Finite Element Analysis of a Simulated Object vs 3D Printed Object

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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, Compression tests.

I. 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 [1]. 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 [2]. 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 [3].

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 [4]. 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 [4]. 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. 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.

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 [3]. 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 [4]. 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 [3, 4]. 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. The filament materials mechanical properties were uploaded onto Autodesk Inventor 2018 for a better representation of the materials being compared via simulation and practical compressions. 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.

II. Experimental Tests

Experimental tests were done with the aid of both a 3D printer to print the test specimens in a verity of matertials and that of a compression testing apparatus with the aid of train gauges to measure the compression experienced. The test specimens were printed in 25x25mm squared cubes. The materials used were HIPS (High Impact Polystyrene), ABS (Acrylonitrile butadiene styrene), TPU (Thermoplastic Polyurethane) and PETG (Thermoplastic Polyester). Once these results were obtained after appliying the loads on the x and y axes the same simulations were done with the aid of AutouDesk Inventor using the FEM to simulate the practical experimental tests.

III. Uploaded Material Properties

In Table 1 the mechanical properties used in uploading the materials file in Ansys are listed. These range from the thermal conductivity to the yield strength and tensile strength of each material. PETG has the highest thermal conductivity of the materials tested with both HIPS and TPU showing the same thermal conductivities. For the other basic properties HIPS appears to have higher values. This is an indication of the heat conduction and retention capabilities of HIPS material. All materials are known to exhibit isotropic behaviours and their densities are also similar. The range in Poisson’s ratio between the 4 tested materials is also very small. Thus the materials show quite similar mechanical properties. However, while HIPS shows a higher yield strength, PETS has a much higher tensile strength showing its ability to resist tensile loads.

Table 1: Mechanical properties of material used for simulations

	HIPS	ABS	TPU	PETG
Basic Thermal				
Thermal Conductivity, btu/(in·sec·°F)	1,34E-07	3,33E-04	1,34E-07	5,55E-04
Specific Heat, btu/(lb·°F)	0,33	0,4	0,024	0,29
Thermal expansion coef (inv °F)	8,00E-05	4,00E-05	5,56E-08	3,80E-07
Mechanical				
Behaviour	Isotropic	Isotropic	Isotropic	Isotropic
Youngs Modulus (psi)	2,80E+05	2,80E+05	3,80E+03	3,20E+05
Poissons ratio	0,41	0,41	0,34	0,38
Shear modulus (psi)	1,45E-03	1,17E+05	7,19E-01	1,45E-03
Density (pound per cubic inch)	0,036	0,038	0,036	0,044
Strength				
Yield Strength (psi)	9,00E+03	5,20E+03	5,65E+03	7,69E+03
Tensile Strength (psi)	4,60E+03	3,83E+03	1,74E+03	6,64E+03

IV. Results and Discussion

For a better understanding of the newly modified materials and their mechanical properties, Simulations were run on a 100% solid test specimen but, instead of using the standard plastic materials found on Inventor, the newly added thermoplastic materials were applied. Keep in mind that the added materials are still to be isotropic and not orthotropic.

Table 2. Simulations of Selected materials of 100% solid density displacements at practical failure loads
100% solid. ipt File

	Displacement (mm)			
Material	Load (KN)	Dimensions (mm)	y-axis	x-axis
HIPS	25,05	50x50x50	0.2588	0,2588
TPU	9,78	25x25x25	14,95	14,95
PETG	4,63	25x25x25	0,08389	0,08389
PLA	16,09	25x25x25	0,319	0,319
ABS	12,2	50x50x50	0.126	0,126

Table 3: Simulated Practical failure loads multiplied by 3.5 to compare displacements of the practical results
100% solid. ipt File Multiplied

		Displacement (mm)		
Material	Load (KN)	Dimensions (mm)	y-axis	x-axis
HIPS	3,5x25,05	50x50x50	0.9058	0.9058
TPU	3,5x9,78	25x25x25	52,33	52,33
PETG	3,5x4,63	25x25x25	0,2936	0,2936
PLA	3,5x16,09	25x25x25	1,117	1,117
ABS	3,5x12,2	50x50x50	0.4412	0.4412

Table 4: Practical displacement after reaching failure

Material	% Infill	Shape, 3D Printed	Dimensions (mm)	Direction of force	Colour	Fn (KN) Failure	Practical Displacement (mm)
TPU	50%	Cube	25mm	Horizontal	White	9.78	5 to 15
PETG	25%	Cube	25mm	Horizontal	White	4.63	0,5 to 0.75
PLA	50%	Cube	25mm	Horizontal	Black	16.09	1
ABS	50%	Cube	50mm	Horizontal	White	12.2	5 to 7
HIPS	50%	Cube	50mm	Horizontal	White	25.05	1,2 to 6,5

Table 4 results were obtained by first printing the 3D tests specimens with the use of FDM (Fused disposition modelling) and then subjecting those test specimens to a practical [1] compressive load with the aid of strain gauges to measure the displacement experienced

In Table. 2 the displacements experienced can be seen to be nowhere near those of the displacements seen in table. 4 except for the TPU material. The second simulations seen in Table 3 were run by multiplying the loads by 3.5 times experienced in Table 2 to see what it would take for the simulations to yield similar results of those experienced in the practical test results seen in Table. 4.

The results obtained of the TPU material in table 2 could be the most accurate due to the values used in the uploaded materials being the closest to that of the filament used within the 3D printing test pieces. The FDM printing method is naturally anisotropic and because the results obtained in tables 2 and 3 with regards to the x- and y- axes being identical were expected. Even though the mechanical values used to be uploaded onto Autodesk Inventor are those of the filaments used for the printing of the practical 3D tests specimens table 1, these properties are still seen as isotropic materials and not that of orthotropic.

Results yielded in Table 3 were those loads experienced in Table 2 but multiplied by 3.5. These results did not meet those of the results yielded in table 4 except for that of HIPS and PLA. The results were similar but cannot be justified.

V. Conclusion and Recommendation

The mechanical properties of the materials are still seen to be that of isometric and therefore cannot accurately represent the properties of those of the 3D printed filaments used. It could be argued that if the loads experienced are perpendicular to that of the FDM printed layering, the results obtained using the isometric material properties can be compared. Even though this could be, the results obtained in Tables 2 and 3 are nowhere that of the results yielded in Table 4.

The results yielded in Table 4 for the practical compression tests are also between that of 25% infill and 50% infill whereas the results of the simulations obtained in Tables 2 and 3 are 100% solid. this could be why the results obtained in Tables 2 and 3 are much smaller than those seen in Table 4. This is also a good comparison to visually see how 3D printing can save on material usage and how 3D printing behaves with different percentage infills in comparison to that of is solid comparisons.

References

[1] D.W.Abbot, D.V.V.Kallon, C.Anghel, P.Dube, "Finite Element Analysis of 3D Printed Model Via Compression Tests," Procedia Manufacturing, vol. 35, pp. 164-173, 2019.
[2] D.W. Abbot. Investigating the Accuracy of 3D Printing via FEA. A dissertation submitted to the University of Johannesburg. 2021.
[3] S. A. and S. J. Al'Aref, "History of 3D Printing," in 3D Printing Applications in Cardiovascular Medicine, 2018, pp. 1–10.
[4] J. P. Graham and L. M. Polizzotto, "Pit Latrines and Their Impacts on Groundwater Quality: A Systematic Review," Environ Health Perspect, pp. 521-530, 22 May 2013.