Determination of Mechanical Properties of Plastic Components Made by 3D Printing

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The presented article deals with the determination of selected mechanical properties of additive materials used for 3D printing (PETG, PLA, ABS, ABS +, PLA ESD, ASA, PC / ABS). Due to the fact that 3D printing has exploded over recent years and additive manufacturing has become popular in some industries, the quality of input materials and their mechanical properties is extremely important. We used 3D printer Original Prusa MK3 to prepare samples for testing. Individual samples printed from all above mentioned materials were analyzed using selected mechanical tests (static tensile test, hardness tests). In the static tensile test, selected parameters (tensile strength limit, tensile modulus, elongation) were determined for all additive samples, which were statistically processed. The parameters for two methods of measuring hardness were also statistically evaluated, namely Shore and ball indentation. All tested additive materials were compared with the aim of obtaining the final ranking (point evaluation of tested materials with quantification of price costs). The best properties after the performed tests were achieved by the additive material PLA Filament Plasty Mladeč.

Keywords: Aditive manufacturing, 3D printing, Fused filament fabrication, Mechanical properties, Tensile test, Hardness tests

1 Introduction

The complex geometry of the final product was always the biggest problem for designers, until the advent of Rapid Prototyping additive technology. Rapid Prototyping technology, also known as 3D printing, consists of several methods developed in the late 1980s. For a long time, this technology was used only in construction and in a professional industrial environment to create prototypes or even finished components. 3D printing is a very broad concept that includes many production methods. One of them is the additive method Fused Filament Fabrication (FFF) [1], [2].

In recent years, the situation has changed sharply and 3D printing has been gradually made available to ordinary users / consumers thanks to reduced acquisition costs. Thanks to this, new printing methods developed rapidly. Additive materials used in 3D printing are also undergoing great development [2], [3]. Nowadays, 3D printing technology offers a wide portfolio of additive materials. In addition to the basic polymeric material, for example, a ceramic, metal or composite additive material is also used. At the same time, the 3D printing technology itself has advanced and is used more in other areas than just in the position of engineering.

3D printing has been widely used, for example, in the field of medicine (implant production), pharmacy (drugs), engineering, construction, food, but also in the automotive, aerospace, energy, consumer industries, etc. [3], [4]. 3D printing technology is no longer only used for the production of prototypes and their testing prior to putting into production, but also as an independent production technology in certain sectors where the technological process and other circumstances allow. It is for this reason that ever higher demands are placed on the quality of the material used, its mechanical properties, health safety (in healthcare), and other parameters according to the type of industry in which the final product is to be used. Many authors in their studies compared devotes just individual parameters of the materials investigated in order to assess their suitability for a particular purpose. One of the most commonly used materials for 3D printing is ABS (Acrylonitrile-butadiene-styrene). Raney et al. [5] tested the tensile strength of this material and found that the tensile force measured against the layers is only 74% to 79% of the force measured along the layers.

Dizon et al. [6] made an extensive research in the field of testing mechanical properties of materials for 3D printing, during which found that the test criteria and the whole testing process is very different in different research groups and often also depends on the purpose of the use of resulting 3D printing products. So far, there is no standardized procedure for testing the mechanical properties of materials and individual studies differ considerably from each other. Most authors focus mainly on the tensile strength of materials [5], [7], [8], [9], [10] and shear [11] or deformation caused by pressure [12], others focus on some other mechanical properties such as "folding behavior" [13] or fracture models during compression loading [14].

Further studies are devoted to examining the specific properties of additive materials for a specific purpose. For example, Alssabbagh et al. [15] analyzed nine materials (including common ones such as PLA, ABS, etc.) to evaluate the mass attenuation coefficient and select the most suitable material to replace human soft tissue. Most authors in their studies test the most common materials used for 3D printing (such as ABS, PETG or PLA). In practice, however, there are also countless special materials for 3D printing for various special purposes (aerospace industry, medicine, energy, etc.). For example, Zaldivar et al. [16] or Kaplun et al. [17] investigated the effect of 3D printing on the mechanical and thermal properties of one of the most durable polymers used for 3D printing ULTEM® 9085. The results were compared with plastic injection technology, where the strength of the examined samples was demonstrably higher by about 40%.

In addition to the type of material, the mechanical properties of additive production products (3D printing) are also affected by the production process itself. According to the findings of Dizon et al [6], the best tensile properties are achieved when the filament is placed longitudinally, ie parallel to the loading direction. Melenka et al [7] in turn tested the elasticity of the sample depending on the fiber volume fraction and Sood et al [18] assessed the influence of five important process parameters (thickness of one fiber layer, orientation, angle and width of the raster and air gap) on the tensile, flexural and impact strength of the sample. The results of research on quality parameters (dimensions and surface quality) carried out on 3D printing products produced by the DMLS method point to compliance with the stated quality of the production technology and an even distribution of irregularities in surface roughness measurements [19].

In our article, we focus on the mechanical properties of additive materials that are commonly used for 3D printing in both industrial production and hobby environments. In addition to the tensile strength of the sample, their hardness is also tested in the form of the resistance of the sample surface to the scratching of another, harder material. This type of test is mostly neglected in the above research, but it is no less important for the quality of products produced by 3D printing technologies [20]. Part of the presented study is also an economic evaluation of all the most commonly available variants of materials. In recent years, 3D printing technology has become quite established in more technologically advanced industries and, together with the use of new materials, makes it possible to improve the price / quality ratio and thus ensure greater competitiveness of the company [21].

2 Fused filament fabriation technology

Fused Filament Fabrication (FFF) is a printing method whose production process consists of melting the input material. The filament wound on the spool is pressed by means of an injection mechanism (two gears connected to the motor) into a heated nozzle, in which it is melted into a semi-liquid state. The molten material is then applied in individual layers to a heated substrate, where it is cooled by ambient air until it solidifies. Printing of one layer takes place simultaneously in X and Y coordinates. After the end of one layer, the print head with the nozzle moves in the Z axis by the layer thickness upwards and a new layer is printed. In this way, the whole process is repeated until the resulting object is created. At the end of the production process, it is necessary to remove the printing supports [22], [23], [24]. Deformation of the PLA material can be caused depending on the heating of the printing pad and the solution can be to cut the object during the printing process [25].

Filament as an input material is made of many types of material. The additive FFF method requires print support for complex shapes that are created in the same way as the resulting model, with only a lower fill density and fewer edge loops. Print supports can be printed from the same material as the resulting model, or a special water-soluble building material. Prototype models produced by this method are used in design testing or product innovation. Models can also be exposed to mechanical and weather conditions corresponding to reality [22], [23], [24]. The density of the PLA material is also affected by the density of the sample filling, which was tested by a tensile test, this test confirmed that the shape of the filler does not affect the values obtained by the tensile test [26].

The main advantages of FFF technology are minimal waste (supports), high printing speed and good mechanical properties [22], [23]. Disadvantages include limited dimensional accuracy depending on the material used, print nozzle diameter, and susceptibility to shrinkage during cooling. [22], [23], [28]. In the experiment, the tensile strength was tested using the higher and lower temperature limits specified by the manufacturer for PLA, PETG and ABS materials, and

it is appropriate to use the upper limit of the temperatures recommended by the manufacturer [27] .

3 Static tension test and hardness tests

In this part of the paper, selected mechanical tests, which were subsequently applied in the experimental part, will be characterized.

3.1 Static tension test

The static tensile test is one of the most often used mechanical tests. The principle of the tensile test is prescribed by the ČSN EN ISO 527-2 standard. The test is usually performed at room temperature (23 °C). It is used to determine the tensile strength Rm, the yield strength Re, the contractual yield strength Rp0,2, the tensile modulus E and other tensile stress-dependent characteristics. [29], [30].

The ultimate strength Rm is the stress value reached at maximum load before the test bar ruptures. The value of Rm is a significant material value, classifying individual types of materials and is determined according to relation (1) [31], [32], [33]:

$$R_m = \frac{F_m}{S_0} \ [MPa], \tag{1}$$

Where:
Rm…Stress at the limit of strength [MPa],
Fm…Maximum load force [N],
S_0…Initial cross-section of the sample [mm²] [34].

Hooke's law represents the relationship between stress and relative elongation, see relationship (3). In the contractile tensile diagram, Hook's law is plotted as a straight line. The direction of the line is given by the modulus of elasticity in tension E and can be expressed by equation (2) [31], [32], [33]:

$$E = \tan(\alpha), \tag{2}$$

Where:
E…Modulus of elasticity in tension [MPa],
α…Angle of the line with horizontal axis [°],
S_0…Initial cross section of the sample [mm²] [34], [35], [36].

$$\sigma = \frac{F}{S} = E \cdot \frac{\Delta L}{L_0} = E \cdot \varepsilon \ [MPa], \tag{3}$$

Where:
σ…Tensile stress [MPa],
F…Loading force [N],
S…Actual cross section of the sample [mm²],
E…Modulus of elasticity in tension [MPa],
ΔL…Change in the length of the test sample [mm],
L_0…Initial sample length [mm],
ε…Relative elongation [-] [34], [35], [36].

Elongation (A_x) determines the scale of formability of the material. The value of ductility can be determined from ε after the rupture of the test bar by equation (4) [32], [33].

$$A_X = 100 \cdot \frac{L_u - L_0}{L_0} = 100 \cdot \frac{\Delta L_u}{L_0} \ [\%], \tag{4}$$

Where:
A_X…Elongation [%],
L_u…Final length [mm],
L_0…Initial length [mm],
ΔL_u…Absolute increment of initial length after rupture [mm] [32].

The index (x) represents the type of test rod. For short test bars, "x" is not given. For long test bars, the ductility is indicated $A_{11,3}$. The ductility of the material measured on the disproportionate test bars is indicated relative to its initial length ($L_0 = 50$ mm is denoted A_{50}). The shorter the test rod, the higher the ductility value [32], [33].

The fracture of the test bar must be in the middle third of the measured length. If the quarry is located in another area, the measured value of A_x may differ from the actual [32], [33].

3.2 Hardness test

Hardness is the most commonly used test defining the mechanical properties of a polymeric material. The resistance of the surface to the penetration of another harder material is defined and the materials are divided into rigid, hard and tough. The measurement of hardness by the penetration method is in principle the indentation of an penetrating body (indenter) of various shape by a predefined force into the surface of the tested material. The measurement method is divided according to the shape of the indenter (ball, cone). After a defined time interval, the penetration depth of the indenter is then measured. In the case of plastic material, both plastic and elastic deformation are taken into account [32], [37], [38], [39].
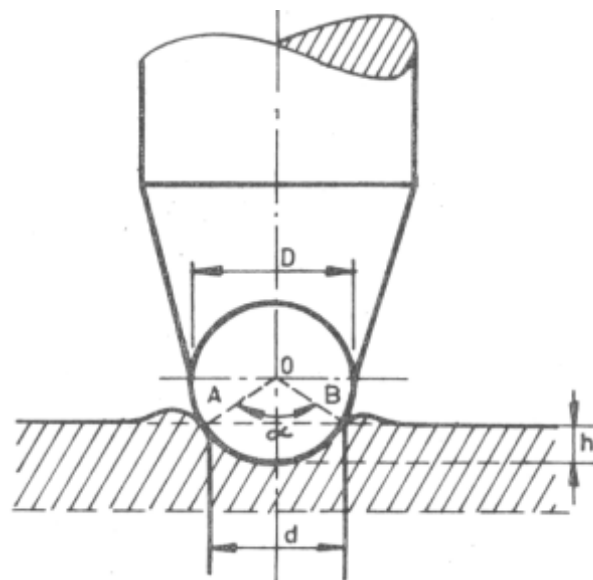

Fig. 1 *Hardness measurement by the ball indentation method [26]*

The ball indentation method is defined by the standard ČSN EN ISO 2039-1: Plastics - Determination of hardness - Part 1: The ball indentation method is a measurement method in which a hardened steel ball of diameter D (5 mm) is pressed into the test material, see Fig. 1 [30], [40], [41].

The test specimen is first loaded with an initial load of 9.8 N and then with a test load of 49 N to 961 N. The magnitude of the test load depends on the resulting indentation depth, which must be between 0.15 mm and 0.35 mm. The hardness is read after 30 s of measurement and calculated according to equation (5) [30]:

$$H = \alpha \cdot \frac{F_C}{h-0,46} \ [\mathrm{N} \cdot \mathrm{mm}^{-2}], \qquad (5)$$

Where:

α…Factor (0,0535) [mm^{-1}],

F_C…Total load [N],

h…Depth of penetration of the ball into the material [mm],

H…Ball indentation hardness [N·mm^{-2}] [30].

Shore hardness is one of the most common hardness measurements in practice. According to the hardness range, a distinction is made between Shore A hardness measurements, used for softer materials, and Shore D, for harder materials. Shore A and Shore D measurement methods differ in the shape of the indented tip. The tips are pressed in by a spring. The depth to which the measuring tip is pressed determines the degree of hardness. The hardness of the plastic material takes on values in the range 0 to 100 HSh for the Shore method [30].

The thickness of the test material must be at least 6 mm for both methods. When measuring with the Shore A method, the value is read after 3 s (measured from the first contact with the surface) and the hardness by the Shore D method is obtained after 15 s of the measurement [30].

4 Experimental part

Individual test specimens were made on an FFF 3D printer Original Prusa MK3. The printing parameters for the individual types of materials were chosen with regard to the information obtained from the material sheets and data of individual manufacturers (extruder and pad temperature). Other necessary parameters, such as print speed, extrusion and cooling, are predefined by the printer manufacturer and are already in the PrusaSlicer computer software.

Tab. 1 *Additive materials used [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53]*

Material	Producer	Rm [MPa]	E [MPa]	At [%]	Hardness [HRH]
ABS	Prusa	-	-	-	-
ABS+	Devil Design	-	-	30	105
PC/ABS	Filament Plasty Mladeč	-	-	-	-
ASA	Devil Design	-	-	20	107
ASA	Filament Plasty Mladeč	-	-	-	-
ASA	Fillamentum	40	1726	35	92
PETG	Filament Plasty Mladeč	-	-	-	-
PETG	Prusament	-	1500	-	-
PETG	Spectrum	27,1	360	9,5	-
PLA	Filament Plasty Mladeč	-	-	-	-
PLA	Fillamentum	53	3600	6	-
PLA	Prusament	-	2200	-	-
PLA ESD	3DXSTAT	55	2560	10	-

Filaments with a diameter of 1.75 mm were chosen for the 3D printer used. In addition to different types of additive material, materials from several suppliers are tested. The additive materials used, including suppliers and basic mechanical properties, are listed in Tab. 1. The test specimens were printed horizontally with 100 % inner fill and three circumferential perimeters.

4.1 Preparation of test samples

Filaments with a diameter of 1.75 mm were chosen for the 3D printer used. In addition to different types of additive material, materials from several suppliers are tested. The additive materials used, including suppliers and basic mechanical properties, are listed in Tab. 1. The test specimens were printed horizontally with 100 % inner fill and three circumferential perimeters.

4.1.1 Static tensile test

The shape and dimensions of the test specimen were chosen according to the ČSN EN ISO 527-2 standard. This standard specifies the conditions for testing of plastic material and the determination of their mechanical properties in the tensile test. The standard was chosen despite the fact that it describes test specimens created by injection molding, pressing or casting because there is still no standard that would

describe the tensile test of samples created by 3D printing technology [55], [56].

For the tensile test, according to the standard ČSN EN ISO 527-2, a test rod marked 1BA was chosen, see Fig. 2. The 1BA test rod was chosen due to the savings of the used additive material for production and shorter 3D printing time [55], [56].
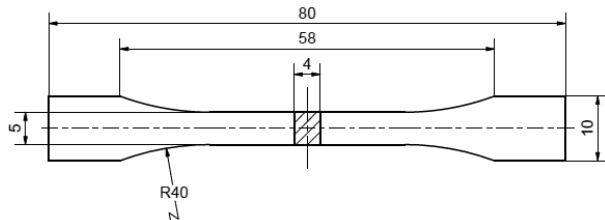

Fig. 2 *Dimensions of tensile test bar*

For better statistical evaluation of tensile tests, 5 pieces of test rods were made from each type of material and supplier. The total print series was 65 pieces.

4.1.2 Shore hardness test

The shape and dimensions of the test specimen for measuring the Shore hardness were chosen according to EN ISO 7619. This standard specifies the conditions for testing specimens made of rubber, vulcanized or thermoplastic elastomer. The dimensions for measuring Shore hardness are shown in Fig. 3.
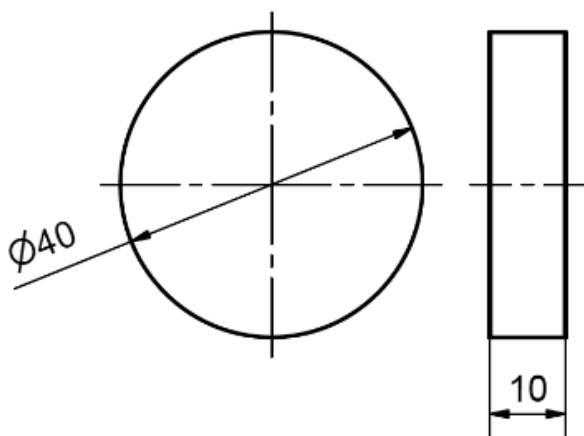

Fig. 3 *Shore hardness test specimen*

4.1.3 Ball indentation test

Neither the shape nor the dimensions of the test specimen for measuring the hardness by the ball indentation method are prescribed in any existing standard. For test specimens, it is important to have a sufficient height so that the measured hardness of the test specimen is not affected in any way by the hardness of the base of the measuring device. The dimensions of the test specimen for measuring hardness by ball indentation are shown in Fig. 4.
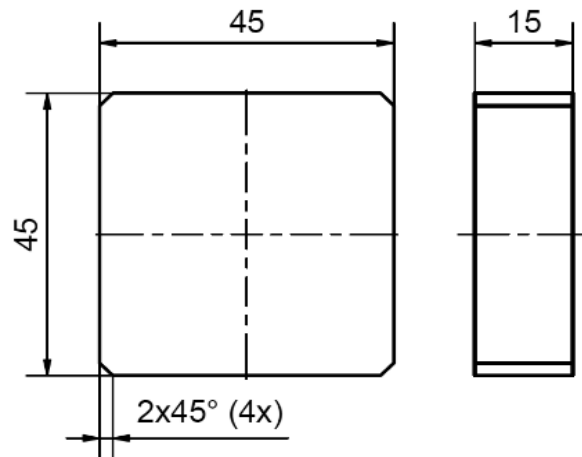

Fig. 4 *Test specimen for measuring the hardness of indentation by a ball*

4.2 Carrying out mechanical tests

4.2.1 Static tensile test

The tensile test was performed on a Zwick Z100 test rig. The test equipment is connected to the computer unit in which the test program XX supplied by Zwick is located via a cable. The program also serves to evaluate the course of tensile tests and the resulting parameters (yield strength, yield strength, modulus of elasticity and plotting the course of records from the tensile test).

At the beginning of the measurement, it was necessary to set the input data. It was the distance between the clamping jaws, which was 60 mm, and the input dimensions of the narrowed part of the test bars. After the test rod has been correctly attached between the jaws, it is possible to start a test measurement using the computer program testXpert. The test is automatically terminated after the test bar ruptures. The program records and then evaluates the individual tensile properties of the material, which are exported to Excel for further statistical evaluation.

4.2.2 Shore hardness test

The Shore D method was used to measure hardness, which allows measuring plastic materials in the hardness range of 10 to 90 HShD. The hardness of the test specimens was measured on a Digi Tech hardness tester. A test specimen is placed on the support of the test equipment. After starting the measurement, the indenter is pressed into the test specimen for 15 s. After the time has elapsed, the resulting measured hardness is displayed on the output device.

4.2.3 Ball indentation test

Ball hardness measurement very unique. A special measuring device is required to measure the hardness, and therefore it was necessary to perform the test in cooperation at the Institute for Testing and Certification based in Zlín. The measurement of the hardness

of the indentation by the ball was performed on one piece of test specimen with five repetitions.

5 Evaluation of results achieved

The experimentally obtained data were evaluated for individual test measurements separately, including a comparison of the values given by the supplier in the material sheets. The evaluated parameters include the tensile strength, tensile modulus, elongation, Shore hardness and ball indentation hardness. The obtained data were individually evaluated using the statistical software Minitab. First, the Anderson-Darling Normality Test was used to determine whether or not the data had a normal distribution. The assumption of normally distributed data is required when calculating

statistical parameters and the Anova test. In general: if the P-value is less than 0.05, data with a reliability greater than 95 % do not have a normal distribution. In this case, it is important to delete some values. Otherwise, the data can be further processed and the mean, mean, error, standard deviation, median, minimum, maximum and confidence interval determined using the One-Sample T-test.

Tab. 2 shows the basic statistically evaluated parameters and their values for the ABS additive material. The evaluation of all additive materials was performed in the same way as for the ABS additive material. With a few exceptions, the material sheets do not contain, see Tab. 1, no mechanical properties specified by the supplier [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54].

Tab. 2 *Basic statistical parameters of ABS additive material*

Parameters	Tensile strength values	Tensile modulus values	Elongation values	Shore hardness values	Ball indentation hardness values
Mean value	37.82 MPa	748.92 MPa	6.88 %	76.73 HShD	55.24 N·mm^{-2}
Mean value error	0.20	88.31	0.18	0.21	1.23
St. deviation	0.46	197.46	0.41	0.87	2.75
Median	37.84 MPa	787.55 MPa	6.76 %	76.90 HShD	55.90 N·mm^{-2}
Minimum	37.20 MPa	438.11 MPa	6.50 %	74.70 HShD	51.80 N·mm^{-2}
Maximum	38.42 MPa	920.15 MPa	7.56 %	77.70 HShD	58.20 N·mm^{-2}
Reliability level (95,0 %)	0.93	0.36	0.26	0.15	0.53
Confidence interval	37.25 MPa 38.39 MPa	503.70 MPa 994.10 MPa	6.37 % 7.39 %	76.27 HShD 77.18 HShD	51.82 N·mm^{-2} 58.66 N·mm^{-2}

6 Discussion on achieved results

The graphical dependence on Fig. 5 shows the mean values of the parameter Rm for individual types of additive materials, including their confidence interval.

From the graphical dependence on Fig. 5 it is evident that the tensile strength Rm of several materials exceeds the others. This is the case, for example, with PC / ABS and PLA materials, regardless of the supplier (other materials do not reach the Rm values of these materials). According to the comparison and performed analysis of individual additive materials, for most of their Rm values they do not reach the

prescribed value from the material sheet, see Tab. 1. According to the available and stated values from the material sheet see Tab. 1 and Fig. 5, the max. value Rm (for PLA ESD additive material) and the min. Rm value (for PETG Spectrum additive material) is always plotted [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54].

From the overall evaluation see Tab. 3 and Fig. 5, it can be seen that the highest value of the tensile strength Rm is reached by the additive material PLA Filament Plasty Mladeč.

Tab. 3 shows the mean values in the 95 % confidence interval.

Tab. 3 *Mean values in the 95% confidence interval*

Material	Producer	Rm [MPa]	E [MPa]	At [%]	Hardness [HShD]	Hardness [N·mm⁻²]
ABS	Prusa	37.82	748.92	6.88	76.73	55.24
ABS+	Devil Design	31.90	906.53	6.20	75.38	85.58
PC/ABS	Plasty Mladeč*	55.52	989.74	5.97	76.23	60.78
ASA	Devil Design	40.38	1086.98	5.33	76.04	73.48
	Plasty Mladeč*	40.46	857.67	6.64	75.76	87.20
	Fillamentum	34.41	832.67	7.34	71.45	43.00
PETG	Plasty Mladeč*	41.90	1053.66	8.65	72.80	67.86
	Prusament	45.74	1946.50	5.53	71.79	64.60
	Spectrum	46.59	1041.46	10.12	74.03	78.15
PLA	Plasty Mladeč*	58.61	1684.03	4.83	77.92	118.14
	Fillamentum	55.61	1259.19	5.08	81.73	99.56
	Prusament	55.98	1551.65	4.67	78.06	92.76
PLA ESD	3DXSTAT	35.62	826.96	16.56	65.75	77.22

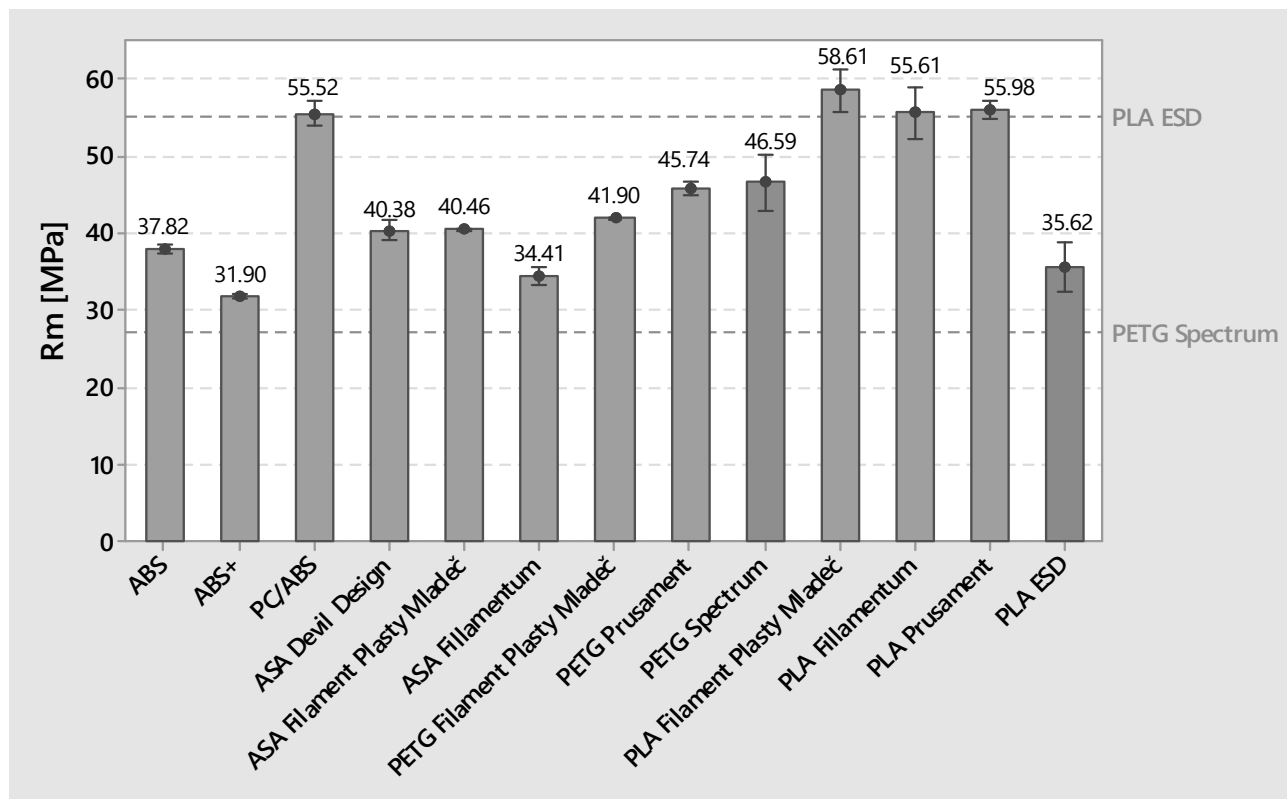***Filament Plasty Mladeč**

Fig. 5 *Comparison of tensile strength Rm [MPa]*

The graphical dependence on Fig. 6 shows the mean values of the parameter E for individual types of additive materials, including their confidence interval.
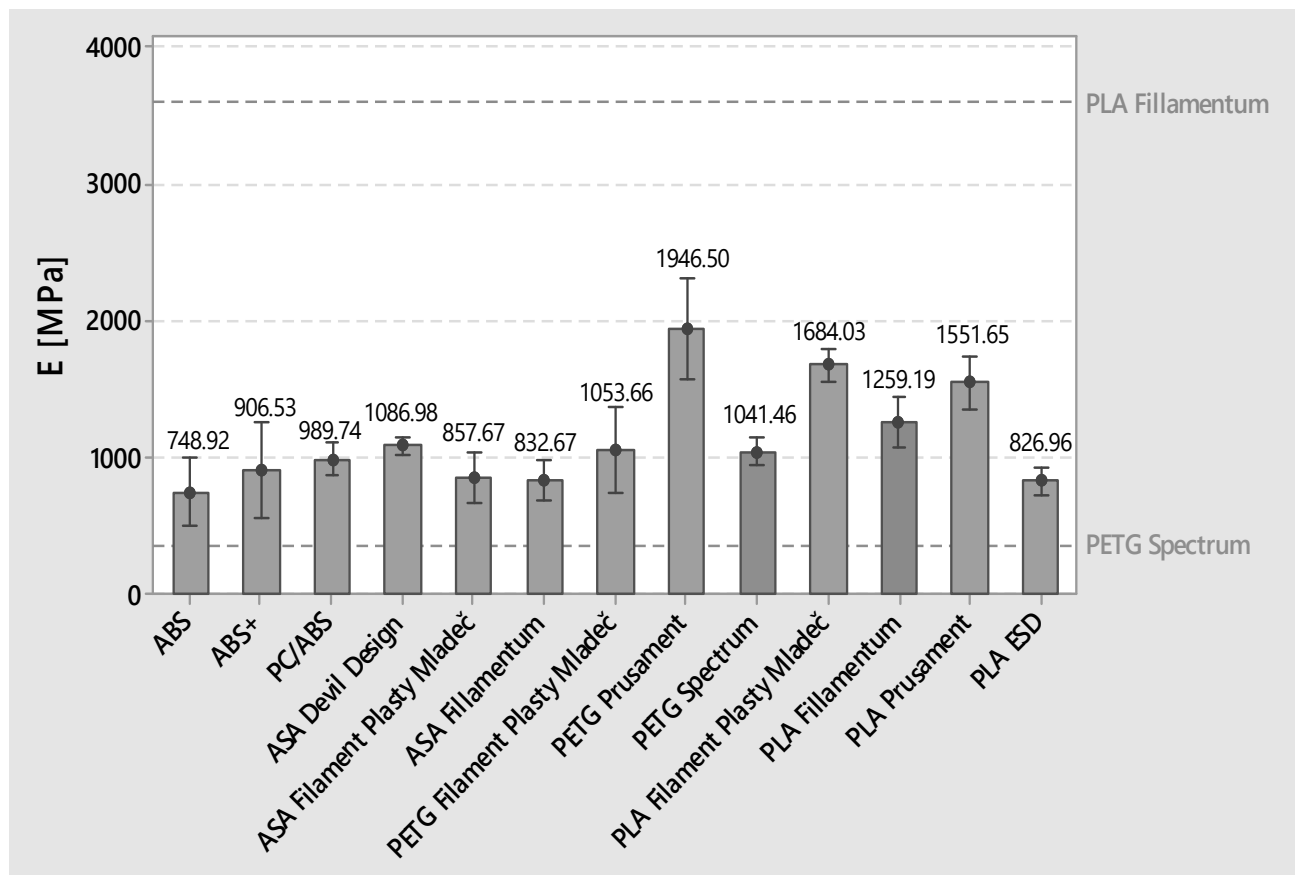
Fig. 6 *Comparison of modulus of elasticity in tension* E *[MPa]*

From the overall evaluation see Tab. 3 and Fig. 6, it can be seen that the highest modulus of elasticity in tension E was reached by the additive material PETG Prusament. The mean value of the PETG Prusament additive material exceeds the two PLA materials, and its confidence interval is much wider than that of the PLA material. During the tensile test, the PETG material showed certain problems, and therefore the best result in terms of the modulus of elasticity in tension E was achieved by the additive material PLA Filament Plasty Mladeč.

If the value of the modulus of elasticity in tension E was prescribed by the supplier in the material sheet, its determined / measured value did not reach the prescribed size (except for the additive material PETG Prusament and PETG Spectrum) see Tab. 1 [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54].

According to the available and stated values from the material sheet see Tab. 1 and Fig. 6, the max. value E (for the additive material PLA Fillamentum) and the min. E value (for PETG Spectrum additive material) is always plotted [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54].

The graphical dependence on Fig. 7 shows the mean values of the parameter At for individual types of additive materials, including their confidence interval.

From the graphical dependence on Fig. 7 it is evident that the highest mean values of ductility At reach the additive material PLA ESD. However, its confidence interval is very wide, and therefore it is not appropriate to consider this material as the best in terms of ductility. For this reason, the best elastic properties are achieved by the additive materials PLA Filament Plasty Mladeč and PETG Prusament.

According to the available and stated values from the material sheet see Tab. 1 and Fig. 7, the max. value E (for the additive material PLA Fillamentum) and the min. E value (for PETG Spectrum additive material) is always plotted [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54].

The graphical dependence on Fig. 8 shows the mean values of Shore hardness for individual types of materials, including their confidence interval. All materials have almost the same hardness. The highest hardness values are achieved by PLA Fillamentum and the lowest hardness values are achieved by PLA ESD.
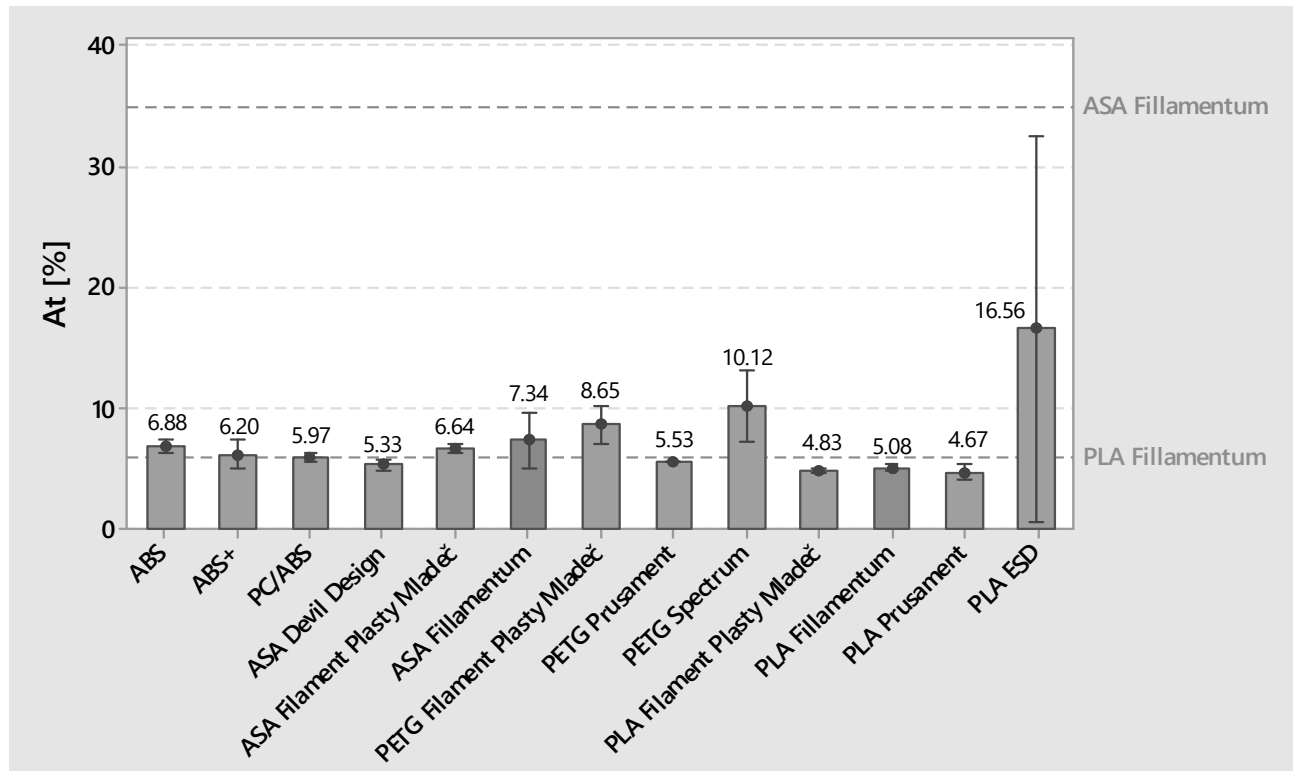
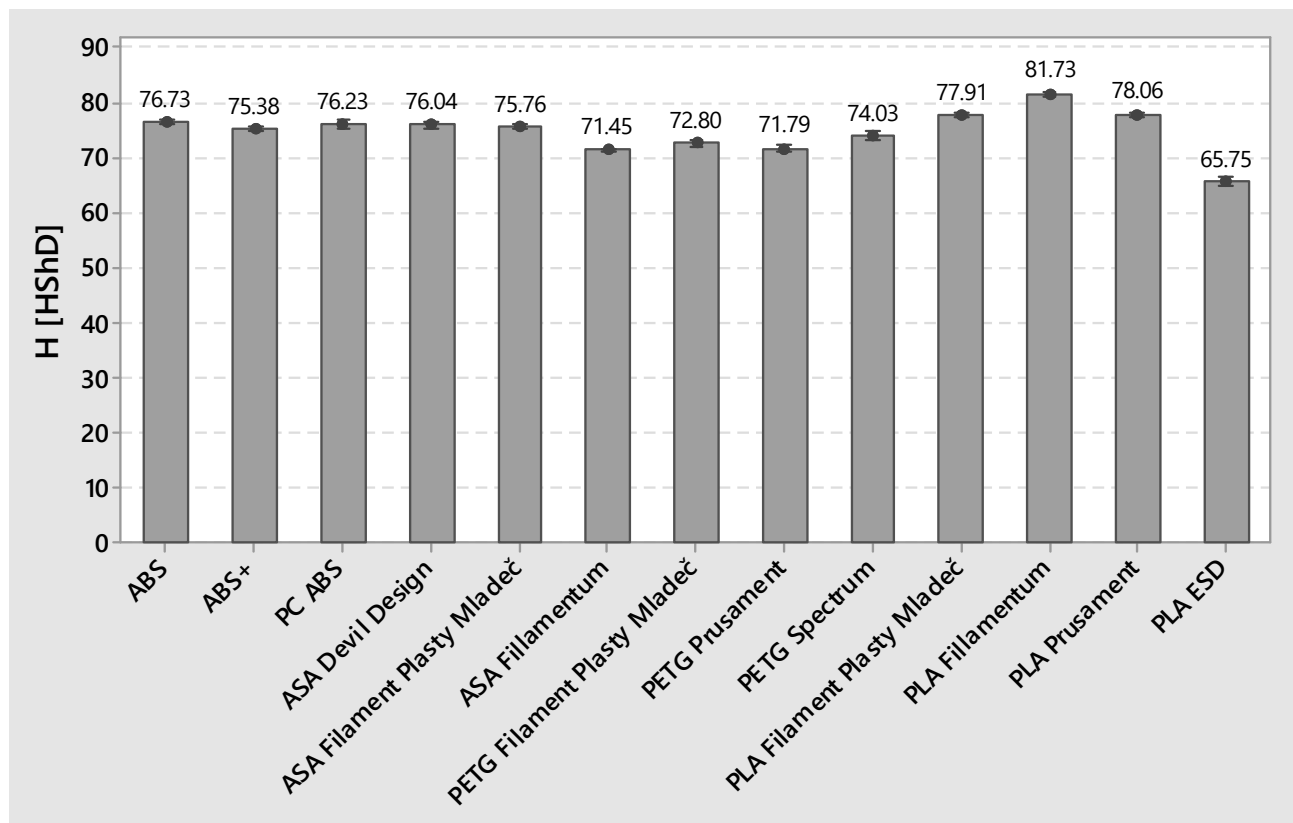***Fig. 7** Elongation comparison At [%]*

***Fig. 8** Shore hardness comparison [HShD]*

The graphical dependence on Fig. 9 shows the mean values of the ball indentation hardness for individual types of materials, including their confidence interval. From the graphical dependence on Fig. 9 it is evident that the highest hardness values are achieved by the material PLA Filament Plasty Mladeč and the lowest hardness values are achieved by the material ASA Fillamentum.
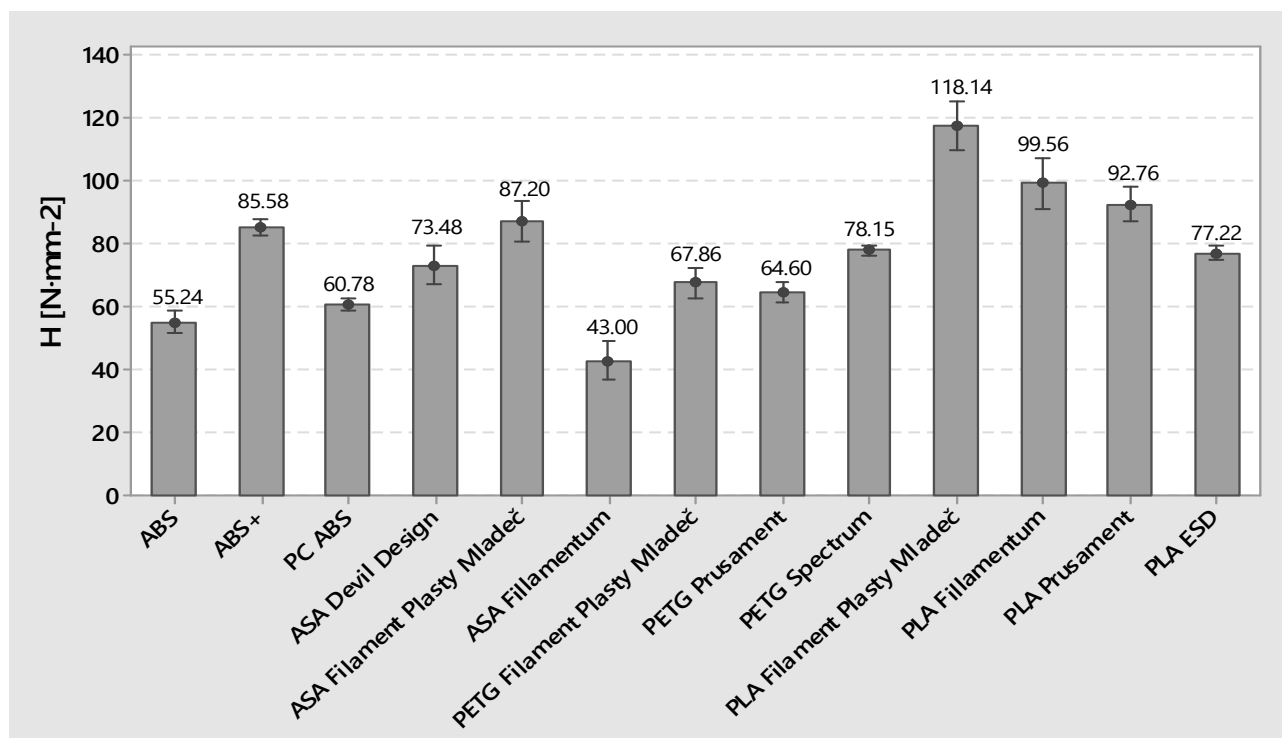
Fig. 9 *Comparison of the ball indentation hardness H [N·mm²]*

For the overall evaluation and the possibility of selecting the additive material with the best mechanical properties, an evaluation scale was prepared, where each material received a certain number of points according to the position in which it was placed after the evaluation of the measured parameters. The first position was evaluated by thirteen and the last position by one evaluation point.

In addition to the mechanical properties of the material, an economic evaluation was also performed, when a reference printing component was selected, for which the price of the material for its 3D printing was calculated. Due to the different input weight of the package of individually tested additive materials, the price of the material was converted to one gram.

The order of additive materials according to the evaluation and costs of materials in Euros [€] (according to the CNB as of 4 August 2020, 1 € = CZK 26.22) are in Tab. 4.

The best point evaluation in terms of mechanical properties was achieved by the material PLA Filament Plasty Mladeč, whose price (per material) is also the third lowest of all additive materials used. PLA Fillamentum and PLA Prusament also show good mechanical properties, but compared to the previous PLA material, their price is higher. PETG as a construction material has proven its potential and also achieves good mechanical properties. There is also a noticeable financial difference between the individual PETG materials (Tab. 4).

Tab. 4 *Point evaluation of materials and price costs*

Material	Producer	Evaluation points	Material costs [€]
ABS	Prusa	27	2.25
ABS+	Devil Design	30	2.01
PC/ABS	Filament Plasty Mladeč	35	3.09
ASA	Devil Design	33	2.22
	Filament Plasty Mladeč	35	2.87
	Fillamentum	19	3,18
PETG	Filament Plasty Mladeč	36	2.56
	Prusament	34	2.95
	Spectrum	42	2.28
PLA	Filament Plasty Mladeč	52	2.25
	Fillamentum	50	3.16
	Prusament	48	2.47
PLA ESD	3DXSTAT	13	14.71

The newly included additive materials PC / ABS and ASA Filament Plasty Mladeč appeared very well during the tests, the price of which is somewhat higher, but it will bring new possibilities when printing various components (Tab. 4).

Among the completely unacceptable material according to the determined mechanical properties, but also costs (for the material) appears PLA ESD, which during all test measurements showed the lowest values and its use will be only in necessary cases (Tab. 4).

7 Conclusions

The aim of the experiment was to determine and verify selected mechanical properties of additive materials (PETG, PLA, ABS, ABS +, PLA ESD, ASA, PC / ABS). Most of them do not have the prescribed mechanical properties. For the remaining materials, the values were compared in the experimental part. For all additive materials used, material characteristics were determined that are not specified by any of the suppliers (Shore hardness and ball indentation hardness).

From the view point of mechanical properties, the additive material PLA Filament Plasty Mladeč appears to be the best, whose price (per material) is also the third lowest of all used additive materials. Other PLA additive materials show significantly better mechanical properties than other investigated additive materials, but their price is significantly higher.

The applied additive materials must be selected according to various criteria, where it is generally necessary to take into account the different properties of different types of materials when selecting them. For example, PLA material is not suitable for long-term exposure to UV radiation, which, on the contrary, ASA material resists. The evaluation of individual materials includes their price, tensile strength, modulus of elasticity in tension, ductility and two methods of measuring hardness (Shore and ball indentation).

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