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The influence of material infill on ABS-X flexural strength

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Abstract This paper contains a comparison of the flexural strength results of two different samples. Both samples were made using additive manufacturing, from ABS (acrylonitrile butadiene styrene) material with the inclusion of an unknown filler designated as X. They also have in common that they are divided into two groups, the first group with a material infill of 100 %, and the second group with a material infill of 50 %. In order to determine that the material infill really affects the flexural strength results, the samples are differentiated by their shape. The first sample consists of tiles, while the second sample consists of pipes. The samples are printed vertically, which doesn't change the material's inherent mechanical qualities but does change the amount of infill and the strength of the bond between the layers. The difference between the values of the stress at failure of the material in the tile group is approximately 20 %, while in the tube group this difference is approximately 6 %. We can conclude that filling with the material in the range of 50 to 100 % during the production of pipes has an insignificant effect on bending strength, while this is not the case with plate samples. Based on this, there definitely is a significant influence of geometry when determining flexural strength. The idea for further research should be to measure the influence of samples treated with acetone on their flexural strength.

1. Introduction

3D printing, also known as additive manufacturing, is a revolutionary technology that allows the creation of three-dimensional objects from digital files. Instead of traditional subtractive manufacturing methods that involve cutting or shaping materials, 3D printing builds objects layer by layer using various materials, including plastic, metal, ceramics, and even biological materials

There is a wide range of AM methods currently forming the product from filaments, droplets, or powder of raw material made of polymers, metals, ceramics, or even a combination of these materials [1]. 3D printing processes vary based on the technology used, but the fundamental principle involves layer-by-layer deposition of material to create a 3D object. The most common 3D printing technologies include fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS), and digital light processing (DLP). While additive manufacturing (3D printing) offers numerous benefits, it also comes with its set of challenges and problems. The imperfections, which can occur during such complex AM processes, namely pores, part distortion, or lack of fusion defects, should not be neglected in the design process [2] but they also cannot be predicted explicitly. It has been shown in numerous studies that the properties of AM products largely depend on the orientation of the structure during the manufacturing process, the size of the structure, or the set of process parameters [3, 4]. From all AM technologies, fused deposition modeling (FDM) is the most used all over the world, due to its cost-effective way of printing [5].

All tested samples were made using additive manufacturing (3D printer German RepRap X400) in laboratory of the Center for Optical Measurement and Rapid Prototyping at the Innovation Center of the Faculty of Mechanical Engineering, Belgrade.

2. Experiment

2.1 Method and materials

The German RepRap X400 is a professional-grade 3D printer manufactured that is based on FDM technique. This printer uses technology with two printer heads, thus allowing printing in two colors or with water-soluble support material such as PVA for PLA or HIPS for ABS parts. Key features of this printer are: large build volume, sturdy construction, open material system, dual extruders, heated print bed, LCD display and user Interface and easy connectivity. This 3D printer stands out on account of its adhesion-optimized build platform, which is achieved by means of a heated bed design that ensures uniform heat distribution. This has a very positive effect on the adhesion of print objects on the build platform, which is important for samples production that was made for this experiment. The X400 typically offers an open material system, allowing to work with a wide range of filaments and materials, including various thermoplastics, flexible materials, and composite filaments, which is why this is an excellent choice of printer for this experiment.

The chosen material is ABS-X, as one of the most common plastics used in injection-molding. ABS-X filament is an improvement over traditional ABS, offering some enhanced properties for specific applications. It's essential to note that the properties and characteristics of ABS-X filament may vary between different manufacturers and brands. 3D Republic (Table 1) is the supplier for the filament used in this study. ABS-X is known for its superior strength and impact resistance compared to regular ABS filament. It can withstand higher stress and strain, making it suitable for functional parts and prototypes that require durability.

The ABS-X filament used in the experiment has very good layer adhesion and minimal curl during printing. ABS-X cracks less than ABS material and has excellent mechanical properties. Due to its properties, ABS-X is a material that has high impact resistance, so it can be tested in such an experimental setting. In order to compare results and examine the influence of infill density on flexural strength of ABS-X, samples with infill density of 50 % and 100 % were tested.

The chosen geometry of the fill structure of printed samples is honeycomb, which can be seen in Fig. 1 for both types of samples, tiles and pipes. Honeycomb was selected, assuming that this type of infill has the highest values of modulus of elasticity and mechanical properties. Honeycomb infill pattern offers several advantages over solid or other infill types, including reduced material usage, shorter printing times, and improved mechanical properties. The honeycomb infill consists of hexagonal cells arranged in a repeating pattern. Each cell shares sides with neighboring cells, creating a strong and stable lattice structure. The honeycomb infill is lightweight and efficient in terms of material usage because it uses less material compared to solid infill patterns. The honeycomb pattern provides excellent structural integrity due to the interconnectedness of the cells. It distributes forces evenly throughout the infill, resulting in a robust and stable interior structure.

Table 1. Filament supplier information.

Name of supplier	3D Republika
Location	Joza Laurencica 8a 11080 Zemun - Belgrade
For more information about the supplier visit the site	https://www.3drepublika.com/

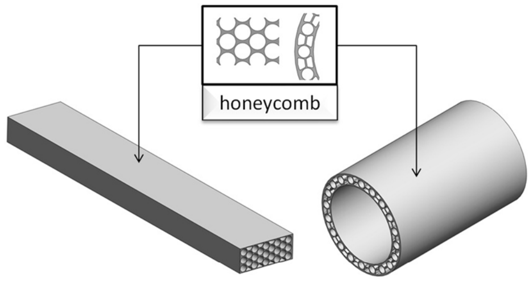

Fig. 1. 3D model of samples with a honeycomb infill structure.

The hexagonal cell design allows for some flexibility and compression resistance. This is beneficial for objects that might experience bending or compressive forces during use. The honeycomb infill can be printed relatively quickly due to its open structure, which allows the printer to move through the pattern with fewer stops and starts. The density of the honeycomb infill can be adjusted to meet specific requirements. Higher infill densities provide increased strength and rigidity, while lower densities offer more lightweight structures with reduced material consumption. The honeycomb infill pattern can also serve as a built-in support structure for overhanging features in the printed object. This reduces the need for additional support material, simplifying post-processing and improving the overall print quality. Most 3D slicing software allows customizing the infill pattern, including the choice of the honeycomb infill, as well as adjusting the infill percentage and pattern orientation, which is a very important detail for this experiment. The orientation of the honeycomb infill can be set to better suit the mechanical requirements of the printed object. For example, adjusting the infill orientation can enhance strength along specific axes or improve resistance to specific types of stresses. Honeycombs are hard to beat in the stiffness-to-weight ratio in their extruded direction but are much softer in the other two orthogonal directions (by around an order of magnitude). In the Ref. [6] it was seen that printing parameters, such as the infill of the object with material, have an impact on the resistance of the material to breakage.

2.2 Experimental setup

The printing parameters for all the samples were set to be

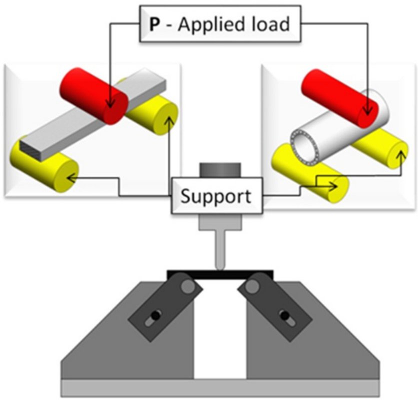

Fig. 2. Display of the setting of the samples on the breaker in the initial position, where P is the applied load.

the same, so that the results of the effect of infill in both groups of samples are more relevant. The printing parameters are as follows: Extruder temperature: 235 °C, bed temperature: 105 °C, layer high: 0.200 mm and printing speed: 50 $^{mm}/_{sec}$.

Determination of the flexural strength of samples was done according to the DIN EN ISO 178 standard [7]. DIN EN ISO 178 is an international standard that specifies the test method for determining the flexural properties of rigid and semi-rigid plastics. The DIN EN ISO 178 standard ensures that flexural testing of plastics is performed consistently and accurately across different laboratories and industries, allowing for reliable comparison of materials and facilitating the proper selection of plastic materials for specific engineering applications. Flexural testing (or flex testing or bend testing) is commonly performed to measure the modulus and flexural strength of all types of materials or products.

The experimental setup entails that the samples are supported on two rollers and centrally loaded (under constant load) in a three-point bending configuration as shown in Fig. 2.

The main advantage of a three-point bend test is its simplicity. The test provides valuable information about the material's ability to withstand bending loads and its deformation behavior under such stress. But some disadvantages occur: the results are sensitive to specimen and loading geometry and strain rate.

As shown in the Ref. [8] unlike a standard compression or tensile test, a bend test does not measure fundamental material properties. This it happens because when a specimen is push and bend all three fundamental stresses are present: tensile, compressive and shear. So the flexural properties of tested specimen are finally the result of the combined effect of all three fundamental stresses.

With help of three point bending tests was concluded that enlargement of bending strength causes an increase of pipe's hardness. The tests were performed on a Shimadzu AGS-Ks 100 kN universal machine.

3. Results

Samples with 100 % infill showed expected approximately higher flexural strength compared to samples with 50 % infill. The amount of sample infill was also reflected in the higher flexural strain. One can tell that the testing samples with 100 % infill showed better mechanical properties in terms of flexural strength. During the test, the temperature in the room was 23 degrees Celsius and the air humidity was 40 %.

Table 2. The results of maximum stress, yield stress (YS) and stress at failure for both groups of samples.

	Max stress [MPa]	YS1 stress [MPa]	Break_stress [MPa]
Tile 50 %	33.89	29.73	21.03
Standard deviation	2.94	1.95	2.12
Tile 100 %	37.85	31.24	26.26
Standard deviation	1.75	2.10	1.11
Pipe 50 %	119.24	48.43	113.5
Standard deviation	4.15	2.13	3.78
Pipe 100 %	125.12	90.09	120.16
Standard deviation	4.45	3.11	4.03

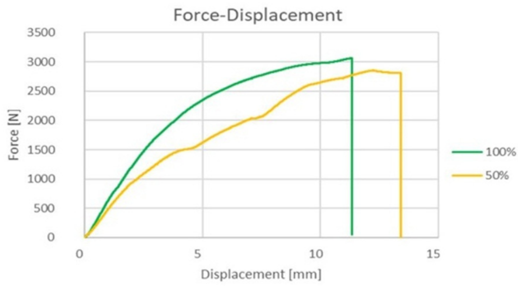

Fig. 3. Diagram of force dependence on displacement on cylindrical structures of the samples.

Diagram in Fig. 3 shows the representative results of measuring the flexural strength of the cylindrical structures of the samples. The difference of approximately 200 N, which we can see in the diagram, represents the general difference of the averaged values, and indicates a difference in the applied force that resulted in a failure of only 6.7 %.

The results of maximum stress, stress at the yield point and stress at failure for both groups of samples are given in Table 2. One can see that the average values by sample groups do not differ to a greater extent.

The measured values of max stress, YS1 and break stress were obtained from Trapezium X software. The difference between the values of the maximum voltage in the group of tiles is approximately 10.5 %, while the difference in the group of pipes is approximately 4.7 %. The difference between the values of the stress at failure of the material in the tile group is approximately 20 %, while in the tube group this difference is approximately 6 %.

The biggest difference measured during the test was seen in the stress values at the yield point especially in the pipe group where it goes up to 46 %, while in the group of tiles it is insignificant. The flexural response of pipe materials largely depend

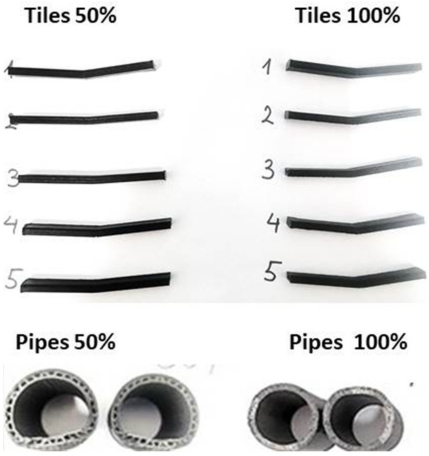

Fig. 4. Samples after completed bending.

on the test factors: the direction of the applied mechanical loading (internal or external pressure), with and without initial notches, notch depths, hydrothermal aging [6].

In addition to understanding the tensile properties of materials when testing cylindrical structures as well as their resistance to fracture [10, 11], it is necessary to understand the bending characteristics of cylindrical structures due to the action of radial forces. In Fig. 4, one can see real samples of tiles and pipes, after testing under load, due to which deformations occurred.

The strength of pipe specimens can be significantly affected by changes in their cross-sectional shape. The cross-sectional shape of a pipe refers to the geometry or profile of the pipe perpendicular to its longitudinal axis. Different cross-sectional shapes can result in variations in the distribution of stresses, which directly impact the strength and mechanical behavior of the pipe.

In engineering and design, it's crucial to carefully consider the cross-sectional shape of pipes and its implications on their intended applications. Factors such as the material properties, intended use, operating conditions, and manufacturing processes should be taken into account to ensure the pipe's strength and performance meet the required standards and safety requirements.

4. Conclusions

As the technology continues to advance, 3D printing holds the potential to revolutionize manufacturing, logistics, and supply chains. Ongoing research is exploring new materials, larger-scale printing, multi-material printing, and bioprinting, which involves using living cells to create tissues and organs for medical applications.

Overall, 3D printing is a transformative technology that continues to evolve and expand its impact on various industries and everyday life.

The deformation mechanisms of ABS-X filament in additive manufacturing can be influenced by various factors and conditions during the printing process. Possible causes that can be seen in the performance of this experiment and that lead to the deformation of ABS-X filament are:

Thermal deformation: ABS-X filament is sensitive to temperature changes. If the printing temperature is too high or the cooling rate is uneven, thermal deformation can occur, leading to warping, curling, or distortion of the printed object.

Residual stress: As ABS-X filament cools down and solidifies after being extruded, residual stresses can build up within the printed layers. These stresses can cause the printed object to warp or exhibit dimensional inaccuracies over time.

Layer bonding: The quality of the bonding between adjacent layers is critical to the overall strength and integrity of the printed object. Poor layer adhesion can lead to delamination and reduced mechanical performance.

Infill density, like one of the focuses of this research: The infill density, which determines the internal structure of the printed object, can influence its deformation behavior. Lower infill densities may lead to reduced overall rigidity, potentially resulting in more deformation under stress.

Printing speed: Printing too fast may not give sufficient time for each layer to cool and solidify properly, potentially causing deformation.

Other possible causes that can lead to the deformation of ABS-X filament are support structures, print orientation, cooling rate, layer thickness, and printing environment.

Based on the given results and everything mentioned above, we can conclude the following:

- The maximum flexural strength values of the examined samples differ by groups (geometrically different) by a maximum of 10 % in favor of samples with a higher value of filling.
- The maximum stress values at material failure differ by a maximum of 20 %, and this difference was observed especially in the tested group of tiles.
- The maximum stress values at the yield point were observed in the group of pipes and reach 46 %.
- Based on these data, we can conclude that filling with material in the range of 50 to 100 % during the production of pipes has an insignificant effect on their bending strength, while this is not the case with plate samples. Based on this, we conclude that there is a significant influence of geometry when determining flexural strength.

These conclusions must be further established on the basis of testing samples printed in the horizontal direction and at an angle of 45°.

In the future, the plan is to compare the flexural strength results of samples with 100 % infill with samples of the same infill, but treated with acetone. In this way, we expect to investigate the impact of treating objects with acetone on their mechanical properties in terms of flexural strength.

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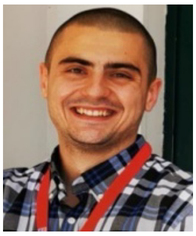

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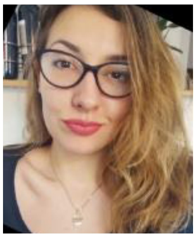

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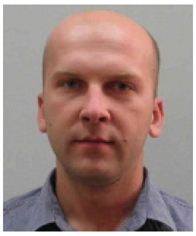

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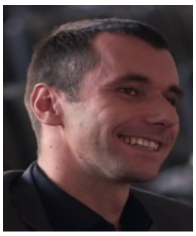

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