VERIFICATION OF CONSTRUCTION PROPERTIES MATERIALS FOR RAPID PROTOTYPING USING SLS TECHNOLOGY

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Abstract
This article discusses the different mechanical properties of samples made using 3D printing, namely SLS-sampled specimens. This article describes 3D SLS printing technology, a selection of SLS 3D printing materials, and the influence of 3D print settings on samples. The article is mainly focused on storing samples in different directions of 3D printing, orientation in the direction of the x, y, z axes and then for the strength evaluation of these samples. The measured results are further evaluated at the end of the article.

Key words: *3D printing; SLS technology; stress strenght;*

INTRODUCTION

Nowadays, Rapid Prototyping technology is experiencing a lot of booming right Is proportionally related to the increase in materials usable by this technology. Although it exists Amount of usable materials, from metals and concrete to biocompatible materials, The most widely used are due to their versatility and price of plastics. This article will describe some of the most commonly used materials for Individual forms of production by Rapid Prototyping, in particular the SLS technologies. The mechanical properties of the samples in different directions of the individual samples will be examined. A brief description of the course of the material tests to be carried out in the practical part will be followed. From the data obtained, the material characteristics are calculated and compared with the values reported by the manufacturer in the material sheet. The results will be analyzed and the reasons for possible deviations between measured and reported values will be determined. The most common materials used in 3D printing today include plastics, metals, ceramics, paper, biomaterials, or even food. Each material is uniquely used and is therefore becoming an increasingly frequent combination of multiple materials to guarantee the best mechanical properties of the manufactured part. The most used material, however, is still plastic and mainly due to a wide range of usable types. Each type is characterized by different strength, flexibility, surface finish or color. Using SLS (Selective Laser Sintering) technology, we can achieve the creation of fully functional prototypes, the properties of which are comparable to prototypes created by injection. It is an ideal method for use in piece production thanks to a favorable price / performance ratio. The benefits of SLS include print speed, the creation of durable, functional and complex parts, while printing does not require the creation of a supporting structure, as well as the choice of a wide range of finishing operations. The drawbacks of printing using this technology are that the parts have different strengths in each direction of printing. This is due to the 3D printing technology itself.

SLS 3D Printing Technology

An additive manufacturing layer technology, SLS involves the use of a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal, ceramic, or glass

powders into a mass that has a desired three-dimensional shape. The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed.
Because finished part density depends on peak laser power, rather than laser duration, a SLS machine typically uses a pulsed laser. The method of creating a 3D model can be seen in Fig.1. The SLS machine preheats the bulk powder material in the powder bed somewhat below its melting point, to make it easier for the laser to raise the temperature of the selected regions the rest of the way to the melting point.

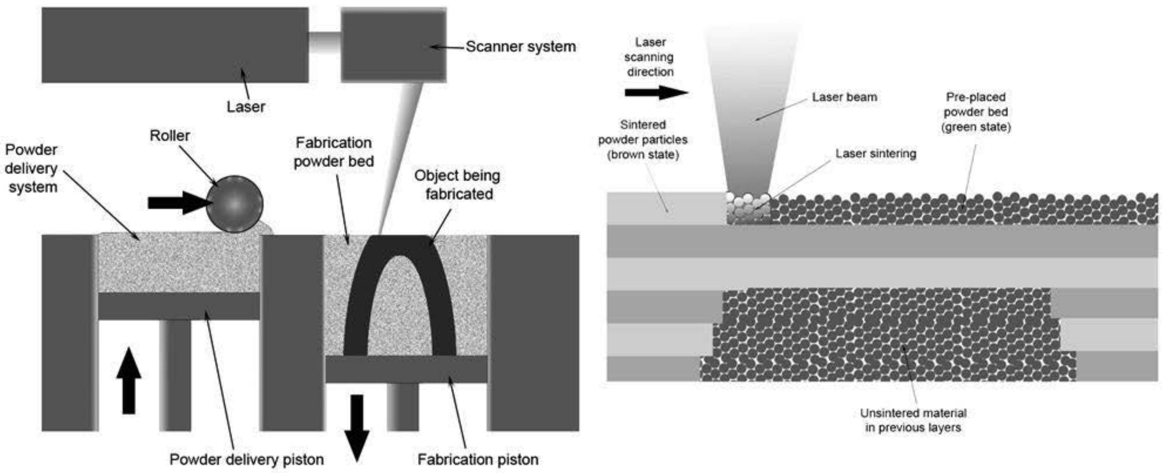


Fig.1 SLS 3D Printing Technology (*Anubis3d, 2017*)

MATERIALS AND METHODS

Materials used in sls technology and methods for testing

By using SLS (Selective Laser Sintering), we are able to create fully functional prototypes, the properties of which are comparable to prototypes created by injection. This is an ideal method for use in piece production thanks to a favorable price / performance ratio. The advantages of SLS include print speed, the creation of durable, functional and complex parts, while printing does not require the creation of a supporting structure, as well as the choice of a wide range of finishing operations.
Technical Specifications:
• Standard accuracy: ± 0.3% with a lower limit of ± 0.3mm
• Minimum wall thickness: 1mm
• Surface Structure: Displays have a typical grainy surface, but can be adjusted by any finishing method, e.g. They can be sanded, impregnated, coated etc .. (*Laser Sintering, 2017*)

PA (Polyamide)

The powder of this material is self-supporting, thus avoiding the generation of a supporting structure in the prototype process. Polyamide makes it possible to produce fully functional samples with high mechanical and thermal resistance and its particles are resistant to most chemicals. The material is also biocompatible due to its application in healthcare (*Laser Sintering, 2017*).

Testing materials used in 3d printing with sls technology

The tensile test is a basic test of the mechanical properties of the materials (*Rapid, 2017*). Testing is performed on standardized specimens clamped in jaws of the tearing machine, with the axis of the specimen being aligned with the force axis. A growing force develops on the sample until it breaks down. During the test the instrument measures the load force and the relative elongation of the rod. By evaluating the measured data we determine for the material to be tested the slope, the tensile strength, the relative elongation and the constriction. Test results are used to select the appropriate material for the required application, quality control, and prediction of material behavior under load. For extruded plastic samples, the test is performed according to STN EN ISO 527-1: Plastics. Determination of tensile properties. Part 1: General principles (ISO 527-1: 2012) and STN EN ISO 527-2: Plastics. Determination of tensile properties. Part 2: Test conditions for pressed and extruded plastics (ISO 527-2: 2012).

Test specimen for tensile strenght testing

The test sample has the most frequent cross-section of square, rectangular or circular shape. At the end of the sample, the so- Arms whose shape is adapted to the shape of the jaws of the jig machine into which the specimen clamps. The shape of the measured sample can be seen in Fig.2 and Fig.4. Among them, there is a calibration part of smaller cross-section that ensures initialization of the crack. Test rods are produced in long or short designs (*STN EN ISO 527-2: 2012, 2012*).

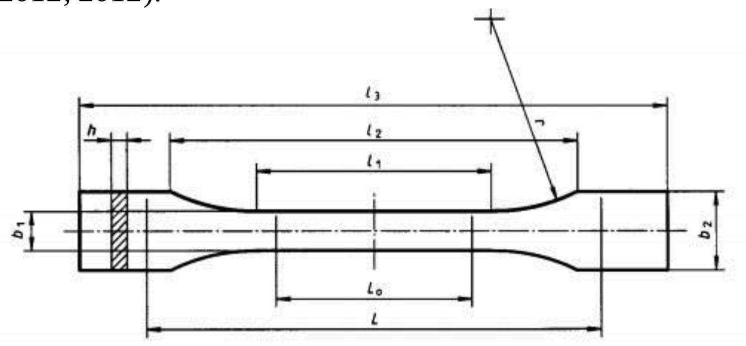


Fig.2 Test rod with rectangular cross section

Exam evaluation

The main result is the Hook diagram, which shows the dependence of the elongation of the bar on the voltage generated. From the graph, in addition to the voltage characteristics, such as the slope Re, the strength limit Rm, the elastic limit Rp, the deformation characteristics determining the plasticity of the material are deformed. Thus, it is possible to determine at what load the material occurs in the area of the elastic deformation, whether it comes into plastic deformation and therefore there is a breakage of the sample. The deformation curve can be seen in Fig.3. Criteria for assessing deformation characteristics are elongation and contraction (*Strojarstvo, 2017*).

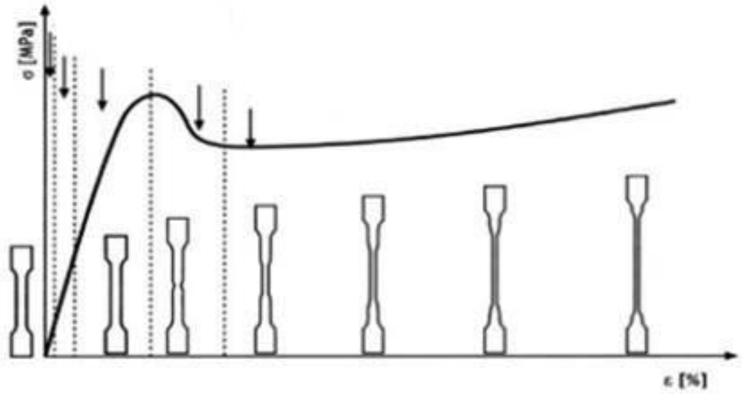


Fig.3 Deformation curve of thermoplastic materials rectangular cross section

Verification of materials properties by means of measuring instruments

The first step was to model the STD EN ISO 527 in the PTC Creo 3 CAD standardized sample for the tensile test. The sample model has been exported to STL, which is used to work with 3D models in modeling software and 3D printer control. Once the settings have been made in the software, samples were printed on the Formiga P 100 printer.

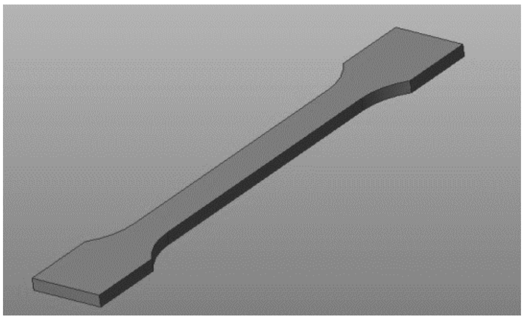
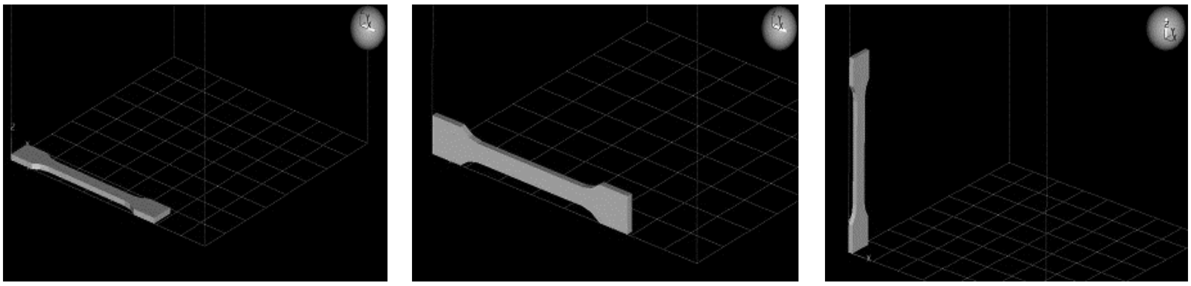


Fig.4 3D Model of specimen

The sample model has been exported to STL, which is used to work with 3D models in modeling software and 3D printer control. After performing the settings in the software, the samples were printed on the Formiga P 100 printer. 11 samples were printed out for the PA 2200 material, three pieces were printed on the X-axis and Y-axis, and five pieces were printed in the Z-axes. Due to such decomposition, it is possible to observe the influence of the printing direction on the mechanical properties of the sample. The orientation of the individually printed samples using a 3D printer is shown in Fig.5 and Fig.6



X axis Y axis Z axis

Fig.5 View samples in interface for 3D printer FORMIGA P100

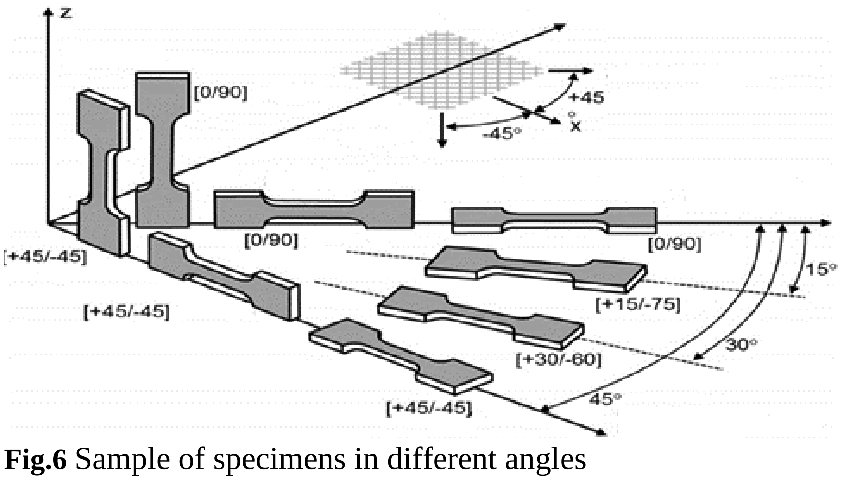


Fig.6 Sample of specimens in different angles

RESULTS AND DISCUSSION

From the measured values, the tensile stresses, elongations and Young's modules were calculated according to the respective relations. For printing in every direction. From these values, a graph and arithmetic mean were produced, the results of which were compared with the values reported by the manufacturer.

In this chapter there are tables and charts that compare the measured values in different axes. From the measured values for individual axes it can be stated that the measured values were almost the same for each measurement.

Evaluation of pa 2200 tensile strenght test

Tab.1 Resulting values for samples printed in X direction

	Specimen X_1	Specimen X_2	Specimen X_3
Duration of the test	97,48 s	95,1 s	98,50 s
Elongation	27,98 %	23,57 %	28,44 %
Tension stress	52,339 MPa	53, 025 MPa	53, 219 MPa
Young modulus	508,125 MPa	698,9 MPa	726,563 MPa

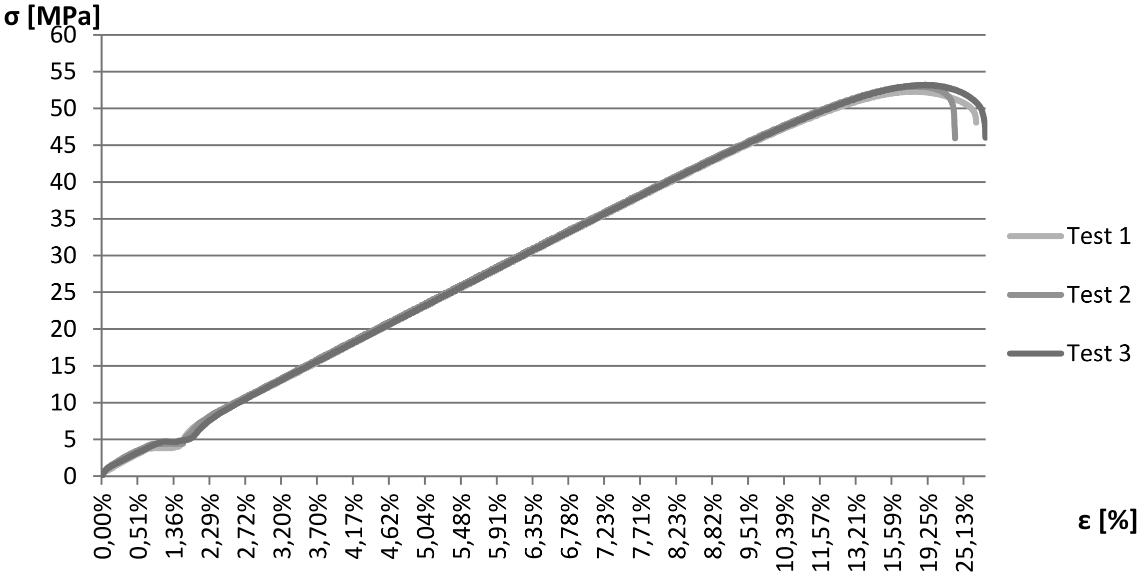


Fig.7 Dependence of the elongation from the stress on the sample pressed in the X-axis direction

Tab.2 Resulting values for samples printed in Y direction

	Specimen Y_1	Specimen Y_2	Specimen Y_3
Duration of the test	98,32 s	96,78 s	97,12 s
Elongation	26,73 %	25,58 %	28,97 %
Tension stress	53,579 MPa	53, 03 MPa	52,309 MPa
Young modulus	719,06 MPa	470,156 MPa	442,06 MPa

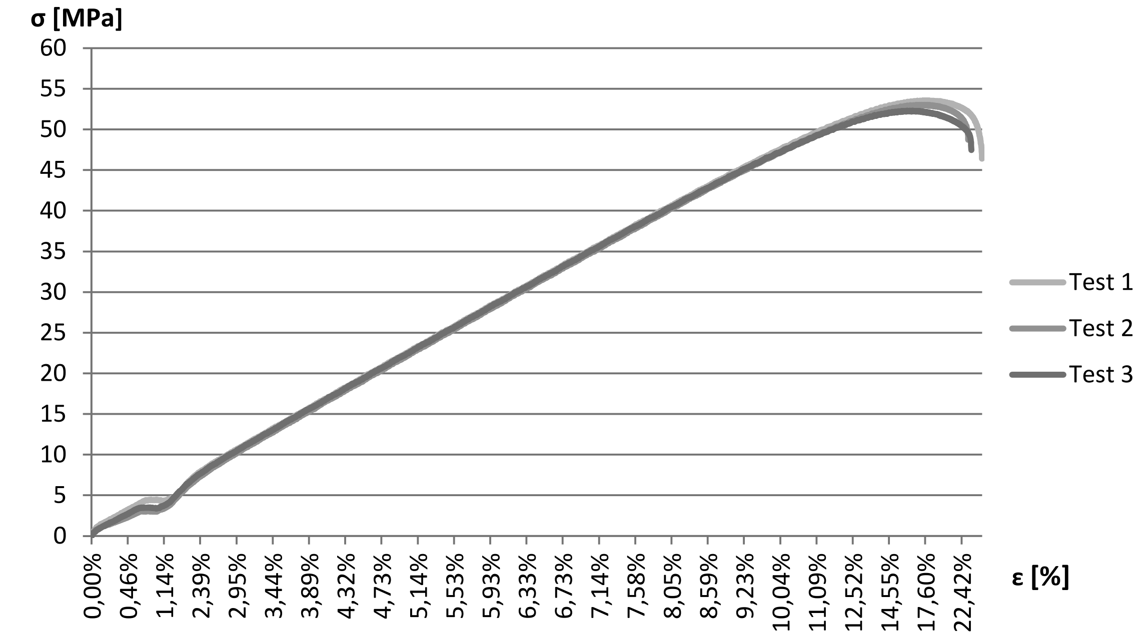


Fig.8 Dependence of the elongation from the stress on the sample pressed in the Y-axis direction

Tab.3 Resulting values for samples printed in Z direction

	Specimen Z_1	Specimen Z_2	Specimen Z_3	Specimen Z_4	Specimen Z_5
Duration of the test	65,3 s	73,38 s	67,92 s	70,02	67,88 s
Elongation	9,7 %	11,02 %	12,58 %	10,04%	10,24 %
Tension stress	41,241MPa	45,60 MPa	41,896 MPa	43,71MPa	42,31MPa
Young modulus	574,218 MPa	624,844 MPa	13,125 MPa	429,375 MPa	508,125 MPa

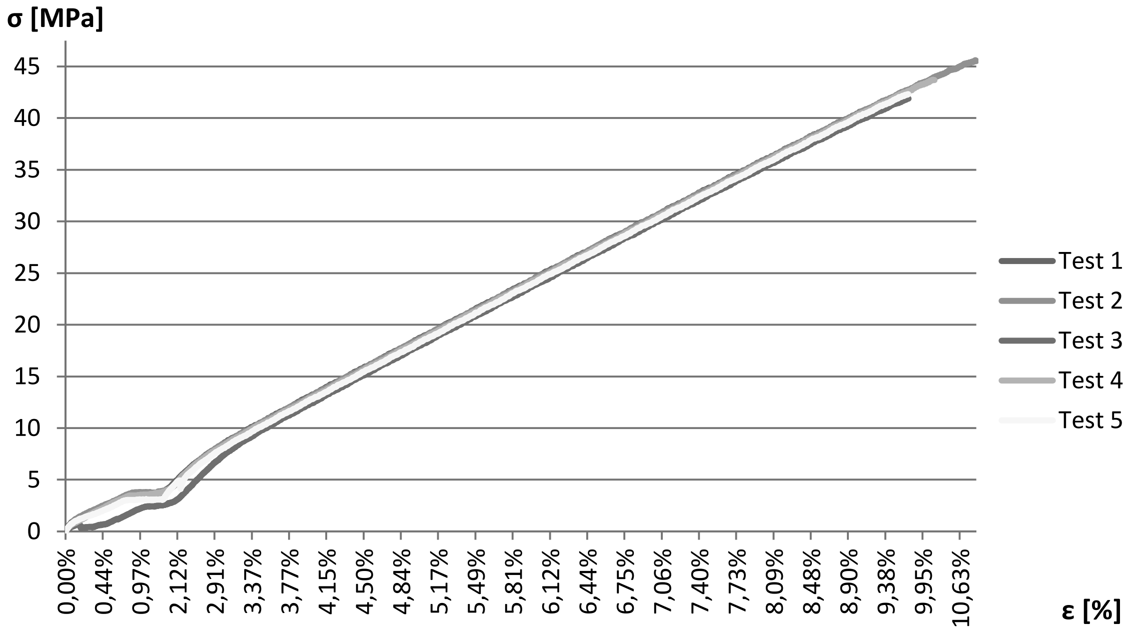


Fig.9 Dependence of the elongation from the stress on the sample pressed in the Z-axis direction

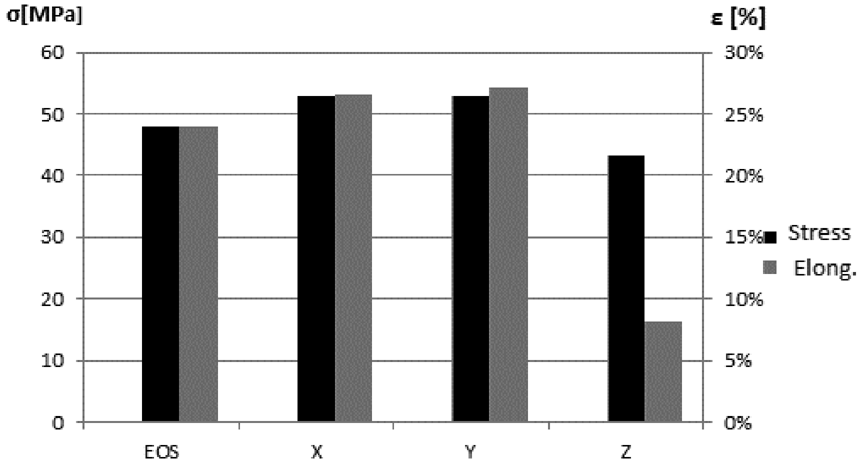


Fig.10 Comparison of declared and calculated values of stress and elongation

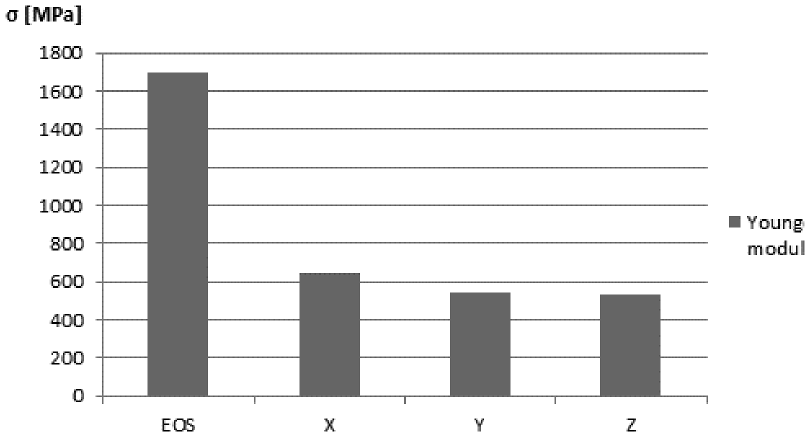


Fig.11 Comparison of the declared and calculated Young's module

Comparison of declared and calculated voltage and elongation values and comparison of the declared and calculated Young's modulus of elasticity can be seen in Fig.10 and Fig.11. Findings show that the printed material PA 2200 in the Y axis there is a marked difference in the allowable tensile stress, but when pushed in the axial direction from the tensile stress of the lower most bar 10 which is a difference of 19%. As far as the extension is concerned, it is again the worst Z axis, where the difference with respect to the axes X, Y is approximately 19 and thus 69.7%. The Young's module has the best X axis at 644.63 MPa followed by Y with 543.76 MPa and Z with 534.14 MPa. Compared to the manufacturer, the tensile stress values in the X and Y axes were higher and in the Z axis lower by approximately 5 MPa, representing a difference of 9.5%. On elongation, the X and Y axis measurements were greater than those reported by the manufacturer, approximately 11% in the Z axis, the elongation was measured by 66%. Younger modules, however, differ considerably from the values given by the manufacturer, since the average value of the manufacturer is 1700 MPa after the averaging is only 644.63 MPa, which is the difference of 62%.

CONCLUSIONS

From the measured values it is possible to find out that the declared values are different in different directions. When designing a 3D prototype, these contexts need to be considered. Different values are based on 3D printing technology, namely SLS. Differences between reported and measured values may be caused by multiple, technical or human factors. There are many

settings you can make on a 3D printer. Direction of bounce, angle rotation on the substrate, layer thickness, print speed, model fill method, quality and Material purity, sample placement on heated pad and method and speed of cooling has all the effect on the resulting properties. If we wanted to finish. The most likely actual mechanical properties of the investigated material, It would be necessary to do a few dozen samples at all Existing combinations of the above factors. The data would then be obtained Appropriate to achieve the most accurate results of the investigated properties. Next the effect of the job it plays during the print process is the temperature of the pad. Right print on a heated pad, there are other thermal passages than when printing a layer of material that affects the interconnection of the initial layers. Even in the middle the pads have a higher temperature than at their edges, measured at this temperature the values between the samples vary. In the static pull test, there are also factors that act on the data obtained. First, the quality of the device itself. As they appear in motion any inaccuracies and defects in the machine cause a deviation of the resulting data.
In the introduction, the article deals with the most frequently used materials for each of the Rapid Prototyping technologies, their properties and possibilities of use. Briefly, the pull test is described. That is, the material tests that are used to determine the mechanical properties of the materials. Also, the basic factors to be considered when determining the appropriate material for the desired application are described. The aim of the thesis was to verify the mechanical properties of the materials and thus to compare the values declared by the manufacturer with the measured and calculated values. The samples modeled in the PTC Creo3 CAD program were printed and then subjected to material testing. Samples were printed in X, Y and Z axes to determine the impact of the print axis on the mechanical properties of the material. After performing the measurements and calculating the values, the graphs and arithmetic means were compiled for comparison purposes.

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REFERENCES

1. https://www.anubis3d.com/technology/selective-laser-sintering/
2. Laser Sintering. [online]. [cit. 2016-11-25] web: http://www.materialise.com/en/manufacturing/3d-printing-technology/lasersintering
3. STN EN ISO 527-2: 2012 (64 0605), Plasty. Stanovenie ťahových vlastností Časť 2 Skúšobné podmienky pre lisované a vytláčané plasty (ISO 527-2: 2012)
4. Strojárstvo. [online]. [cit. 2017-1-7], web: http://www.engineering.sk/images/stories/pdf/stroj10_cb_kompl.pdf.
5. Rapid Prototyping Materials: Past, Present and Future, web: http://www.rapidprototyping-china.com/rapid-prototyping-materials-pastpresent-future

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