



(RESEARCH ARTICLE)



Strength produced parts by fused deposition modeling

Juraj Beniak *, Miloš Matúš, Ľubomír Šooš and Peter Križan

Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering, Nam. Slobody 17, 812 31 Bratislava, Slovak Republic.

Publication history: Received on 15 November 2020; revised on 23 November 2020; accepted on 26 November 2020

Article DOI: <https://doi.org/10.30574/gjeta.2020.5.2.0101>

Abstract

The aim of using additive manufacturing technologies is to be able to produce a wide range of component designs on a single device, using a wide range of materials and minimizing material consumption. There are several technologies that work on different principles. The present article is focused on Fused Deposition Modeling (FDM) technology, which is focused on the application of layers of semi-molten polymer. The advantage is the lower cost for obtaining of FDM device, but also the low operation cost. The output of production are complex components designed for prototyping, but also for final use. Due to the fact that there is requirement to produce parts also for final use, it is necessary to know the strength properties of the parts after production. Because the structure of parts volume is not homogeneous, it is not possible to subject it to conventional calculations and simulations, but it is necessary to take into account the specifics that are produced during production by FDM technology.

The present paper shows the results of experimental determination of the tensile strength of manufactured parts. A series of samples with different properties was used on the FDM device and the tensile strength of the components was subsequently measured. The measured values were compared and evaluated.

Keywords: Additive manufacturing, Fused deposition modeling, FDM, Material strength, tensile strength,

1. Introduction

Additive manufacturing uses a large number of materials and technologies for the production of parts. It uses solid materials (in solid form), liquid materials, but also materials in powder form. Various principles are used in the production of parts, from the simplest, which is the melting of plastic in the form of plastic wire and the application of such a fiber layer by layer, to the use of a laser beam to sinter a thin layer of metal powder to obtain a solid layer of the manufactured part [1, 2, 3].

The most widespread technology is just the melting of plastic wire and the application of semi-liquid material, the fiber next to the fiber and layer by layer until the production of the entire volume of the part. The technology is called Fused Deposition Modeling (FDM) or Fused Filament Fabrication [4, 5].

The advantage of such a method of production is the possibility to produce a specific and complex geometry, which cannot be produced in any other way. Another advantage is that it is not necessary to use other equipment, but only one production equipment will suffice. It is a very widespread and currently very popular technology. The most common material in this area is ABS material (acrylonitrile butadiene styrene). In this area, too, there is a whole range of polymers suitable for the production of various parts for various applications [6, 7, 8]. The need for practice is to know the material and strength properties of manufactured parts. Although the material data sheets contain detailed

* Corresponding author: Juraj Beniak

Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering, Nam. Slobody 17, 812 31 Bratislava, Slovak Republic.

information on the materials used, the properties of parts produced by FDM technology are not given [9, 10]. The various production methods are not taken into account and also the fact that the volume of parts produced is not homogeneous as in the case of the production of plastic parts in a conventional manner. This article provides a description of the experimental determination of the tensile strength of manufactured parts, taking into account the different method of production and positioning of parts during production [11, 12].

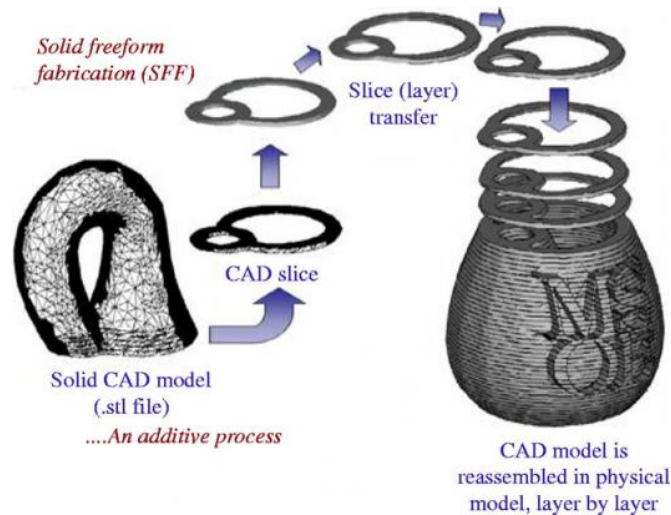


Figure 1 Description of 3D printing process – *layer manufacturing* [3]

2. Material and methods

As is mentioned above, the paper is focused to ABS thermoplastic polymer as most used material for FDM printing. This is why we chose this kind of material. For production is selected Dimension SST 3D printer. This device is fully automated for production of plastic parts, with automatic support material placement, so the quality of manufactured parts is really good. Setting of temperature and printing speed is also defined by producer database. The production chamber is heated to ensure the best environment and prevent warping, which is the main disadvantage of this material. For prepared experiment is stated the design of produced specimens, which is shown on Figure 2 and the produces and tested parts are on Figure 3.

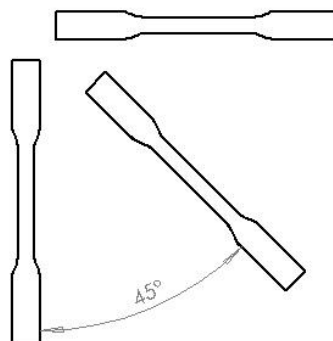


Figure 2 Orientation of specimens within manufacturing process

The main purpose is to determine the effect of product positioning in the production area of a 3D printer. It is a positioning in two directions. It is a horizontal direction where we orient parts with either a rotation angle of 0 degrees, 45 degrees, or 90 degrees. Such is the location of the part and the printing platform (Figure 2). We determined only 2 positions in the vertical direction. 0 degrees and 55 degrees. Other positions were not specified because it was not necessary to determine the material properties. If the part is manufactured in the vertical direction, it has a very low strength because it tears in the direction of application of the layers where the strength is lowest. We chose an angle of 55 degrees, at which the software does not need to apply a supporting structure and printing is very fast.

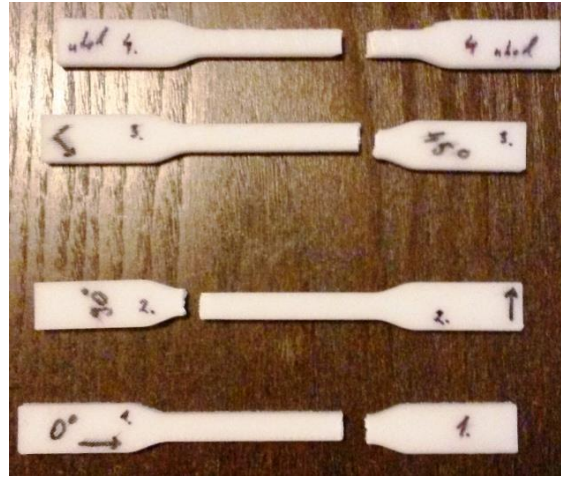


Figure 3 Presentation of tested specimens after experiment

All models were produced with 100% filling, i.e. the maximum possible amount that is possible when filling the interior of the component. This setting allows us to measure the maximum possible strength of manufactured parts. Any reduction in the volume of applied layers of material also results in a reduction in the strength of the manufactured parts. When setting the production parameters, the height of the individual applied layers was chosen to the level of 0.33 mm. For a component type such as a test sample, this setting is optimal. The design of the experimental plan can be seen in Table 1, where the combinations of model orientation in the x-y plane and in the x-z plane are given.

Table 1 Experiment design for tensile strength testing

Sample	orientation x-y	orientation x-z
1	0°	0°
2	90°	0°
3	45°	0°
4	0°	55°

When layering the model using the service software and then checking the individual layers, it is possible to monitor the path of the extruder, the direction of the individual applied fibers. Examples of fiber routing are shown in Figure 4 and Figure 5. This could affect the strength of produced parts.

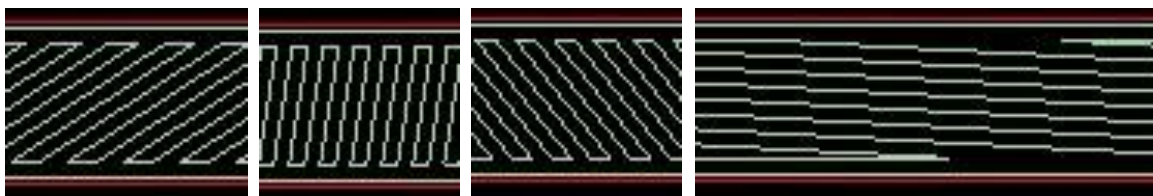


Figure 4 Extruded fibers orientation – sample 1



Figure 5 Extruded fibers orientation – sample 3

3. Results and discussion

Produced parts are tested on universal testing machine and measured maximum tensile force and collected are all data during the whole measurement. Diagram from each measured samples are shown on Figure 6. Measured and calculated values are also visible in Table 2 and Figure 7.

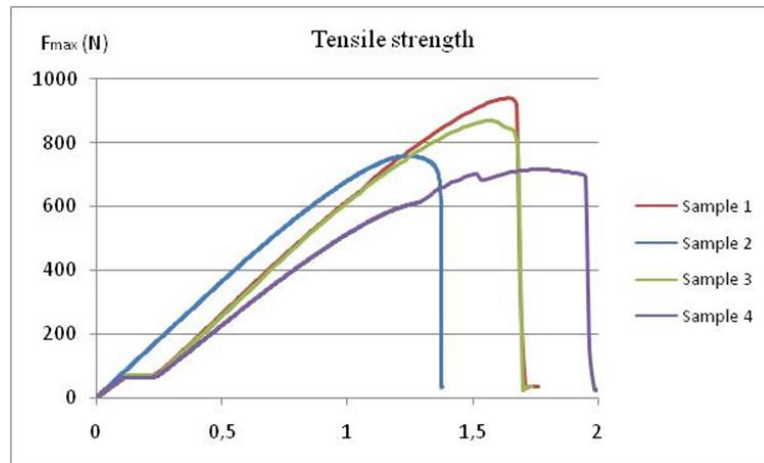


Figure 6 Measuring diagram for tested specimens

Based on mathematical formulas (1) and (2) Young's modulus of elasticity E (1) and Ultimate Tensile Strength σ (3) were calculated and checked.

Young's modulus E is expressed as ratio of Tensile strength and Extensional strain in elastic (initial, linear) part of stress-strain curve:

$$E = \frac{\text{tensile stress}}{\text{extensional strain}} = \frac{\sigma}{\epsilon} = \frac{F_{max}/A_0}{\Delta L/L_0} = \frac{F_{max}L_0}{A_0 \Delta L} \quad (1)$$

where: E is the Young's modulus (modulus of elasticity);

F_{max} is the maximum measured force;

A_0 is the original cross-sectional area through which the force is applied;

ΔL is the amount by which the length of the object changes;

L_0 is the original length of the object.

σ is Ultimate Tensile Strength

$\Delta\sigma$ is percentage deviation from table values of Ultimate Tensile Strength

The strain, ϵ , can be measured by integrating the change of unit current length. This measure of strain is called true strain or logarithmic strain [8]:

$$\epsilon = \int_{L_0}^L \frac{1}{L} dL = \ln\left(\frac{L}{L_0}\right) = \ln(\lambda) \quad (2)$$

The ultimate tensile strength is calculated as follow:

$$\sigma = \frac{F_{max}}{A_0} \quad (\text{MPa}) \quad (3)$$

From the technical data sheet of used material (ABS) is possible to reach basic material properties. This values are on the next step used as table values for comparison to see difference between conventional material properties and material properties of specimens produced by FDM technology.

Ultimate Tensile Strength $\sigma_{tab} = 40\text{MPa}$

Young's modulus of Elasticity $E_{tab} = 2200\text{MPa}$

Elongation at break $\varepsilon = 50\%$

All the measured and calculated values are mentioned in Table 2. If we take the 40MPa tensile strength from technical data sheet as 100%, our measured and calculated values of tensile strength are evaluated in Table 2. The maximum reached value with sample 1 is 24,9MPa, what is 62,3% of table value. This is the best value with 0 degree orientation in both planes. The lowest value is 18,9MPa reached by sample 4 and it is just 18,9%. This lowest value is caused by vertical orientation of specimens in the production chamber, where the specimens are braked between produced levels. Instead of others samples which are oriented on the production platform and the layers are oriented longitudinal not across and in case of sample 4.

All measurements are made and repeated minimum 7 times, because the statistical evaluation process.

Table 2 Measured and calculated values

Sample	orientation x-y	orientation x-z	σ (MPa)	$\Delta\sigma$ (%)	F_{max} (N)	E (MPa)
1	0°	0°	24,9	62,3	939,5	1139,5
2	90°	0°	20,1	50,3	758,4	1124,54
3	45°	0°	23,0	57,5	870,1	1029,82
4	0°	55°	18,9	47,3	715,1	749,03

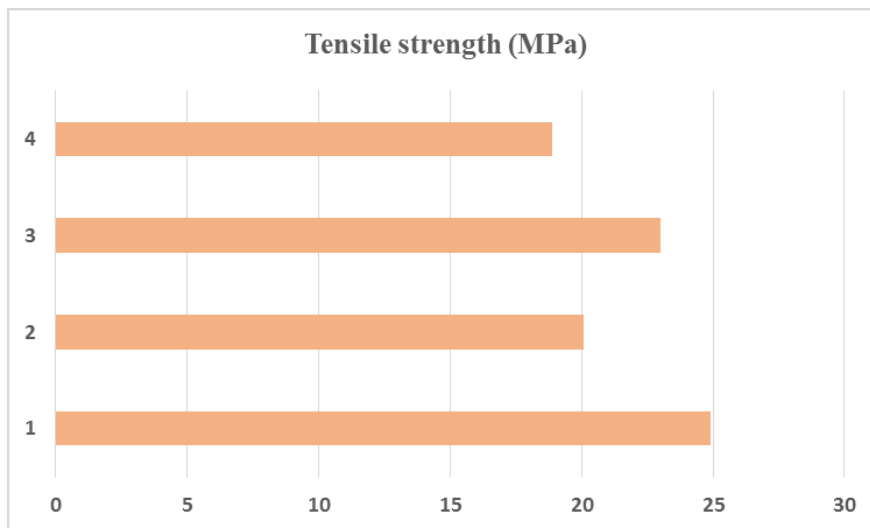


Figure 7 Calculated Tensile strength

4. Conclusion

From the measured and calculated values is possible to state, that the maximum strength of parts produced by FDM technology in on the level 62,3% from the value reached by conventional production technology. There is significant measured difference between samples produced with specified orientation in horizontal and also vertical direction.

Specimens produced in 45 degree direction have lower tensile strength as specimens produced in basic orientation. In case of sample 4 is possible to see that there is the lowest tensile strength value, because its across layering.

Compliance with ethical standards

Acknowledgments

The paper is a part of the research done within the project APVV- 18-0527 “Development and optimization of additive manufacturing technology and design of device for production of components with optimized strength and production costs” funded by the Slovak Research and Development Agency.

The paper is a part of the research done within the project APVV- 16-0485 “Biomass compacting tools cast from the advanced wear-resistant cast irons”. The authors would like to thank to the Slovak Research and Development Agency

Disclosure of conflict of interest

There are no conflict of interest.

References

- [1] Rapid Prototyping & Manufacturing Technologies, IC LEARNING SERIES, The Hong Kong Polytechnic University, Industrial Centre
- [2] Williams Ch., Rapid Prototyping with Metals: A Review of Technology and Associated Material Properties, Georgia Institute of Technology, Systems Realization Laboratory, November 2003,
- [3] SIGLER D. Additive Manufacturing for Electric Motors [Internet], [Cited 2014 Mar 04]. Available from: <http://blog.cafefoundation.org/additive-manufacturing-for-electric-motors/>
- [4] PHAM D.T, DIMOV S. Rapid Prototyping, A time compression tool, Manufacturing engineering centre, Cardiff University.
- [5] Chua C. K, Leong K. F, Lim C. S. Rapid Prototyping, Principles and Applications, Nanyang Technological University, Singapore, World Scientific Co. Pte. Ltd, 2003; ISBN 981-238-117-1
- [6] BENIAK J. Rapid prototyping and accuracy of created models, ERIN, - ISSN 1337-9089. roč. 5, č. 6 (2012), s. 2-9
- [7] Lipina J, Kopec P, Marek J, Krys V. Thread variants and their load capacity in components made by rapid prototyping technology, ERIN, - ISSN 1337-9089. roč.6, č. 11 2013; s. 11-15.
- [8] Persson H, Adan K. Modeling and experimental studies of PC/ABS at large deformations, Div. of Solid Mechanics, Sony Ericson, Lund, Sweden, 2004.
- [9] Samykano M, Selvamani S.K, Kadirgama K. Mechanical property of FDM printed ABS: influence of printing parameters. Int J Adv Manuf Technol 2019
- [10] Rajpurohit S, Dave H. Effect of process parameters on tensile strength of FDM printed PLA part. Rapid Prototyping Journal. 2018.
- [11] Kung C, Kuan H, Kuan C. Evaluation of tensile strength of 3D printed objects with FDM process on RepRap platform, 2018 1st IEEE International Conference on Knowledge Innovation and Invention (ICKII), Jeju, 2018
- [12] Warnung L, Estermann S, Reisinger A. Mechanical Properties of Fused Deposition Modeling (FDM) 3D Printing Materials. RTEjournal - Fachforum für Rapid Technologien, Vol. 2018.