Strength of 3D prints with variable print orientation

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Abstract. The purpose of this paper is to present the analysis of the efficiency and strength of 3D printed parts due to the variation shown in print orientation. Fused deposition modeling (FDM) is a widely used technique in which the melt extrusion method is used to deploy the thermal plastics as filaments in a specific pattern. In recent years, the revolutionary method has changed the field of rapid manufacturing. This has become one of the most common methods for printing polymer-based composite components. The investigation is done based on the print orientation effects on the macrostructure, the mechanical properties, and the strain field behavior of PLA (polylactic acid) filament. Based on the analysis, the properties of an object are optimized to increase mechanical strength when manufactured. By fixing the similar print properties across all different orientations helps to identify the differences in the structural and other mechanical properties, which projects a clear understanding of the impact received and thus provides a way to enhance the structural strength of the prints.

Keywords: FDM, Filament Orientation, Natural Fibers

1. Introduction

The usage of 3D printing technique has been rapidly adopted in recent years. The possibility of providing high precision components with more accuracy has been one of the major achievements in the field. However, there is hardly any guarantee that a printed model is structurally strong. To represent the structural strength of 3D printed objects as a function of layer thickness and other print properties, an effort was undertaken by investigating the correlation between the mechanical properties of parts manufactured using fused deposition modeling and print orientation. In general, the 3D printed components are formed in a layer-by-layer fashion. Which is due to the melt extrusion in the nozzles of the 3D printers. These printers are known to work in both horizontal and vertical movement. As the design takes shape, the layers along the horizontal direction become visible. During this process, additional support layers are formed that make contact with the component and the build platform, which can be removed later.

Even after 25 years of research in the field of rapid prototyping, the applications and the processes are still in its primary stages of existence[1-5]. Fused deposition modeling or FDM technology is additive manufacturing (AM) technology popularly used for prototyping applications that has low levels of surface finish quality, that needs some hand finishing tool for even the necessary levels of 3D printed parts. In the recent days light weight materials widely used in various industrial applications [4-16].
This additive manufacturing method is described as 3D printing technology and using this technology 3D components are printed in the layer by layer process and it’s been sliced up and layers are determined by the software. In this methodology, the 3D object is designed using CAD software and then it’s sliced using a slicing software; later the 3D model is converted into a .stl file to feed into the 3D printing device. Depending upon the manufacturing methodology it can be categorized as prototyping, solid free form layered manufacturing and computer automated manufacturing.

![Figure 1. Types of additive manufacturing techniques](image)

Our study process starts with the design. A model of the cuboid is designed in Solidworks and the .igs file is then imported into ANSYS Workbench. And now, the selection of engineering materials along with the geometric specifications is done to start the analysis of its mechanical properties. On the next step, the mechanical properties of the model are specified and taken into consideration to proceed with further experimentation. The fixtures are made to run the analysis and the tensile properties are specified. Finally, with all the properties put together, the entire model was meshed to provide the results. The results show the semi-analytical experimental tests that are taken to evaluate the structural strength and efficiency of the model.

![Figure 2. Flow of Process](image)
2. Fused Deposition Modeling
Fused Deposition Modeling (FDM) may be a 3D printing technique pioneered within the 1990s by Stratasys. Actually, the term ‘FDM’ is the trademark of Stratasys. During this process, the thermoplastic material is extruded through a nozzle that moves along the component's cross-sectional geometry layer by layer. The build material is typically supplied in filament form contained in a spool, but few setups utilize plastic in the form of pellets that are used with a hopper instead. The presence of resistive heaters in the nozzle keeps the plastic at a temperature just above its melting point in order that it flows easily through the nozzle and forms the layer. The plastic gets hardened immediately after flowing from the nozzle and bonds to the layer below. Once a layer is constructed, the platform lowers, and therefore the extrusion nozzle deposits another layer. The extruder’s diameter determines the vertical dimensional accuracy and layer thickness of the component.

![Fused Deposition Melting](image)

Figure 3. Fused Deposition Melting

1. The component to be printed is initially designed in any available CAD software. 2. Slicing software is used to slice the model into a set of layers. 3. Once slicing is done, the file has to be converted into a format that can be read by the 3D printer, usually, it’s .stl (Stereo-lithography) format. 4. During printing, these materials are formed like plastic threads, or filaments, that are fed through an extrusion nozzle which is unwound from a spool of filament and. The nozzle melts the filaments and extrudes them onto a build platform or table. A computer controls the base and the nozzle via software and X, Y and Z coordinates are translated for the nozzle accordingly to follow during printing.

3. Types of Filament Material
PLA (Polylactic Acid) is one of the widely used 3D printing filaments. It is widely used because of the vast range of printing applications, also it’s odorless and possesses low distortion qualities as well, and does not require a heated bed. There are various other materials or filaments that can be used for various purposes. Each and every filament has its own properties and characteristics that have different effects on a component.
Figure 4. Pyramid of various filament materials with respect to performance and temperature

The above pyramid explains the various filaments segmented along the vertical with respect to temperature and their performance. For commercial and simple requirements, we have picked the PLA material which is economical and also provides ease of use at low temperatures with suitable performance.

MATERIAL SELECTION - POLYLACTIC ACID

![Chemical structure of Polylactic acid](image)

Figure 5. Chemical structure of Polylactic acid

Table 1. Physical properties of PLA

| Property          | Value                        |
|-------------------|------------------------------|
| Melting point     | 150° to 160°C                |
| Density           | 1.210 to 1.430 g.cm⁻³        |
| Tensile Modulus   | 2.7 - 16 GPa                 |
4. Designing
A Solid model of a cuboid of dimensions 15x15x50 mm was designed and extruded in Solidworks. And, that file is converted into .igs format and imported into ANSYS. During the design process, the mass and other physical parameters of the part are noted.

![Figure 6. Physical properties of the designed model](image)

Through this design, we were able to find some of the properties like mass, surface area, the moment of inertia and volume of the designed component. Moving on to the next step, we gave custom inputs for the material properties to create a model based on PLA. With the Linear Elastic Isotropic model in the Plastics category we were able to create a customized plastic with the properties of PLA, eventually making it PLA itself.

![Figure 7. Property table of Polylactic acid - Solidworks](image)

**Table 2.** Mechanical properties of PLA

| Sample | Tensile strength (MPa) | Elongation at break (%) | Young’s Modulus (MPa) |
|--------|------------------------|-------------------------|----------------------|
| PLA    | 41.83 ± 0.63           | 4.07 ± 0.37             | 2004.33 ± 62.9       |
Figure 8. Elastic Strain

The above two figures show the analysis of elastic strain and equivalent stress obtained in the ANSYS software. The middle layers are where the force is least due to the equal tensile forces acting at either ends. The figures also give a clear image of how the stress and strain are equally distributed throughout the component’s structure.

The analysis results gave an almost constantly increasing graph due to the uniform distribution of strength and stress across the component’s body. This infers that although the component is printed in a layer by layer fashion, the entire component is actually taken as a single uniform body and the analysis is made further. We can also find that the structural strength is also uniform due to the uniform distribution of layers across the component.

Further, the calculations were based on the assumption of considering mass=1kg. While calculating the structural strength, some of the tensile properties were also calculated based on the load distribution factors, which were also found to be a uniform one.

Figure 9. Equivalent Stress

Figure 10. Stress-Strain relationship
5. Conclusion and Future Proposal

It can be seen that since the layers are uniformly distributed along with the component’s structure, the tensile strength, structural properties, and other mechanical properties tend to be uniform throughout the body of the component. Changing the print orientation can also produce the differences in the results due to the formation of layers in a different direction which can be either vertical, horizontal or diagonal based on the parameters that have been set into the 3D printing software. In the future, the study can be made based on the microscopic analysis of internal layer formation with more complex structures with different materials. Also, different shapes of layers can also be used to determine the structural properties and efficiency of the component. Different infill patterns and density can be modified and the analysis can be carried out to find the strength and tensile properties of the component. This can lead us to create more strong and complex structures that can be used in various fields like the automotive industry, aerospace, medical, etc. We can find a vast scope using this technique to manufacture components with more upcoming research in the thermoplastics and other material filaments can produce revolutionary products the can bring further progress on a huge scale.

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