

Influence of Infill Pattern on 3D-Printed Parts Compression Strength

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Abstract: Article presents analysis of the influence of infill pattern on 3D printed parts compression properties. Most of the researches from this field covered tensile 3D-printed parts properties, but for some applications compression mechanical properties are far more important. For the analysis of compression strength, 3D-printed specimens were produced by Fused Filament Fabrication (FFF) process from acrylonitrile butadiene styrene (ABS) with different shapes of infill pattern. Testing results showed that honeycomb infill pattern results with the highest compression strength. Unexpected result was the lowest compression strength of gyroid infill pattern, which must be more deeply investigated.

Keywords: Acrylonitrile Butadiene Styrene (ABS); additive manufacturing; compression strength; Fused Filament Fabrication (FFF); infill pattern

1 INTRODUCTION

Fused Filament Fabrication (FFF) is a 3D printing technology that is based on material extrusion (MEX) and it is one of the most common Additive Manufacturing (AM) technologies used today [1]. When printing, various parameters can be changed such as model orientation, printing temperature and layer thickness, but in this paper the focus is on the infill structure. Most mechanical properties of the 3D printed parts, such as the tensile strength, have been thoroughly studied in the literature, but this paper analyses the compressive strength that is largely based upon the infill structure. The experimental part of this paper compares the compressive strength of samples manufactured from acrylonitrile butadiene styrene (ABS) with various infill patterns produced by FFF 3D printing. Within experiments, infill patterns such as rectilinear, triangle, cubic, honeycomb, as well as 3D honeycomb and gyroid are analysed.

2 MATERIAL AND METHODS

2.1 Acrylonitrile Butadiene Styrene (ABS)

Compression specimens were produced from acrylonitrile butadiene styrene (ABS) thermoplastic filament. It is amorphous thermoplastic which is used when higher thermal resistance and higher toughness are expected. Temperature range of ABS filament processing with FFF process is 230 - 260 °C, which is at relatively higher level compared to most common thermoplastic materials used for FFF. In case of ABS filament, printing bed also has to be heated to higher temperatures in order to reduce warpage of the first 3D-printed layers and their peel of the bed (most often in the corners of the 3D-printed part) (Fig. 1 - left). ABS also shows tendency to cracking between the layers during 3D printing because of cold air flow against the printed part (Fig. 1 - right), and this is the reason why it is recommended to have closed chamber when printing ABS. One of advantages of the ABS 3D printed parts is possibility to smooth 3D-printed part surface with acetone. [2, 3]

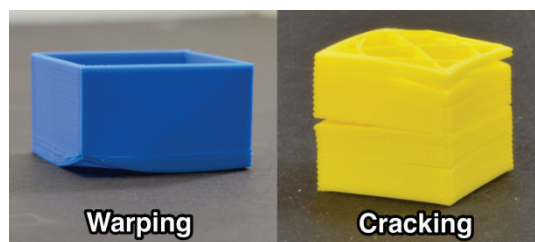


Figure 1 Common problems in 3D printing ABS parts [4]

2.2 Fused Filament Fabrication (FFF)

FFF is currently one of the most popular additive manufacturing processes due to its simplicity and low running and material costs. FFF works on a principle of material extrusion through numerically controlled nozzle on printing bed (Fig. 2) [5].

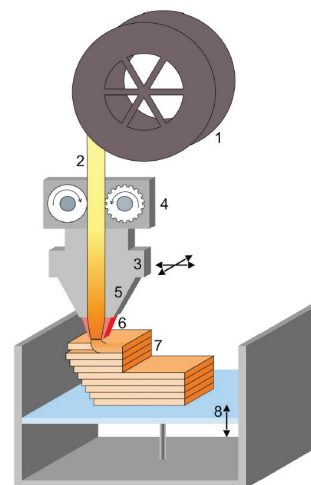


Figure 2 Schematic illustration of the material extrusion process: (1) spooled material, (2) filament, (3) heated deposition unit consisting of (4) counter-rotating driving wheels, (5) a liquefier, (6) a nozzle, (7) element fabricated in a layer-by-layer manner, (8) vertically movable build platform [5]

For research in this article, ABS filament was extruded on a modified Creality Ender 3 fused filament printer (Creality 3D Technology Co. Ltd, Shenzhen, China) with installed nozzle diameter of 0,4 mm, shown in Fig. 3 [6].

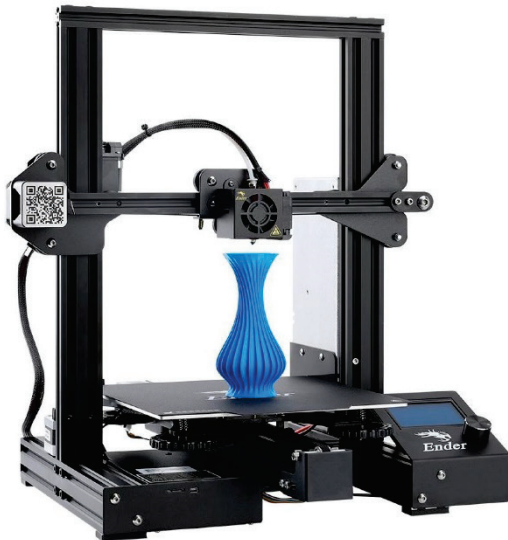


Figure 3 FFF printer Creality Ender 3 [6]

The software PrusaSlicer (Prusa Research, Prague, Czech Republic) was used to prepare the G-code for dog-bone specimens' production with the following parameters which were kept constant through all trial runs:

- Layer thickness 0,2 mm
- Infill density 30 %
- Printing speed 40 mm/s
- Extruder temperature 260 °C
- Bed temperature 110 °C.

2.3 Specimens Geometry and Infill Patterns

Specimen geometry for the compression properties testing is determined with standard HRN EN ISO 604 [7]. Standard specimen dimensions for compression strength testing are $10 \times 10 \times 4$ mm.

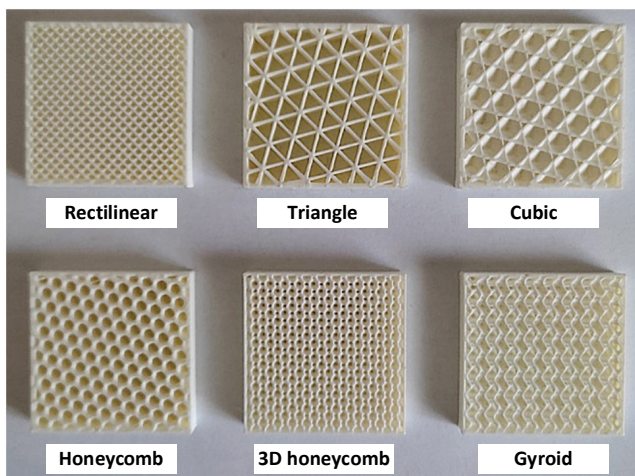


Figure 4 Tested infill patterns

For FFF manufacturing it was determined to create 1 outline for side specimen walls, and 3 layers on the bottom and top of the specimens. This resulted with wall thickness of 0,6 mm at the bottom as well as on the top of the specimen,

and only 2,8 mm of specimen was left for infill structure. As the main aim of this research was not to determine nominal compression strength of specimens according to standard, but to compare different shapes of infill patterns, standard specimens were enlarged by scale of 3 to dimension $30 \times 30 \times 12$ mm

For the infill, six different pattern shapes were selected. Four of them were 2D-infills: rectilinear, triangle, cubic, honeycomb; and two of them 3D-infills: 3D honeycomb and gyroid (Fig. 4).

For the analysis of the influence of infill pattern shape on compression strength, 5 specimens were printed with each type of the infill pattern (total of 30 specimens).

2.4 Compression Testing

Tensile testing of 3D printed compression specimens was performed on a universal static testing machine Messphysik Beta 50-5 (Messphysik Materials Testing GmbH, today ZwickRoell, Fürstenfeld, Austria), shown on Fig. 5.

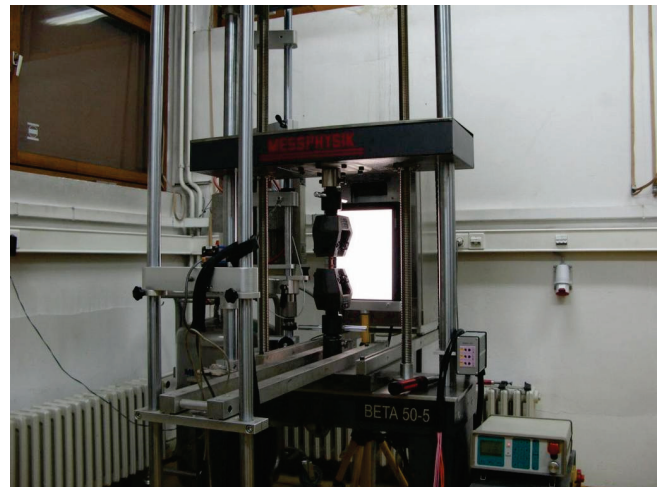


Figure 5 Messphysik Beta 50-5 compression testing machine

Maximum testing force on this machine is 50 kN. Specimens from ABS were tested at deformation speed of 2 mm/min at the temperature of 20 °C. Specimen after the testing is shown on Fig. 6.



Figure 6 Compression specimen after the testing

3 RESULTS AND DISCUSSION

Time necessary for 3D printing each type of the specimens is presented in Fig. 7.

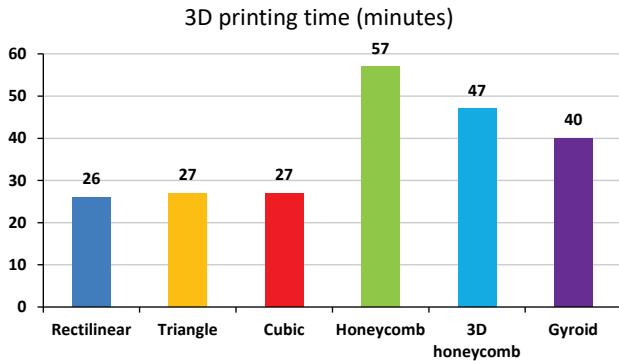


Figure 7 3D printed time for specimens (5 specimens for each infill type)

In case of infill pattern types that require frequent changing in print direction, printing times are increased. Therefore, it can be concluded that infill pattern selection can significantly influence on 3D printing time.

Obtained masses of the specimens with included standard deviation (SD) are presented in Tab. 1.

From specimen’s mass point of view, they can be divided into two groups: with simple infill shapes (rectilinear, triangle and cubic) and with more complex infill patterns (honeycomb, 3D honeycomb and gyroid). The trend is: increasing specimen mass with increasing infill complexity, with exception of gyroid, where the most complex infill

pattern results with the lowest specimen mass. In this case variations are not so significant and the difference between the specimen with lowest mass, and with highest mass is 24 %, but the research was performed on specimens with relatively small dimensions. For larger 3D printed parts, shape of infill patterns will have more significant influence on their mass.

Table 1 Specimens mass

	Infill pattern	Specimen (average) mass (g)
1	Rectilinear	4,84 ± 0,01
2	Triangle	5,10 ± 0,01
3	Cubic	5,10 ± 0,02
4	Honeycomb	5,50 ± 0,01
5	3D honeycomb	5,64 ± 0,01
6	Gyroid	4,54 ± 0,01

Compression strength testing results with included standard deviation (SD) of each type of infill pattern are shown in Tab. 2.

Table 2 Compression testing results

	Infill pattern	Compression strength (MPa)
1	Rectilinear	11,79 ± 0,66
2	Triangle	21,10 ± 0,45
3	Cubic	12,57 ± 0,23
4	Honeycomb	23,73 ± 0,11
5	3D honeycomb	22,03 ± 0,96
6	Gyroid	9,71 ± 0,10

Fig. 8 presents compression stress – strain diagram for one representative specimen from each infill type group.

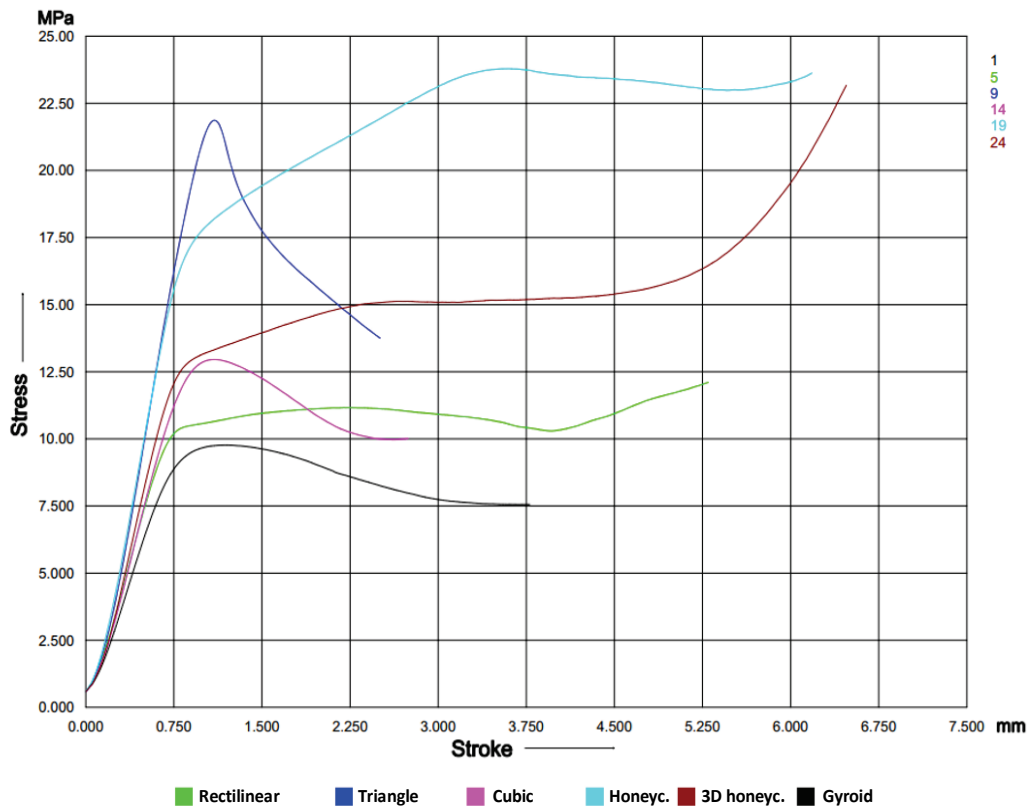


Figure 8 Compression stress – strain diagram

The highest results of compression strength obtained for specimens with honeycomb and 3D honeycomb infill patterns were expected, as they are more complex. Compression strength of specimens with triangle infill patterns was unexpectedly high. The specimens with gyroid infill pattern showed the lowest compression strength. Gyroid infill pattern generally shows equal strength in all directions, and although it is not the strongest infill pattern, it offers obtaining the smallest 3D printed part mass (more than 20 % compared to the honeycomb patterns).

Rectilinear infill pattern as well as all complex types of infill pattern (honeycomb, 3D honeycomb and gyroid) shown higher elasticity compared to triangle and cubic infill patterns.

If we are comparing all analysed infill patterns through two criteria: compression strength and time (Fig. 9), it can be concluded that triangle infill pattern can be in some cases favourable, because with almost the shortest 3D printing time, this type of infill pattern results with compression strength comparable with honeycomb infill patterns. Here it should be taken into account that compression testing was performed in direction of specimen's layer deposition, where 2D infill patterns in general have higher strength due to their anisotropy.

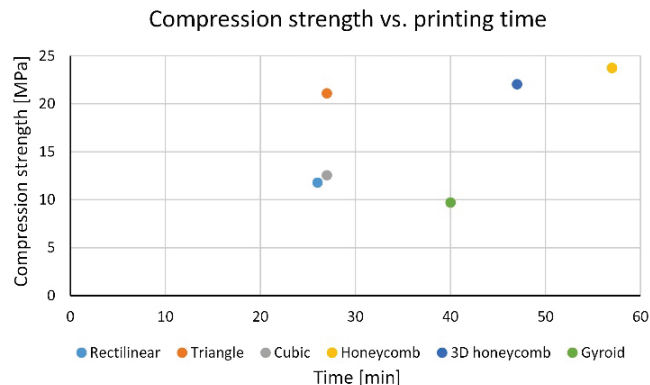


Figure 9 Compression stress vs. printing time for different infill patterns

4 CONCLUSION

The goal of the presented research was determination of the influence of different infill pattern on the compressive strength of 3D printed specimens from ABS material. Specimen masses and 3D printed times were also compared. In case of masses, the difference between specimen with highest (3D honeycomb) and the lowest mass (gyroid) is 24 % which for smaller 3D printed parts is not so large, but in case of larger parts it can present significant difference.

In case of 3D printed time, all three simple infill patterns require considerable shorter printing time (up to 55 % shorter time), compared with both honeycomb infill patterns. Gyroid infill pattern requires longer 3D printing time compared to simple infill patterns, but 15-30 % shorter time compared to the honeycomb infill patterns.

Both honeycomb infill patterns achieved the highest compression strength. Gyroid infill pattern showed the lowest compression strength, around 60 % lower compared

to honeycomb infill pattern. Surprising result was obtained with triangle infill pattern which shown compressive strength similar to the strength of honeycomb patterns but requires significant shorter 3D printing time.

Compression testing in presented research was performed on specimens in direction of 3D printing. For the future research, specimens will be tested in direction orthogonal of 3D printing, where 3D infill patterns – 3D honeycomb and gyroid – should maintain their compressive properties due to their isotropy, and 2D infill patterns, due to their anisotropy should show significantly lower strength.

Another way to improve infill pattern strength, for example in cases where 3D printed part mass is crucial (transportation sector), is development of hybrid gyroid and 2D infill patterns. [8, 9]

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Notice

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