Compression Test Correlation of 3D Printed Structures Using Finite Element Modelling

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Abstract

The 3D printing revolution has led to many opportunities for structural and mechanical research that did not exist before the development of this technology. However, performing this basic research comes at a high cost in time and materials. Preparing and completing individual print runs for even small structures can take days and consume large amounts of materials for both the test structure itself and any supports needed to complete the production of complex three-dimensional shapes.

Additionally, the process of additive manufacturing itself can change the underlying properties of the base materials in unexpected ways due to the mechanics of the printing process. During the printing process, as the base material is heated and cooled and the printer generates the object layer-by-layer using a limited array of fill patterns, because of this small changes in the mechanical properties of the base materials are introduced.

In the lab, both solid and lattice structured materials were tested using both compression and high-speed impact tests. Using computer-based finite element modelling (FEM) in conjunction with the results of these laboratory tests of our selected 3D printed structures, we are correlating, in an accurate and reproducible way these manufacturing effects on structures generated by this new technology. By doing so, we are developing new methods to reduce time and materials waste during the research process.

Introduction

Tetrahedrally linked lattice structures show great promise to achieve an extremely high strength to mass ratio for both compression and impact resistance (fig 1). In nature, face-centered cubic (FCC) lattices represent some of the strongest materials known to man, such as diamond and boron nitride. Our goal with this research is to test the mechanical properties of tetrahedrally linked face-centered cubic lattices, and variations thereof, when printed on a macroscopic scale.

Once beyond relatively small and simple structures, though , generating these objects manually becomes impossible and even using algorithmic systems to create these models take days or even weeks. Once the model generation is complete, a stereolithographic (STL) model is created as the input for the 3D printing process and printing can begin. During the printing process, though, in addition to the material for the desired lattice, support materials are required due to the voids present in the crystalline structure adding time and complexity to the print. As a result, the 3D printing process can last several days. Once the shape has been 3D printed, more additional time is required to remove these support materials before testing can commence.

Using FEM to create accurate simulations of these structures in advance of printing and testing can be used to eliminate those that do not meet desired criteria, thereby reducing time and materials waste For these simulations to be valid, however, strong correlations must exist between the FEM models and the real-world objects.

References

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Methods and Materials

A series of structures from solid cubes to tetrahedrally linked lattices were printed by a Stratasys® uPrintSE Plus™ using the manufacturer' s P430 acrylonitrile butadiene styrene (ABS) filament. These objects were tested using compressive loads in a laboratory. For the solid cubes, testing continued beyond the ultimate strength of the ABS material until a permanent distortion of approximately 16mm (or ~42%) was achieved. Testing for the tetrahedral lattices continued to the point of failure by fracture (fig. 2).

Finite Element Models were then created in and simulated using both Dassault Systèmes SolidWorks 2017 and Abaqus CAE v6.4.15. SolidWorks was used for its shape creation and basic physical simulation systems. Initial simulations using SolidWorks determined the load absorption potential for a selection of structures. For FEM modelling, the more advanced Abaqus is used on the models created in SolidWorks.

Creating a FEM behavior model for future testing, initial correlation work used a model of a solid 38.1 x 38.1 x 38.1mm cube. This model matched the dimensions of the printed solid and used the stated specifications for the P430 printer filament used in the test solid. To replicate laboratory testing, the model had one surface with a fixed boundary condition (BC), while the opposite surface used a displacement BC which was moved by 16mm along the negative y-axis over 16 seconds. The simulation used Abaqus' double-precision solver to run a dynamic, explicit simulation type with non-linear geometry.

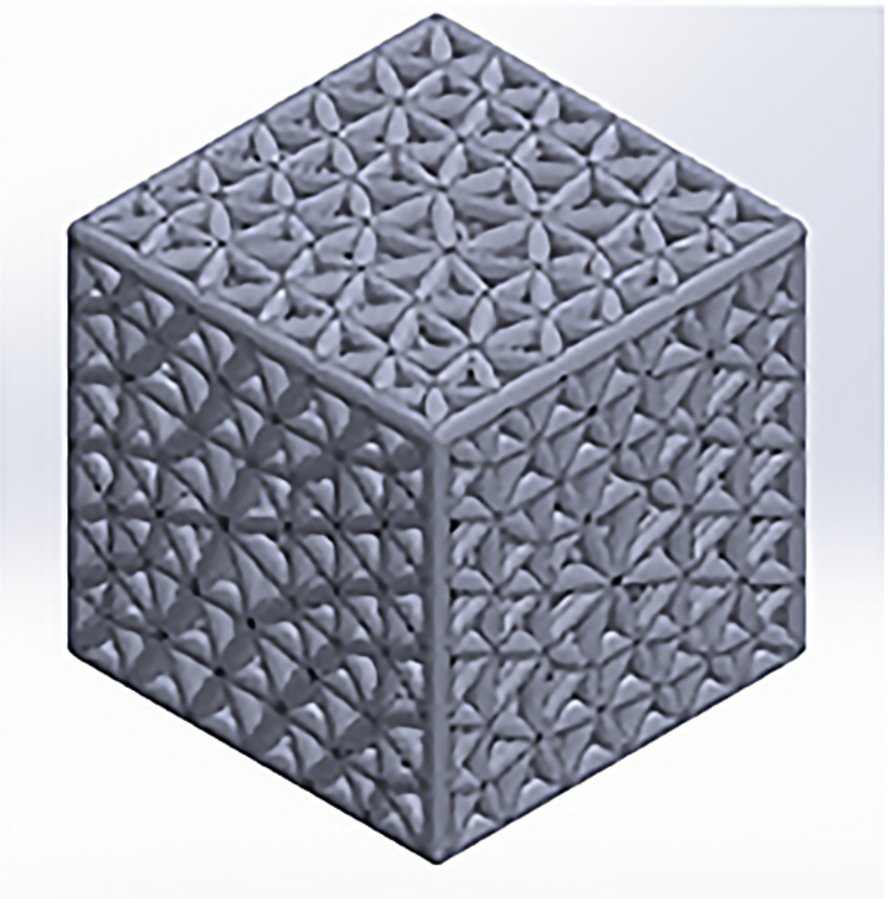

Figure 1 – SolidWorks model of a tetrahedral solid

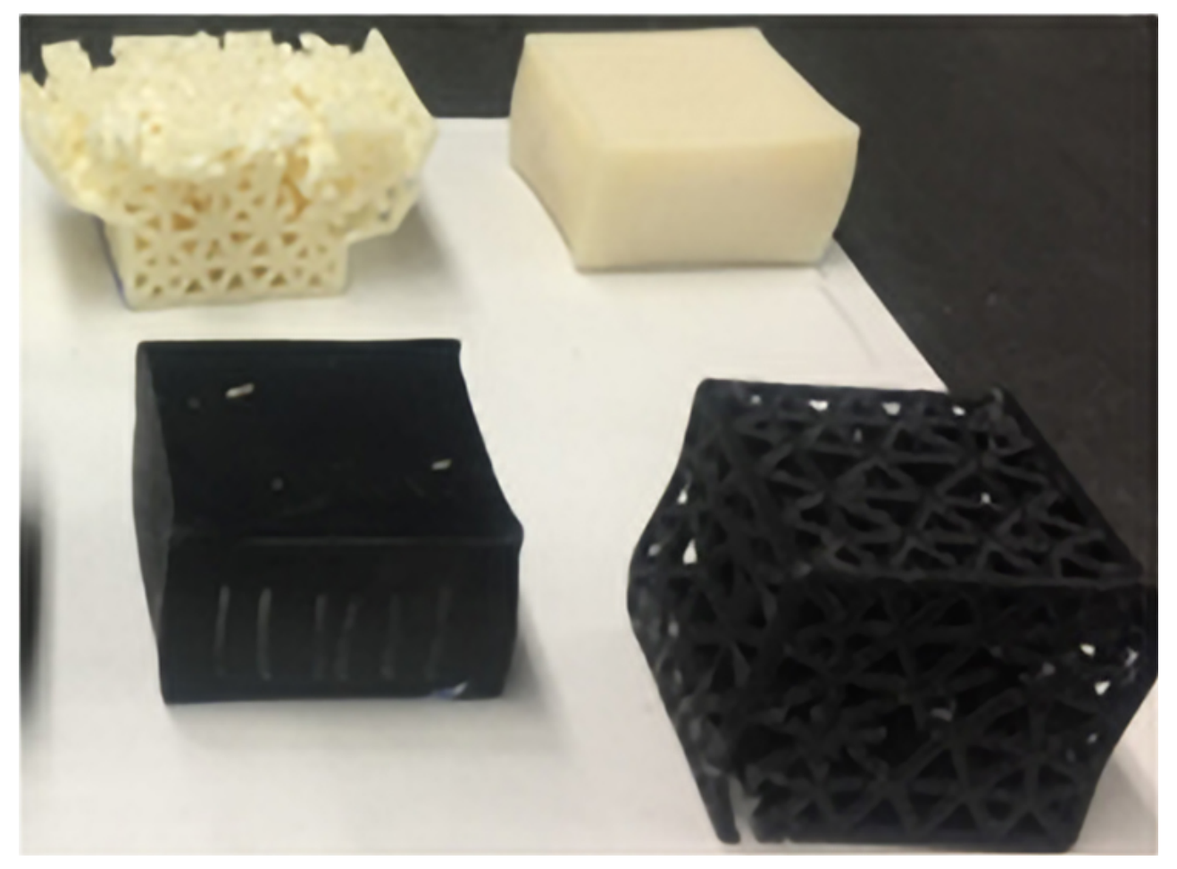

Figure 2. – 3D printed structures after compression testing

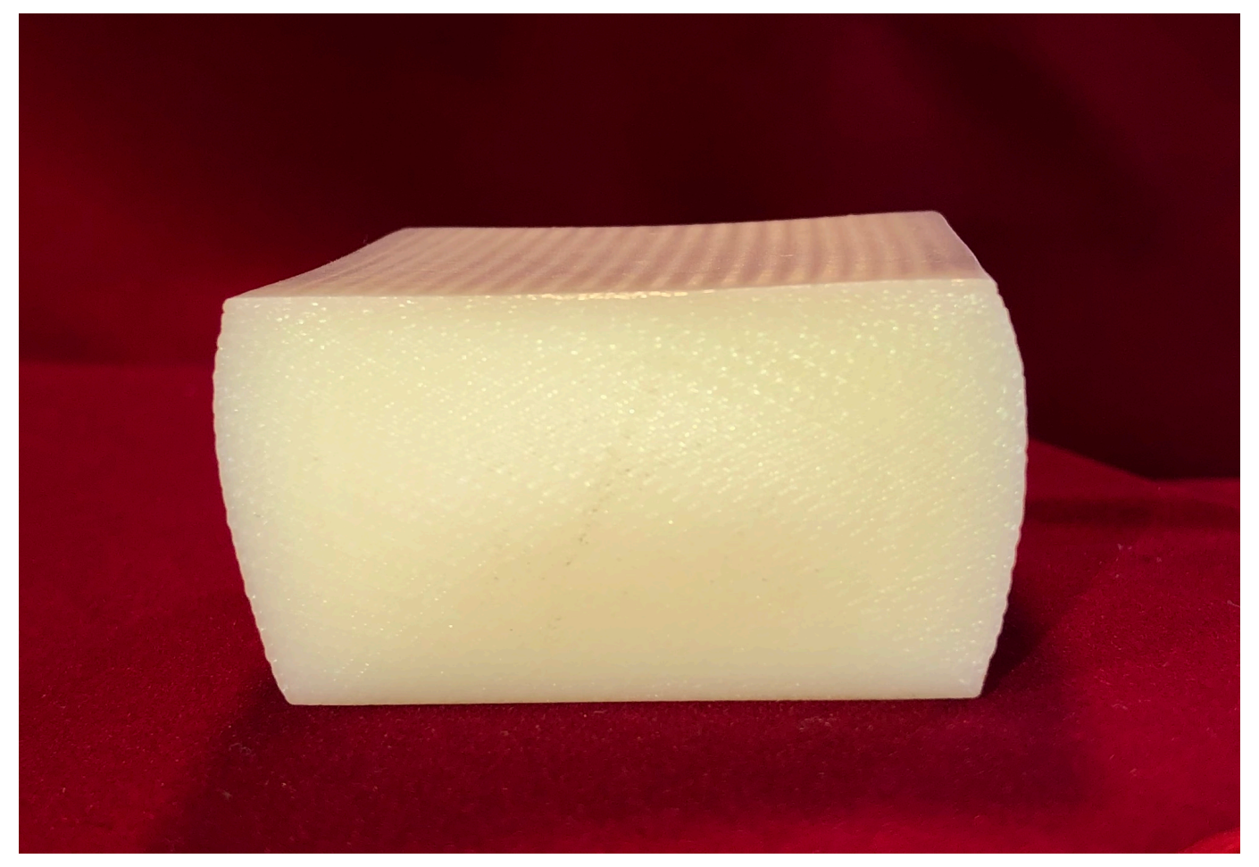

Figure 3 – 3D printed solid after testing

Results

Comparing the FEM model to the 3D printed cube is still at the qualitative, rather than quantitative stage. The FEM model visually shows distortions around the fixed face of the simulated ABS cube (figs. 3 and 4), which do not exist in the lab-tested sample item. However, close examination of the physical sample (fig. 5) indicates that this difference may be an artifact created by the FEM software's boundary condition definitions.

Further, the physical solid exhibits bowing along the sides and a lateral skew between the upper and lower surfaces (fig. 6) which are not present in the FEM model.

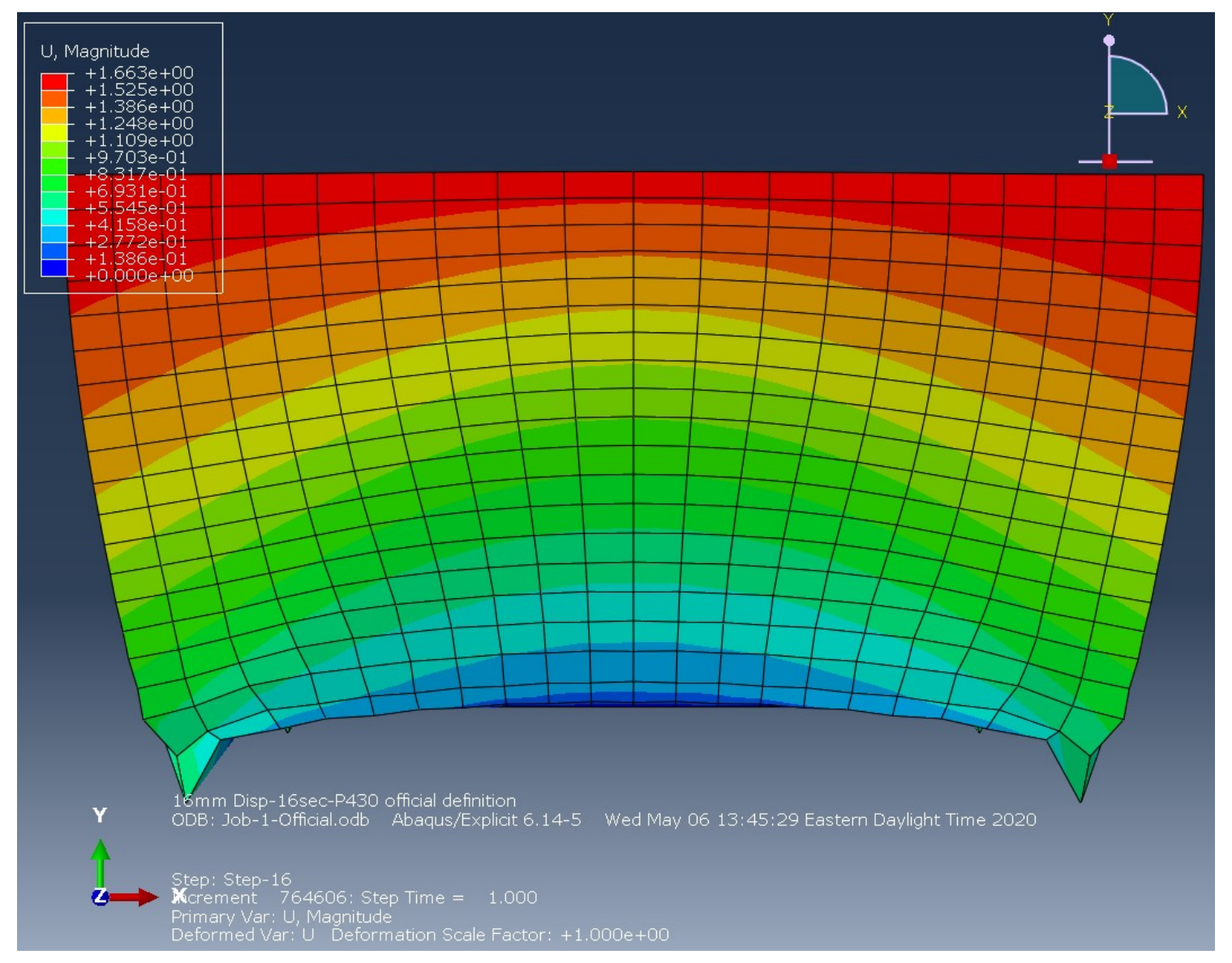

Figure 3 – FEM model of cube after simulation

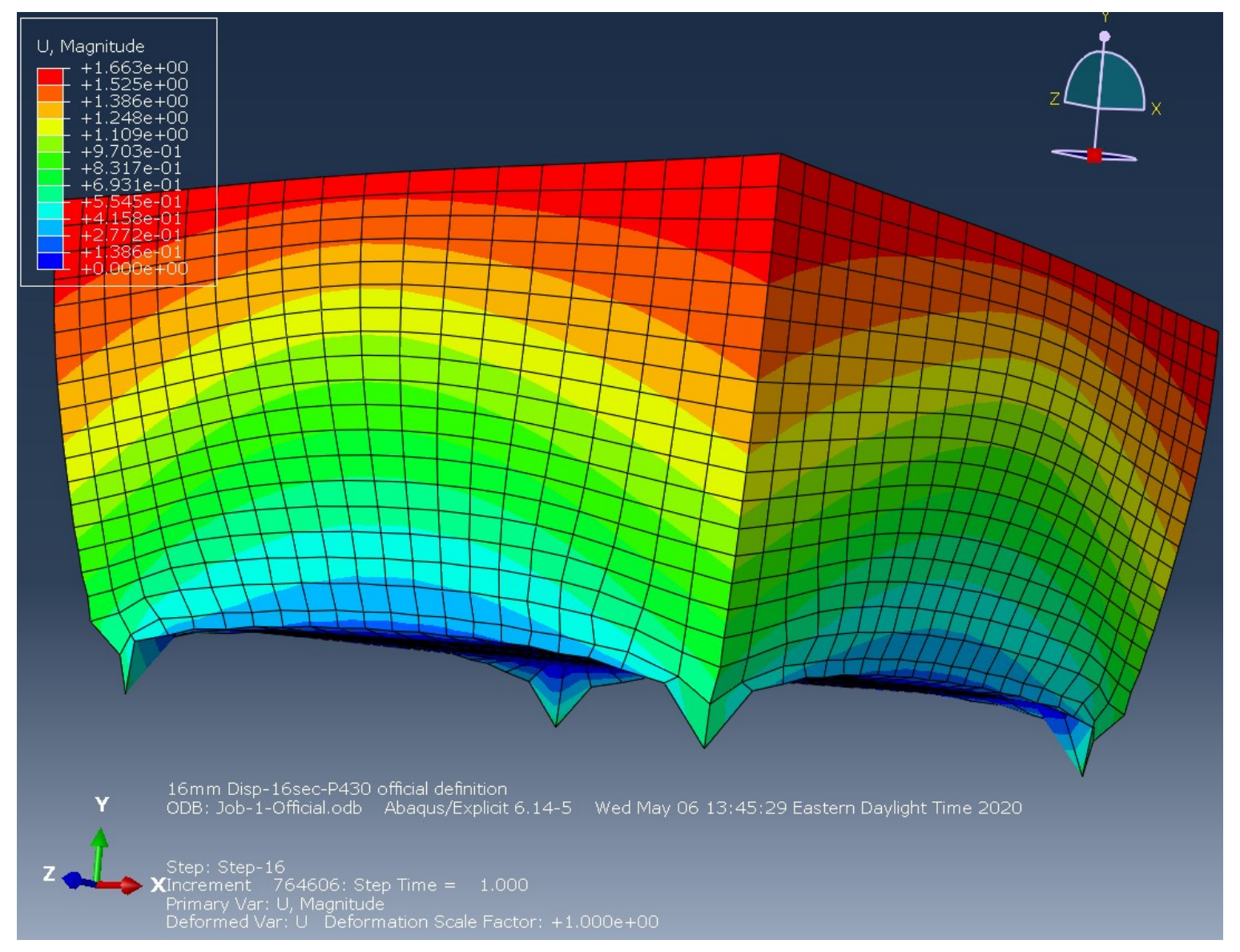

Figure 4 – FEM model offset

Figure 5 – Close up showing corner distortions on lab tested solid

Figure 6 – 3D printed solid showing test-rig induced skewing

Conclusions

Several differences exist between the lab-tested physical objects and their FEM simulated counterparts. Some of these differences are easily accounted for, and can be corrected for in future models. However, further testing of the physical objects will be needed to determine the sources of other variances between model and reality. At the current stage of research, though, FEM results are beginning to converge with reality. This indicates that there should a model with a level of correlation close enough to be used for early determinations regarding the suitability of certain structures for physical testing, thereby increasing efficiency in time and material utilization during the research process.

Discussion

- Layer deposition as a possible source of variation in the mechanical properties of physical vs. FEM simulated materials
- Ultimate limits on correlation between physical testing and FEM simulation.
- Limitations on lab testing resulting from COVID-19 related restrictions.

Future Work

- Determine differences in mechanical properties variations in ABS caused by printing process for incorporation into FEM model.
- Generate FEM model with non deformable bottom surface to more closely represent actual test conditions.
- Modify material definition to allow for internal frictional heating effects in ABS during simulation.
- Quantitative analysis of laboratory results for energy absorption as compared to FEM models
- Begin FEM model compression simulation of tetrahedral based lattices.
- Introduce appropriate damage models to FEM simulations to account for failure in physical ABS models.