Investigating mechanical properties of 3D printed parts manufactured in different orientations on Multijet printer

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Abstract

Polymer material based products in the engineering field are most widely produced by the multi jet printing (MJP). These products impart inherent benefits in manufacturing intricate contours and shapes at less additional expenses. This emphasizes the importance of studying the mechanical behavior of the manufactured parts, using polymeric materials in different orientations. In this investigation density, tensile behavior & hardness were studied for 3D-printed parts produced in four different orientations (A, B, C and D). It is found that for the best mechanical properties part should be fabricated using orientation 'A'. Furthermore, for density and tensile strength part should not be fabricated using orientation 'C'. Also in case of hardness part should not be fabricated in orientation 'B'.

1. Introduction

Intended for the manufacturing of complex geometries, structures and physical models at low fabrication cost additive manufacturing (AM) or three dimensional (3D) printing is a quick growing engineering tool. In comparison to the outmoded engineering processes (casting, welding and machining) AM fabricate the part in multiple layers printing manner [1]. The ability of AM in the manufacturing of complex compound parts make it suitable for mechanical engineering [2], biomedical sciences [3], construction (civil engineering) [4], aerospace (aeronautics) [5], and food processing industries [6] as well as in educational sector for research. On the basics of 3D printing AM can be classified as seven different fundamental processing methods, namely, vat photo polymerization, sheet lamination, powder bed fusion, material extrusion, material jetting, direct energy deposition and binder jetting [7–8]. Among all these, multi jet 3D printing (MJP) is the material jetting oriented mode used to manufacture polymer-based parts and models [9–10]. Raw material for MJP technology is in the form of liquid. During printing the liquid is injected through nozzle that travels according to the guidelines specified as a result of the slicing software. The layer by layer deposition of hot material from the nozzles is remain sustained, till the model is completed [11–12]. The process of MJP is shown in Fig. 1. Many researchers have given significant contribution in the 3D printing. Shanmugam et al [14] explored the effect of the FDM process controls on the fatigue behavior of polymeric materials and provided their recommendations, also advocated further investigation in this area. Dai et al [15] emphasized the compression properties of (HP nylon PA12) open-cell hollow-sphere parts experimentally and mathematically. The parts were fabricated by multi-jet melting (MJF) printing technology. Rosso et al [16] examined the mechanical properties of polyamide powder (pA12). Specimens are fabricated using both the SLS (selective laser sintering) and MJF technologies. It was reported that MJF had less surface roughness then the SLS. SLS and MJF exhibited the single peak for the melting temperature. More over the SLS part had more porosity then the MJF. SLS gave good tensile strength then the MJF. SLS fracture was the brittle and the MJF fracture was ductile. Mirzaali et al [17] studied the fracture mechanism, Young's moduli, ultimate strengths of the soft-hard polymeric composites, functionally graded materials (FGM) by means of image relationship, digital microscopy and SEM. The Parts were fabricated by voxel-based multiple-material AM technology. They achieved that from the micro-mechanical characterization point of view elastic modulus of FGM part fabricated through bitmap3D-printing did not obey the rule of blends. Although the chemical configuration had the significant effect on mechanical properties. Zhu et al [18] explored the outcome of different energy inputs on porosity and mechanical properties of polyamide (p-12) mechanical parts. The parts were fabricated by powder bed fusion (AM) technique. It was reported that the high energy input caused less porosity and provided improved density, ultimate tensile strength and

percentage increase in elongation. Dana et al [19] investigated that the outcome of the printing orientation and the build direction on the compressive properties of the printed specimen on 3D sand printing process (3DSP). It was found that at 90° to the X-Y plane mechanical properties were excellent as compared to other directions. Khabia et al [20] compared the three different kind of FDM printers for three different kinds of Acrylonitrile butadiene styrene (ABS) material at the constant parameters. It was reported that the printer-1 (Arya UNO Printer, low cost ABS filament, Ultimaker Cura3.6-Slicing Software) exhibited the good tensile strength (35MPa). Bilkar et al [21] considered the effect of the carbon nanofiber (CNF)(1–2%wt) added to ABS on mechanical properties (tensile test, dimensional accuracy and surface roughness. It was reported that ABS + 2 wt % CNF enhanced the mechanical properties of the ABS polymer. Liu et al [22] exhibited the outcome of orientation and the layer thickness of the two type of materials (rigid polymer material and soft rubber). The parts were fabricated by multi material poly jet AM 3D printing. They stated that the orientation and coat thickness had the significant effect on the tensile behavior and stiffness. Valean et al [23] studied the effect of part orientation and layer thickness. The parts of PLA were fabricated on FDM 3D printer. The results stated that the object orientation had less effect on the modulus of elasticity and high effect on stretchable tensile strength. Increase in quantity of layer lead to decrease in the Young's modulus and tensile strength. Mele et al [24] introduced the new analytical model for the Multi jet fusion process (MJF) and for polymeric material (Pa-12). This reduced the capillarity effect (edges of part gets deformed), causing the reduction in dimensional accuracy and increase in surface roughness. Maurya et al [25] investigated the effect of the process parameters (raster angle and orientation) for the poly jet process. Parts fabricated of RGD 840 were investigated for mechanical properties (Young's elastic modulus, tensile strength at peak load, true stress-strain and plastic strain). The optimized results were found at raster angle (90°), horizontal orientation and glossy surface finish. Ali et al [26] compared the two mid soles of helical spring with variable dimensions (VDS) and uniform-dimension helical spring (UDS) mechanical-structure and the commercially available wave spring midsole fabricated on multi jet fusion. Experimental and numerical methods were used to improve energy absorption and strength. It was deduced that VDS has higher strength, better flexibility and better stability as compare to UDS. Kuo et al [27] optimized the process parameters (laser power, layer thickness, scanning speed and hatching space,) for the direct metal laser sintering of the mold fabricated from maraging stainless steel powder. The optimization tool used was Taguchi and analysis of variance (ANOVA). The results stated that permeability of gas and the thickness of layers were the important parameters that effected the mechanical properties of the material. Yang et al [28] considered the effect of different speed ranges (30, 50 and 70 m/s) on the density, flexural strength and compressive behavior of wood fiber/polylactic acid composite (WPC). The results indicated that density of the part improved as the speed of the FDM feeder was reduced. Tensile and flexural strength remained unaffected with the travel speed. Whereas with the increase in travel speed compressive strength of the part decreased. Dejaki et al [29] deliberated the effect of the infill pattern (solid, honeycomb, wiggle, grid, and rectilinear) on the tensile strength. PLA was used on the FDM for the fabrication of part. Honey comb and grid have highest strength. Samples at 0° gave the strongest layer adhesion and 60° and 75° showed the weakest layer's adhesion. Yadav et al [30] explored the effect of different type of infill patters (Hilbert curve, honeycomb, line, rectilinear, Archimedean curve and actogram spiral) for the PLA base parts fabricated on FDM. The compressive strength was studied at the different in fill densities (20 to 80%) is 20 steps. The results stated that Hilbert curves exhibited maximum compressive strength. It was concluded that with the increase in in fill density the compressive strength also increased. With the increase in the infill density the roughness also increased and rectilinear paternal exhibited the lowest roughness.

An extensive range of research has been conducted on the effect of the parametric variation on the mechanical behavior of FDM part. However, there is less work about the effect of part orientations on the mechanical properties in case of multijet printer. So due to this reason in the current study the impact of part orientation on the mechanical behavior is investigated. The methodology adopted to study is schematically represented in Fig. 2.

2. Materials And Method

In order to study the various mechanical properties for the parts fabricated by the MJP. The part designed is a combination of a rectangle, cylinder, fillets and inclined planes as shown in Fig. 3a. These shapes provided an opportunity to examine the density and hardness concerning different orientations of the product. In the orientation A, B, C and D the product is aligned along the faces 3, 4, 2 and inclined at 45° to the face 2 and 3, as shown in Fig. 3b. All the parts were manufactured from the same IGES (Initial Graphics Exchange Specification) files using a Project MJP 2500 series 3D printer. The fabrication of all designed parts was done with same material, that is VisiJet M2R-WT [13] (Table 1). In the present study, the shore-D hardness test is performed. Durometer hardness tester (Model No. Hiroshima-5915) is used to measure the hardness.

Table 1
properties of the VisiJet M2R-WT material [23]

Density at 20°C (solid) (g/cm ³)	Tensile Stress in Elastic (MPa)	Elastic Modulus (MPa)	Increase in length at Break	Flexural Strength (MPa)	Flexural (EI) Strength (MPa)	Toughness (Notched Izod) (J/m)	Shore D Hardness	Water Absorption (24 hr)
1.16	35–45	1500–2000	20–30%	50–60MPa	1700–2200	20–25	77	0.5%

Some technical specification of the printer are Printing Mode High Definition, for (XYZ) total Build Volume (294 x 211 x 144 mm), DPI-Resolution (XYZ) 800 x 900 x 790, 32 μ (micron) layers thickness. Material supported: VisiJet M2 -SUP is the only full cured support material for Project MJP2500 [13]. After fabricating the part on the MJP 3D printer, the Post processing of the printed part was done. In the post processing the part is put in to the oil bath which is preheated at 50°C for the ten minutes. Due to post processing the support material will be dissolved in the oil bath and desired part is left behind. After taking out part from oil bath, the part is washed with water and is ready to use.

Four parts in different orientations along with tensile and SEM samples were fabricated Fig. 3 (c and d). The D 638-14- Type-V specimens were fabricated in the four orientations of A, B, C and D on the same machine. For tensile test Computerized Twin Screw UTM-NX was used. The UTM machine had load limit 1000 kg, travel limit 850 mm. The rate of loading 1mm/min was used to perform the tensile test. For each orientation five samples were tested. The average of tensile strength at the peak load(TSPL) for all the five samples was considered as a single value of TSPL.

3. Results And Discussion

3. Results and discussions

In the field of the AM for the polymers the most widely used 3D printing technique are FDM and MJP printing [7]. But in case of FDM due to less fusion in the layers and high thermal contraction, mechanical properties variations are high [11]. So in order to investigate the variations MJP is considered in the current work. SEM is also considered to investigate the variation in mechanical properties.

3.1 Density analysis:

Density is defined as the measure of how closely the material is packed. Regarding the study of density variation, Archimedes principle is used. This method works on the principle that the volume of liquid displaced by a body is equivalent to the volume of the body, further with the weight balance, density and mass equation ($\text{density} = \text{mass} / \text{volume}$), density can be calculated [31]. The results obtained were presented in Fig. 4, it was found that the density of material in orientation A is maximum and minimum at the orientation C. While talking a glance on the SEM images Fig. 5 (a and c), it was found that for the orientation C (Fig. 5c) the material did not fuse well and the density is low. On the other hand, in the orientation A (Fig. 5a), the SEM image reflects that the material is tightly packed and the part in orientation A offers more density. So orientation A is the best orientation for high density of the part and C is the worse one.

3.2 Tensile test analysis:

The effect of orientations A, B, C and D on tensile strength, Fig. 6 represents the result for different orientations, it is concluded that the maximum amount of TSPL is for orientation A, As compared to rest of the orientations TSPL is decreasing. It will become minimum for orientation C. At the orientation D, TSPL increased again with a small amount as compare to orientation A. The SEM images (Fig. 7d) are well supporting the experimental results. For the orientation A the TSPL is maximum and the SEM image (Fig. 7a) reflects the same. Where traction on the fractured surface is maximum as compared to other SEM images (Fig. 7b-d). By taking the Fig. 7a as a reference, it is observed that the orientation A will have the maximum tensile toughness and higher proof resilience than other orientations. On the similar footsteps, it is found that the variation of the height of the up (top of valley) and down (bottom of valley) for the orientations B and D is decreasing at the fractured surface. This is the proof of evidence for the experimental results. For the orientation C, the height of up and downs(traction) at the broken surface is almost negligible, that's why at the orientation C the TSPL was minimum. Figure: (4 and 6) density variation and TSPL are behaving in similar fashion. So it is observed that the density of the material is the function of the fusion of material. The degree of close packing of the material in different orientations is similarly affecting the tensile strength. So for the high TSPL orientation A is the best and C is worse.

3.3 Hardness test analysis:

Hardness is the resistance to indentation, penetration and scratching [30]. At the nine different places named Face 1, 2, 3, 4, 5, 6, Curved face (CF), inclined face (IF) and Top Rectangular Part – 1 (TRP-1) of the fabricated parts in different orientations (Figure: 3) were used as a surfaces on which hardness is measured. The average of five readings on each face is considered as a single reading.

With reference to the Fig. 8b, for Face-V more variations are observed in orientation D and minimum is in orientation B. While considering for Face-VI huge variation is seen in orientation D and the minimum is in orientation A. It can be seen that in curved face maximum variation is in orientation D and the minimum is in

orientation A. Noting for inclined face maximum variation is in orientation B and the minimum is in orientation C.

Supporting Fig. 8c, for top rectangular Face-I and II maximum variation is in orientation A and the minimum is in orientation D.

From the Fig. 8, it can be observed that at the orientation A has the maximum hardness that means in the orientation A, the material is uniformly fused and tightly compacted. The SEM images (Fig. 5a) are well supports the results. For orientation B hardness is reduced with respect to orientation A. The surface has so many inclusions that cause micro-cracks and waviness near the inclusion nuclei Fig. 5b. That causes the roughness and also reduces hardness. Similarly, in the orientation C, the layers of the material are not well fused Fig. 5c. That causes a reduction in hardness. In the orientation D Fig. 5c. The layers are well combined as compared to orientation C. In the orientation D, the unfused material remains in between the layers that may cause an increase in hardness accompanier to orientation C. The hardness is found to be maximum for orientation A and minimum for B.

While considering the average values of the density for all the faces. The best orientation is 'A' and worse is 'C' (Fig. 8d).

4. Conclusions

The study presents the mechanical behavior of the part fabricated by MJP 3D printer in different orientations (A, B, C and D). The important conclusions are given below.

- For manufacturing high density parts orientation "A" should be preferred and orientation "C" should be avoided.
- For high tensile strength of the part, it should be fabricated in orientation "A" and orientation "C" should be avoided.
- In case of hardness orientation "A" will give higher hardness and orientation "C" will give minimum.
- Then over all best orientation for better mechanical properties is "A" orientation should be preferred and "C" should be avoided.
- It is worth noting that as the density of the parts in different orientations is changing the other mechanical properties tensile behavior at peak load and hardness for the 3D printed parts are also changing in same manner.

Declarations

Ethical Approval

There are no potential conflicts of interest among the authors.

The author declared that there is no human and animal part is function.

All the authors are well aware of the article titled.

Consent to Participate

The authors consent to participate all the authors to participate in the article.

Consent to Publish

The authors consent to publish the document titled as “Investigating dimensional accuracy and surface roughness for 3D printed parts fabricated in different orientations”.

Authors Contributions

The authors declare that they are all participants in the work and none of them performed only administrative functions.

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Competing Interests

The authors declare that they have no competing interests.

Availability of data and materials

All the key findings related to data and material are detailed in the manuscript.

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Figures

Figure 1

Schematic representation of Multi jet 3D printing process

Figure 2

Methodology

Figure 3

Part design, orientations and Part face for hardness test *(H) – Faces for hardness measurement (a) Isometric view of part, (b) Various views of part/face, faces on which hardness is measured (c) Orientations of part, (d) Part fabricated

Figure 4

Variation of density at different Orientations

(a)

(b)

(c)

(d)

Figure 5

SEM images for density variations. (a) A-Orientation, (b) B-Orientation, (c) C-Orientation, (d) D-Orientation

Figure 6

Variation of Tensile strength at peak load at different orientations

(a)

(b)

(c)

(d)

Figure 7

SEM images for tensile strength variation after tensile test (a) A-Orientation, (b) B-Orientation, (c) C-Orientation, (d) D-Orientation

Figure 8

Variation of Shore-D hardness at different faces and orientations (a): Face (I), (II), (III) and (IV), (b): Face (V), (VI), (Curved face) and (Inclined face), (c): Top rectangular part-I and Top rectangular part-II, (d): Average variations in hardness