Estimation of Viscoelastic Properties by Additive Manufacturing for Poly Ethylene Terephthalate Glycol (PETG) Material

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Abstract. Fused Deposition Modeling (FDM), a renowned Rapid Prototyping (RP) process, has been successfully implemented in several industries to fabricate concept models and prototypes for rapid manufacturing. This study furnishes terse notes about the material viscoelastic properties of FDM processed Poly Ethylene Terephthalate Glycol (PETG) samples considering the effect of FDM process parameters. Dynamic Mechanical Analysis (DMA) is carried out using Dynamic Mechanical Analyzer equipment to study the dynamic response of the FDM processed material subjected to dual cantilever loading under periodic stress. Three FDM process parameters namely layer thickness, feed rate, infill density were contemplated. PETG parts are fabricated using 100% infill density at a feed rate of 40mm/sec with three different layer thicknesses of 0.17mm, 0.23mm and 0.3mm. DMA is performed with temperature range from room temperature to 130°C at five different fixed frequencies of 1, 2, 5, 7 & 10Hz. This aims to explore the effect of FDM process parameters and frequencies on viscoelastic properties of Storage Modulus, Loss Modulus and damping behaviour of 3D printed parts.

Keywords: Fused Deposition Modelling, PETG, Dynamic Mechanical Analysis.

1. Introduction

Additive manufacturing (AM), also known as additive manufacturing, enables the manufacture of entirely designed items with a high level of geometrical complexity at reduced time and cost of manufacturing. Polymers have become a widely researched class of materials for AM applications in addition to metals and ceramics. The synthetic versatility and adaptability, as well as the wide range of properties that can be achieved with polymer materials, have made polymers the most widely used material class for AM methodologies [1]. Abhinav Chadha et al. studied the effect of fused deposition modeling process parameters on the mechanical properties of 3D printed parts and stated that tensile strength and flexural strength increases first and then decreases with increased bed temperature. Tensile strength and flexural strength improve with the rise in primary layer thickness. In terms of infill types, there is good tensile strength and better flexural strength in the triangular and honeycomb [2]. The effect of process parameters on the mechanical properties of poly ethylene terephthalate glycol (PETG) material has been well investigated by performing tensile and flexural tests; layer thickness, feed rate of the material will be minimum with higher percentile of infill density shows good tensile properties; minimum layer thickness, medium feed rate and lower percentile of infill density shows good flexural properties. Further, the authors reported the contribution of layer thickness is higher among feed rate and infill density [3].

The experimental results show that the polymer blend of PLA + PETG, unlike other polymers, would be an ideal choice because of its superior mechanical properties, which can be useful in various engineering applications [4]. Mansour et al. studied the mechanical and dynamic behavior of 3d printed polyethylene terephthalate glycol with carbon fibers reinforced by fused filament manufacturing. The researchers stated that the unfilled PETG's compressive strain was lower than that with carbon fibers, while the carbon / PETG product compressive modulus was low. The results of the cyclic compression test showed lower loss factor values for the PETG samples, suggesting faster dissipation of energy at different amplitudes; they are stable with less vibration. Including carbon fibers in PETG also resulted in moderate damping capacity reduction [5]. The polyetherimide (PEI) blends modified by either polycarbonate (PC) or glycol-modified polyethylene terephthalate (PETG) have been prepared and thoroughly described in terms of their rheological, morphological, thermo mechanical and tensile properties. The immiscibility of PC contents higher than 20 wt % deteriorated the tensile properties, making it less appealing to applications, while melting viscosity further decreased to increase PC contents [6]. The flow rate (F) and print acceleration (PA) are the parameters with the greatest influence. The flow rate is responsible for the more or less circular portion of the deposited filament. The speed of printing is responsible for keeping this portion on the printing path more or less uniform. The profile and behavior obtained in each sample are unique in each case, depending on the programmed parameters [7].

2. Experimental Procedure

The following section elaborates the experimental procedure carried out and the steps involved are Filament Materials, Fabrication of Specimens and Dynamic Mechanical Analysis.

2.1. Filament Material

Poly Ethylene Terephthalate Glycol has been selected for the fabrication of specimens. PETG material is a thermoplastic type which has low shrinkage, very strong, not brittle and mostly layer adhesion is fantastic. The properties of PETG material for printing condition were mentioned in table 1.

Table 1: Properties of the PETG material

1	Filament diameter	1.75mm
2	Density of the Filament	1.27g/cc
3	Favorable Working Temperature	235°C
4	Bed Temperature to be maintained	60°C

2.2. Fabrication of Specimens

The test specimen is initially designed by using CAD (solid works) software of dimensions (60x10x3mm) as per ASTM D4065 standard and shown in Fig.2. This 3-D part model is then saved in the form of '.STL' format. Varying the process parameters could be achieved by the use of slicing software of "CURA ULTIMAKER version 3.6.0" where we include or introduce or change the processing parameters values such as infill density, layer thickness, feed rate, bed temperature, extruder temperature, controlling over cooling fan, specimen orientation, etc., Finally the saved G-code file will be run by the FDM printer to get the fabricated ASTM standard specimens. The schematic view of fused deposition modeling as shown in Fig.1.The specimen fabrication as shown in Fig.3 involved varying of process parameters of PETG material are:

3D printing technique : Fused Deposition Modelling (FDM)

Printer model : DRONA "CS300"

Material used : PETG (Poly Ethylene Terephthalate Glycol)

Operating temperature : 220°c - 250°c

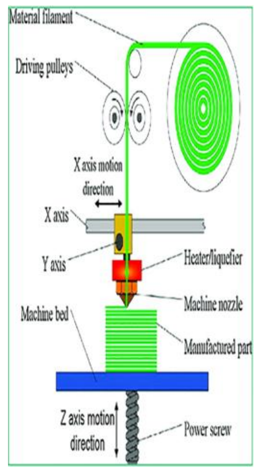
Layer thickness : 0.17mm, 0.23mm & 0.3mm

Feed rate : 40mm/sec

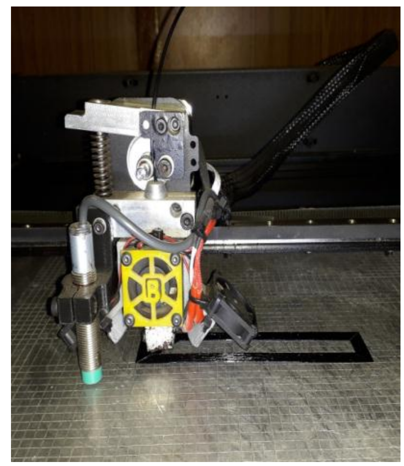
Infill density : 100%

Extruder temperature : 235°c

Bed temperature : 60°c



(a) Schematic view of FDM [9]



(b) Fabrication of Specimen on FDM printer

Fig.1 Fused deposition modelling method

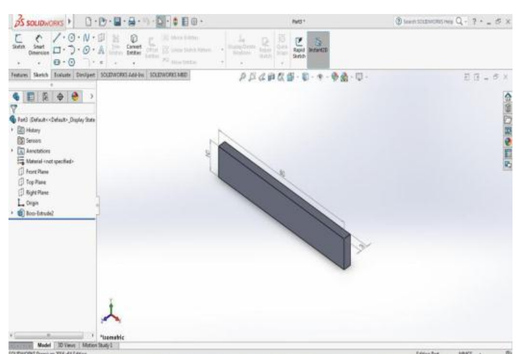


Fig. 2. Design of test specimen in solid works

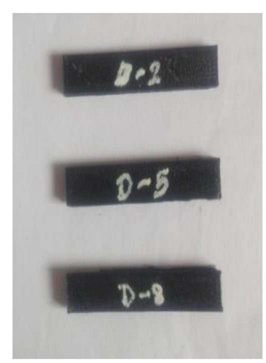


Fig. 3. FDM processed PETG test specimens

2.3. Dynamic Mechanical Analysis

Dynamic Mechanical Analysis is a tool used to analyze and classify materials and is very useful to study polymers viscous behavior. Sinusoidal stress is applied and the stress is measured in a sample of the temperature material and the rate of stress is often modified or both, resulting in variations in damping values. The temperature of product transition from the glass region to the rubber region can be obtained through this analysis. The polymer's viscoelasticity is studied by means of dynamic mechanical analysis where the resistance of the sinusoidal force is applied to the material and the resulting displacement (strain). In the orthogonal phase of stress, the displacement strain of the viscous fluid will be completely delayed in relation to stress. There are features of elastic viscous polymers between where phase lag occurs during DMA testing. The storage module measures stored energy, represents the elastic component, and measures the energy loss module dissipating as heat, representing the viscous part. Experiments are conducted by applying a small cyclic deformation to a sample over a wide temperature range. The dynamic mechanical testing of specimen as shown in Fig.4. The following experimental conditions were used to analyze the PETZ sample.

Instrument used : Diamond DMA

Heating rate : 5°c/sec

Temperature range : 25°c to 130°c

Frequencies : 1, 2, 5, 7 & 10 Hz

Deformation mode : 3-Point Bending (Shown in Fig. 3)

Sample dimensions : 60x10x3mm (ASTM D4065)

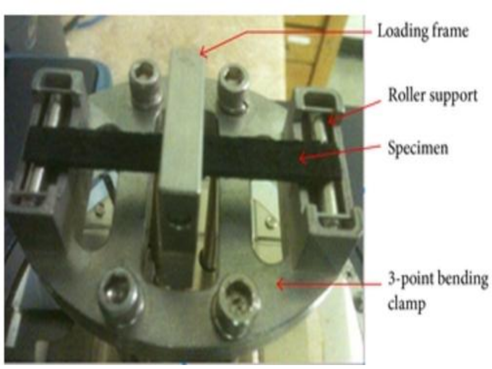


Fig. 4a. Loading of PETG specimen in DMA

Fig 4b. Diamond DMA

3. Results & Discussions

After each experiment a frequency scan graph is generated with storage modulus (E') and loss modulus (E") on left Y-axis and damping coefficient (tanδ) on right Y axis against the temperature(ºc) on X axis. For each sample with different parameters (by keeping feed rate constant and varying layer thickness) a frequency scan graph is obtained.
All the graphs of the samples with particular layer thickness and at different frequency are overlaid. Fig. shows such an overlaid graph of samples with layer thickness of 0.17mm at five different frequencies (1, 2, 5, 7, &10Hz).

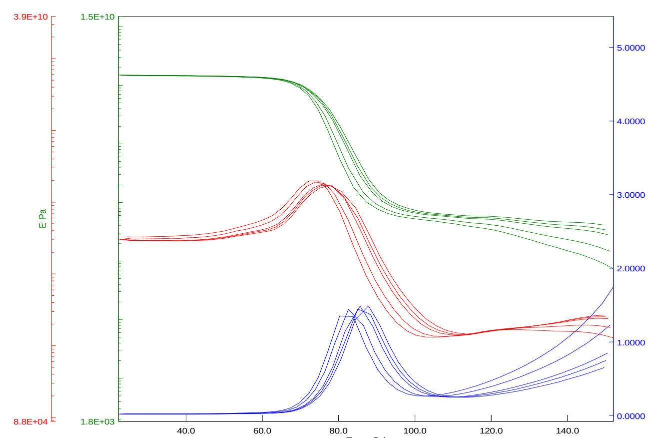


Fig.5. shows graph of samples with layer thickness of 0.17mm at five different frequencies (1, 2, 5, 7, &10Hz).

The variation of storage modulus, loss modulus and damping factor as a function of temperature and layer thickness at a frequency(1Hz) of FDM processed PETG material are shown in Figs. 6 to 8. At layer thickness of 0.23mm we found that the value of storage modulus and loss modulus is maximum compared to that of 0.17mm & 0.3mm layer thickness. Further, at layer thickness of 0.3mm we found that the value of damping coefficient is maximum compared to that of 0.17mm & 0.23mm layer thickness.

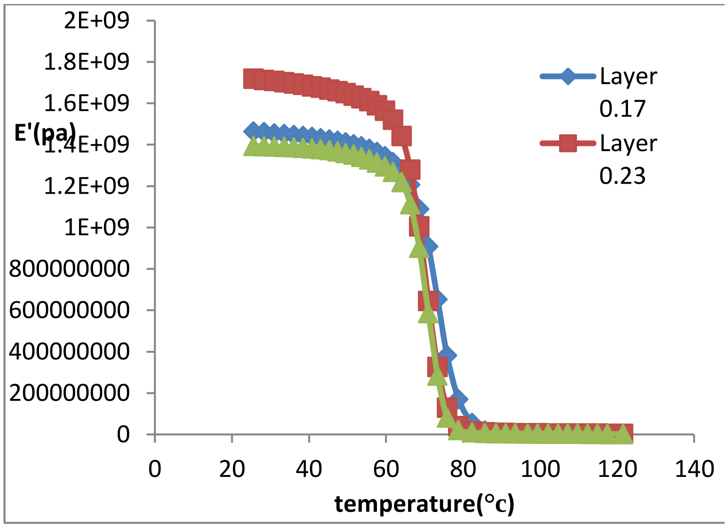


Fig.5. Effect of layer thickness on storage modulus (E') at frequency of 1Hz

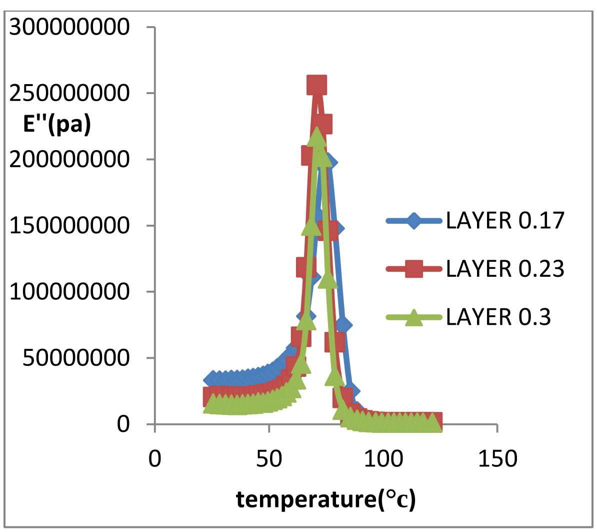


Fig. 6. Effect of layer thickness on loss modulus (E'') at frequency of 1Hz

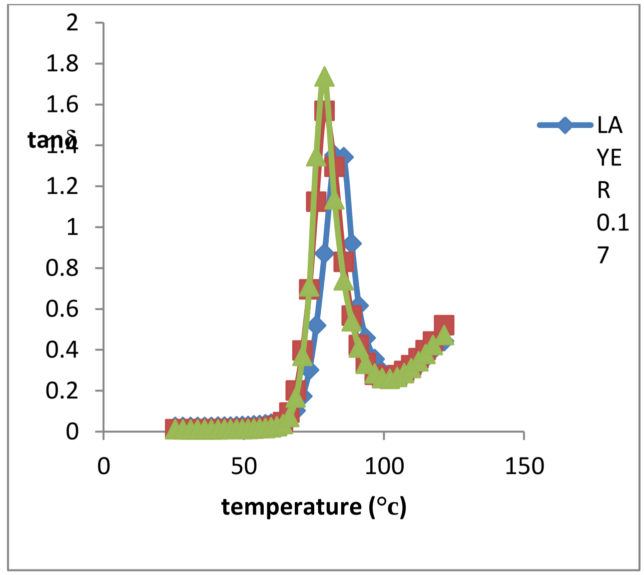


Fig. 7. Effect of layer thickness on damping coefficient (tanδ) at frequency of 1Hz

The variation of storage modulus, loss modulus and damping factor as a function of temperature and frequencies at different layer thicknesses of FDM processed PETG material are shown in Figs. 8 to 10. There is a minute variation in storage modulus by varying frequencies. It is observed that the loss modulus values are decreased with the increase in frequency. The peak of this tanδ curve gives the value of glass transition temperature (t_g). Also, it is observed that with the increasing in frequency the value of glass transition temperature (t_g) is increasing.

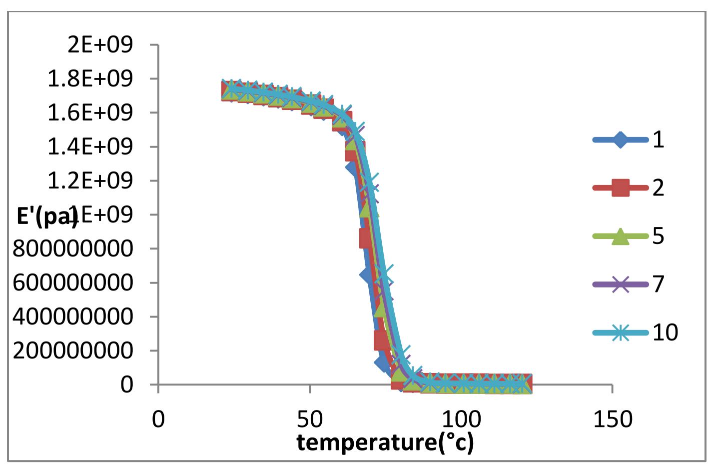


Fig. 8. Effect of frequencies on storage modulus at 0.23mm layer thickness.

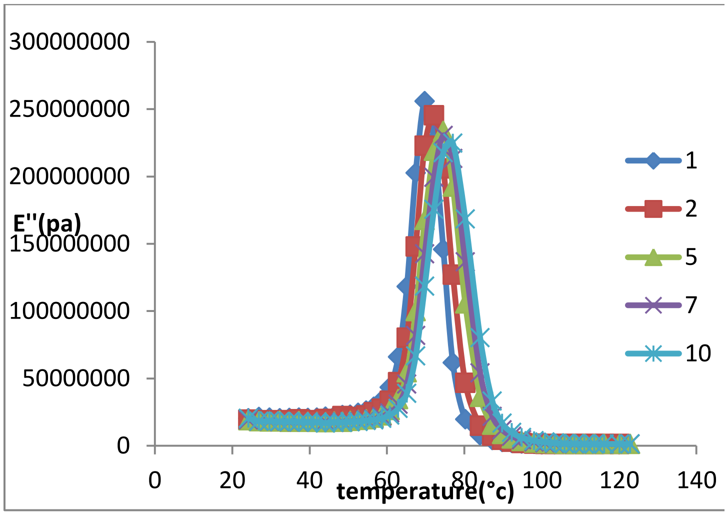


Fig. 9. Effect of frequencies on loss modulus at 0.23mm layer thickness

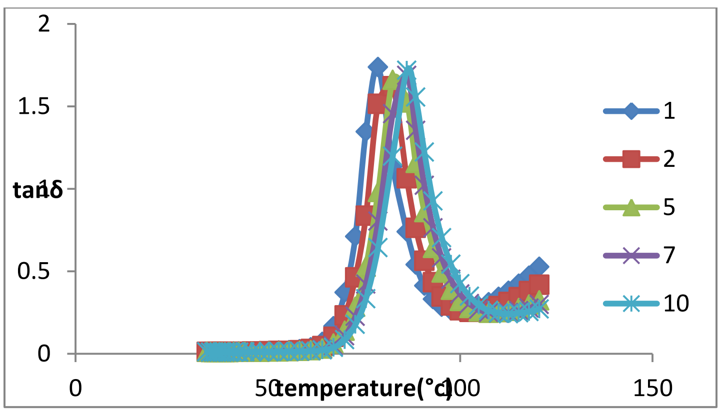


Fig. 10. Effect of frequencies on tanδ at 0.3mm layer thickness

4. Conclusions

This paper mainly focused on the dynamic mechanical properties of PETG samples fabricated by FDM technology and investigated how the process parameters affect these properties. In dynamic mechanical analysis, this study compared and discussed the experimental data obtained in temperature sweep. From the results it is clear that for PETG samples built with different layer thickness (0.17, 0.23, 0.3mm), the storage modulus values are gradually decreasing with the increase of temperatures. Whereas the values of loss modulus and tanδ increases to some extent (up to glass transition temperature t_g) and then falls. Storage modulus and loss modulus values are maximum at 0.23mm layer thickness irrespective of frequency variance. Tanδ values are maximum at 0.3mm layer thickness. Frequency shows minute effect on storage modulus, loss modulus values are decreased with the increase in frequency. The glass transition t_g temperature value increases with the increase in frequency.

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