Strength Measurement on Additive Manufactured Specimens

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***Abstract*: When using some technology for production of final parts, it is necessary to know what parameters will be reached. If this parameters are sufficient for selected purpose. The same situation is with using of new or specific materials. It is necessary to test it formerly. It is necessary to test and figure out what is the strength of selected material. In additive manufacturing are used more technologies which works with wide spectrum of materials. Such technologies use materials in different forms, as liquid, powder or solid state.**

Presented paper deal withtesting of specimens which are produced on additive manufacturing device.Used device is 3D printer from the group of Fused Deposition Modeling technology (or Fused Filament Fabrication), which work with polymers filaments. Processed experiment is focused to measuring of tensile strength of produces specimens. Shape and dimensions are designed by standards. Material of produced specimens is polylactic acid (PLA), what is ecological polymer. Paper brings results about tensile strength of PLA material produced by different settings regarding prepared design of experiment.

***Keywords*: additive manufacturing, 3D printing, tensile strength, measurement, strength**

I.INTRODUCTION

Additive production is a name for production technologies that work on the principle of material adding and its layering, till creation of the final shape of the part [1-3]. These technologies are currently very popular and deployed on several levels in the industry. The systems could be used, for example, in development workshops in the design of new products, in piece or small series production, but even in special areas as airspace industry [4-6].

A wide range of materials is used. What material will be used depends on what technology is available, what type of product will be manufactured, the purpose of its use, demands on strength or flexibility, and a number of other factors. The most available technology is FDM technology. It works on the principle of melting plastic wire, which is deposited by the control program applied to the necessary places by means of a print head and a nozzle of defined diameter [5-7].

There are currently a large number of polymeric materials suitable for FDM technology. At the beginning of the development of this technology, ABS material was the most used. It is widely used, for example, in the automotive industry. ABS plastic is a durable and strong thermoplastic used in many industries [8-10]. Thanks to this, this material is ideal for conceptual prototypes, for verification of design and functionality. This material has excellent impact resistance, good strength and rigidity (Table 1) and a relatively low cost [11-13].

Table I: Basic Material properties of selected polymers

Material	ABS plus	PLA
Tensile strength (ultimate)	37 MPa	65,7 MPa
Elongation at Break	3%	6%
Flexural Strength	53 MPa	80 MPa
Heat deflection (455kPa)	96°C	65°C

The current generation of FDM devices are able to process a wide range of plastic materials. For example, they can produce components or functional parts from nylon (polyamide), PC (polycarbonate) or PLA (polylactic acid), PET (polyethylene terephthalate), but also many other composite materials [14]. The composite material always contains a polymer as a base and the additive can be various types of materials, such as wood particles, ceramics, glass, aggregates, or even carbon fibers, which ensure high strength of the manufactured parts. The ratio of base material to added particles is often 60% of a polymer such as PLA and another 40% is made up of additional particles [15-16].

Today, PLA is probably the most widely used material for FDM devices [17-18]. This is because the material is environmentally friendly, as it is made from natural raw materials and can be decomposed, for example, in a composter when it is used.As we have already written above, PLA material is ecological. It also has more other advantages compared to ABS material [19]. It is produced from renewable sources such as corn starch, tapioca roots, potatoes, starch or sugar cane (Fig. 1).

The temperature at which this material is used in production is somewhere at a level of 180 °C. For comparison, ABS plastic is processed at temperatures up to about 240 °C. PLA material do not need to have heated building platform, but ABS need to be heated. Parts made of ABS plastic tend to deform during cooling, which is a big disadvantage [20].

The PLA polymer is degradable under specified conditions. Unlike classic plastics such as ABS, PC, Nylon or others, which practically do not decompose. This eco-polymer is degraded primarily by bacteria in composters. The long chains of conventional polymers are difficult to degrade for many bacteria [21].

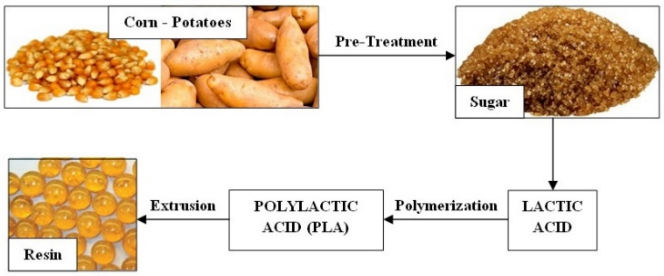

Fig. 1 Schemeof polylactic acid (PLA) production process

With PLA plastic, where the production is made from starch, the role of bacteria is much easier. PLA is fully biodegradable when composted at temperatures of 60°C and higher. Chemical formula and structure of PLA plastic is visible on Figure 2.

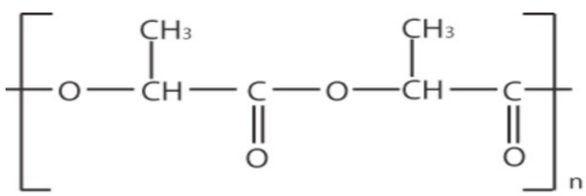

Fig. 2 Formula of Polylactic Acid material $C_3H_4O_2$ [22]

PLA material may be a suitable alternative to other conventional plastics. However, it is necessary to verify what its material properties are when applied using FDM technology. How different device settings affect these features. For this purpose, the following experiment was prepared to measure the tensile strength on parts made of PLA plastic on an FDM device.

II. MATERIALS AND METHODS

Before starting the experiment itself, it is necessary to determine its process, to select the factors whose influence on the measured quantity we will examine, as well as to select the equipment for the production of samples, the equipment for measurement and others.There will be measured tensile strength of produced specimens. Design of specimens is visible on Figure 3.

The dimensions are adapted to our conditions to be suitable for available testing device. In our case it is Universal measurement device Inspekt Desk 5N (Figure 4).

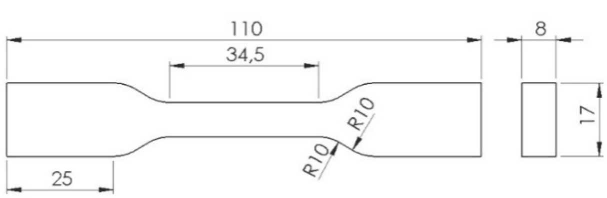

Fig. 3 Design of specimen suitable for tensile strength testing

Device is fully supported with computer and all measured data are automatically collected to the software database and could be easy evaluated by digital methods and stored for example in excel file.

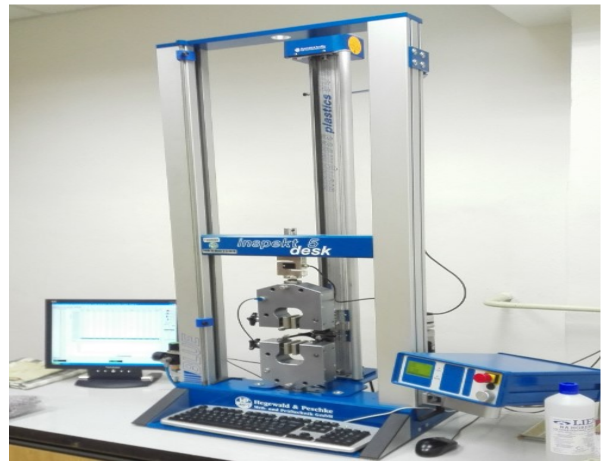

Fig. 4 Universal testing device Inspekt Desk 5 kN

Specimens are produced on FDM additive manufacturing device with trade description DeeGreen (Fig. 5). Technical information are described in Table I. Device could work with different materials. For purpose of our experiment choose ecological PLA plastic (polylactic acid). Material have been printed with temperature 185°C and printing speed 50mm/s.

Fig. 5 DeviceDeeGreen for FDM production

TableI : Technical Parameters of FDM printer

Rapid Prototyping Technology	FDM
Printing area	150x150x150 mm
Precision	0,1 mm
Layer thickness	0,15 / 0,1, / 0,2 mm
Nozzle diameter	0,4 mm
Printing speed	90 mm/s
Material	PLA, PVA
External dimensions	495x395x390 mm
Weight	20 kg

As mentioned above, for experiments have to be chosen some factors which will be changed and operated. The purpose of experiment is test, what is the weight of this factor to measured tensile strength. From the previous experiments and testing we know that the mass of material deposited within the component will influence the final strength of it. This assumption is also basedon the mechanical engineering theories. To be sure that the change of this factor let the influence on measured tensile strength, we chose 25% infill and 50% infill of inner specimen space. The next chosen factor which will be changed during the printing of specimens is layer thickness or we can call it layer height. 3D printer allows define this parameter by our own. Also based on previous experiences we chose two levels, 0,1mm and 0,2mm. We expect that there will be difference in measured values of tensile strength. In Table II are the described factors and also the levels of this factor.

Table II: Factors and their Levels

Factors	1	2
A – Filler volume	25%	50%
B – Layer Thickness	0,10 mm	0,20 mm

III. EXPERIMENTAL MEASUREMENT AND EVALUATION

When is clear what we want to measure and what are the selected factors and their levels, we can make design of experiment. Depending on selected factors and their levels we prepared full factors experiment (complete experiment plan). This plan consists from all possible combinations of all factor levels. It is the simplest and the most comprehensive plan of experiment. Allows to estimate all parameters of regression model and easy find outinfluence and weight of most important factors and their interactions to measured parameters [6].

If we have in our case k = 3 factors and measurement will be realized on h1 = 2 levels for one factor and on h2 = 3 levels for 2 factors. With accepted q = 3 repetitions, the total number of measurement will be Nc = q · h1k · q·h2k = 3 · 21 · 32 = 54 repetitions. The design of experiment is shown in Table 4.

Based on described materials and methods, the experiment was performed. Measurement was repeated 10 times for each setting, or better said that there have been produced 10 specimens with the same settings. This is because we need enough of data to be able make statistical evaluation of measured data. Average values from each experiment are calculated by formula (1) and are visible in Table III.

$$R_m = \frac{\sum_{i=1}^{k} R_m}{k} \quad (1)$$

where i = 1, 2, 3...k (k = 10)

When we look on the numbers, we can say that the values from experiment No. 1 and No. 3. Are very close. The same situation is with numbers from experiments No. 2 and No.4. There is just small difference.

Much bigger and significant difference is between this two groups of experiments. The visual comparison is possible also from graphical comparison on Fig. 6.

TableIII: Plan of Experiment with measured values of tensile Strength

No.	A	B	R_{m1} (MPa)	R_{m2}(MPa)	R_{m3}(MPa)	R_m (MPa)
1	1	1	27,1	26,2	27,8	27,03
2	2	1	29,9	29,1	30,8	29,93
3	1	2	26,3	26,6	27,5	26,8
4	2	2	30,7	30,7	30,7	30,70

When we look on design of experiment – combination of factors and their levels – we can recognize what make the change within measurement of tensile strength.

Comparing experiment 1 and 3, the only change is in factor B, what is layer thickness. The difference of this average values is just 0,23MPa.

Also when we compare experiments 2 and 4, where the only change is in factor B (layer thickness). And the difference of average values of this experiment is just 0,77MPa.

This change is not significant compare to the others measured values. From this we can state that the layer thickness is not so significant factor with selected levels. This expression is valid for described experiment.

On the other hand, when comparing experiments 1 and 2, or experiments 3 and 4, the difference between values is 2,9MPa and 3,9MPa. The differences are much significant. When we see the design of experiments for this, we can see that the change is made by change of factor A – Filler volume.

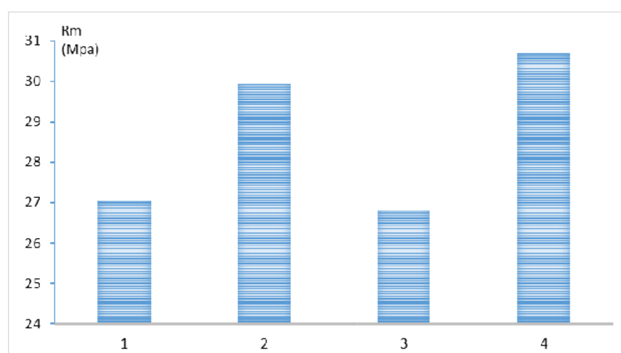

Fig. 6 Measured values of Tensile Strength

IV. CONCLUSIONS

Based on the realized experiments which is described above and based on measured values we can say that the selected factor A (Filler volume) have significant influence to measured tensile strength so it is very important take this factor info the consideration when preparing the parts for production by FDM technology. From presented results in Table III and also graphical representation of measured values (Fig. 6) is possible to see that there are differences between measurements 1 and 2 (2,9MPa, 9,7%) and between measurements number 3 and 4 (3,9MPa, 12,7%).

The next factor B (Layer thickness) do not have significant influence to measured tensile strength. When compare the measured values from measurements number 1 and 3, the difference is only 0,23MPa. Comparing measurements 2 and 4, the difference is only 0,77MPa. In percentage it is only around 0,85% or 2,85%, what is very low compare to factor A change.

So by changing of percentage of infill we can very good control strength of produced parts. Layer height influence this strength in the minimal way.

It is necessary to say that the others experiments should follow to be able specify also others factors which are significant for different properties of produces parts.

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