Ambient vibration conductance of FDM-printed PLA components

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Abstract

Fused deposition modelling(FDM) fabricated components are used in many engineering applications. Recent mechanical characterization studies focus mainly on their static load-bearing capabilities. In this study, we subject FDM-printed polylactic acid(PLA) samples to ambient vibration-like conditions and measure their structural responses with high-sensitivity accelerometers. The samples had their printing layer height and infill percentage varied to see if there were any differences in their structural responses to such vibrational loading. Investigations have preliminarily concluded that the PLA samples tend to produce amplified dynamic responses in x,y and z directions. However, 2 samples with a 20% infill percentage produced damped responses when subjected to transverse vibration loading. This crucial finding hints that bulk-printed FDM components may have variations in their dynamic performances. From this study's insights, practitioners can have a clearer understanding of how FDM-printed PLA components may affect dynamic precision before integrating them into engineering applications.

Introduction

Engineering applications which require custom design components often use AM for the fabrication of those parts. AM techniques can be grouped under the 7 categories, VAT photopolymerization, material jetting, binder jetting, material extrusion, powder bed fusion, sheet lamination and directed energy deposition[1]. FDM, which falls under the material extrusion category is a mature AM technology that is economical and allows low melting point metal or polymer components to be produced.

Till now, many studies have characterised the static mechanical properties of polymer material FDM materials. Pszczółkowski et al conducted a review of the various techniques for measuring Young's modulus of FDM PLA components[2]. Bembenek et al studied how the elastic loading direction on the sample and its shape affect the elastic modulus using only four printed PLA samples[3].

Studies on the dynamic properties of FDM-printed PLA components are minimal at the moment. Under most circumstances, ambient vibrations will conduct themselves into any engineering, or manufacturing setup and affect operational performance. Such vibrations may range from 4Hz to 100Hz and may have displacements at few hundreds of micrometres[4]. The study Palmieri et al had undertaken on printed PLA components was done for a highly complex y-shaped sample and only for understanding fatigue loading effects[5]. Avramov et al had also investigated but with a numerical approach and no experimental verification with high-sensitivity accelerometers[6].

In this paper, the dynamic structural response of FDM-printed PLA samples subjected to ambient vibration-like loading is studied. Similar to Bembenek's approach, only 4 PLA samples are used for this study and a piezoelectric actuator that outputs dynamic loading in a sine sweep motion from 4Hz to 100Hz will be used for providing ambient vibration. The accelerometer measurements of the samples' dynamic response will also be presented as a time series.

Experimental setup

4 different samples were manufactured with the same FDM printer from Tiertime and their characteristics are presented in Table 1. The samples are 50mm wide,30mm depth and 10mm thick. No post-processing was done on the printed components and printing orientations were constant for all samples. Only layer height and infill percentage were varied.

<table>
<tr><th>Sample No.</th><th>Material</th><th>Layer height(mm)</th><th>Infill (%)</th></tr>
<tr><td>1.</td><td rowspan="4">Polylactic acid (PLA)</td><td rowspan="2">0.15</td><td>20</td></tr>
<tr><td>2.</td><td>99</td></tr>
<tr><td>3.</td><td rowspan="2">0.35</td><td>20</td></tr>
<tr><td>4.</td><td>99</td></tr>
</table>

Table 1. PLA printed samples' characteristics

The experiment setup for testing the FDM printed components' response to ambient vibration is shown in Figure 1.

A piezoelectric actuator, PAZ005 from Thorlabs, and a waveform signal generator, Agilent 3320A, are used together to produce the ambient vibration loading. Since external vibrations are generally found to be within 4Hz to 100Hz, the waveform/vibration signal generator is set to output a sine sweep signal from 4Hz to 100Hz for 5 seconds. 10 seconds worth of readings were captured to ensure responses were at a steady state. Throughout all frequencies, the piezoelectric actuator extends to its maximum displacement at 40μm.

The dynamic structural responses of the FDM printed components are measured with an accelerometer from Kistler 8766A100BB. The data acquisition device (DAQ), Dewesoft Krypton ACC, collects accelerometer readings at 5000Hz sampling frequency. The piezoelectric tip, printed sample and accelerometer were fastened to each other with adhesives on a precision metal stage.

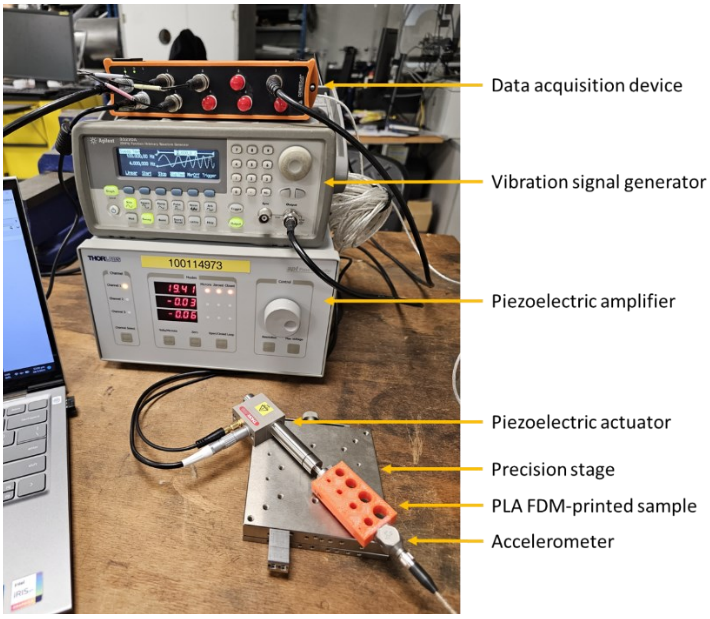

Figure 1. Experiment setup

Each of the 4 samples was vibrationally loaded and measured under 4 different configurations as shown in Figure 2. Vibrations were transmitted longitudinally and transversely with an accelerometer mounted at the left or top face of the sample. The accelerometer mounting orientation, which is shown in inset 2A of Figure 2, was kept consistent for all configurations. At each configuration, at least 4 experimental iterations were conducted. The x, y and z accelerometer measurements describe the samples' dynamic response to the piezoelectrically generated vibrations in those directions.

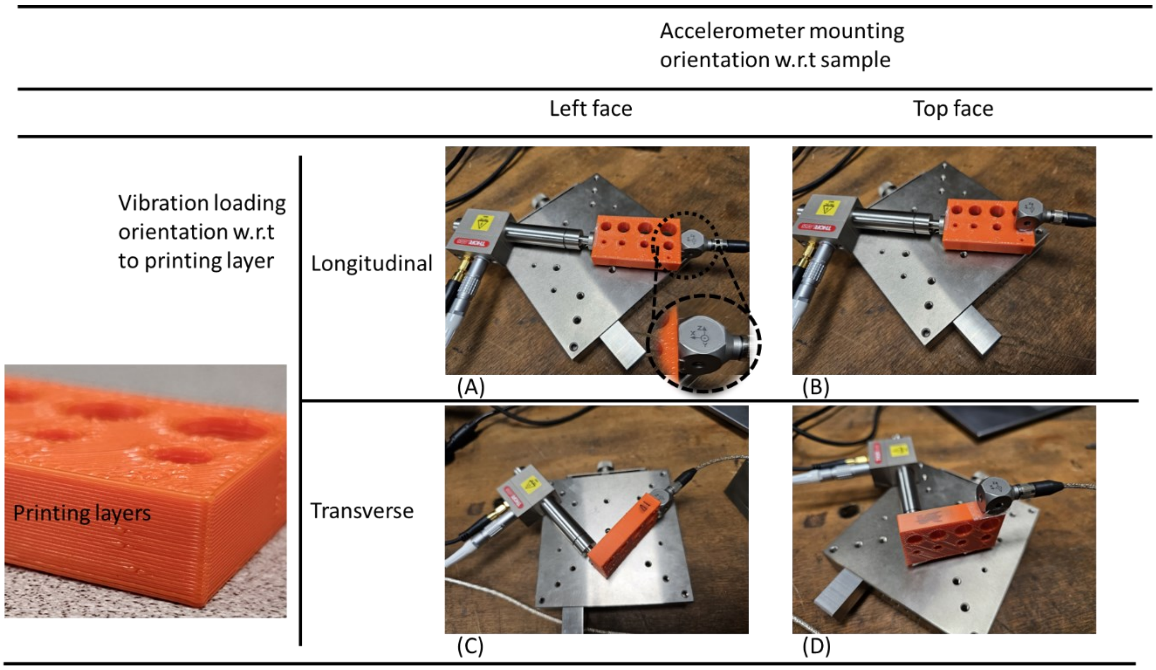

Figure 2. Vibration loading and accelerometer positioning layout for every sample. In (A) and (B), the vibration is transmitted parallel to the printing layer axis. In (C) and (D), the vibration is transmitted transversely to the printing layer axis.

Results and discussion

With the piezoelectric actuator actuating tip directly connected to the accelerometer, the maximum and minimum vibration amplitudes in the x,y and z directions are recorded in Table 2. These are the values plotted out as horizontal maximum and minimum reference lines in Figure 4 and Figure 5. From Table 2, the ambient vibration simulated by the piezoelectric actuator had the greatest amplitude in the x-direction.

Direction	Accelerometer readings(m/s^2)	
x	Max	27.0048
	Min	-30.4905
y	Max	1.9598
	Min	-2.1091
z	Max	3.1707
	Min	-5.4739

Table 2. Accelerometer measurements of vibration source that is air loaded, or has no sample coupled to it.

Figure 3 shows the summary of the PLA samples' structural responses to ambient vibration loading. Longitudinal and transverse vibrations are applied parallel to and perpendicular to the printing layer axis as shown in the insets A and B respectively. Directional conventions for the accelerometer readings are also shown in black in the figure. 'Top' and 'side' indicate the faces on which the accelerometer was mounted on.

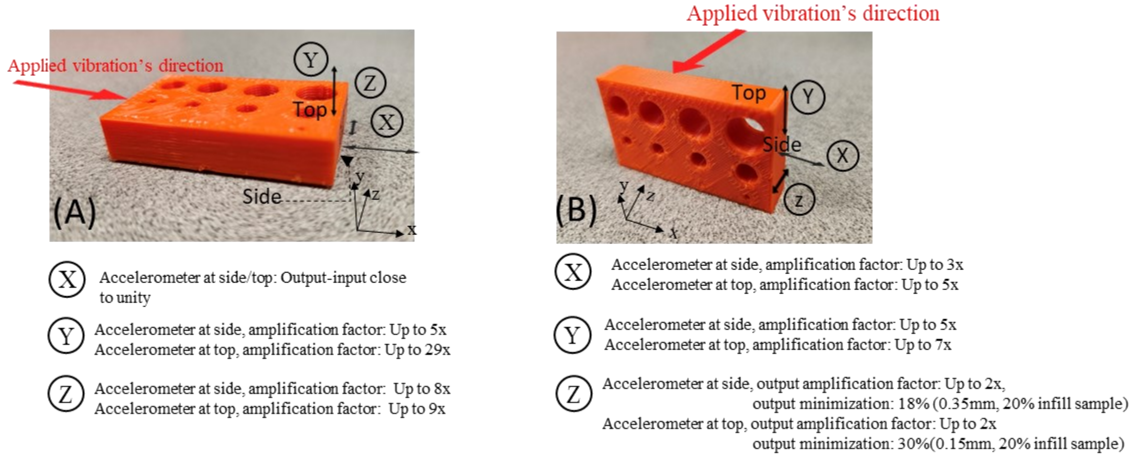

Figure 3. Vibration responses in the 3 axes were measured at the top and side faces of samples. (A) Longitudinal vibration loading along the printing layer axis. (B) Transverse vibration loading perpendicular to the printing layer axis.

Figure 4 shows an example of how data captured from the accelerometer would appear in all 3 axes when plotted out. Measurements surpassing those lines indicate structural amplification. Each coloured plot belongs to an experimental iteration.

In the example below, the sample undergoes vibration amplification in the y and z direction at frequencies greater than roughly 48 Hz. The value of 50Hz is obtained by considering the actuator outputting a sine sweep motion from 4Hz to 100Hz in a span of 5s, which at 2.5s corresponds to 48Hz.

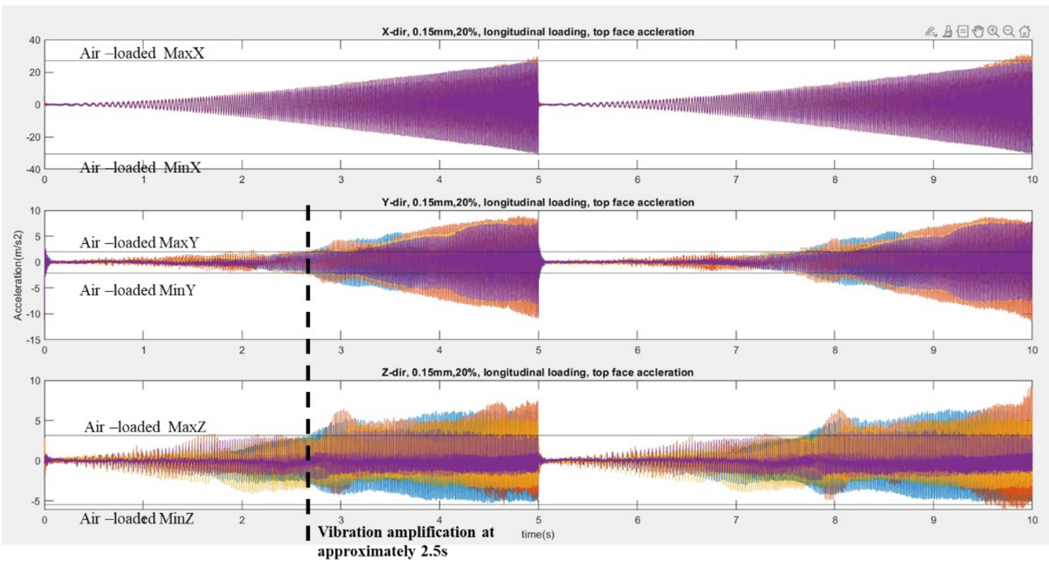

Figure 4. Example plots of x, y and z accelerometer readings for a longitudinal vibration loaded sample which has 0.15mm printing layer height and 20% infill percentage.

FDM sample’s dynamic response from longitudinally loaded vibrations

There was noticeable vibration amplification in the y and z directions as summarized in Figure 3. The extreme vibration response was observed in the y-direction, with vibration amplification at a factor of 29, when measured at the sample’s top face. In the z-directional responses, amplification was no more than a factor of 9 when measured at both faces. In the x-direction, the structure output response was at unity with the input ambient vibration.

The printing height layer and infill percentage had no observable effect on the vibration responses of the samples.

Dynamic response due to transverse vibration loading w.r.t printing layer plane

In the transverse vibration loading, output minimization in the x and z-direction was produced for two samples, both at 20% infill percentage and with differing printing layer heights. The accelerometer reading for them is shown in Figure 5 below. This response was only observed with these 2 samples and may indicate a printing defect requiring further investigation.

Acceleration amplification was observed for the y direction.

Similar to the longitudinally loaded scenario, the infill percentage and the printing layer height had no distinguishable effect on the vibration response for the samples.

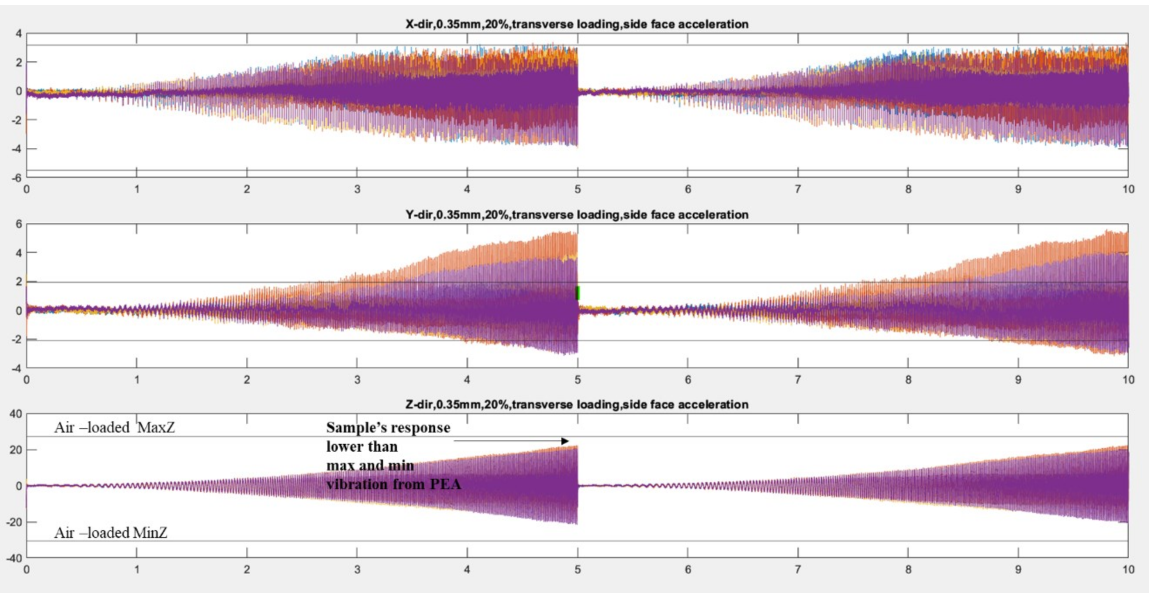

Figure 5. Accelerometer reading of sample with damped response at z-direction. The accelerometer measurements for this particular sample with 0.35mm printing layer height and 20% infill percentage had a reduced structural response at the z-

direction as shown by the 3rd plot of the figure. The middle plot, in the y direction, showed that the structure's response surpassed the vibration source's amplitude.

Conclusion

In this study, the vibration response of FDM-printed PLA samples subjected to artificially induced ambient vibrations was studied. From preliminary data collections, infill percentage and printing layer height had not much effect on the dynamic structural responses of the tested samples except for one sample which had output minimization in only one particular direction. This implies that identical components produced via the FDM method may not all have similar dynamic performance. The samples' responses to vibrations were mainly dependent on how they were loaded, transverse or longitudinal to the printing layer axis. Future work from this study would investigate how different infill patterns will affect the dynamic response of PLA components.

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