ABAQUS Simulation of Different Critical Porosities Cubical Scaffold Model

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Abstract. Scaffold or porous architected structure is essential in biomedical application for cell growth or for mass reduction if to be used in automotive and aerospace applications. The structure was once impossible to fabricate but now viable using additive manufacturing techniques. However, in order to reduce weight structure and save on materials using porous structure, strength is one key feature must be maintained to serve the function. The aims of the study are to compare the part strength with different cell repetition and porosity (ranging 56% to 70.45%), and also to determine pattern of stress concentration in different unit cell size. In this study, cubic scaffold-based structures with critical porosity range were simulated using ABAQUS. From the simulation it can be observed generally that strength will reduce with higher porosity, while 58.96% of porosity showed less stress concentration. For each porosity, stress concentration and deflection can be observed and compared. The result of the study is important to help designer to choose suitable design and porosity prior to fabrication.

1. Introduction

The emergence of Additive Manufacturing in 1996 has opened new possibilities for manufacturing world. One of the most prominent advantage is the ability to fabricate complex geometry, practically the complexity that are not feasible before using other conventional manufacturing techniques. There are many techniques for AM but employing similar concept of adding material collectively layer-by-layer based on CAD data file. Upon designing, architected structure also known as scaffold, lattice or porous structure is important mainly to reduce material usage and mass [1-2]. While mostly in medical application, porous structure is purposely employed to enable cell growth in artificial bone structure and also as protective structure for energy absorption [3]. The emerging of additive manufacturing technology has made the objectives to produce complex and lightweight structure possible [4]. Examples of architected structure are bio inspired bone structure, which initially fabricated as simple porous design, later on the aim was to mimic real bone structure namely trabecular and cortical bones with different strength and currently studies found out that bone is made of hierarchical of multi scale structure [5]. In aerospace part design, topologically optimized brackets which are porous and thus save on material usage was employed for aerospace application [6]. Upon application however, strength of
the part is priority over lightweight structure. Strength to weight ratio is nevertheless important and from past research, it is direct translated from the porosity of the structure where the best mechanical properties observed in scaffolds of low porosity [7]. In previous study, ABAQUS simulation was being conducted on cubical designs with wider range of porosity 0-89.6% and as expected, very low porosity made high strength parts with result and stress distribution was similar to the solid cube. At 89.6% porosity, the structure could not even bear one third of the load, and it seems like good mechanical properties lied at some point around 60% porosity. Building orientation is one vital parameter in additive manufacturing process. For ABS parts under compression loading, the sample with a transverse build direction has a lower strength when compared with the sample having the axial build direction, and the compressive strength of the specimen is 80% to 90% of the injection moulded part. In a similar study, experimental approach was found unable to determine compression strength or failure trend of architectured compression test [4]. The objectives of the study are to compare the strength of parts with different cell repetition but same porosity (ranging 56% to 70.45%), and to determine pattern of stress concentration in different unit cell size.

2. Materials and methods

2.1. Design

Figure 1. Porosity: (I) 70.45 %, (II) 67.65%, (III) 64.80%, (IV) 61.9%, (V) 58.96% and (VI) 55.99%. (a) Scaffold structure (b) Single Unit cells (c) & (d) Repetitive Unit.
Architectured structure can be simple and complex polyhedra shapes [8] but in this work, the chosen model was simple lattice cubical cell structure. The part model sized 100mm x 100mm x 100mm in outer dimension whether it represented single or repetitive cell unit. The structure were made with different strut size, thus different porosity range from 70.45% which is very porous to 55.99% porosity. Models designs of open-porous lattice structures with different porosity are as shown in Figure 1, where (I) − (VI) represent range of porosities while (a) - (d) show different representations of design employed in this study which are final model of different unit number, single, double and repetitive units respectively.

All models were designed inside the Abaqus and not outsourced nor imported from other CAD designing software. In order to eliminate the effect size variable, all models are in similar base size of 100mm x 100mm x 100mm whether the cube is a single unit or scaffold.

2.2. Simulation

Analyses were performed using Abaqus Standard 6.14-2 by Dassault Systems Simulia. The analysis was on general static step, and based on previous study using 500N load [4] compressing the specimen. The model was meshed using 10-seed size tetrahedral elements as recommended for lattice design except for solid cubical design which was meshed using 10-seed size hex units. Number of generated nodes and elements varies for all the design.

The works in this study were based on simulation only and material properties were input using collected data from previous experimental works. These data consist of Young Modulus and stress-plastic strain relationship.

The simulation steps are part designing where basically there were five parts, properties input based on material properties such as density and elastic-plastic behaviour information and assembly for combining instances. During the simulation, each part model was loaded with 500N force on top surface and encastre fixed at the base. After all input is done, the model was meshed before simulation job is submitted. From the simple simulation, the result is observed and recorded for each model and will be discussed in the next section.

3. Results and discussions

From the simulation, some important results to expect are to observe the Von Mises plane stress on each model when loaded, to see if similar scaffold design would show pattern in stress distribution and to know if the sharp corner can possibly be stress concentration which may induce failure initiation. For all the result, colour coded legend as shown in each simulation result figure can be referred, where red represents highest value, green is for medium and blue shows lowest value of stress reading. The real value and range for each viewport is actually different and should be referred individually.

3.1. Single unit

From Figure 2, it can be clearly seen that area of stress concentration is on the connecting vertical strut and as the porosity getting lower, higher stress can be observed and green coloured shading has become wider as compared to lower porosity structure. The single cell structure is quite simple and therefore, stress distribution is generally in both vertical and horizontal struts. Only on the base where the structure was encassted, the horizontal struts exerted less stress than the upper did.
Figure 2. Static loaded for each porosity of single cell: (I) 55.99%, (II) 58.96% (III), 61.9%, (IV) 64.80%, (V) 67.65% and (VI) 70.45%

3.2. Double unit

Figure 3. Static loaded for each porosity of double repetitive cell: (I) 55.99%, (II) 58.96% (III), 61.9%, (IV) 64.80%, (V) 67.65% and (VI) 70.45%.
Interestingly, close observation showed that highest plane stress is on outer struts and less was distributed in centre strut. However, as the strut getting smaller and porosity become higher, the centre strut started to experience stress concentration. As can be seen from Figure 3, pattern of stress distribution is similar as single unit but the stress was not distributed on lower horizontal frame.

### 3.3. Multiple unit

From figure 4 it showed that all forces are exerted on the top plane and highest stress can remarkably be seen on the four top corners of the cube when the porosity is lower. At highest porosity of 70.45%, the upper vertical strut began to distort and this area is expected to initiate failure upon loaded.

![Figure 4. Static loaded for each porosity of multiple cell: (I) 55.99%, (II) 58.96% (III), 61.9%, (IV) 64.80%, (V) 67.65% and (VI) 70.45%](image)

For all porosities and repetitions, it is observable that all structure showed similar stress distribution on the parts. Struts along y-axis exerted stress more than horizontal x-z plane and stress distribution was more on upper than on the base of the structure.

### 3.4. Deflection and mises stress

Some studies considered porosity of 64% and below is acceptable range in maintaining mechanical and fatigue strength. However, this value depends on several variables such as type of material, processing method and application. Deflection is considered the highest deformed reading taken from the y-axis (or u2 in ABAQUS modelling). From Figure 5(a), deflection pattern for single structure is linearly proportional although the pattern can also be observed in double cell repetitive unit. As the repetitive unit increased, it seems the deflection trend is no more linearly proportional. However, it is suggested in future, study can be further extended by adding more repetitive cell to see the trend.
Figure 5 (a) Deflection, (b) Von Mises Stress for different cell type and porosity

Figure 5 (b) shown plot of plane stress (S Mises in ABAQUS) according to cell arrangement (single, double and multiple). From the figure, cell with 58.96% porosity exhibited the best strength for all type of cell arrangement. Von Mises reading for 58.96% porosity is low and congregated disregard of cell arrangement. While for each cell arrangement, the plane stress reading did not according to any specific pattern.

4. Conclusions
Simulation using Abaqus software was conducted successfully and all the results has been analysed and compared. From the study it can be concluded that 58.96% porosity is the best within the range studied in this work (55.99% - 70.45%) in term of Von Mises stress and shows less failure initiation using this porosity.

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