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Research Article

INVESTIGATION THE EFFECTS OF 3D PRINTER SYSTEM VIBRATIONS ON MECHANICAL PROPERTIES OF THE PRINTED PRODUCTS

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ABSTRACT

In recent years, three-dimensional (3D) printing is attracting widespread interest due to functional rapid prototyping and products by reducing the time and material involved in process. Most of 3D printer users focus on mechanical properties of products neglecting vibration characteristics of printer system effects on products. The aim of this study is to investigate the effects of 3D printer system vibrations on mechanical properties of printed products. Fused Deposition Modeling (FDM) technology which is one of most used additive manufacturing process was used to print test samples and Polyethyletherphthalate Glycol (PET-G) was used as material for printing. Vibration measurements were taking for eighteen printed test samples. Vibrations data were measured from 3D printer movement in three axes (x, y, and z) by accelerometers. The processing parameters were selected as occupancy rate, filling structures orientation, and processing speed.
The samples in rectilinear filling structure with occupancy rate of 50 % having different orientations (45° by 45° and 60° by 30°) and processing speeds (3600, 3900, and 4200 mm/min). Tensile test was used to test mechanical properties of test samples. The findings have shown that induced vibration has significant impact on mechanical properties which can be used to control the mechanical properties in terms of tensile stress and elongation of printed products during mass printing. Results showed that vibration amplitude values for orientations of 60° by 30° and processing speed 3600 mm/min are much lower compared to the other test samples. While tensile strength increases about % 5 when orientation is 45° by 45° with 3600 mm/min processing speed. From result obtained, it can be said that orientation of the product has a significant effect on the response of the printer system in terms of vibrations.
Keywords: 3D printer, vibration, mechanical properties, PET-G.

1. INTRODUCTION

Nowadays have seen increasingly rapid advances in manufacturing processes. Additive Manufacturing (AM), broadly known as three-dimensional (3D) printing, is the process that a product is printed layer by layer [1] in a Cartesian system. One of the most used AM process is Fused Deposition Modeling (FDM). FDM is commonly used for printing products with complex

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geometries n eeded in medical, aerospace, and automotive industry [2-5]. Most of the 3D printer studies focus on mechanical properties neglecting vibration characteristics of printer system effects on printed products. A study [6] reviewed a literature survey on the state of art of AM. Additional information on AM process can be found in overviews studies [7-10]. A few studies [11-13] carried out on vibration analysis for quantifying the printing parameter effects on the structural characteristics of printed products. Also, a study [14] presents vibration data obtained from printer table in terms of impact of mechanical behaviors on printing quality. Several studies [15-18] have investigated the relationships between printing orientation or processing speed and mechanical properties of printed products. However, studies relating mechanical properties of product have been relatively few and that there is no study focusing on the effect of 3D printer system vibrations taking printing orientation in account. Therefore, this study aims to experimentally investigate the effects of 3D printer system vibrations on mechanical properties of printed products with respect to processing speeds and orientation of products.

2. MATERIALS AND METHODS

A schematic drawing of 3D printer setup used in this study is shown in Figure 1. The driver of each axis of printer is performed by a stepper motor namely NEMA 17 bipolar stepper. The stepper motor specifications include 1.8^{o} for each step of 200 steps per revolution, 4 voltages on phase, 1200 mA operational current, 3,3-ohm phase resistance, and 3.2 kg-cm holding torque.

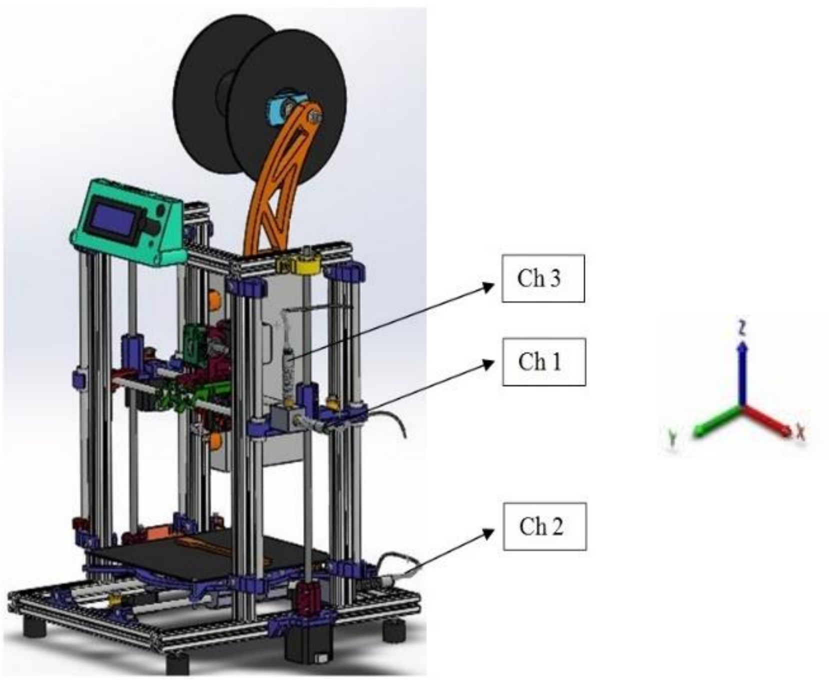

Figure 1. Schematic drawing of 3D printer setup

In order to measure vibrations of extruder head and plate of printer in Cartesian coordinate, three accelerometers (608A11) were employed. Two accelerometers were attached to head system for detecting vibration in the up and down motion. Another one was attached to table which moves front and back for dete cting vibration from side to side. The accelerometers were set as Ch1, Ch2, and Ch3 for x, z, and y axis respectively. The captured vibration signals have been analyzed in time domain. A data acquisition unit and analysis software of VibraQuest are used during the vibration data collection. Vibration amplitudes were collected for different orientation and processing speeds in order to understand the effects on mechanical properties of printed products. FDM based printer was used to print the test samples in rectilinear filling structure with occupancy rate of 50 % having different orientations (45^o by 45^o and 60^o by 30^o) and processing speeds (3600, 3900, and 4200 mm/minute). Test samples shown in Figure 2 were designed as 3D model according ISO 527 standard for tensile test using a designing software and transferred to 3D slicing interface program to be printed.

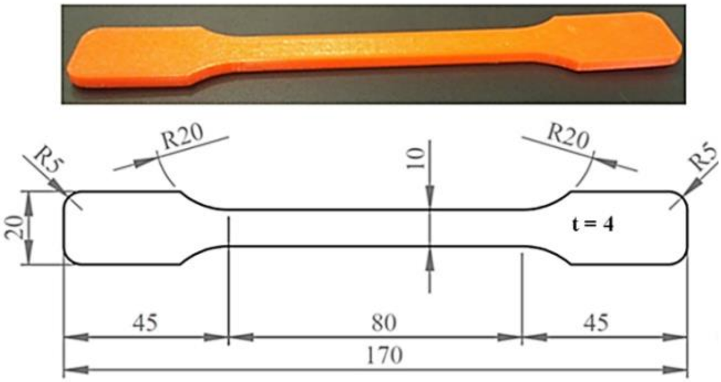

Figure 2. Dimensions of ISO 527 standard test sample

It has been industrial practice for many years to print product with PET-G material. So, PET-G is used as filament material for printing. Properties of PET-G material are given in Table 1.

Table 1. Properties of PET-G filament material [19].

Filament Material Properties	
Material	PET-G
Filament color	Orange
Filament diameter (mm)	1.75
Density (g / cm³)	1.27
Tensile strength at yield (MPa)	50
Tensile modulus (MPa)	2140
Elongation (%)	120
Melting point (ºC)	135
Heat deflection temperature	70

Eighteen test samples were printed using E3D type extruder nozzle with 0.40 mm diameter. The printing table has 200 mm width and 200 mm length. Printing parameters are given in Table 2.

The table moves in y direction and the nozzle moves in x and z direction which helps in printing test samples in different orientations as shown in Figure 3.

Table 2. The printing parameters

Printing Parameters	
Average Weight (gr)	10
Filling structure	a) Rectilinear, angle (45^o by 45^o) b) Rectilinear, angle (60^o by 30^o)
Layer Height (mm)	0.20
Occupancy rate (%)	50
Nozzle Diameter (mm)	0.40
Nozzle Temperature (°C)	230
Processing Speeds (mm/min)	3600, 3900, 4200
Speed for non-print moves (mm/min)	4800
Extrusion of Material (layer width) (mm)	0.35
Horizontal Shells (top and bottom layer)	3
Vertical Shell Number	2
Cooling Rate	Build-in

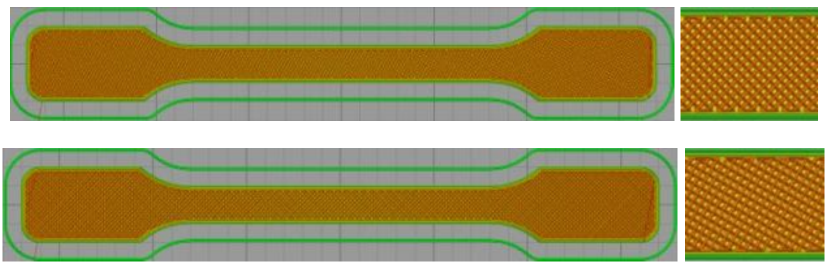

Figure 3. Test sample with rectilinear filling structure and two different orientations angles: 45^o by 45^o and 60^o by 30^o

Test samples specification for experimentation is given in Table 3. Three samples were printed for each of test samples.

Table 3. Test samples specification for experimentation

Sample Code	**Processing Speed (mm/min.)**	**Orientation Angle (Degree)**
SC1	3600	45^o by 45^o
SC2	3600	60^o by 30^o
SC3	3900	45^o by 45^o
SC4	3900	60^o by 30^o
SC5	4200	45^o by 45^o
SC6	4200	60^o by 30^o

Tensile tests for samples under the same condition were conducted with tensile test machine referenced UTEST shown in Figure 4.

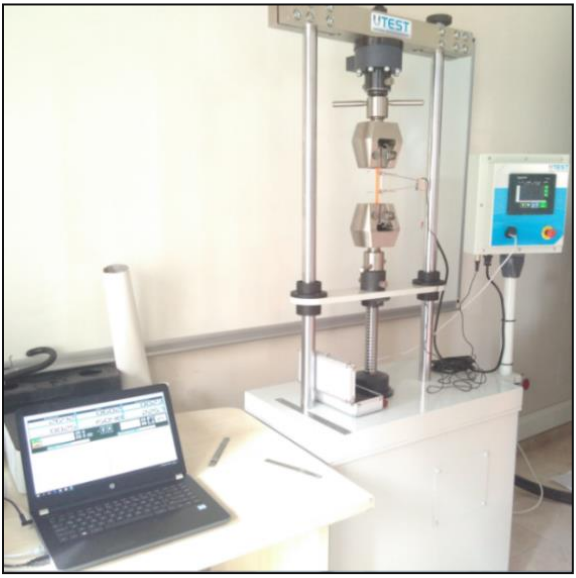

Figure 4. Tensile Test Machine

3. RESULTS AND DISCUSSION

Figure 5 shows test samples after breaking and Table 4 gives tensile strength of test samples measured by tensile test machine.

From Figure 5, it can be seen that breaking line is 45° with horizontal angle for orientations of 45^o by 45^o, 60° with horizontal angle for orientations of 60^o by 30^o. And also, it can be seen that the processing speeds have inverse proportion with elongation rate (%).

Table 4. Tensile test results

	Tensile Strength (MPa)			
Sample Codes	**Test 1**	**Test 2**	**Test 3**	**Average value**
SC1	18.86	18.80	17.58	18.41
SC2	16.41	16.22	17.52	16.71
SC3	15.62	15.89	15.83	15.78
SC4	16.44	17.43	18.46	17.44
SC5	17.92	17.81	17.06	17.59
SC6	17.22	17.69	17.70	17.53

From Table 4 and Figure 6, it can be seen that the minimum tensile strength value is 15.62 MPa for orientations of 45^o by 45^o and processing speeds of 3900 mm/minute while the maximum tensile strength value is 18.86 MPa for orientations of 45^o by 45^o and processing speed 3600 mm/min. The stress focuses with 45 degree in the region of material bonding during the tensile test. Therefore, maximum resistance has also emerged at this region, and orientation of 45° by 45° shows more tensile strength.

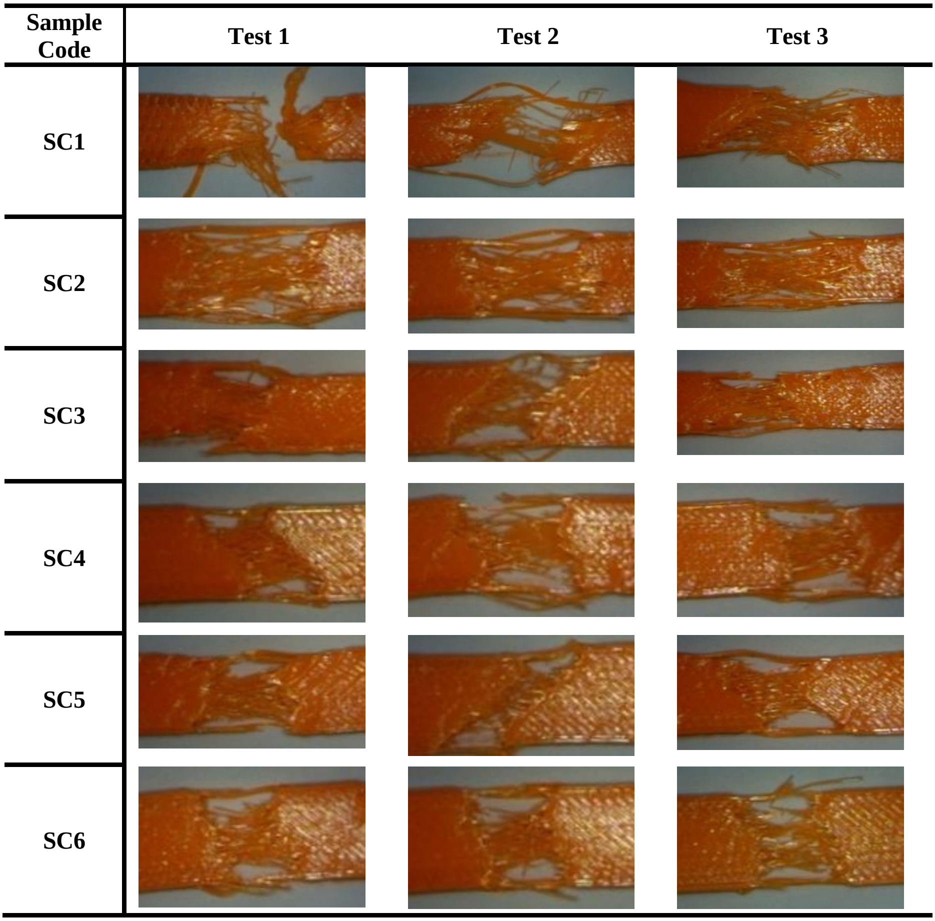

Figure 5. Picture of test samples after breaking

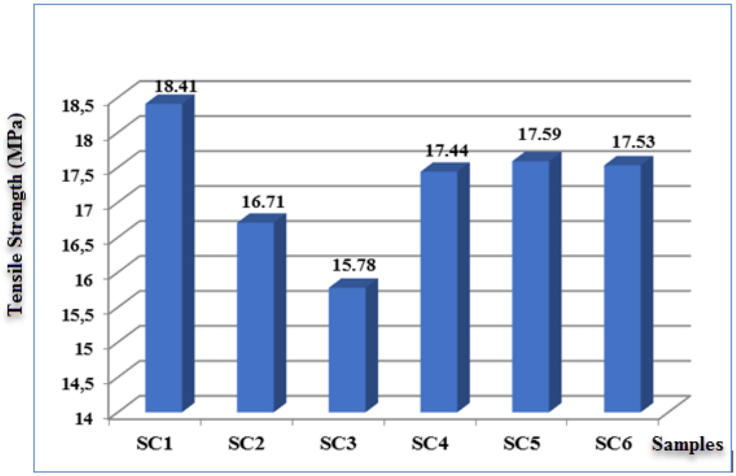

Figure 6. Tensile test results

When the average values are compared, it is realized that for orientations of 45° by 45° has more tensile strength value than orientations of 60° by 30°. In addition, when the processing speed increased tensile strength is decreased.

Table 5. Elongation at break

	Elongation (%)			
Sample Code	**Test 1**	**Test 2**	**Test 3**	**Average values**
SC1	0.26	0.23	0.17	0.22
SC2	0.17	0.16	0.17	0.16
SC3	0.24	0.13	0.16	0.17
SC4	0.09	0.13	0.12	0.11
SC5	0.15	0.12	0.13	0.13
SC6	0.12	0.10	0.11	0.11

From Table 5 and Figure 7, it can be seen that the maximum elongation value is 0.26 % for orientations of 45° by 45° and processing speeds of 3900 mm/minute and the minimum elongation value is 0.09 % for orientations of 60° by 30° and processing speeds of 3900 mm/minute.

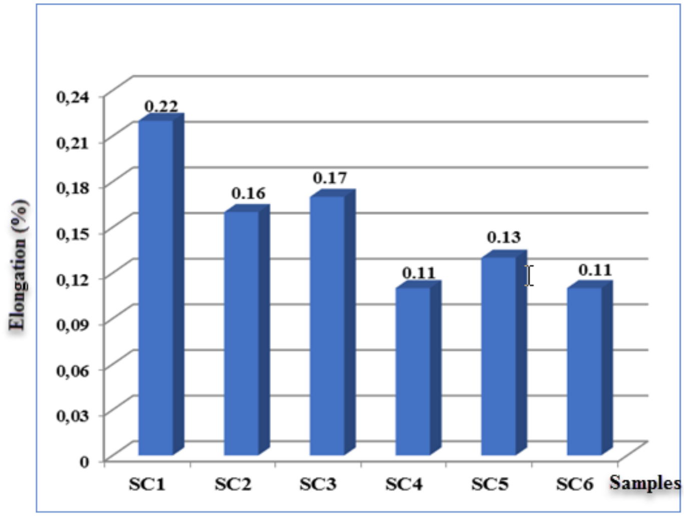

Figure 7. Elongation at break

When the average values are compared, it is realized that for orientations of 45^o by 45^o has more elongation percentage value than orientations of 60^o by 30^o. In addition, when the processing speed increased elongation rate (%) is decreased.

Many of today's 3D printers especially those printing functional products require the superior stability characteristic of printer structure to prevent improper printed products. So, a printer system must be designed to operate without excessive vibration. Spectral analysis provides important information about printer structure vibrations. Spectral analysis is simply the examination of frequency domain captured from the waveform. The time waveform displays an excellent picture of disturbances over time. Vibration amplitude values in Figure 8 were measured in x direction for printer table motion and in y and z direction for extruder head motion. Time domain data are presented with amplitude as the vertical axis and elapsed time as the horizontal axis for all test samples while printing. The table motion in y direction (Ch 2) has the maximum amplitude values compare to motion of extruder head in x and y direction. Also, it can be seen that vibration amplitude values for orientations of 60^o by 30^o and processing speed 3600 mm/minute are much lower compared to the others test samples. It can be said that orientation of the product has a significant effect on the response of the printer system in terms of vibrations. Thus, the test sample in 60^o by 30^o orientation displayed better damping capacity compared to one in 45^o by 45^o orientation. Increasing print speed results in a significant increase in the vibration amplitude value. From the plots, it also shows that induced vibration has significant effects on mechanical properties of printed product which is proportional to table acceleration with respect to orientation and processing speed.

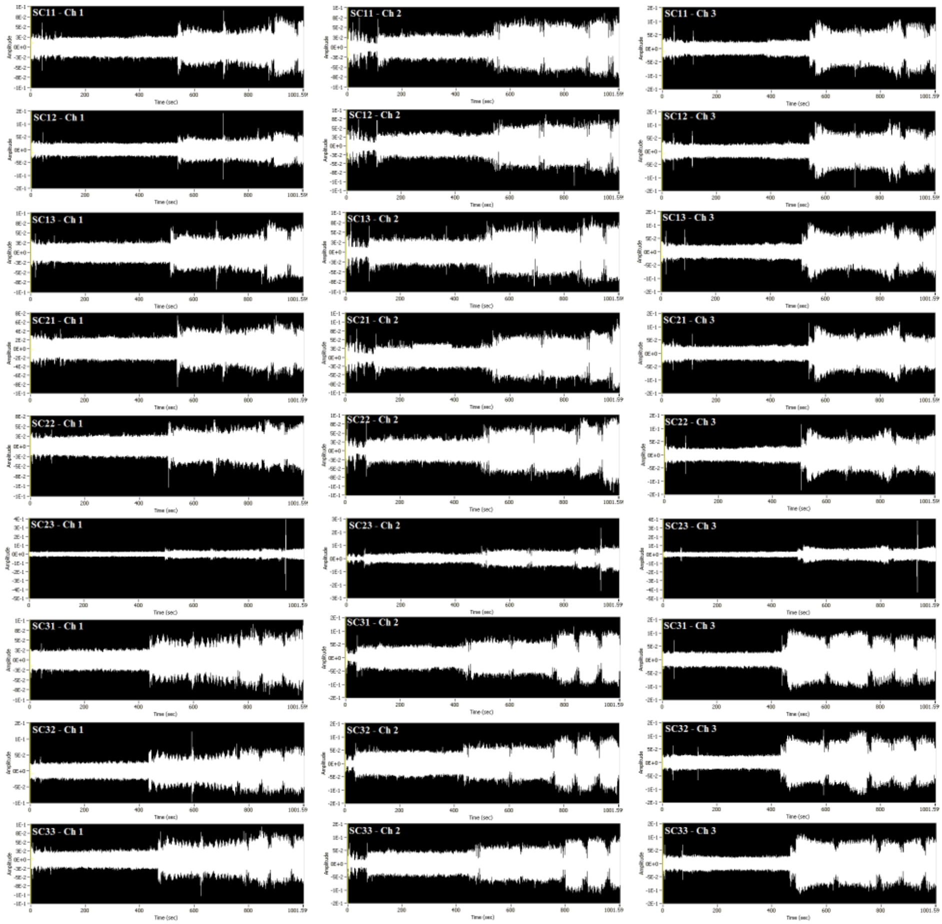

Figure 8. Vibration amplitude values

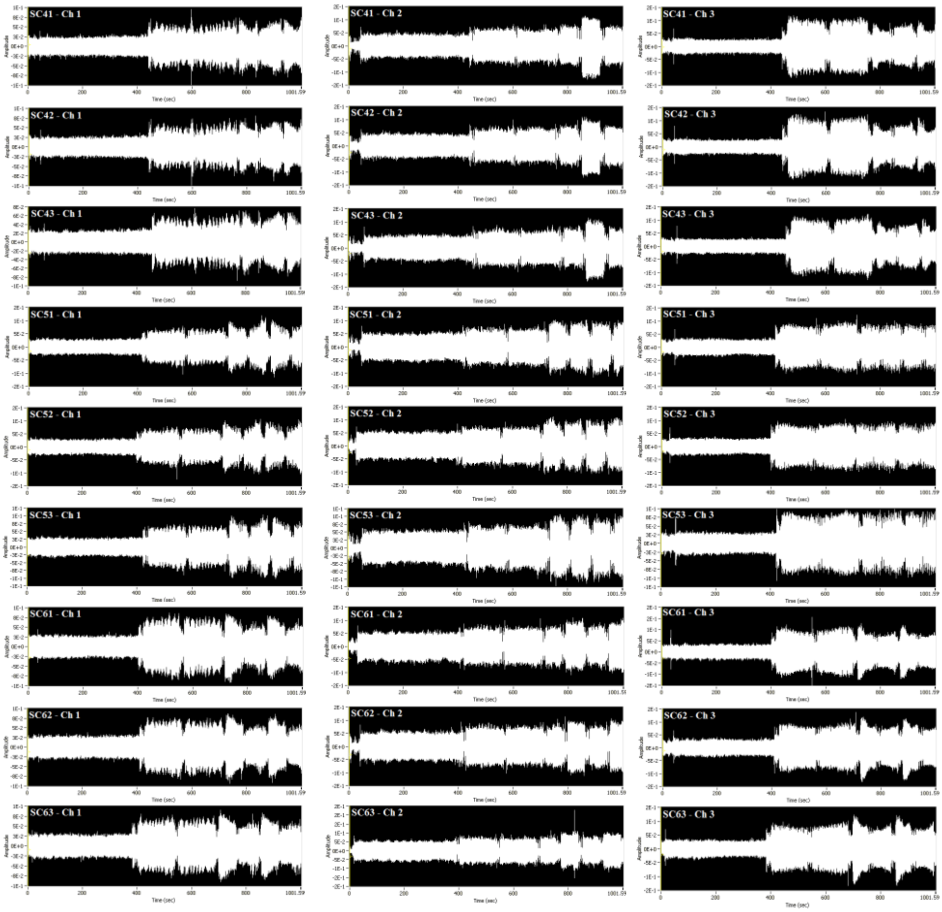

Figure 9. Vibration amplitude values (continued)

Figure 8 and Figure 9 show that the maximum vibration amplitude values are obtained in the y axis. The reason for this, movement of the y axis changes direction more frequent than the other axes due to layout of the test sample on the table. And also, vibration amplitude values are directly proportional with orientation and processing speed.

4. CONCLUSION

3D printer system vibrations with respect to orientation and processing speed have a significant influence on mechanical properties in terms of tensile strength and elongation of printed products. The composition of the printing process is complicated. Vibration in 3D printer system exist throughout the printing process while influenced by many sources such as 3D printer structure, nozzle type, filling structure type and orientation, processing speeds etc. Controlling vibrations in 3D printer processing is important for improving mechanical properties of printed products. The purpose of this study was to investigate the effects of 3D printer system vibrations on mechanical properties of printed products. Vibration amplitudes were analyzed for different orientation and processing speeds in order to understand the effects on mechanical properties of printed products. Polyethyletherphthalate Glycol (PET-G) was used as material for test sample printing. FDM based printer was used to print the test samples in rectilinear filling structure with occupancy rate of 50 % having different orientations (45^o by 45^o and 60^o by 30^o) and processing speeds (3600, 3900, and 4200 mm/minute). Vibration amplitude values were measured in x direction for printer table and in y and z direction for extruder head. Tensile strength of test samples was measured by tensile test machine. The results have shown that induced vibration has significant impact on mechanical properties which can be used to control the mechanical properties of printed products during mass printing. It can be concluded that vibration amplitude values for orientations of 60^o by 30^o and processing speed 3600 mm/minute are much lower compared to the others test samples. It can be said that orientation of the product has a significant effect on the response of the printer system in terms of vibrations.

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