Finite Element Analysis on Multiple Axes Of 3D Designs

D.W. Abbot
Department of Mechanical and Industrial Engineering Technology
University of Johannesburg
Johannesburg, South Africa
devabbot5@gmail.com

D.V.V. Kallon
Department of Mechanical and Industrial Engineering Technology
University of Johannesburg
Johannesburg, South Africa
dkallon@uj.ac.za

Abstract
3D Printing has grown tremendously over the past few years and continues to do so as the industry grows with new technologies. 3D Printing makes design easier and allows engineers to create prototypes and mock-ups of these designs faster than ever before. Edits can be made in hours rather than days and best of all, it can be done on the desktop, rather than on the factory floor. The question of replaceability of conventional manufacturing technologies with 3D prints, and the accuracy of finite element analysis on a 3D printed-like model is the focus of this study. This study conducted an FEA of some simple structures and compared results of the simulations to that of lab tests on 3D printed parts. Sample specimens in the shape of a block, 25 mm x 25 mm x 25 mm in diameter is designed using Autodesk Inventor 2018 and tested in a simulation environment of Autodesk Inventor to gain insight into the responses of these objects under compressive loads on different axes. The same designed 3D objects are then printed using a 3D printer out of several different materials and infills using the FDM (Fused Disposition Modelling) method. These objects are exposed to the same external forces applied in the FEA with strain gauges used to measure the response and thus providing a comparison with the FEA. The results of these tests are analysed and presented herein.

Keywords: Ansys, Autodesk Inventor, 3D objects, 3D Printer, FEM, FDM, Strain gauge.

1. Introduction
The 3D printing technology is an additive manufacturing process, which proceeds by making three-dimensional solid objects from a digital file. This process involves printing layers of material until the object has been formed with the use of a 3D printer. 3D printing has enabled the production of complex geometries with minimal waste in material, when compared to the traditional manufacturing methods, which mostly proceed using subtractive method. This technology offers the flexibility of "embedded" manufacturing- manufacturing components in place where it is needed, thus reducing transportation cost, and reducing throughput in prototyping. This is due to mobility of the printer compared to the massive weights associated with subtractive machine tools. Finite element analysis (FEA), a technique has provided insight into complex engineering problems over the years with continuous values of elements calculated across the model from one element to another. It is highly useful in estimation of mechanical properties of models with dissimilar material properties to obtain local effects and accurate solution of the whole model via an element-wise approach.

There has been a tremendous revolution in the 3D printing technology over the past 30 years since the first form of additive manufacturing was developed. In 1981 Dr. Hideo Kodama came up with a functional prototyping system using photopolymers to build up a solid printed model which consisted of cross-sectional layers within the model. It is the build-up of these layers that creates the 3D shape of the object. A few years later in 1984 Charles Hull came up with a process of using a UV laser beam and a vat of resin photopolymer to create 3D models called Stereolithography (SLA), a process known as vat photopolymerization which he then patented. This was done by exposing the photopolymer to the UV laser beam which would cause the resin to solidify into a solid piece of plastic (Al'Aref, 2018: Wen et al, 2018). The object is printed from bottom to top leaving behind a solid piece of material.3D printing has numerous amounts of processes which change in their layering methods and materials used that will play a deciding factor in what process would best suit the ability to use the FEM to ensure reliability and consistency (Abbot, 2021: Abbot et al, 2019).

The FEA is a computer-based method of simulating/analysing the behaviour of engineering structures and components under a variety of conditions, such as structural or fluid behaviour, thermal transport, wave propagation, and the growth of biological cells. The FEA tool is primarily concerned with investigating the response of physical system models upon specific imposed conditions, thus enhancing strategic and operational decision-making process. The technique is fast becoming a suitable alternative to the time-consuming and expensive experimental runs and has proven to be a suitable tool in investigating the behavioural susceptibility of a model in almost any environmental condition. The FEM has previously been used successfully on prototyped objects for several years but still needs to be proven to be successful on 3D printed objects.

In this study several 3D printed blocks were printed using a 3D printer with the capability of printing 3D objects using the FDM printing method in a wide variety of materials such as, ABS, PLA, and other materials. Square blocks were chosen to be printed for the use of compression testing because these tests can be evaluated with higher accuracy and will distribute the stresses of the load applied equally across each of their surfaces. Engineers are yet to fully trust the use of FEM on printed prototypes. In this study research is conducted with the use of experimentation and software simulations and comparison is generated between the experimental and the simulated models.

2. Printing Process

FDM (Fused disposition modelling) is by far the most commonly used form of 3D printing within the use of 3D desktop printers. There is a wide variety of materials available and it is cost effective. FDM is a process that imports SDL (stereolithography) files to a printer that uses an extrusion process to extrude a thermoplastic in filament form through a nozzle, layer by layer it forms these objects leaving behind a complete 3D design.

3. Structural Differences of 3D Printed Parts

3.1 Layering

3D printing technique uses a layering process to build up objects with the use of minimal materials. Although this technique has its benefits of minimal material wastage, there could be a compromise in the strength and rigidity of the desired solid model. 3D printing often leaves voids in-between the layers when printing, which could lead to design failures, or it could increase the objects strengths due to stress distributions, but this depends on what processes are followed and materials are used.

3.2 Anisotropic Layering

Anisotropic layering occurs in 3D printing when the printed model is stronger along one axis than it is in the other, Figure 1. This is a challenge in 3D printing because of the layering affect the printing has, building from bottom to top. Each layer that is placed on top of the next does not bond completely to the lower layer, even though the bottom layer is still partially melted, the above layer does not adhere completely. This in turn creates voids in-between each layer printed and so, finite deposition method (FDM) printed objects can only withstand certain stresses depending on the direction of layering. The compression test unveils the material property of the model as either isotropic or anisotropic, Figure 1.

3.3 Orthotropic Layering

Orthotropic materials are a subset of anisotropic materials as their properties are dependent on the direction, they are measure, much like that of anisotropic material.

3.4 Isometric Layering

Isometric layering means that the object that has been 3D printed is able to withstand forces in all directions and not only limited to that of the x any y direction but can now include the z axis. Ensuring that it is just as strong in one direction as it is in an another. This process is essentially plausible in the process of printing in metal, such as DMLS or DMLM but the bonding of the materials molecules is not quite that of the standard as casting with just the printing process alone. It requires the printed object to be baked in and oven to insure a better molecular bond but even this comes with its challenges of warping shrinking and cracking of the printed object. The improved DLS process it better explained further on in this paper under processes.

4. Results

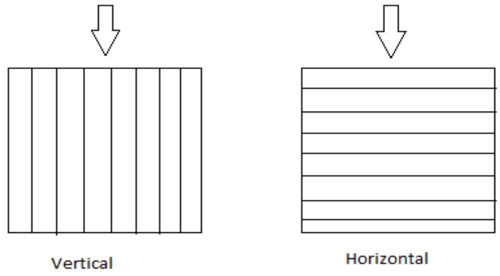

Figure 1: A visual representation of the Load applied vs Material printed axis.

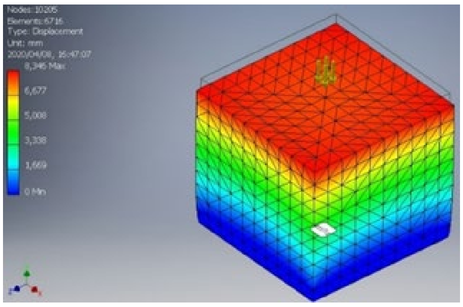

Figure 2: load of 25Mpa applied to the y-axis.

As seen in Figure 2 the load applied on the y-axis has yielded a displacement result of 8.346mm. The load applied on the x-axis yielded a displacement of 8.345mm (Figure 2). a very small difference was observed but is expected from an isometric material. Multiple other comparisons were simulated using different materials to see if there is a trend, Table 1.

Table 1: Simulated y and x axis load and displacements

30% infill 25x25x25mm .stp			
		Displacement (mm)	
Material	**Load (Mpa)**	**y-axis**	**x-axis**
HIPS	25	8,346	8,345
PETG	25	0,5734	0,5733
50% infill 25x25x25mm .stp			
		Displacement (mm)	
Material	**Load (Mpa)**	**y-axis**	**x-axis**
HIPS	25	8,35	8,35
PETG	25	0,5738	0,5737

The loads applied in Table 1 were first simulated on an infill of 30% 3D print design and then for comparison reasons was applied on a 50% infill. Loads were applied on both the x and y axis to grasp if the .stp generated files were to be anisotropic or isometric objects. For practical comparisons tests specimens were printed and subjected to compression loads until failure as seen in Table 2.

Table 2:. Practical displacement after reaching failure

Material	% Infill	Shape, 3D Printed	Dimensions (mm)	Direction of force	Colour	Fn (KN) Failure	Practical Displacement (mm)
PETG	25%	Cube	25mm	Y-Axis (Vertical)	White	0.1	0,1 to 0,15
PETG	25%	Cube	25mm	X-Axis Horizontal	White	4.63	0,5 to 0.75
PETG	50%	Cube	25mm	Y-Axis (Vertical)	White	6.5	14,4
PETG	50%	Cube	25mm	X-Axis Horizontal	White	6.4	3 to 4,8
HIPS	50%	Cube	50mm	X-Axis Horizontal	White	25.05	1,2 to 6,5

5. Discussions

Observing the results seen in Table 1 is clear to see that even though there is a very slight difference on some of the displacements regarding their x and y axes, it is not enough to state that these objects are in fact anisotropic but are in fact isometric objects. The issue with these results is that the materials used have been set as isometric materials mentioned in section 3, as they are standard materials, and this could be the reason for the small displacement differences. There is little information on the 3D Printing Materials that stipulate the properties required to run an Orthotropic material test.

What appears to be the largest indecency of this study is that the results obtained in Table 1 have been that of a distributed load measured in Mpa and the results obtained in Table 2 are that of a distributed load measured in

KN. Therefore, it is assumed that the loads in Table 1 are Mpa and subsequently the loads in Table 2 are KN/mm^2. this would give a ratio of 1KN=1000Mpa.

The results obtained in Table 1 do not differ regardless on which axis the loads have been applied but keep in mind that the materials used are that of an isotropic nature and not the natural form of the filament used with the FDM 3D Printing method. Even though the same loads were applied to that of the 30% and 50% simulations the tabulated results were almost identical and only verified slightly. The results observed in Table 2 clearly show that 3D printed objects with the use of the FDM method are in fact anisotropic material. The practical PETG results in Table 2 have established that there is an inconsistency in the 3D printed test specimens, the displacements.

6. Conclusion and Recommendations

The study can conclude that the FEM simulations on Autodesk inventor are in fact isometric and in order to overcome this, orthotropic values will need to be uploaded in the new materials list. For a more accurate comparison the simulated results could rather be simulated with loads using the ratio of 1KN=1000Mpa. This could possibly represent similar values between Table 1 and Table 2 but observing these results seems unlikely.
Using the FDM printing method this study shows the inconsistency of each 3D print load failure. To better the outcome of this study more test specimens can be used and tested for a larger list of values to compare. This study has proved that Autodesk Inventor 2018 standard isometric material values do not yield accurate simulated results when in comparison to that of the practical results (Abbot, 2021: Abbot et al, 2019).

References

D.W. Abbot, D.V.V. Kallon, C. Anghel, P. Dube. Finite Element Analysis of 3D Printed Model via Compression Tests. *Procedia Manufacturing*. Volume 35, 2019. Pp 164 – 173.
D.W. Abbot. Investigating the Accuracy of 3D Printing via FEA. A dissertation submitted to the University of Johannesburg. 2021.
S. A. and S. J. Al'Aref, "History of 3D Printing," in 3D Printing Applications in Cardiovascular Medicine, 2018, pp. 1–10.
(Coulter et al 2018). "Production Techniques for 3D Printed Inflatable Elastomer Structures: Part II—Four-Axis Direct Ink Writing on Irregular Double-Curved and Inflatable Surfaces," *3D Print. Addit. Manuf.,* vol. 5, no. 1, pp. 17–28.
Y. Q. et al. (2018). "A Review of 3D Printing Technology for Medical Applications," *Engineering, no. 4*, pp. 729–742.
(Verstreken et al. 2019). "Optimization of Extrusion Based Ceramic 3D Printing Process for Complex Body Designs," *Miner. Des., no*. 162, pp. 263–270.
Y. Wen, X. Yue, J. H. Hunt, and J. Shi. 2018. "Feasibility analysis of composite fuselage shape control via finite element analysis," *J. Manuf. Syst.,* vol. 46, pp. 272–281.