Investigating the effect of orientation, infill density with Triple raster pattern on the tensile properties for 3D Printed samples

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Abstract
The main objective of this study is to characterize the effect of infill percentage, printing orientation and raster angle on ABS samples prepared with 3D printing technology. In this research, samples used were fabricated with two different infill percentages (50% & 75%), 6 different raster patterns and three different orientations. The influence of these parameters on tensile properties were studied with the help of 3D printed samples as per ASTM standard D638 Type IV. From the experimental analysis it was found that the tensile properties were highly anisotropic. Stress strain graphs are plotted for all the samples and the variation of strength with respect to the three parameters are analysed. It was observed that Infill density is directly proportional to mechanical properties. Flat and vertical orientation have better strength and stiffness in comparison with vertical build. The experimental results proved that flat oriented samples exhibited variable strength for changes in raster orientation, other samples have shown minimal changes only.

1. Introduction

3D printing is a technology where raw material in the form of filament is passed through heated nozzle at controlled temperature to melt and get deposited layer by layer as per the requirement along x-y plane which solidifies on cooling before the nozzle traces its path over the existing deposition as the table moves downwards along the z axis (figure 1). 3D printing gives the advantage of flexibility to design complex parts which can be manufactured easily straight from digital CAD files. It finds applications in aerospace, automobile sectors etc. Though 3D printing gives the advantage of quick and flexible manufacturing it lags behind comparatively in terms of component strength with respect to conventionally manufactured parts. ABS is the most commonly used material as it provides chemical resistance, impact resistance and toughness, along with rigidity and easy post processing. The properties of the printed components depends on the process parameters used at the time of printing. This necessitates to study the influence of parameters on the mechanical properties of the parts. In 3D printing bonding between the layers determine the strength of the specimens. The bonding of the layers in turn is decided by the bed and nozzle temperatures along with the raster orientation and thickness. According to Popenescu et al the classification of parameters is as follows. 1. Slicing parameters: Layer height, feed rate, raster pattern, number of contours, 2. Build orientation, 3. Temperature conditions: Bed and Nozzle temperature. All these three classified parameters influence the properties of the final structure [1]. Raster orientation and air gap influence the strength of objects [2].

It was found that the properties of rapid prototyped samples were anisotropic and affected by the directional processing of laminates. Further, air gap and raster orientation have a significant effect on the strength in comparison to other parameters, [45°/−45°] shown higher strength compared to 0°, 90°, [0°, 90°] [3]. Raster orientation have significant effect on fatigue performance also and fibers aligned with axis of loading provides good fatigue life [4]. The number of contours and infill density has direct influence over tensile strength. The number of contours and infill density is directly proportional to the strength [5]. Researchers, in the past have considered the following five parameters (Layer height, Part orientation, raster angle, raster width and air gap with two levels) to conduct DoE and obtained the most optimised results for tensile strength of 3D printed components, Minimum layer thickness samples, negative air gap, and 0° raster angle produced stronger parts [6]. Anoop Kumar Sood et al [7] considered 3 levels for the
same parameters mentioned above parameters performed experiments based on central composite design and optimal settings for tensile and fatigue were reported, multiple heating and cooling cycles results in distortion, peeling and interlayer cracking leading to lesser strength. Raster aligned with axis of loading will result increased stress accumulation along the direction of deposition resulting in more distortion and weak bonding. Miguel Fernandez-Vicente et al pointed out that there is difference of tensile strength in 3D printed components when the infill pattern and density is changed, rectilinear pattern with 100% infill produced higher tensile strength [8]. They conducted experiments using line, rectilinear and honeycomb infill pattern to prove that tensile strength will differ based on the infill pattern and density. Layer height, raster angle, infill density were the chosen parameters by Samykano et al [9], 55° raster angle with 80% infill resulted in more strength. Linear infill pattern resulted in higher tensile strength as a result of small space between individual layers. Matching of printing speed and nozzle temperature needs to be ensured for proper melting of filaments and also to control the material solidification process [10].

Abbreviations
1. Acrylonitrile Butadiene Styrene (ABS)
2. Design of Experiments (DoE)
3. Universal Testing Machine (UTM)
4. Ultimate tensile strength (UTS)

2. Gap Analysis

The current research on tensile strength of 3D printed components have been based on raster angle, infill density, infill pattern, layer thickness, air gap, layer height etc both separately and in combinations. Few authors have optimised the parameters to get desired results with single and double layer raster only. While gaps have been left in the experiments where in triple layer raster pattern, infill density and orientation combined together have not been done so far. We are filling this gap that has been existent to conduct experiments and obtain results. Hence we aim to use triple layer raster along with infill density and orientation combined together to identify the effects on the tensile strength of the printed parts.

3. Materials and sample preparation methodology

The tensile specimen used in this work was modelled using solid works as per ASTM standards [11] (D638–Type IV). CoLiDo Print-Rite 3D printer universal filament was used with 1.75 mm wire diameter. CoLiDo X 3045
machine was used for printing samples. The present researchers so far have only done unidirectional and bidirectional printing. The idea of our research is to go ahead with a triple layer raster. Wherein 3 layered raster ($0^\circ$–$90^\circ$–$45^\circ$) specimens were prepared, i.e. First layer was deposited with $0^\circ$, Second layer was deposited with $90^\circ$ and third layer was deposited with $45^\circ$ as shown in figure 2. This process was repeated layer by layer for the specimen to obtain full thickness. The specimens were prepared with a layer thickness of 0.2 mm (Based on Nozzle diameter) print speed of 60 mm s$^{-1}$ (based on complex of the geometry), Nozzle extrusion temperature

![Figure 2. Triple raster pattern.](image1)

![Figure 3. Orientation of samples.](image2)

| Infill density (%) | Orientation | Raster angle (Degree) |
|--------------------|-------------|-----------------------|
| 2 Level 50%        | Flat        | 1. 0–90–45            |
|                    |             | 2. 0–45–90            |
|                    | On Edge     | 3. 90–0–45            |
|                    |             | 4. 90–45–0            |
| 75%                | Vertical    | 5. 45–0–90            |
|                    |             | 6. 45–90–0            |

Table 1. Process variable considered with level.
of 250 °C, Bed temperature of 90 °C (Fixed for ABS). The number of solid layers on top and the contours were 2 in numbers. The raster angles were shuffled such that all six possible combinations were obtained as given in table 1. Six different combinations of raster layup with two different infill densities were printed in three different orientations totalling to 36 different combinations of samples printed. Three orientation of the samples is shown in figure 5. For each combination 2 samples totalling to 72 samples were printed. Sliced samples in three different orientations are represented below in figure 4 for better understanding of raster orientation clearly.

### 4. Testing procedure and observation

Tensile tests were performed using Instron 8801 UTM with a displacement rate of 1 mm min⁻¹ and tested. The machine used along with the samples tested are shown below in figure 5. It can be observed flat oriented samples get broken at the middle and most of the on Edge samples also get broken at the middle, while the same is not observed in vertical oriented samples. This can be attributed to the number layers formed during printing. In the
flat orientation the bonding of layers is much better as the number of layers are lesser in numbers due to its thickness while in the case of vertical orientation the number of layers are many which in turn results in a comparatively looser bonding and slanting orientation while printing.

5. Results and discussion

UTS may be defined as the maximum stress that a part can withstand when subject to pulling. From the above figure 6 which is the Ultimate tensile strength of the samples with various combinations, it can be observed that the highest tensile strength is achieved through printing of flat oriented sample with 45°–90°–0° raster orientation for both 50% as well as 75% infill. This can be attributed to the raster alignment in parallel to the axis of loading as well as the improved bonding between 45°–90°. It can be observed that in the flat orientation there is a variation of up to 10 MPa due to the change in the raster pattern for both the infills. It can also be observed that the variation in vertical and on Edge samples were very minimal unlike the flat orientation. The loading is along the raster in flat orientation resulting in higher strength while in case of vertical orientation it needs to be noted that the load is applied perpendicular to the raster. Hence the strength will be only as good as the bonding strength between layers, which will be lower that flat orientation. Further it can be observed from figures 7(a) and (b) that the stiffness varies in correlation to the raster in the flat orientation components due to the bonding between the outer shell and the infill material attributed to higher surface contact area. While the same results are not to be seen in case of On Edge samples due to delamination between the infill material and outer shell. Similarly, in case of vertical build the inter layer bonding is weak due to which the samples break easily. Hence we cannot observe much variations.

6. Conclusion

In this research, the significant effects of triple layer, infill density and orientation on mechanical properties of the 3D printed ABS samples have been experimentally studied. It was found from the experimental analysis flat oriented samples have shown high variations in strength represented in the table 2 below. From the above work done it can be concluded that in 3D printing the raster and infill along with the changes in orientation can have a

| Orientation  | 50% Infill | 75% Infill |
|--------------|------------|------------|
| Flat         | 39.5       | 29.4       |
| On—Edge     | 10         | 36.5       |
| Vertical     | 22.7       | 23.3       |

Figure 6. UTS of tested samples.
considerable effect on the tensile properties, such as ultimate tensile strength and stiffness. The various combinations of raster angles is ample proof that variation in angles has an effect on the tensile properties of components printed using 3D printing technology. Hence it can be concluded that flat orientation printed parts gives increased strength in comparison to vertical and on edge parts. The research can be furthered with several other combinations of raster and infill densities to obtain the best of tensile strength of parts.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary information files).
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