Compression Properties of 3D Printed Honeycomband Re-Entrant Sandwich Core Materials

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Abstract. In the research, various thermoplastic filaments were used to create honeycomb (cellular) and re-entrant (auxetic) structures using a 3D printer of the FDM type, and their compression properties were examined. The thermoplastic polymers PP, ABS, PLA, and PA were used to create the samples. The samples' stress-strain relationships were established after they were compressed quasi-statically in both edgewise and flatwise directions. Digital-image correlation was used to measure full-field displacements on the sample surfaces and evaluate the behavior of compressive deformation in the elastic and plastic regimes up to densification. Re-entrant type auxetic core components were shown to have higher compression failure stresses than cellular honeycomb core components through compression tests in flatwise and edgewise directions. The honeycomb cores have higher energy absorption for the same polymer types, according to the stress-strain curves of the re-entrant core failure.

Keywords: 3D printing, honeycomb, re-entrant, core materials, thermoplastic filaments.

1 Introduction

Cellular and auxetic materials as a typical sandwich core structures has a high relative strength and stiffness, heat insulation, and energy absorption properties. They have utilized in typical sandwich materials in medical, construction, sport and military applications. Cellular and auxetic materials have also paid attention characteristic localization during compression behavior [1]. Cellular (honeycomb) structures can be manufactured by traditional mass production methods while auxetic (re-entrant) structures can be produced modern manufacturing methods due to their complex geometries, and tight placement tolerances. The additive manufacturing technologies offer improvements in the production of auxetic structures [2].

Three dimensional (3D) printing is used for manufacturing haptic products in complex geometrical forms from digital environment to solid forms in reality. Manufacturing haptic objects in intricate geometrical forms from a computer environment to concrete forms in reality via three dimensional (3D) printing. People can now easily access prototype productionbefore mass manufacture as a quick tooling technique. The necessity for 3D printing will growin the

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near future since it allows for the creation of customized devices to meet unique conditional requirements [3]. One of the most well-known 3D printing techniques, fusion deposition modeling (FDM), can create parts using a variety of materials, including elastomers, PLA (poly lactic acid), ABS (acrylonitrile butadiene styrene), and other thermoplastic engineering polymers. The rolled filament is fed up to the head through the hose when the FDM printer has been turned on. Many methods for improving the mechanical properties of the 3D printed components have been suggested, such as design optimization [5], and process parameter optimization [6].

In sandwich composites, the primary loads were carried out by face sheet composites. However, especially under compression loading, the critical part of the loads was also carried by core materials. Industrial applications the most common cell design is honeycomb which is cross-sectional slice of a beehive due to flexibility and best strength to weight ratio properties [7]. Re-entrant cell design having a negative Poisson's ratio behaviour becomes wider when stretched and thinner when compressed. This property especially enhances certain physical properties such as the density, stiffness, fracture toughness, energy absorption and damping in different applications [8]. This paper aims to evaluate compression behaviours of honeycomb and re-entrant cores produced with common types of 3D printer thermoplastic polymers.

2 Materials and Methods

2.1 Design of Cells

A commercial honeycomb as a typical cellular geometry and re-entrant as a typical auxetic geometry commonly used in the selection of core material designs have been determined as a reference for comparison. The geometry used in cell design of honeycomb and reentrant patterns is given in Figure 1. Cell geometry of the core materials with all auxetic and cellular pattern is designed to have cell length of 6 mm and wall thickness of 0.6 mm. Core materials are designed using Solidworks, a computer assigned design program. The schematic representation of these core materials is designed in a similar geometric relations for cell wall length (t) and cell length (l). The designs have been converted to .stl (Standard Triangle Language) format using the Solidworks program so that the slicer required for the operation of3D printers can be transferred to the programs.

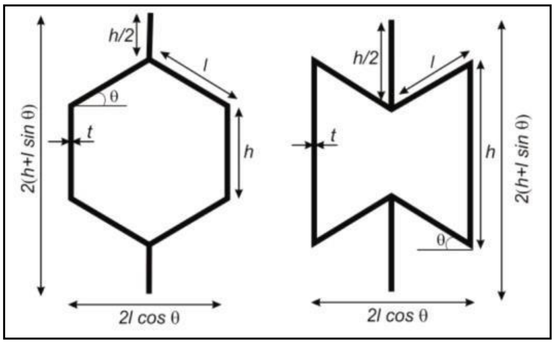

Fig. 1. Typical unit cell geometry of honeycomb and re-entrant

2.2 Production of Core Materials

Different patterned core material sample designs converted to .stl format were transferred to the slicer program called Cura, which is open source software that allows control of the print parameters in the 3D printer. The three-dimensional different patterned core material sample models transferred to the Cura program for produced in 3D printer. The production of the core materials was carried out on the Ultimaker 3 model printer which is a 3D printer of FDM (Fused Deposition Modeling) type. The printed core samples were given in Figure 2.

Each sample of auxetic (re-entrant) and cellular (honeycomb) structure printed using four different raw materials which are PA (Polyamid 6/6), PP (Polypropylene), ABS (Acrylonitrile butadiene styrene) and PLA (Polylactic-Acid). The printer temperature of the each raw material was set differently based on melting temperature of the thermoplastic filaments. The PLA, ABS, PP and PA thermoplastic filaments were printed as 196, 235, 240 and 255ºC, respectively. The other important printer parameters are determined the same for all filaments as described below in Table 1.

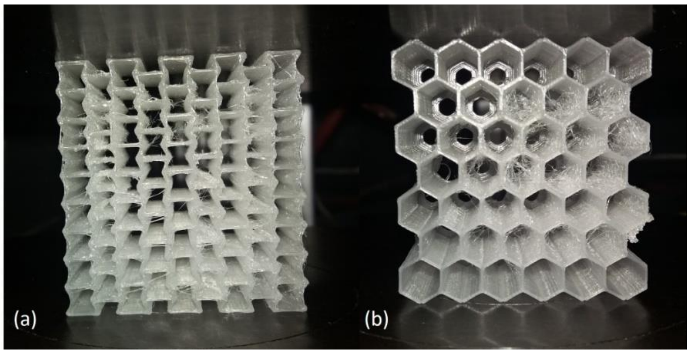

Fig. 2. (a) 3D printed honeycomb core sample (b) re-entrant core sample

Table 1. Common print parameters for different thermoplastic filaments

Parameters	Unit	Value
Bed Temperature	[°C]	80
Nozzle Diameter	[mm]	0,4
First Layer Thickness	[mm]	0,1
Layer Thickness	[mm]	0,1
İnfill Density	[%]	100
Flow	[%]	100
Print Speed	[mm/s]	

2.3 Mechanical Testing of 3D Printed Specimen

Printed polymers have different properties than properties of solid injection molded polymer samples. For this purpose, basic mechanical properties (tensile, flexural, compression and impact properties were investigated based on relevant ASTM standards. For each test, at least five samples were printed based on specific shapes.

2.4 Compression Testing of Cellular Structures

Three samples of each core material were used for compression testing. The compression test was carried out at a speed of 0.5 mm / min in the MTS universal testing machine with a 10 kN load cell in accordance with c flatwise test (ASTM C365) and edgewise test (ASTM C364-99) standard followed by stress-strain graphs were obtained. Deformation of the specimens at various loading conditions was monitored by video camera at 60 FPS. As a typical cellular geometry, the honeycomb and re-entrant cell geometries were designed for compression testing in flatwise and edgewise directions. The representative stress-strain graphs of 3D printed test samples with different types of raw materials were presented based on the average value of three measurements of printed core materials.

3. Results and Discussion

Table 2 shows mechanical properties of 3D printed test samples based on different raw materials. It is clearly seen that tensile and impact strength of the PA and ABS When the raw materials used were compared in terms of given mechanical properties, PLA polymer is become prominent in its highest tensile, compression and flexural properties among others. PA polymer also show significantly highest impact properties among other polymer raw materials. Lee et al. [9] investigated the anisotropic characteristics of FDM components in compression and discovered that part orientation affected compressive strength by 11.6%. The FDM type 3D printed materials exhibit similar mechanical qualities to those made on a commercial machine, according to Tymrak et al.'s [10].

Table 2. Mechanical properties of 3D printed samples using thermoplastic filaments

Raw Materials	ile Strength(MPa)	ssion Strength(MPa)	ral Strength(MPa)	act Strength(KJ/m^2)
PA	55.4±4.8	53.1±6.5	8.3±2.1	44.9±3.9
PP	9.01±1.1	-	12.4-1,3	18.1±5.2
PLA	59.1±2.2	66.1±6.2	19.1±4.6	2.5±1.2
ABS	40.8±4.8	43±1.2	13.8±4.2	37.9±1.4

Figure 3 show compression stress and strain behaviour in flatwise direction for 3D printed core materials. According to flatwise compression testing, re-entrant cores for the same kind of raw materials increased their compressive modulus and strength more than honeycomb cores did. It was discovered that a linear stress-strain relationship operated up to the highest stress level. Cells collapsed after reaching the maximum load level, and the load level drastically fell. It was discovered that the shear and local buckling of the cell walls during failure may have contributed to the decline. The samples printed with PA polymer demonstrated noticeably higher stress strain behavior than other polymers for both re-entrant and honeycomb configurations.

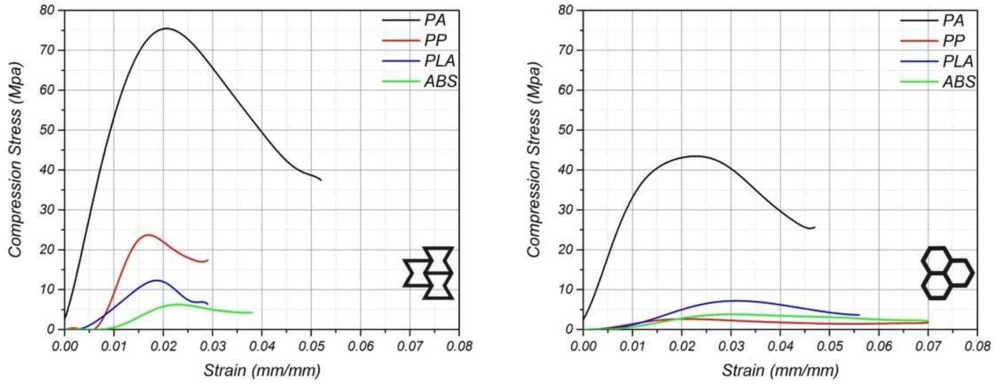

Fig. 3. Stress-strain (flatwise) for 3D printed structure (a) re-entrant, (b) honeycomb

For edgewise compression tests (Figure 4), cell geometry factors are more critical for under compression loads. The stress strain curves have a linear portion at the beginning. After buckling of the first cells close to surfaces contacting crossheads, plastic deformation was seen clearly in wavy curves by localisation and collapse deformations. The small increase and drop in load capacity at plastic region is caused by the densification of the folded cell walls. The load continued to increase with a small slope after the initial drop. Figure 3 shows multiple reflections from the edges leading a stronger localization and cause large drop in stress especially for re-entrant structures. Failure generally carried out by shear forces after certain cell bucking deformations happens during compression testing in edgewise direction.

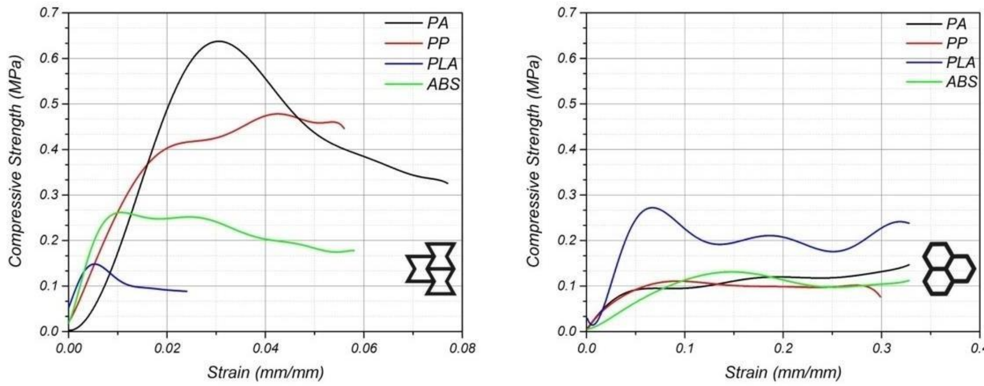

Fig. 4. Stress-strain (edgewise) for 3D printed structure (a) re-entrant, (b) honeycomb

Table 3 shows the flatwise and edgewise compression modulus and strength values as a function of core cell pattern and raw materials. It is seen that the highest flatwise compression modulus values was obtained in re-entrant core samples printed with PLA, the lowest compression modulus was obtained in re-entrant core samples printed with PP polymers. The highest edgewise compression modulus (1.6 GPa) and compression strength (0.63 MPa) was obtained for re-entrant type core samples printed with PA polymer. Although the edgewise compression strength and elastic modulus of the re-entrant cell designed core samples for PP and PA raw materials were significantly higher than those of honeycomb core samples, the edgewise compression properties of reentrant core samples for PLA and ABS raw materials shows comparable values than those of honeycomb samples.

Table 3. Flatwise and edgewise compression strength and elastic modulus of 3D printed cores

Pattern	Material	Flatwise Compression Strength (MPa)	Flatwise Elasticity Module (GPa)	Edgewise Compression Strength (MPa)	Edgewise Elasticity Module (GPa)
Honeycomb	ABS	3.7±0.9	4.2±0.9	0.13±0.2	0.1±0.04
	PLA	7.2±1.1	6.6±0.8	0.28±0.3	0.3±0.06
	PA	43±3.4	3.8±0.6	0.14±0.4	0.1±0.03
	PP	3.2±0.7	1.9±0.3	0.11±0.4	0.07±0.03
Re-entrant	ABS	6.2±1.2	4.7±0.6	0.14±0.2	0.4±0.02
	PLA	12±1.1	7.5±0.4	0.26±0.6	0.9±0.04
	PA	75.5±5.7	5.5±0.3	0.63±0.8	1.6±0.2
	PP	23.3±2.4	1.7±0.2	0.48±0.7	0.2±0.09

4. Conclusions

FDM type 3D printers was used to produce honeycomb and re-entrant cores with the same wall thickness and cell length variations using ABS, PLA, PP and PA plastics. It is clearly indicated that the honeycomb core structures are more susceptible to plastic deformation witha lower yield point than the re-entrant core structures. Cell geometries show significantly different behaviours under both flatwise and edgewise loading conditions. Different types of material properties were also found to be critical for the compression behaviour of the sandwich core materials.

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