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Vibrational Analysis of 3D Printed Components

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Abstract:

3D printing technology is an additive manufacturing process which is based upon layer-by-layer material deposition technique. It is being widely used owing to its various advantages like precision production in a short period of time, desired design and complexity of product, easy procedure, rapid prototyping and hence find wide range of applications in industries, automobile sectors, oil and power sectors, aerospace sectors. There are various technologies of 3D printing among which Powder Bed Fusion (PBF), Fused Deposition Modelling (FDM) are widely used 3D printing technologies. Though 3D printing has substantial advantages, the effects of vibrations of 3D printers on mechanical performance of the products developed using 3D printing are often overlooked and this can lead to catastrophic failure.This paper aims to review the effects of vibrations of the printer system on the 3D printed products with the help of tests like fatigue and tensile tests performed on Acrylonitrile butadiene styrene (ABS) material and Polyethyletherphthalate Glycol (PET-G). The analysis has shown that vibrations of the printer system produce substantial impact on the mechanical properties of the components produced by 3D printing. Test shows that due its low fatigue strength, these components might not be suitable for applications with high strength requirements but can be effectively used in various low strength applications.

Keywords-**3D Printing, Vibrational Analysis, Mechanical Performance, ABS, fatigue test, Applications.**

I. Introduction

3D Printing is an additive manufacturing (AM) technology which basically uses the technique of layer-by-layer material deposition. Several techniques have been developed in the 3D printing domain such as Powder Based Fusion (PBF), Direct Energy Deposition (DED), Selective Laser Sintering (SLS), Stereolithography (SLA), Direct Metal Laser Sintering (DMLS), Fused Deposition Modelling (FDM) and others. Fused Deposition Modelling (FDM) is employed where complex design and geometries are to be produced for automobile, aerospace or medical sectors.

There is larger stress over the mechanical properties of these AM manufactured products and the effects of vibrations on the products are overlooked. These vibrations have substantial influence on the mechanical performance on the products. There are only few studies concerned with the vibrational analysis and hence this review paper aims to study and review these vibrational characteristics of 3D printer system and their effects on the products produced.

II. Materials

A wide variety of materials are used in 3D printing depending upon the required properties and application. Nylon, Resin, PLA (Polylactic Acid), Ceramics, PET/PETG (Polyethylene terephthalate/Glycol), HIPS (High Impact Polystyrene), TPU (Thermoplastic polyurethane), ABS (Acrylonitrile Butadiene Styrene), Carbon fiber, Titanium, Stainless Steel, Aluminum and alloys, nickel-based alloys are a few commonly used materials in 3D printing.

Acrylonitrile Butadiene Styrene [ABS]

Acrylonitrile Butadiene Styrene commonly known by its abbreviation ABS is a thermoplastic material. It one of the most popular material in 3D printing owing to its various advantages like durability, low cost, lightweight, easy extrusion and other technical properties. The technical specifications which make ABS a go to material for 3D printing are given below.

Technical Specifications [3]:

- Density- 1-1.4 gm/cm3
- Dielectric constant- 3.1 to 3.2
- Elastic modulus- 2 to 2.6 GPa
- Elongation at break- 3.5 to 50%
- Flexural modulus- 2.1 to 7.6 GPa
- Flexural strength- 72 to 97 MPa
- Heat deflection temperature at 1.82 MPa -76 to 110°C
- Heat deflection temperature at 455 KPa- 83 to 110°C
- Tensile strength: 37 to 110 MPa
- Thermal expansion- 81 to 95 µm/m-K Material Properties of Acrylonitrile Butadiene Styrene [ABS]
- Temperature - 225°C
- Flow Tweak - 0.93
- Bed Temperature - 90°C
- Bed Preparation - apply glue stick 2 layer & then abs glue 1 layer

III. Fatigue characteristics of 3d printed ABS material

Fused deposition modelling (FDM) technology was used for this investigation. Acrylonitrile butadiene styrene (ABS) was used as material and a dog bone shaped part was produced. Fatigue test was conducted on specimens at 40%, 60% and 80% of the tensile strength. The tensile testing was carried out using Universal Testing Machine (UTM) to determine the mechanical properties of ABS materials such as yield strength, ultimate tensile strength and modulus of elasticity[2].

Fatigue testing was performed using machine SERVOPULSER, at a frequency of 1 Hz with tension-tension cyclic loading, R=0. Two different applied loads were used, which are 40%, 60% and 80% from UTS value. Fatigue test was run until the specimen breaks [2].

It was found that 3D printed component might not be suitable for high strength industrial application owing to its low fatigue strength. But 3D printed components may be grown in low volume, customized design components and are suitable for low strength application.

IV. Effects of vibrations on 3D printed components

Effects of Vibrations of 3d printers on the components are neglected as compared to mechanical properties and advantages of 3d printers.

Throughout the printing process there are vibrations in the printer which depends upon various factors such as structure of printer, nozzle types, processing speeds, orientation of product etc. The vibrations produced in 3d printers are forced vibrations. Neglecting these vibrational properties can lead to catastrophic failure of components produced through 3d printed technology and hence it becomes essential to control these vibrations in order to obtain better mechanical properties of printed components.

V. Investigation on PET-G

The technology used for this investigation was FDM (fused deposition modelling). Polyethyletherphthalate Glycol (PET-G) was used as the material for printing test samples. 18 test specimens were used for investigation, Vibration data were determined from 3D printer movement in three axes (x, y, and z) using accelerometers. The parameters for processing were occupancy rate, filling structures orientation, and processing speed. The specimens 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). In addition to this tensile testing was carried out to test the mechanical properties and effects of vibrations of 3d printers [1].

The induced vibrations showed substantial impact on the mechanical properties which can further be used to control the mechanical properties in terms of tensile stress and elongation of printed products. Investigations showed that the vibration amplitude values for orientations of 60° by 30° and for processing speed of 3600 mm/min are much lesser when compared to the other test specimens. Although, the tensile strength increases by about 5% when orientation is changed to 45° by 45° with processing speed of 3600 mm/min [1].

It can be observed from the investigation and testing that the orientation of product or component shows a substantial effect on the response of the printing system with respect to vibrations.

b. Investigation on ABS

FDM (Fused Deposition Modelling) technology was used to print a rectangular beam using ABS plastic material for printing. The printing orientation (flat, side, vertical) and layer thickness (0.1mm, 0.2mm, 0.3mm) were varied during the investigation. For every orientation, different layer thickness of 0.1mm, 0.2mm and 0.3mm was implemented and for every layer thickness three samples were printed [7]. So,nine samples were printed for each orientation and a total of 27 samples were built for all three orientations. An impact hammer modal analysis was carried out on the beam to find the natural frequency, deflection and damping of beam and the results are compared with theoretical values.

The results obtained from experiment varied significantly from the theoretical calculations made. The natural frequency of the beam obtained from experiment onobservation shows the fact that the value changes when the layer orientation and layer thickness of the beam is changed. This insinuates that catastrophic failures may occur if proper layer orientation and layer thickness is not selected in real life situations. Further experiments are needed to verify the vibration properties of the RP made components [7].

c. Effects of ultrasonic vibrations

Effect of ultrasonic vibration on the mechanical performance of 3D printed non-crystalline and semi-crystalline polymers on investigation showed that, with ultrasonic strengthening, the tensile strength, bending strength, and dynamic mechanical properties of the non-crystalline polymer (ABS) and semi-crystalline polymer (PLA) were substantially enhanced.

Moreover, the ultrasonic vibration did not affect the properties of the forming material itself. The enhancement of the mechanical properties with ultrasonic strengthening was mainly due to the deeper interdiffusion and re-entanglement at the raster interface caused by the ultrasonic vibration. The gaps were attenuatedas well aseliminated, the interfacial area was improved, and the bonding strength between the rasters was also improved. The ultrasonic enhancement compensated for the pores in the forming samples and defects in the printed rasters caused by the raster-by-raster and layer-by-layer characteristics of FDM technology [12].

The mechanical properties of FDM 3D printed parts were enhanced without modifications in the 3D printed material or adjustment in the forming process parameters. The ultrasonic-strengthened area is restricted to the horn area and the ultrasonic-strengthened depth is calculated by the input ultrasonic vibrational energy. The ultrasonic strengthening system may be amalgamated with FDM 3D printer into one device [12].

The sample can be strengthened by printing various layers at a single time during the process of 3D printing. It will increase the application of low-cost FDM 3D printed parts in industries and other fields.

VI. 3D printing of metallic materials

In-case of metallic materials generally technologies like powder bed fusion (PBF), direct energy deposition (DED), binder jetting (BJ), and sheet lamination (SL) are used.Powder bed fusion (PBF) is a popular technique in 3D Printing. It uses a high-energy power source to selectively melt a metallic powder bed. Based on the type of power source used, PBF can be further classified into two major techniques: selective laser melting (SLM) which uses a high-intensity laser, and electron beam melting (EBM), which uses an electron beam. Both the processes require a building platform to hold the powder.Direct Energy Deposition is another popular technique in 3D printing. Instead of using a powder bed, DED process uses injected metal powder flow or metal wire as feedstocks, along with an energy source such as laser or electron beam, to melt and deposit the material on the top of a substrate [15].

VII. Applications of 3D Printing technology

3d printing owing to its advantages like freedom of complex design, part complexity, light weight, high precision has made 3D printed components popular in several industries. Prominent applications of this tool less manufacturing process is in aeronautics and aerospace industry, biomedical sector, automobile applications, oil and marine applications, jewellery, architectural models and many more. Optimization is easier in 3D printing technology as compared to other conventional methods and hence it has become widely popular in industries that demand high precision optimization. Wide range of material can be used for 3D printing process which makes it a very versatile manufacturing technology.

VIII. Advantages

- Lesser waste – 3d printing technology is an additive manufacturing technology. Unlike traditional subtractive manufacturing technology in 3d printing the scrap is minimum and hence it is a more sustainable choice.
- Lesser Errors – in traditional manufacturing process, components go through a serious process to obtain the desired parts and aesthetics. Each of these processes could result in some error resulting to possibility start over. This would lead to loss of resources, energy and time. 3d printing being a single manufacturing process saves us from this.

CAD models with varied part complexity can be designed and produced in a single step.

- Lesser Time – this technology substantially reduces production time by producing the components in a matter of few hours without much supervision need.
- Lesser Cost – Cost reduction is always one of the considerations during manufacturing. In 3d printing labour costs are cut down by huge margin, in traditional methods various skilled labours would be needed to run various different machines to achieve one complete product but 3D printing being a single step process eliminates that cost. Materials are also readily available and most filaments used in this case result in reduced cost of production.
- On demand production – 3d printing gives full freedom to design components and customize them according to changing needs. The ability of customization plays an important role in dental and medical sectors.

IX. Disadvantages

- Size – There is a certain restriction to the size of components that be printed using 3D printers due to the size of print chambers in current printers.
- Raw Materials – Even though a variety of materials can be 3D printed, yet when compared to conventional methods of manufacturing limited raw materials can be used.
- Machine cost – 3d printers not quite cheap that regular or very small-scale industries can afford as different types of 3D printer are required for printing different objects.
- Reduction in jobs – Since the labour requirement is reduced by a great margin in 3D printing it affects the employment of people in various manufacturing jobs.
- Copyright issues – being a popular technology now issues of producing fake products have been noticed.

X. Conclusion

Additive manufacturing is gaining immense popularity in the domain of manufacturing. Various techniques, materials and technologies have been and are been developed in 3D Printing. It is revolutionizing manufacturing in terms of on demand and faster production. It has found to be widely applicable specially in biomedical field. However, the effects of vibrations of the 3D Printing systems have certain effects on the components. This article was intended at reviewing the vibration effects on components manufactured by 3D printing. Investigation results on two prominent materials namely PET-G and ABS was reviewed along with effects of ultrasonic vibrations. The induced vibrations showed substantial impact on mechanical properties which further can be used to control the mechanical properties in terms of tensile stress and elongation of printed products. Investigations showed that the vibration amplitude values for orientations of 60° by 30° and processing speed of 3600 mm/min are much lower compared to the other test specimens. Although tensile strength increases by about5% when orientation is changed to 45° by 45° with 3600 mm/min processing speed [1]. Throughout the printing process there are vibrations in the printer which depends upon various factors such as structure of printer, nozzle types, processing speeds, orientation of product etc. The vibrations produced in 3d printers are forced vibrations. Neglecting these vibrational properties can lead to catastrophic failure of components produced through 3d printed technology and hence it becomes essential to control these vibrations in order to obtain better mechanical properties of printed components.

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