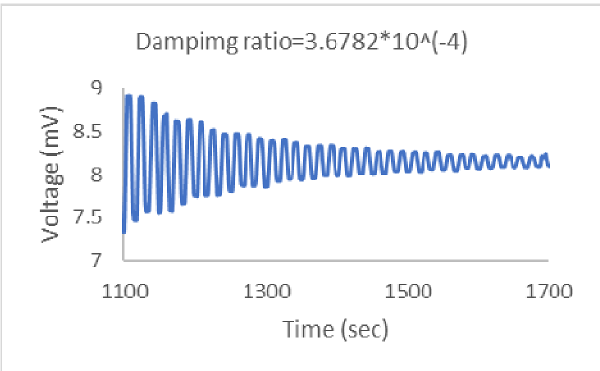

Figure 9. Showing the variation of natural frequency for sample 6 with respect to time and voltage.

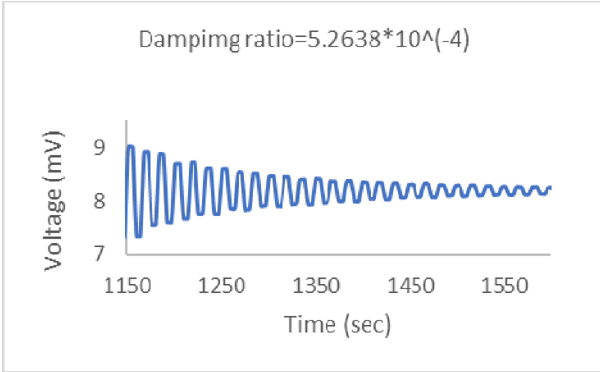

Figure 10. Showing the variation of natural frequency for sample 7 with respect to time and voltage.

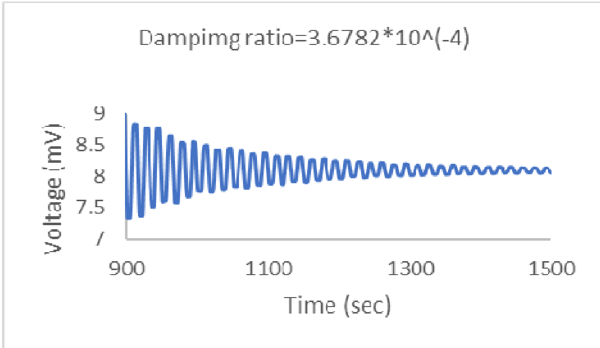

Figure 11. Showing the variation of natural frequency for sample 8 with respect to time and voltage.

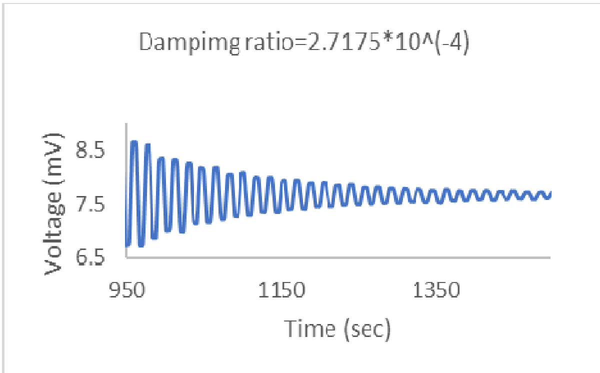

Figure 12. Showing the variation of natural frequency for sample 9 with respect to time and voltage.

Here for figure 4, sample 1 at 40 mm/sec print speed, 215 ^{o}C nozzle temperature and 0.1 mm layer size found maximum natural frequency 64.54 Hz. And it decreases as the time increases, time is taken as (1=1000 times).

For figure 5, sample 2 at 40 mm/sec print speed, 220 (^{o}C) nozzle temperature and 0.2 mm layer size found minimum natural frequency 52.32 Hz. And it also decreases as time increases.

5.1 Effect of Single Variable

Following observation have been made

- With the increase in printing speed, the average strength of the object first increases then decreases.
- With the increase in nozzle temperature average strength of the object first decreases then increases.
- With the increase in layer size, the average strength of the object first decreases then increases.

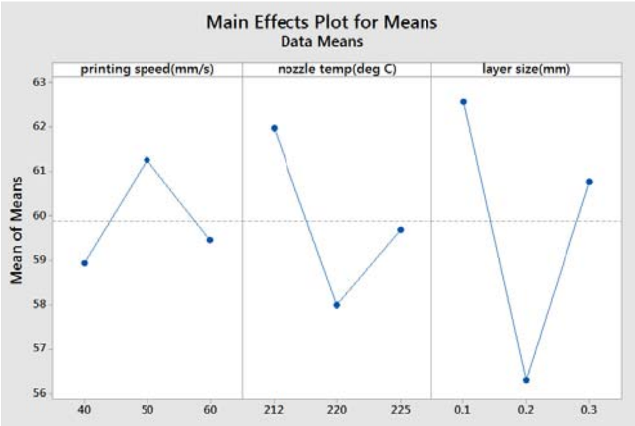

Figure 13 single variable main effects plot for means

6. CONCLUSION

Following conclusions have been made during the study and are given below:

1. For the same material and same geometrical shape, the strength of the object differs at different nozzle temperatures, printing speed, and layer sizes.
2. The maximum frequency for the object is obtained at a minimum layer size (0.1mm) and 40 mm/sec printing speed.

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