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INVESTIGATION OF THE MECHANICAL PROPERTIES OF ABS-BASED 3D PRINTED SCAFFOLDS BY USING THE SOFTWARE SOLIDWORKS 2020

***Abstract**: 3D printing techniques are becoming state-of the art technique in the field of engineering research, enabling for the rapid and low-cost creation of prototypes and components using computer-aided design (CAD). In addition, interest to 3D printed scaffolds is also increasing in using these techniques in a clinical setting to create anatomically 3D printed models from medical imaging for research, training, and teaching. We discuss the benefits of common features of 3D printing and 3D printed scaffolds for patient education, healthcare professional education, interventional planning, and implant creation in this article. We also try to explain how to learn mechanical properties of 3D printed Acrylonitrile Butadiene Styrene (ABS)- based scaffolds during the printing and post printing and how to prepare them for 3D printing by using software Solidworks 2020. We preferred use ABS - based scaffold as example. We hope this knowledge will be of use to researchers, teachers and students with little or no previous experience in 3D printing scaffolds processing who have identified a potential application for 3D printing in a medical context, or those with a more general interest in the techniques.*

***Key words**: 3D bioprinting, 3D printed scaffolds, ABS based material, Scaffolds, printable biomaterials, biodegradable materials, mechanical properties, stress and strain, Young module.*

***Language**: English*

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Introduction

Currently there are shortage in bone implants three of the most important characteristics of living tissues: 1) the ability to self-regeneration; 2) the ability to maintain a blood supply; and 3) the ability to modify their structure and properties in response to environmental factors such as mechanical load. As we know the tissue engineering is a multi-disciplinary field that includes cell and molecular biology, materials science, chemical and mechanical engineering, chemistry and physics. In turn, mechanical and thermal feature of them is considered one of the most priority property. For instance mechanical load, stress and strength, bending coefficient, Young module, breaking point and liner extension coefficient from heat. To achieve the required functionality, the scaffolds must be; 1) biocompatible, maintain and facilitate cell functionality, and match the growth of cells and tissues; 2) have sufficient mechanical strength to support structural integrity. [1] This work were dedicated on the learning of mechanical and thermal properties of 3D printed scaffolds through software Solidworks's laboratory function, and also tried to give some general informations about types of potential scaffold materials, ABS – based materials.

1.1 Classes of potential scaffold materials.

When materials are implanted, they have a biological response from the body. Many are poisonous to the body, whereas others are biocompatible (not toxic). Biocompatible materials are divided into three categories: bioinert, resorbable, and bioactive.

ABS or Acrylonitrile butadiene styrene is a common thermoplastic polymer typically used for injection molding applications. This engineering plastic is popular due to its low production cost and the ease with which the material is machined by plastic manufacturers.

Bioinert materials

We can not say all material is completely inert on implantation, but the only response to the implantation of bioinert materials is encapsulation of the implant by fibrous tissue (scar tissue). Samples of bioinert materials are medical grade alumina, zirconia , stainless steels and high-density polyethylene that are used in the total hip replacements. We can not say all material is completely inert on implantation, but the only response to the implantation of bioinert materials is encapsulation of the implant by fibrous tissue (scar tissue). Samplas of bioinert materials are medical grade alumina, zirconia , stainless steels and high-density polyethylene that are used in the total hip replacements.

Resorbable materials

Resorbable materials are those that dissolve when they come into touch with body fluids and can then be secreted through the kidneys. Polymers that breakdown through chain scission, such as polyglycolic (PGA) and polylactic acids (PLLA), and their co-polymers, are the most prevalent biomedical resorbable materials, and are commonly used as sutures. There are some bioceramics that they are also resorbable in vivo, for instance calcium phosphates.

Bioactive materials

Bioactive materials cause the body to respond biologically, such as tissue bonding. This days known two classes of bioactive materials: osteoconductive and osteoproductive. Osteoconductive materials bond to hard tissue (bone) and stimulate bone growth along the surface of the bioactive material, e.g. synthetic hydroxyapatite and tri-calcium phosphate ceramics. Bioactive glasses, for example, which can connect to soft tissue such as gingival (gum) and cartilage, are osteoproductive materials that induce the formation of new bone on the material away from the bone/implant interface. The mechanism of bone bonding to bioactive materials is thought to be due to the formation of a hydroxyapatite layer (HA) on the surface of the materials after immersion in body fluid. This layer is similar to the apatite layer in bone and therefore a strong bond can form. The layer forms quickest on osteoproductive materials.

1.2 Polymer scaffolds

Degradable polymer materials are a famous choice of material for tissue-engineered 3D printed scaffolds for three reasons. Particularly, polymers are easy to process in the shape of a 3-D scaffold with a pore morphology suitable for tissue engineering fields. Secondly, polymers can have high tensile properties and high toughness and the mechanical properties of polymers can be controlled very easily by changing the molecular weight (chain length) of the polymer. Thirdly, bioresorbable polymers have been used successfully as dissolving sutures for many years. Therefore, these degradable polymers, such as the polyesters of poly(lactic acid) (PLA), poly(glycolic acid) (PGA) and poly(lactic acid-co-glycolic acid) (PLGA) are used for scaffold applications because they have passed FDA regulations, and scaffolds made from these materialscan provide a quick route to a commercial and clinical product. The methods used to produce porous networks in these polymers are fibre bonding or weaving, solvent casting, particulate salt leaching, phase separation, gas foaming, freeze drying and extrusion.

To create an open pore structure, the polymer solution can be foamed. Blowing agents, gas injection, supercritical fluid gassing, and freeze–drying can all be used to accomplish this.

The polymers that can be used for supercritical fluid gassing must have an high amorphous fraction. Polymer granules are plasticised due to the use of a gas, such as nitrogen or carbon dioxide, at high pressures. The dissolution of the gas into the polymer matrix results in a reduction of the viscosity, which allows the processing of the amorphous bioresorbable polyesters in a temperature range of 30–40 °C. However, on average, only 10–30% of the pores are interconnected.

2. Materials and methods (Experimental section)

2.1. Materials.

Drying treatment: Drying treatment before processing is necessary. The humidity should be less than 0.04%, and the recommended drying condition is 90~110℃, 2~4 hours. Melting temperature: 230~300 ℃. Mold temperature: 50~100℃. Injection pressure: depends on the plastic part. Injection speed: as high as possible.

ABS is widely used as a material for 3D printing, as it is a strong and cheap thermoplastic. For 3D Printing purposes, ABS is extruded into Filament so it can be fed through the 3D printer. When being used in a 3D printer, ABS is often melted in a 3D printer at temperatures close to 240°C (463°F), as it very quickly melts it. ABS is only used in FFF/FDM 3D printers, as resin 3D printers can not melt plastic.

2.2. Fabrication and design of the ABS scaffolds.

All 3D printed patterns and constructs were designed through Solidworks 2020 software. The information sets were at that point spared as stereolithography (STL) records and continued by utilizing Simplify 3D computer program to create a set of G-code for 3D printing. ABS filament through a heated extrusion head 175 µm diameter at 225 ◦C was preferred as filler for prototype. A close collection distance (0.5− 2 mm) enables the controllable deposition of melted ABS filament on a 110ºC collection surface affixed to the stage with X-Y-Z linear motion. Respective modulation of X, Y and Z motion generated various patterns of ABS filament in a layer-by-layer manner. Two ABS scaffolds were designed and printed Anycubic 3D Printer. For the porous cylinder scaffolds, the scaffolds were produced directly from the printer. After that, the compacted rolling scaffold was fixed into a temperature-tunable holder, which was preheated to about 65 ℃ to soften the printed filaments and enhance the adhesion between different layers.

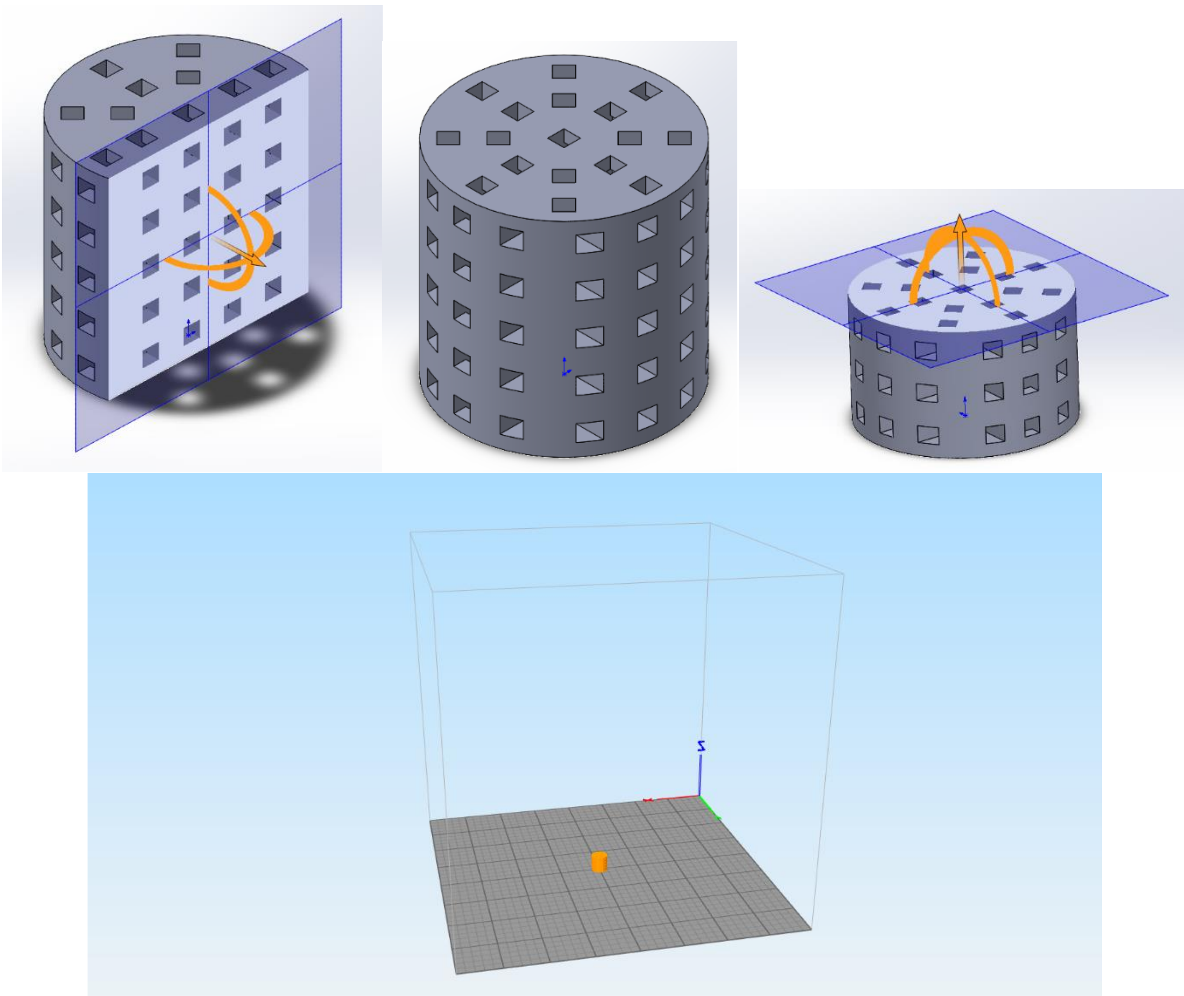

Fig.1. (a) cylinder scaffold (b) cross sectional view (c) longitudinal view (d) G- code converting process

2.3. ABS scaffold characterization.

Acrylonitrile butadiene styrene (**ABS**) (chemical formula $(C_8H_8)_x·(C_4H_6)_y·(C_3H_3N)_z$) is a common thermoplastic polymer. Its glass transition temperature is approximately 220 °F (104 °C). ABS is amorphous and therefore has no true melting point.

ABS is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15% to 35% acrylonitrile, 5% to 30% butadiene and 40% to 60% styrene. The result is a long chain of polybutadiene crisscrossed with shorter chains of poly(styrene-co-acrylonitrile). The nitrile groups from neighboring chains, being polar, attract each other and bind the chains together, making ABS stronger than pure polystyrene. The acrylonitrile also contributes chemical resistance, fatigue resistance, hardness, and rigidity, while increasing the heat deflection temperature. The styrene gives the plastic a shiny, impervious surface, as well as hardness, rigidity, and improved processing ease. The polybutadiene, a rubbery substance, provides toughness and ductility at low temperatures, at the cost of heat resistance and rigidity.[3] For the majority of applications, ABS can be used between −20 and 80 °C (−4 and 176 °F), as its mechanical properties vary with temperature.[5] The properties are created by rubber toughening, where fine particles of elastomer are distributed throughout the rigid matrix.

2.3.2.Porosity measurment

The porosity of the scaffolds (n = 3) was measured by using the Archimedes' principle in D.I. H_2O. The porosity was calculated according to the following equation: Porosity=$(W_{sat}–W_{dry})/(W_{sat}–W_{sus})\times100\%$ Where W_{sat} stands for the weight of scaffold saturated with water, W_{dry} is the dry weight of the scaffold, and W_{sus} represents the weight of the scaffold suspended in water.

2.4. Mechanical testing

The mechanical properties of ABS-based 3D printed scaffolds were simulated by using Solidworks 2020 software. The stress-strain data were converted from the load-displacement data and the compressive modulus was found out from the slope of the stress-strain curve.

3. Results and discussion

3.2. Mechanical properties of the 3D ABS scaffolds

The mechanical properties of 3D structures are an important feature when considering the final application of the scaffolds. As shown in Fig. 2, the compressive stress of porous cylinder scaffolds were found to be 4.47 $*10^8$ N/m^2 , 4.02$*10^8$ N/m^2 respectively. More specifically, the cylinder scaffold had the maximum compressive stress increased by 29.61 % and 61.23 % when compared with porous cylinder. The highest compressive stress of the cylinder scaffold was due to its solid structure. When the load was applied parallel to the stacking direction, layers were strongly connected to each other to increase the mechanical strength. In contrast, the porosity in the scaffolds causes a reduction in mechanical properties because it impairs the structural integrity of the scaffold, which as a result will not be suitable for load bearing . Generally, the higher the percentage of porosity, the lower the mechanical strength will be. In addition, the displacement modulus was calculated from the slope of the linear portion of the Stress-Strain curve. Fig. 3 exhibits the data corresponding to the Young's modulus for the, porous cylinder. Like the compressive stress, cylinder scaffold shows the largest Young's modulus of 0.35 ± 0.04 GPa, while porous spiral with the highest porosity shows the smallest Young's modulus of 0.19 ± 0.02 GPa. In this figure datas were given by descending order . Although porous cylinder scaffold present lower compressive stress and Young's modulus, it is still appropriate for the bone regeneration. This is because the typical compressive stress of cancellous bone ranges from 0.5–85 MPa and its Young's modulus is in the range of 0.01 to 0.2 Gpa.

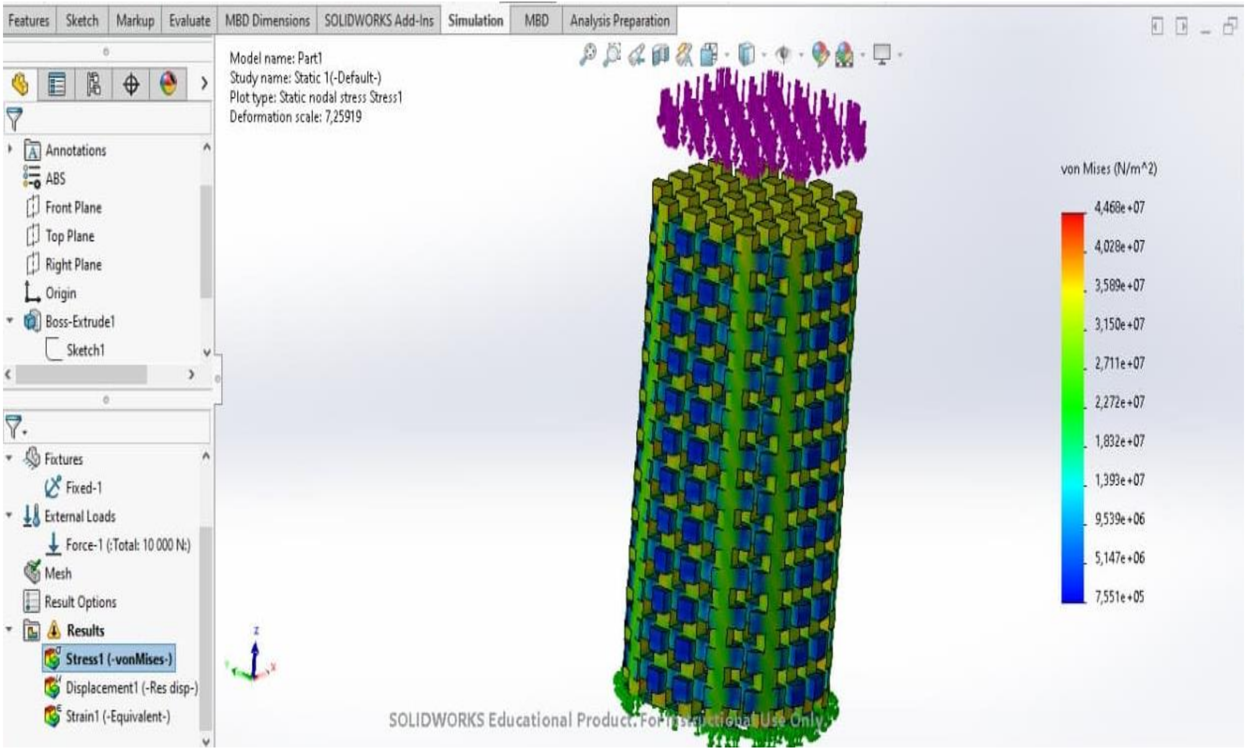

Fig. 2. compressive stress

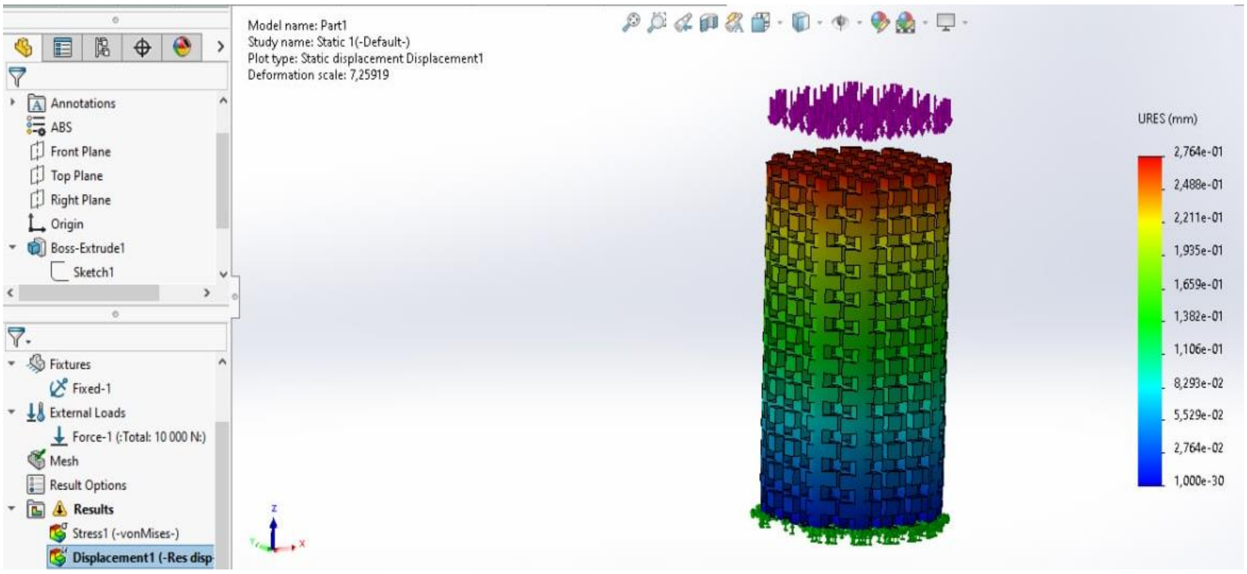

Fig. 3. Displacement

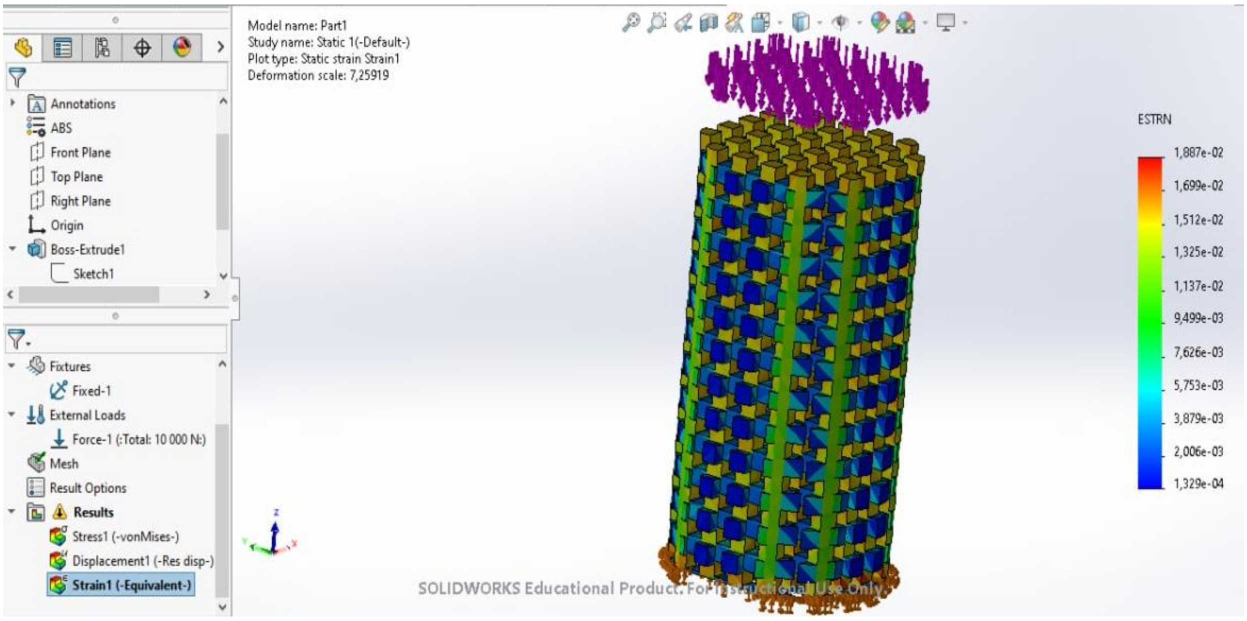

Fig. 4. Strain

4. Conclusion.

In this article , we tried to learn mechanical properties of ABS -based scaffolds and design and fabricate the ABS porous cylinder scaffold (as a model) by using the 3D printing method and Solidworks 2020 software. A porous cylinder scaffolds have an average pore size approximately of 928 nm and all pores were interconnected. The pores were large enough to improve cell implantation, new blood vessel infiltration, and high oxygenation. The porous cylinder scaffold with low porosity (around 30 %) could be fabricated directly from the printer. However, in order to prepare highporosity scaffold, we worked on combined the traditional bio-fabrication method with the novel 3D printing, because the current 3D printing method cannot obtain a high-quality and well-structured scaffold with high porosity. The literature review showed that, the compressive properties of porous scaffolds were found to be appropriate within the range of human cancellous bone.

We tried to identify the young modulus, stress and strain, displacement of ABS porous cylinder scaffold (as a model) under the mechanical loading . All data and results were analyzed. At the next part of the research we are going to work on thermal and mechanical properties of PLA based scaffolds.

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Conflicts and interest

If you will face to any conflicts during the read this work you should know they are only my mistakes which come from my inexperience. I will be happy if you share about your interests on the topic by this contact, dilmurod.juraev.92@gmail.com

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