Effect Of The Support Structure On Flexural Properties Of Fabricated Part At Different Parameters In The Fdm Process

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Abstract: Traditional fused deposition modeling (FDM) is an additive manufacturing method in which a part is fabricated using layer upon layer approach. Due to the imminent nature of this approach, support structures are needed to sustain overhanging elements of the parts, particularly for the production of metal components and complex geometries. Several works are going on to minimize the usage of supports by using improved support strategies. However, the use of different support strategies at different pre-defined machine settings may lead to varied properties of the final printed part. In this work, the influence of support strategies on flexural properties at four different parameters is experimentally determined in the fused deposition modeling process. Two support strategies, Line and Grid, are adopted while fabricating the same 3D part at three different printer parameter settings. The flexural properties of the samples are compared for assessing the impact of two support strategies, as well as the support material usage and printing time. Results reveal that two support methods lead to varied flexural strength and print qualities at varied parameters.

Keywords: Fused deposition modeling, Additive manufacturing, Support strategies, Flexural properties

1. Introduction

Additive Manufacturing (AM), or 3D printing, or rapid prototyping, since the 1980s has been a preferred manufacturing technique for fabricating prototypes and is rapidly progressing towards being the most affordable, fastest and reliable approach to mass-producing custom goods. There are many types of commercial AM techniques available today, but the most widely used, as it is simple to operate and environmentally friendly, is a fabricating process known as Fused Deposition Modeling (FDM). Fused deposition modeling (FDM) is an additive manufacturing method that uses an uninterrupted thermoplastic filament fed through a spool, which is heated to its melting point and then extruded and deposited layer-by-layer, to create an object or a part. Scott Crump, the co-founder of Stratasys, developed a commercial model of Fused Deposition modeling in 1988. Parts with intricate geometries and complex shapes can be fabricated quickly and accurately, putting an end to the restrictions and drawbacks of traditional manufacturing techniques.

Additionally, reducing or eliminating the necessity to assemble multiple components in FDM might result in the considerable minimization of fabrication time and human effort. Using additive
manufacturing techniques, required parts or objects can be quickly fabricated on-demand, reducing the need to store the inventory of final or spare parts. By virtue of the above-cited advantages, fused deposition modeling is increasingly becoming most favoured mode of fabrication for mass-producing high-performance parts for automotive, medical, aerospace applications, and even for fabricating personalized products [11]. However, one of the significant disadvantages of FDM is that as in this technique fabricating begins from the bottom and proceeds layer upon layer progressively to the top layer, it ends up in issues for overhangs, holes, or edge features. Support structures have to be fabricated simultaneously for these overhang features and then discarded manually once printing is completed, thus wasting print material, printing time, and also undesirably increasing cost; yet it is inescapable to print support structures where there are extreme overhangs and intricate geometries.

2. Literature Review

Jingchao Jiang et al. [1] experimentally evaluated the effect of three different supports on the properties of the fabricated sample. They found out that line support consumes less material and zigzag support gives relatively superior flexural strength. They concluded that the line support is the most reliable method of the three used.

Jiangchao Jiang, Pai Zeng et al. [2] benchmarked part geometry with different features like flat & round support surfaces for company printed qualities by taking two support strategies. Results showed that the concentric support method gave better-printed qualities than line support, but takes more time. G. Strano, L. Hao et al. [3] presented a novel optimization algorithm to adopt pure and real mathematical 3D implicit functions in order to draft & create cellular support structures. Their investigation into this novel algorithm found that this new approach can bring about significant material savings thereby reducing the cost.

Ratima Suntornnond et al. [4] presented a viewpoint on the role of support materials and discussed various support materials used in bio-printing like hydrogels. The authors opined that current hydrogels are too soft to hold the shape and proposed improvements needed for support materials. Jiangchao Jiang et al. [5] evaluated the influence of three support strategies on the printed properties such as surface roughness, print time, and flexural properties.

Shen Hongyao et al. [6] designed a device that forms an external support structure, controlled to rise and fall, which comprises of small discretized pieces, called as basic units, forming various kinds of support structures to substitute for the one that is generated by the printer itself for different models. Elliot Sanders et al. [7] experimentally investigated the impact of various printing parameters on the mechanical properties of samples fabricated polypropylene filament in the FDM process.

Dongyun, Zhang et al. [8] carried out experimental analysis on how the heat treatment affects the mechanical properties of Inconel 718 super-alloy in the selective laser melting process.

Nascimento et al. [9] examined how thermal treatment effects the mechanical properties of the part printed using a nano-composite made of polypropylene/calcium carbonate.

Jing chao et al. [10] reviewed fifty seven papers related to support structure optimization and they categorized them into six groups to setup a standard framework for future works.

Jusung lee and Kunwoo lee [12] developed a new algorithm for inner support generation in order to reduce manufacturing time and volume of material used. When compared with conventional method this new method reduces time and material wastage.

Much of the research work has gone into optimizing the support structures in additive manufacturing in a quest to reduce or eliminate the support structures required, which will save time
and material. In cases where supports are inevitable, research on choosing the right support strategy for the given parameters of the printer, to achieve optimum strength and superior print qualities, is still missing in the fused deposition modeling (FDM) process.

In present work, the effect of support structures on flexural properties at three different printer parameter settings is investigated on an FDM machine. After experimentally determining the impact of supports structures on the flexural properties of the 3D printed part at four different parameter settings, the behavior of support strategies at these settings in evaluated to find optimum machine settings for the given support.

3. Theoretical Analysis
Since additive manufacturing fabricates parts by joining & building up material one layer at a time, from bottom to the top, the extent of the bonding between two consecutive layer is dictated by parameter settings of fabricating machine like extruder and bed temperatures, speed of fabrication, infill density and layer thickness. Many researchers experimentally studied the influence of various machine parameters on the mechanical properties and print qualities of the final product [1]; [2]; [9]. And number of researchers across the planet is working to cut back on the support structure utilization. Nonetheless, the support structure’s influence on the final flexural properties at various printer parameters, which is an important factor for intricate geometries and complex shapes, is still widely and comprehensively not studied. From Figure 1 observed that the unsupported area will have some sort of droop. Drooping can be minute or huge. Layers that do not have any supports can influence the subsequent layer deposited upon them and also the quality of binding among those layers [13]. Thus, the support structures perform a vital role in influencing the flexural properties of the final fabricated part. The final flexural properties of the same part fabricated with varied supports will be different.

![Figure 1. Support’s effect on final printed qualities](image)

Thermal actions that occur between support structures and the actual portion of the part are very critical to the mechanical properties of the fabricated part. As the supports and their contact with the actual portion of the part vary, the thermal conduction also varies [14]. Thus, for different support strategies, thermal conduction will be different, resulting in different mechanical properties. The supports help to dissipate heat from the printed part, like fins on a combustion engine, thus influencing the mechanical properties of the final part. Figure 2 shows two ways of heat conduction using two different support strategies.
4. Methodology

For studying the effect of support structures on the flexural properties, two distinct support methods, line & grid support, provided by Cura software utilized at three different printer parameter settings for fabricating the samples. In Figure 3, different colors represent various structures. Red color represents the wall. Blue color represents support structures and the yellow color for infill. The printing of the two support strategies was conducted at three different conditions. Therefore, six samples were obtained totally.

PTC Creo 3.0 software is used to draft the 3D model of the required part. In PTC Creo 3.0 software, part type and solid sub-type is selected. A two-dimensional sketch of printed part is drafted as per required dimensions as shown in Figure 4. Extrude feature is used to generate the 3-D model with a thickness of 20mm. The final 3-D model of the sample part is shown in Figure 5. The two raises to the actual part are designed to promote the support generation under the part. These two will have no impact on the mechanical properties of the part as they sit at the ends of the part. This 3-D model is then converted into STL format. This format translates and stores the data of the CAD model in a language that the printer understands.
CURA 15.04.2 software is used in setting up printing parameters and slicing the 3-D model. CURA is used as it an open source software and compatible with any 3D printer commercially available. CURA slices the model into printable layers and generates G-codes specific to the printer. These G-codes were sent or fed to the printer.

PRAMAAN 500 3D printer was utilized for fabricating the sample parts for experiments. The maximum object build volume of the printer is 500mm x 500mm x 500mm. It has a brass nozzle with the diameter of 0.4mm and filament diameter is 1.75mm. Maximum printing temperature of the printer is 265°C. Print temperature of 220°C is used for printing the samples. Alongside PLA, ABS plastic is another popular material used in AM. ABS (Acrylonitrile-butadiene-styrene) is popularly used low-cost impact-resistant engineering thermoplastic that can be thermoformed and machined easily. ABS material has excellent chemical, stress, and creep resistance offering a good balance of impact, chemical, heat and abrasion resistance, dimensional stability, rigidity, and tensile strength. It is widely used in making plumbing parts, prototypes, bumpers, dashboard components, etc. Table 1 shows the parameters used in 3D printing process to print the final product.

**Table 1. Parameters used in 3D printing process**

| Item             | Sample 1 | Sample 2 | Sample 3 |
|------------------|----------|----------|----------|
| Layer Height (mm)| 0.21     | 0.18     | 0.15     |
| Infill Density (%)| 80       | 60       | 40       |
| Printer Speed (mm/s) | 90      | 100     | 80       |
Sample printing on the 3D printer is shown in Figure 6 and Figure 7 shows the printed part with support.

![Figure 6: Printing the part using 3D printer](image)

![Figure 7: Final printed part along with support using 3D Printer](image)

Three point bending test was performed using the TUE-C-200 model universal testing machine (UTM) for the purpose of getting flexural properties of the part samples. Tests were performed under ASTM standard for 3 point flexural test ASTM D790 at a span length of 55 mm. The flexural strength is measured using following mathematical equation:

\[ \alpha = \frac{3FL}{2bd^2} \]

Where \( \alpha \) = Flexural strength, N/mm\(^2\)
\( F \) = Load at peak, N
\( L \) = Length of the span, mm
\( b \) = Width of the Specimen, mm
\( d \) = Thickness of the Specimen, mm

5. Results and Discussion

For each support strategy, three samples at four different printer settings are considered. To comprehensively get the measure of different support strategies, samples are tested for flexural properties and compared. The support material used to improve the quality of printed product with appropriate printing time for all the samples were also recorded and compared as shown in Table 2
Table 2: Percentage of ABS material used for printing final product

| % of Material used to print the product (Grams) | Sample 1 | Sample 2 | Sample 3 |
|-----------------------------------------------|----------|----------|----------|
| Line with support                             | 25.24    | 26.31    | 20.57    |
| Grid with support                             | 21.13    | 21.39    | 17.00    |
| Final product                                 | 21.13    | 21.39    | 17.00    |
| Support                                       | 4.11     | 4.92     | 3.57     |
| % of material used for support                | 16       | 19       | 17       |

The support material helps to improve the quality of the product. The grid support improved flexural strength to the material than the line support material as shown in Table 2. The reason is more amount of material deposited due to closed lines in all the samples. As shown in table 2, the line support consumes relatively least support material i.e. it saves slightly less material than the grid support strategy. And the percentage of material used for supports of the total material consumed is around 3% more in grid support at every parameter. Therefore, change in parameters does not impact the amount of material used for supports.

5.1 Printing Time:
The time consumed for printing a whole part including support material. Printing time mainly depends on the amount of material to be extruded and the path nozzle has to travel while printing. The printing time also depends upon shape and size of the part. The printing time required more in case of grid support compared line support as shown in Table 3.

Table 3: Printing time to print the product in 3D printer

| Sample 1 | Sample 2 | Sample 3 |
|----------|----------|----------|
| Line support | 4506 | 4201 | 4327 |
| Grid support | 4556 | 4263 | 4456 |

Line support strategy takes slightly less printing time compared to the grid support strategy. This difference can be attributed to the amount of material which line support consumes being less than grid support. Therefore, it can be concluded that the printing time does play a role in selecting the appropriate support strategy.

5.2 Flexural Properties:
Due to varied thermal conditions and support designs in different support strategies, they tend to influence the mechanical properties of the final printed samples and even the parameters that are used for printing a particular part can influence the properties. The experimental flexural test conducted on different samples in two support strategies as shown in Table 4.
Table 4: Mechanical properties of the final product

| Sample No. | Layer height, mm | Infill Density (%) | Printer speed (mm/s) | Load (N) | Elongation (mm) | Flexural strength (MPa) |
|------------|------------------|--------------------|----------------------|----------|-----------------|------------------------|
|            |                  |                    |                      | Line     | Line            | Grid                   |
|            |                  |                    |                      |          | Line            | Grid                   |
| I          | 0.21             | 80                 | 90                   | 1445     | 2.530           | 51.01                  |
| II         | 0.18             | 60                 | 100                  | 1154     | 2.540           | 44.24                  |
| III        | 0.15             | 40                 | 80                   | 489      | 1.660           | 18.35                  |

It is observed that the flexural strength is high for grid support in all the samples. But sample 2 shows the flexural strength are close for line and grid support. Final printed part shows excellent elongation with grid support strategy due to more amount material deposited. This can be attributed to the support structures ability to reduce the droop caused by overhang or inclination and gravity. Also combination of infill density, layer height and printing speeds. The printer speed and infill density influences the flexural strength is higher for grid support as shown in Table 4.

6. Conclusion
In this work, the effects of support strategy at three different printer settings on the flexural properties of the final printed parts were experimentally studied. Also taking in to account printing time and material used for supports. Two support strategies (Line and Grid), for printing part using ABS material. The following conclusions are drawn from the experiment:

- The mechanical properties are influenced due to varied thermal conditions and support designs in different support strategies.
- Final parts fabricated with grid support has higher flexural strength (56.4 MPa).
- Part printed with grid support shows excellent elongation with more than 7% than the line support.
- Grid support absorbs more load than the line support as the drooping will be less and part & support contact is more in grid support.
- It also suggest that grid support consumes relatively more material (26%) for supports and also takes more time to print the part.
- The percentage of material used for supports of the total material consumed is around 3% more in grid support at every parameter.

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