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# TENSILE MECHANICAL PROPERTIES COMPARATION OF PETG, ASA AND PLA-STRONGMAN FDM PRINTED MATERIALS WITH AND WITHOUT INFILL STRUCTURE

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**Abstract**

Additive technologies have certainly brought many novelties into today's industry. Also, the development of AM technologies directly depends on the development of AM materials themselves, so the examination of the mechanical properties of new AM materials is of great importance. The aim of this research is to examine the tensile mechanical properties of three different FDM 3D printed materials: PETG, ASA and PLA-Strongman. The advantage that certainly distinguishes AM technologies compared to classic production technologies is the production of materials with an infill structure. So, the tensile properties of the materials with and without the infill structure were also analysed. For all materials, tensile and yield strength, tensile strength at brake, elastic modulus and deformation at brake are analysed, compared, and presented in this paper.

**Keywords:** FDM material; Infill; PETG; ASA; PLA.

## 1. Introduction

Today, one of the most popular and fast-growing production technologies are surely additive technologies (AM). On the market, there is a huge interest in AM technologies, and certainly the key factor in the development of AM technologies is the development of AM materials. In addition to a large number of different technologies, one of the most frequently used is Fused Deposition Modeling (FDM) technology, also known as Fused Filament Fabrication (FFF), or material extrusion [1], [2]. Some of the reasons why FDM is such a popular technology today are certainly the simple application, safe to use at home, the relatively low cost of the 3D printers and materials themselves and a wide range of available materials [3], [4]. So currently, FDM 3D printers are so prevalent that we can find them in homes where children use them, in schools, creative hubs, universities, medicine, bioengineering, automotive and aviation industry, food industry and more [5].

FDM technology is based on the layer-by-layer production of products, using a previously created CAD 3D model. The process of 3D printing with FDM technology is presented on Fig. 1. The material, known as filament, comes in the form of wire wound on rolls, and is fed to the extrusion body (print head) via a feeder. In the extrusion body, the material

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is heated until it turns into a semi-liquid state and further trough the nozzle it is transferred to the print bed. Then on the print bed product is 3D printed layer by layer along the Z axis [6], [7].

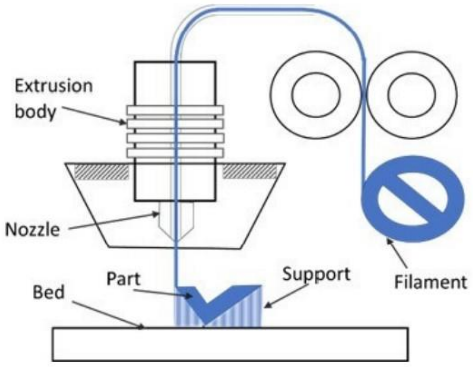


Fig. 1. The working principle of FDM technology [8]

As the engineering approach to designing a new product consists of a basic ide[illegible]ate planning, material selection, all with the aim of optimizing the production process, surely the technology that can answer these challenges is FDM as well as other AM technologies [9].

Generally, AM technology provides many advantages, as well as FDM, and among some interesting (important) are rapid prototyping, production of products with complex geometries, savings in the production of individual products and small-series products, etc. [10].

FDM technology basically uses amorphous thermoplastic mat[illegible]ials [11], but there is an increasing focus on the development of other materials such as composite materials with sho[illegible]nd continuous fibers, metals, etc. Certainly, the most popular thermoplastic materials in FDM technology are PLA (polylactic acid) and ABS (acrylonitrile butadiene styrene) [12], but in addition to them, PETG (polyethylene tere[illegible]thalat[illegible] glycol), PC (polycarbonate), PP (polypropylene), ASA (acrylonitrile styrene acrylate), PA6 (polyamide, nylon), PEEK (polyetheretherketone), TPU (thermoplastic polyurethane), PEI (polyetherimide), PVA (polyvinyl alcohol) are widely used [3].

The material selection is essential when it comes to product manufacturing with FDM or other AM technologies, especially products for engineering applications. Knowing the mechanical and other material properties is of great importance when selecting material through an engineering approach [13]. This study aims to analyse the tensile mechanical properties of PETG, ASA and PLA-Strong[illegible] (PLAs) FDM printed materials. One of the goals is to compare the mechanical properties of these materials.

From literature review and analysing recent studies, it can be seen that the research of lightweight materials is of great importance [14]. FDM technology enables the production of materials with an infill structure, which achieves a smaller mass of the finished product as well as lower printing time and material consumption, which leads to lower overall costs presented in Fig. 2.

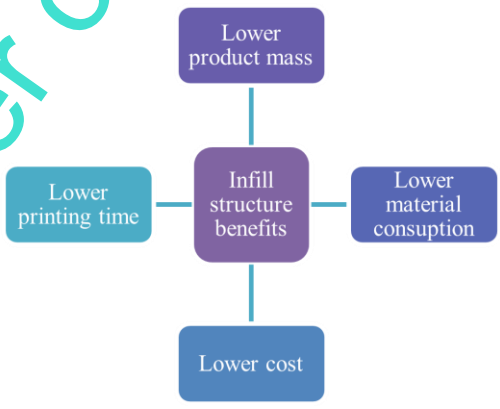


Fig. 2. Benefits of materials with infill structure

Due to the advantages of using the infill structure in FDM printed materials, the tensile mechanical properties of mentioned materials with the infill structure were also analysed.

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## 2. Materials

In this paper, all materials (PETG, ASA and PLA-Strong) are from the same manufacturer, the company AzureFilm. PETG filament is a thermoplastic polymer, an environmentally friendly material that can also be recycled. It is a material that is relatively easy to 3D print and combines the properties of both ABS and PLA materials. Due to its good chemical stability, PETG material meets the European Parliament requirements for use in products that come into contact with food products and medicines. PETG is a material with good durability, solid and odourless. It is a material that has a combination of strength and durability, which is why it is also used to make functional products [6], [15]. Mechanical properties of AzureFilm PETG material are presented in Table 1.

| Material properties | Value | Test method |
|---|---|---|
| Infill density | 100 % | - |
| Colour | Transparent | - |
| Specific density | 1,29 g/cm$^3$ | ASTM D-729 |
| Tensile strength | 51 MPa | ISO 527-2 |
| Elastic modulus | 2,98 GPa | ISO 527-2 |
| Deformation at brake | 29 % | ISO 527-2 |
| Tensile testing speed is not mentioned. | | |

Table 1. PETG material – mechanical properties [15]

ASA is an amorphous thermoplastic polymer quite similar to ABS material when comparing mechanical properties and 3D printing conditions. With a 118.5 °C glass transition temperature, ASA material has good resistance to ultraviolet (UV) resistance and good resistance to weather conditions [16]. Products made of ASA material are very durable and impact resistant, also it can withstand higher temperatures and exposure in rain, cold and sea water [15]. Due to its good properties, ASA material is used in aerospace, automotive industry and other fields [16]. Mechanical properties of AzureFilm ASA material are presented in Table 2.

| Material properties | Value | Test method |
|---|---|---|
| Infill density | 20 % | - |
| Colour | - | - |
| Specific gravity | 1,07 | ASTM D-729 |
| Tensile strength[1] | 48 MPa | ASTM D638 |
| Elastic modulus[2] | 2,12 GPa | ASTM D638 |
| Deformation at brake[1] | 25 % | ASTM D638 |
| [1]Tensile testing speed 50 mm/min<br>[2]Tensile testing speed 1 mm/min | | |

Table 2. ASA material – mechanical properties [15]

PLA-Strongman is high performance polylactide with high impact toughness and good printability like standard PLA material. PLAs properties are similar to ABS material, but the essential difference is that PLAs is easier to print. Compared to standard PLA material it is much tougher and with better impact-resistant. PLAs is used for manufacturing drones parts, bearings and other products that require materials with increased strength and toughness [15]. Mechanical properties of AzureFilm PLAs material are presented in Table 3.

| Material properties | Value | Test method |
|---|---|---|
| Infill density | 20 % | - |
| Colour | - | - |
| Specific gravity | - | - |
| Tensile strength[1] | 41,2 MPa | - |
| Elastic modulus[2] | 2,9 GPa | - |
| Deformation at brake[1] | 8,9 % | - |
| [1]Tensile testing speed 50 mm/min<br>[2]Tensile testing speed 1 mm/min | | |

Table 3. PLAs material – mechanical properties [15]

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## 3. Experimental methodology

This study is based on experimental research, where specimens for each material were FDM 3D printed with different infill density (20%, 40%, 60%, 80% and 100%), and then the tensile mechanical properties were examined, and results were statistically analysed. The experimental methodology is presented on the flow diagram in Fig. 3.

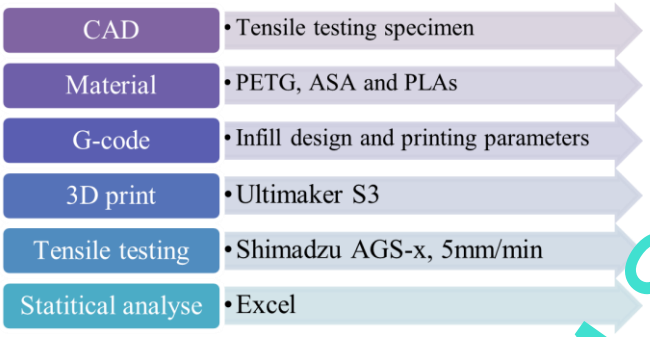


Fig. 3. Experimental methodology flow diagram

Using the Solidworks CAD tool, a 3D model of the test specimen was designed according to then ISO 527-2 standard. Technical drawing of test specimen is presented on Fig. 4.

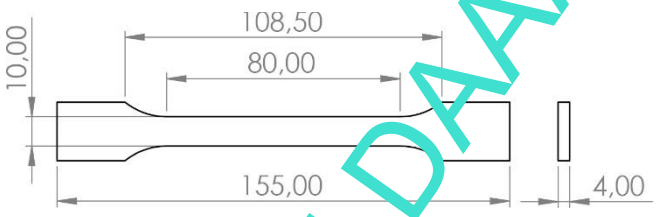


Fig. 4. Test specimen design according to ISO 527-2

The materials were in the form of wire (filament) with a diameter of 2,85 mm wounded on 1 kg rolls. As the colour of the material affects the mechanical properties, it is important to state the colours of the analysed materials, PETG and ASA materials were in black and PLAs in white.

G-code and 3D printing parameters were defined using Cura 3D printing software, so-called. slicer, from Ultimaker. The printing parameters are presented in Table 4. PETG material is 3D printed with predefined "generic PETG" parameters from the Cura software were used, for PLAs material "generic PLA" and for ASA material "generic ABS" with modified parameters.

| Printing parameters | PETG | ASA | PLAs |
|---|---|---|---|
| Layer height | 0,15 mm | | |
| Printing temperature | 240 °C | 240 °C | 200 °C |
| Build plate temperature | 85 °C | 80 °C | 60 °C |
| Infill pattern | Triangles | | |
| Infill density | 20%, 40%, 60%, 80% and 100% | | |
| Print speed | 60 mm/s | 60 mm/s | 70 mm/s |
| Fan speed | 20 % | 10 % | 100 % |
| Retraction distance | 6,5 mm | 3 mm | 6,5 mm |

Table 4. Test specimen printing parameters

As already mentioned, all materials were tested with and without the infill structure. In the case of samples with infill structure, a triangle infill pattern was used, with varying infill densities of 20%, 40%, 60%, 80% and 100%. It should be noted here that when the infill density is defined as 100%, the product is 3D printed in the same way, regardless of the defined infill pattern.

Tensile testing specimens are 3D printed on Ultimaker S3 professional desktop FDM 3D printer. Ultimaker S3 is composite-ready dual extrusion 3D printer, compatible with over 110 materials.

For each material and infill density five replicates and a total of 75 tensile test specimens were 3D printed and then tensile tested. Tensile testing was performed using Shimadzu AGS-X universal testing machine, with maximum load of 10 kN (Fig. 5). Tensile testing was performed according to ISO 527-1 with testing speed 5 mm/min.

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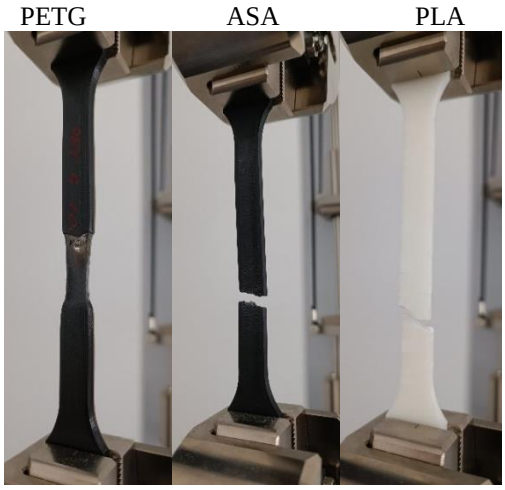


Fig. 5. Tensile testing of PETG, ASA and PLAs FDM printed materials

Mechanical properties data monitoring was performed using Trapezium-X software by Shimadzu. During the test, tensile mechanical properties such as tensile strength ($R_m$), yield strength ($R_y$), tensile strength at brake ($R_b$), elastic modulus (E) and deformation (strain) at brake (ε) were analysed.

After testing, collected data was statistically analysed and results are presented trough stress-strain diagrams and histograms.

## 4. Results and discussion

The results obtained from testing the tensile mechanical properties of FDM printed PETG, ASA and PLA-Strongman materials are presented in this section. A total of seventy-five specimens were tested and analysed. Stress-strain diagram for PETG, ASA and PLAs materials is presented on Fig. 6.

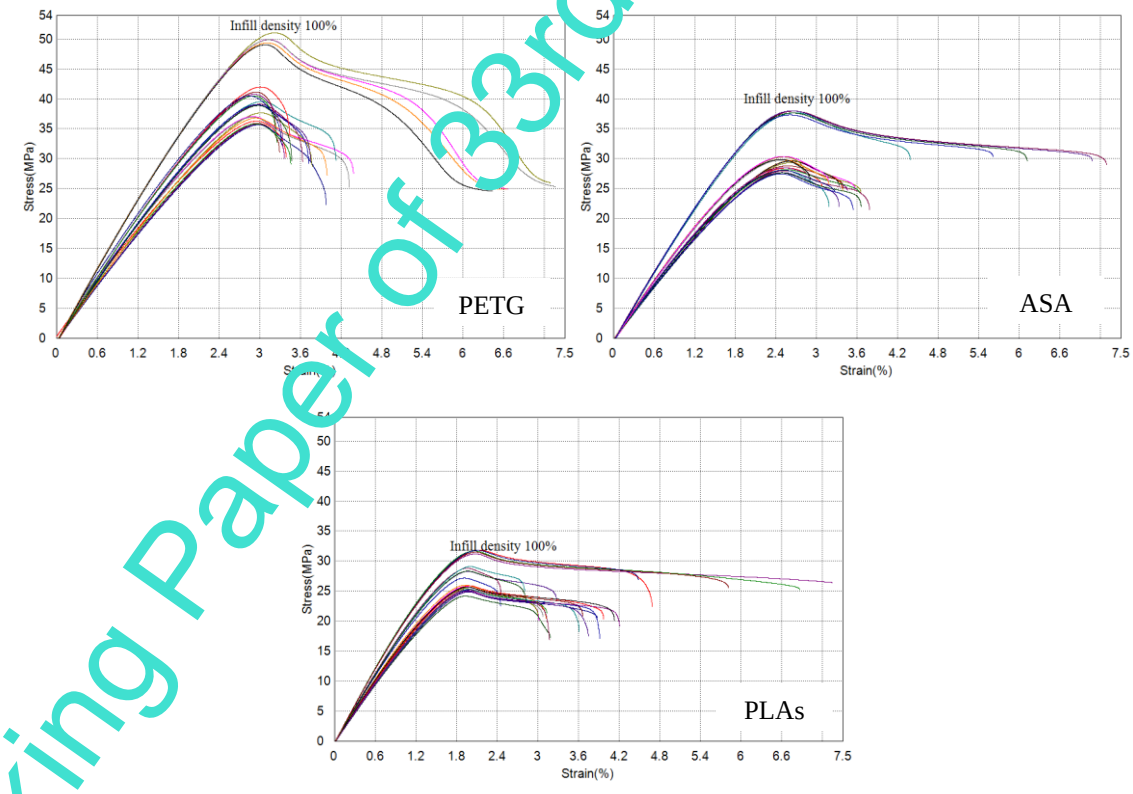


Fig. 6. Stress-strain diagram for PETG, ASA and PLAs material

The average values of the measured tensile mechanical properties, based on five replicas, for PETG, ASA and PLAs materials, are presented in Table 5.

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| Infill density | $R_m$ | $R_y$ | $R_b$ | $E$ | $\varepsilon$ |
|---|---|---|---|---|---|
| **PETG** | | | | | |
| 20% | 35.88 | 27.86 | 28.53 | 1.56 | 3.52 |
| 40% | 37.08 | 26.64 | 26.56 | 1.72 | 4.08 |
| 60% | 39.08 | 30.86 | 29.53 | 1.72 | 3.74 |
| 80% | 40.98 | 31.16 | 33.11 | 1.86 | 3.30 |
| 100% | 49.84 | 38.80 | 25.13 | 2.10 | 6.88 |
| **ASA** | | | | | |
| 20% | 29.56 | 24.82 | 24.93 | 1.50 | 3.48 |
| 40% | 27.74 | 23.90 | 21.76 | 1.50 | 3.50 |
| 60% | 28.40 | 23.44 | 24.84 | 1.54 | 3.38 |
| 80% | 30.06 | 25.10 | 26.55 | 1.70 | 3.00 |
| 100% | 37.70 | 31.34 | 29.70 | 1.98 | 6.10 |
| **PLAs** | | | | | |
| 20% | 24.96 | 22.42 | 17.37 | 1.66 | 3.52 |
| 40% | 25.46 | 22.58 | 20.44 | 1.70 | 3.78 |
| 60% | 25.68 | 22.48 | 20.47 | 1.80 | 3.66 |
| 80% | 28.34 | 24.68 | 23.73 | 1.94 | 2.78 |
| 100% | 31.62 | 26.54 | 24.83 | 2.10 | 5.94 |

Table 5. PETG, ASA and PLAs materials – average tensile test results

An analysis of the stress-strain diagram for PETG and ASA materials FDM printed specimens without infill structure (100% infill density) showed significantly higher tensile strength and deformation compared to samples with infill structure (Fig. 7.). While the PLAs material with 100% infill density did not show a significant difference in tensile strength compared to the specimens with infill structure. While analysing the deformation at brake for the PLAs material (Fig. 10.), a significantly higher total deformation can be seen for the specimens without infill structure.

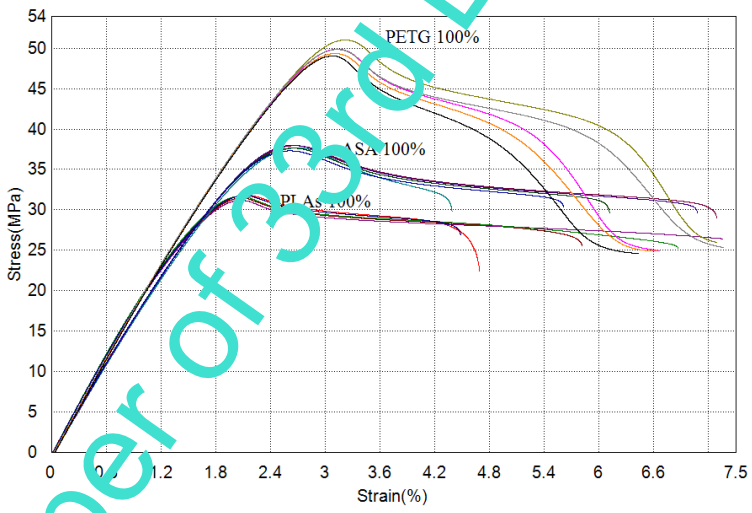


Fig. 7. Stress-strain diagram for PETG, ASA and PLAs material with 100% infill structure

Generally, PETG specimens without infill structure have highest tensile strength. It is not possible to see significant differences in elastic modulus and deformation at brake based on the curves from the stress-strain diagram for specimens with 100% infill. By using PETG material compared to ASA material, the tensile strength increases by 32%, while compared to PLAs material it increases up to 57% (Fig. 8a). Comparing the yield strength of the materials without infill structure, the highest values are observed for the PETG material (Fig. 8b). Yield strength of PETG material is 23% higher than ASA and 46% than PLAs material.

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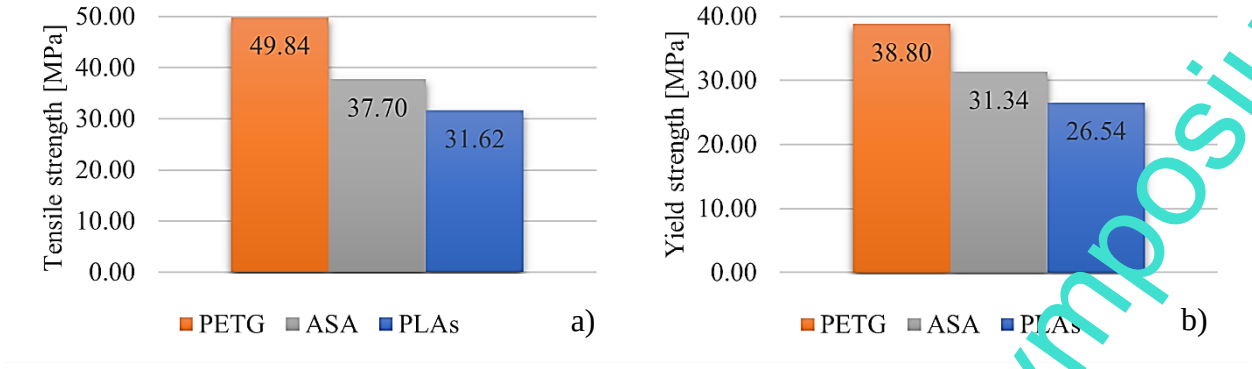


Fig. 8. PETG, ASA and PLAs tensile (a) and yield (b) strength comparison – 100% infill density

The highest values of tensile strength at brake were obtained with specimens made of ASA material (Fig. 9a). Comparing to PETG and PLAs materials, ASA material with infill density of 100% showed up to 20% increase in tensile strength at brake. Between PETG and PLAs materials, there is no significant difference in tensile strength at brake, not greater than 1%. Comparison of elastic modulus values for specimens with 100% infill density is shown in Fig. 9b. The elastic modulus of PETG and PLAs materials is 2,1 GPa, and compared to ASA material, it is higher by 6%.

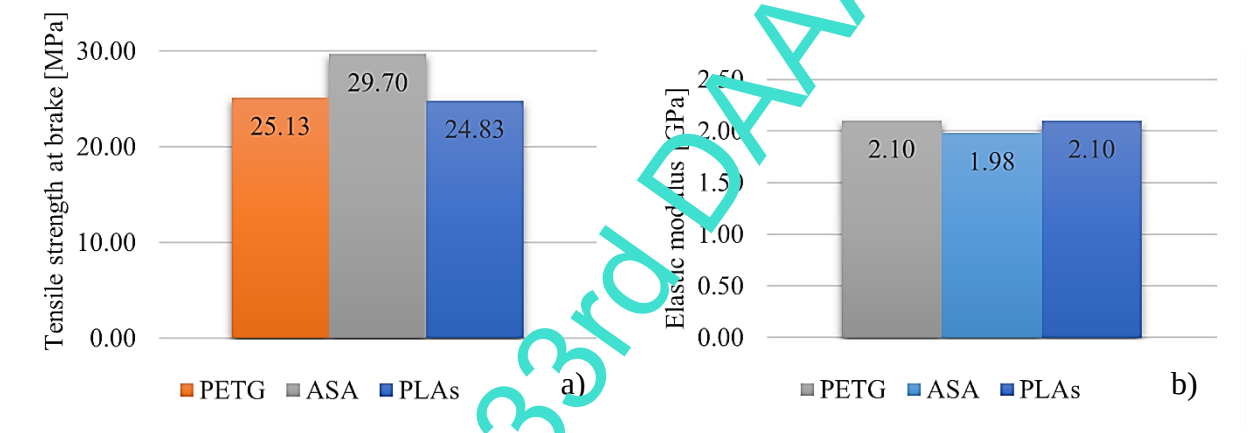


Fig. 9. PETG, ASA and PLAs tensile strength at brake and elastic modulus comparison – 100% infill density

Deformation at brake for PETG, ASA and PLAs materials without infill structure is presented on Fig. 10. The PETG material showed the highest deformation values, which was 13% higher than ASA and 16% higher than PLAs material.

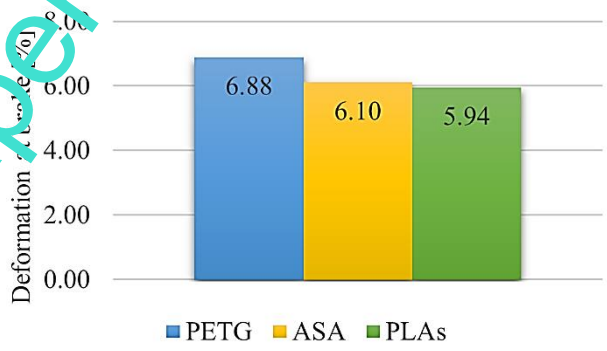


Fig. 10. PETG, ASA and PLAs deformation at brake comparison – 100% infill density

Analysis of PETG, ASA and PLAs material specimens with infill structure was also performed and results are compared with samples without infill structure. Different infill density for all materials was analysed and presented in further text.

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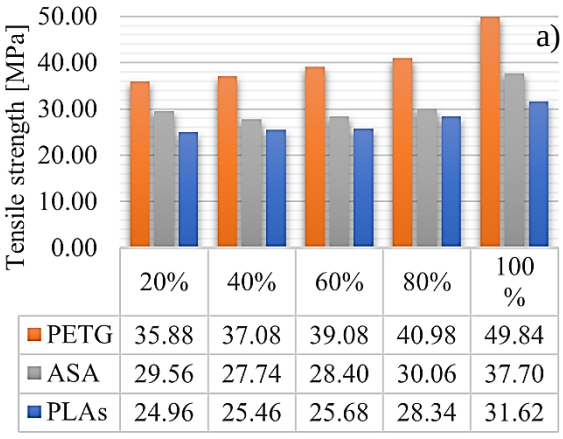
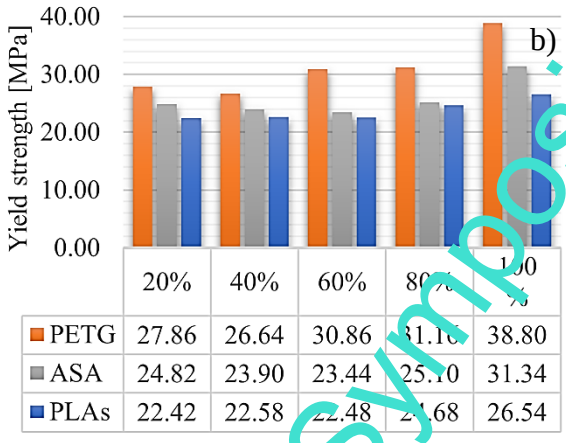



| | 20% | 40% | 60% | 80% | 100 % |
|---|---|---|---|---|---|
| PETG | 35.88 | 37.08 | 39.08 | 40.98 | 49.84 |
| ASA | 29.56 | 27.74 | 28.40 | 30.06 | 37.70 |
| PLAs | 24.96 | 25.46 | 25.68 | 28.34 | 31.62 |



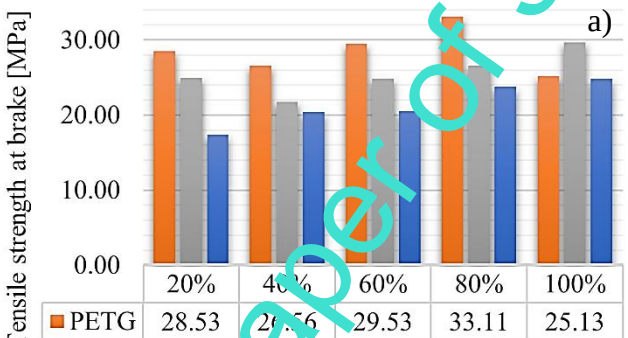

| | 20% | 40% | 60% | 80% | 100 % |
|---|---|---|---|---|---|
| PETG | 27.86 | 26.64 | 30.86 | 31.16 | 38.80 |
| ASA | 24.82 | 23.90 | 23.44 | 25.10 | 31.34 |
| PLAs | 22.42 | 22.58 | 22.48 | 24.68 | 26.54 |

Fig. 11. PETG, ASA and PLAs tensile (a) and yield (b) strength comparison – different infill density

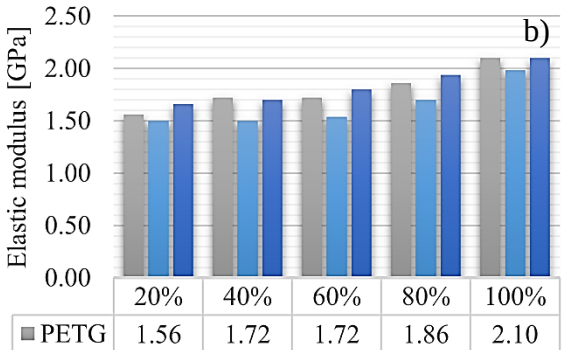
Tensile strength comparison of PETG, ASA and PLAs materials with different infill density is presented on Fig. 11a. In general, for all tested materials, the results showed a linear increase in tensile strength with increasing infill density. For all analysed infill densities, the highest tensile strength values were determined for PETG, while PLAs material showed the lowest tensile strength. By changing the infill density from 20% to 100%, for PETG material, the tensile strength can be increased up to 39%, i.e., it changes from 35,88 MPa to 49,84 MPa. Analysing only the results of samples with an infill structure (infill density from 20% to 80%), the tensile strength of PETG material can increase up to 14%, of ASA material up to 8%, and of PLAs material up to 14%, depending on the infill density.

What could also be noticed in the case of ASA material with an infill structure, is that for specimens with 20% infill density, the results showed higher tensile strength than specimens with 40% and 60% infill density, which was not expected. Although the difference is not significant, not over 5.5%, the test should be repeated for ASA material with 20% infill density.

Yield strength comparison for PETG, ASA and PLAs materials with different infill density is presented on Fig. 11b. The yield strength didn't show a linear increase with increasing infill density. For PETG and ASA materials, the yield strength for 20% infill density is slightly higher than for samples with infill density of 40%, after which it increased slightly with increasing infill density. While for PLAs material, for infill density from 20% to 60%, the yield strength did not change by more than 1%. Analysing the yield strength change for an increase in infill density from 20% to 100%, the results showed that yield strength increases up to 46% for PETG, up to 34% for ASA, and up to 27% for PLAs material.




| | 20% | 40% | 60% | 80% | 100% |
|---|---|---|---|---|---|
| PETG | 28.53 | 27.56 | 29.53 | 33.11 | 25.13 |
| ASA | 24.93 | 24.76 | 24.84 | 26.55 | 29.70 |
| PLAs | 17.37 | 20.44 | 20.47 | 23.73 | 24.83 |




| | 20% | 40% | 60% | 80% | 100% |
|---|---|---|---|---|---|
| PETG | 1.56 | 1.72 | 1.72 | 1.86 | 2.10 |
| ASA | 1.50 | 1.50 | 1.54 | 1.70 | 1.98 |
| PLAs | 1.66 | 1.70 | 1.80 | 1.94 | 2.10 |

Fig. 12. PETG, ASA and PLAs tensile strength at brake (a) and elastic modulus (b) comparison – different infill density

Tensile strength at brake comparison for PETG, ASA and PLAs materials with different infill density is presented on Fig. 12a. As expected, tensile stress at brake is lower than tensile and yield strength for all analysed materials. For PLAs material, tensile strength at brake increased linearly from 17,37 MPa to 24,83 MPa (up to 9%) with increasing infill density. In the case of ASA material, the results show higher values of tensile strength at brake for samples with a infill density of 20% compared to samples with a density of 40%. While with the increase of infill density from 40% to 100%, the tensile strength at brake continued to increase linearly. Analysing the PETG material, it can be seen a similar behaviour of the material for tensile strength at brake, with the fact that the lowest values were measured at an infill density of 100%, which can also be seen from Fig. 7.

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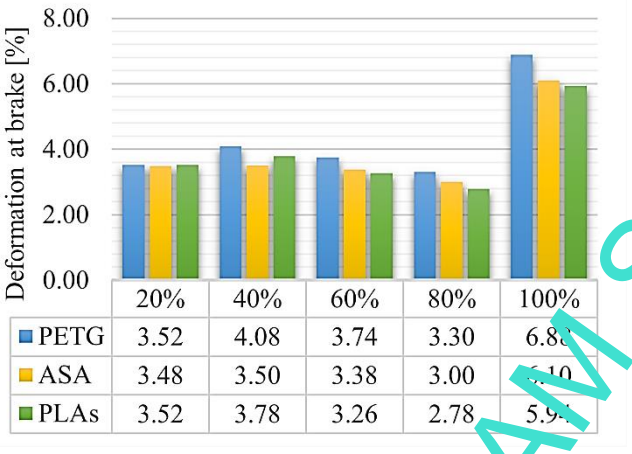
Elastic modulus comparison for PETG, ASA and PLAs materials with different infill density is presented on Fig. 12b. With the increase of infill density, the elastic modulus also increased for all analysed materials. By analysing the specimens with the infill structure, the PLAs material generally showed the highest values of measured elastic modulus. When increasing the infill density from 20% to 100%, the elastic modulus increases for PETG up to 35%, for ASA up to 32% and for PLAs material up to 26%.




| | 20% | 40% | 60% | 80% | 100% |
|---|---|---|---|---|---|
| PETG | 3.52 | 4.08 | 3.74 | 3.30 | 6.8 |
| ASA | 3.48 | 3.50 | 3.38 | 3.00 | |
| PLAs | 3.52 | 3.78 | 3.26 | 2.78 | 5.9 |

Fig. 13. PETG, ASA and PLAs PLAs deformation at brake comparation – different infill density

Deformation at brake comparison for PETG, ASA and PLAs materials with different infill density is presented on Fig. 13. As expected, the highest values of deformation at break were obtained for samples with a infill density of 100%. For samples with an infill structure, as the infill density increases up to 80%, a slight decrease in the deformation at break can be seen. Materials with 100% infill density have significantly higher deformation at break compared to samples with a infill structure, and in the case of PETG material it is higher up to 108%, for ASA material up to 103% and for PLAs material up to 114%. Also, the lowest deformation at brake, for all tested materials, were for specimens with 80% infill density, which is not expected.

## 5. Conclusion

As expected, materials without infill structure (100% infill density) showed higher strength and deformation at brake compared to materials with infill structure.

Analysing only the materials without infill structure, the results showed that the tensile strength is 32% higher when using PETG material compared to ASA and 57% compared to PLAs material. By comparing the yield strength, the results showed the highest values for PETG material, where the yield strength is 23% higher compared to ASA and 46% compared to PLAs material. ASA material showed highest values of tensile strength at brake, and it was 20% higher compared to PETG and PLAs materials. The same elastic modulus values were measured for PETG and PLAs materials, which are 6% higher than ASA material. By comparing the deformation at break, PETG material has higher values by 13% compared to ASA and 16% compared to PLAs material.

By analysing the tensile strength of materials with infill structure, a linear increase can be seen for all materials with increasing infill density. From 20% to 80% of infill density, PETG material showed the highest and PLAs material the lowest values of tensile strength. Also, by increasing the infill density from 20% to 80%, tensile strength goes up to 14% for PETG, up to 8% for ASA and up to 14% for PLAs material. Higher tensile strength values were measured for ASA material with 20% infill density compared to samples with 40% and 60% infill density, which was not expected, so the testing of these samples should be repeated.

In relation to the tensile strength, the yield strength did not increase linearly for PETG and ASA materials with infill structure. For PLAs material, the yield strength did not change more than 1% with increasing infill density from 20% to 60%.

As expected, the tensile strength at brake was lower compared to tensile and yield strength for all materials with infill structure. A linear increase in tensile strength at brake is visible only for PLAs material. In contrast to ASA and PLAs materials, PETG material with 100% infill density had lower tensile strength at brake values compared to samples with 80% infill density.

The values of the elastic modulus increased linearly with the increase of infill density for all three materials. Generally, the PLAs material with infill structure showed highest values of elastic modulus. With the increase of infill density from 20% to 100%, the elastic modulus values increase by 35% for PETG, by 32% for ASA and 26% for PLAs material.

Analysing the deformation at break, a slight drop in the value can be observed when the infill density increases from 20% to 80%, and a sudden jump for samples with an infill density of 100%. Materials without infill structure showed

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higher values of deformation at brake up to 108% for PETG, up to 103% for ASA and up to 114% for PLAs materials compared to the same materials with a infill structure.

Certainly, for future research, other mechanical properties of these materials should be analysed to better understand the behaviour of the PETG, ASA and PLAs materials under different loads, with the aim of their application for engineering and other applications.

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## 7. References

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