EVALUATION OF THE IMPACT OF PRODUCTION PARAMETERS ON THE FINAL PROPERTIES OF THE PART MADE OF NYLON 12 WITH RAPID PROTOTYPING TECHNOLOGY (FDM)

JIRI SAFKA, MICHAL ACKERMANN, MARTIN SEIDL, LUBOS BEHALEK, JIRI BOBEK, JAKUB KLUNEJKO

Technical University of Liberec, Liberec, Czech Republic

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e-mail: jiri.safka@tul.cz

Nylon is a widespread polymer material employed primarily for engineering applications. Its rheological behavior is suitable for a wide range of manufacturing techniques which produce parts with very specific properties. Representatives of prototype systems are included among these production technologies and this article is focused especially on 3D printing. FDM technology, that allows processing of nylon filaments, was selected to analyze the effect of various processing parameters on the final properties of the product and the overall production procedure. The effect of orientation of the components in the production machine work space on the final strength and structural compactness was analyzed. The product quality and overall economic aspects, based on production time and the total amount of material, including the supporting materials were other evaluating criteria.

KEYWORDS

fused deposition modelling, nylon 12, tensile test

1 INTRODUCTION

In today's technical practice, 3D printed parts are getting more and more employed in direct applications as structural elements. This step is nothing but natural because it dramatically shortens the time needed to obtain functional part or an assembly. As a consequence, influence of various mechanical loads and long-term influence of the environment to the final part must be taken into account. Due to demand of the market, materials and 3D printing technologies themselves are being constantly developed. This article deals with Nylon 12, a thermoplastic material which can be processed with use of Fused Deposition Modelling (FDM) technology. Final parts made with selected approach show outstanding mechanical properties and chemical resistivity [Gross, 2014]. In this work, the influence of part orientation during building on its overall mechanical performance is studied.

The principle of the FDM technology is shown in Fig. 1. During the building process, input material in the form of the filament is extruded via heated nozzle. Thin fiber of the melted material is then spread in horizontal plane according to the STL data. In the next step, build platform is lowered in vertical direction in the extent of corresponding layer thickness and the whole process is repeated. Crucial element of the FDM process is definition of support structures which provide additional reinforcement of the model and which preserve it form collapsing. Typically, support structures are possible to be removed either chemically (dissolving in appropriate solution) or mechanically.

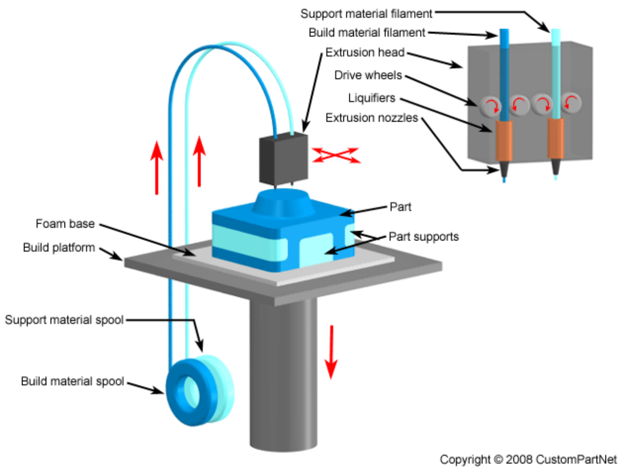

Figure 1. Principle of the FDM technology [Custompartnet.com 2015]

Drawbacks of the FDM technology are possible distortion and shrink of the final part due to applied heat and subsequent cooling [Sun 2008]. On the other hand, such issues can be minimized with choice of suitable technological conditions [Hossain 2013, Montero 2001].

2 MATERIAL AND METHODS

Specimen which was selected to test the influence of part orientation to its mechanical properties is shown in Fig. 2. Specifically, the part is tensile test specimen which is commonly used for determination of mechanical properties for plastic materials. Shape and dimensions were selected according to EN ISO 527-2.

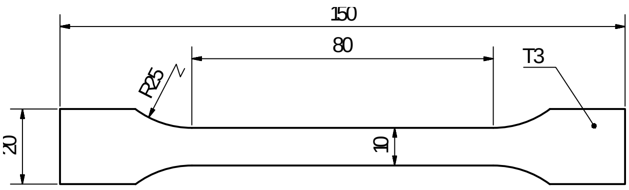

Figure 2. Tensile test specimen

Parametric CAD model of the specimen was created in Autodesk Inventor 2017 and exported to standard STL format. In the preprocessing stage of the print which was done in Insight software, the part was sequentially positioned in four different orientations with respect to building direction (Fig. 3). First three models are tilted around longitudinal axis in following angles: 0°, 45° and 90°. With this setup, commonly used layering of the material is covered. Last position of the specimen refers to the best surface orientation. According to the manufacturer, final model should have the best visual appearance when using this orientation. For each of the part orientation, five specimens were printed in order to verify repeatability of tensile test.

2.1 3D print of the specimens

After the preprocessing stage was done, all the parts were printed on Fortus 450mc machine (Stratasys Ltd.). Layer thickness was set to 178µm and corresponding diameter of nozzle with commercial label T12 (nozzle diameter of 0.012 in) was selected. Physical models were supported with SR-100 material during building process.

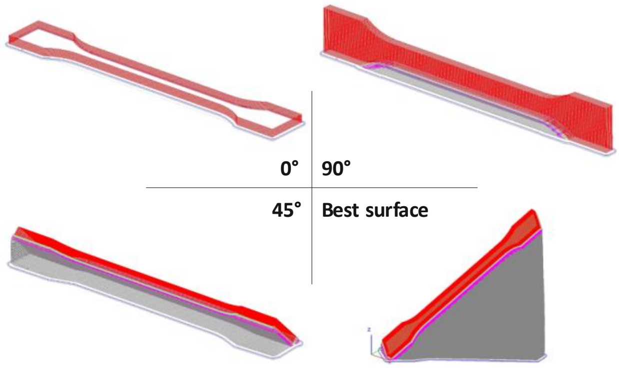

Figure 3. Orientation of the specimens

In the Fig. 4, output of 3D print is shown. Last step of the fabrication was removing of the samples from building sheet and dissolving of supports in sodium hydroxide solution.

Figure 4. Specimens after print.

2.2 Tensile tests

3D printed specimens were subjected to standard tensile test which were carried out on TiraTest 2300 universal testing machine. Tests were done under position control with load rate of 50 mm/min. During the testing procedure, strain was monitored with use of Epsilon 3542-010M-025-ST extensometer (Fig. 5) and force response of the material was recorded using 100 kN load transducer (producer A.S.T. GmbH).

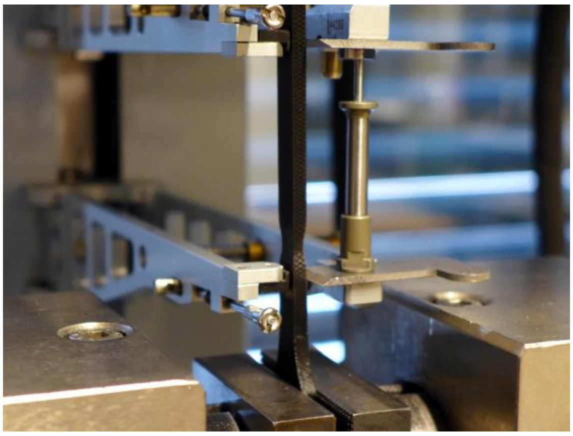

Figure 5. Tensile test of the specimen

3 RESULTS

Cross-sectional dimension of each tensile test specimen was measured with use of digital caliper in order to obtain data for calculation of engineering stress. Strain data were determined according to readings from extensometer and known initial length of 50 mm.

In Fig. 6 – 9, all the tensile test diagrams are shown in engineering stress – strain coordinates. In some cases, the rupture occurred outside of monitored length of the specimen. Specifically, such condition is apparent in the case of specimens which were tilted 45° and 90°around longitudinal axis. With respect to consistency of tensile testing data, the samples which broke outside of extensometer's clips were excluded from final evaluation.

In general, specimens of the same orientation show very good repeatability of measurement. Especially the initial stages of the diagram up to tensile strength of the material are almost coincident.

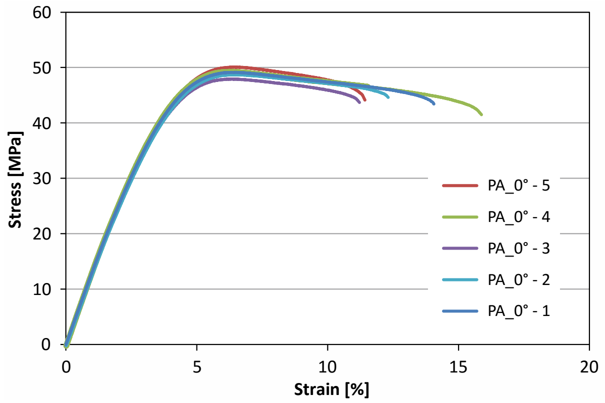

Figure 6. Tensile test diagram; specimen orientation 0°

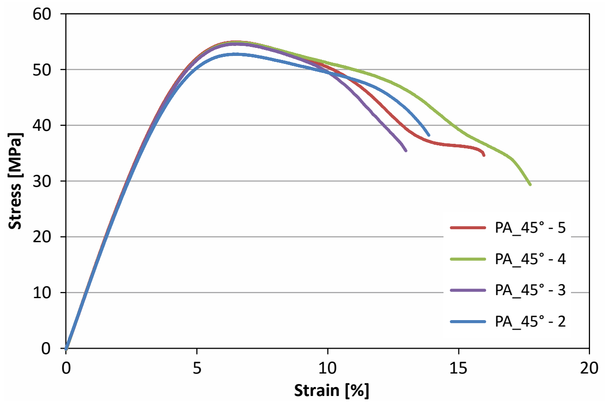

Figure 7. Tensile test diagram; specimen orientation 45°

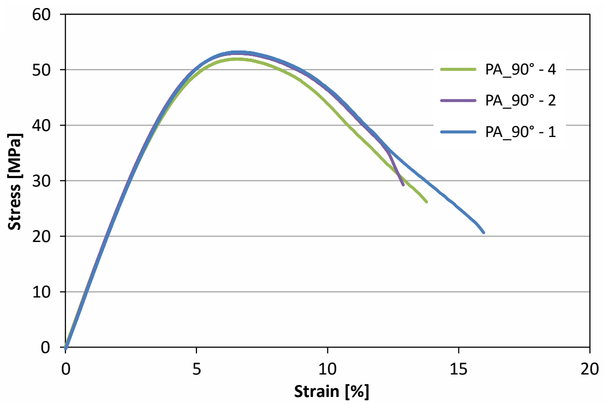

Figure 8. Tensile test diagram; specimen orientation 90°

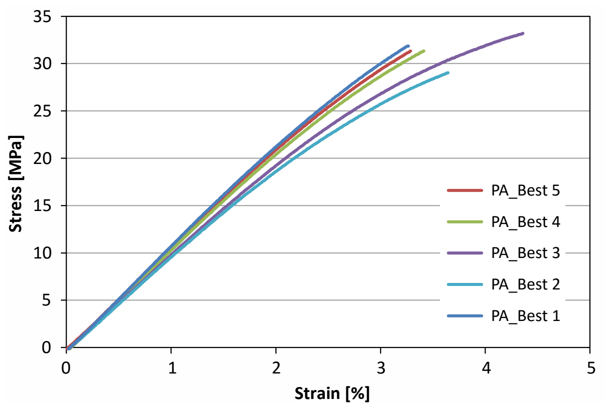

Figure 9. Tensile test diagram; Best surface

In the following bar graphs (see Fig. 10 and 11), yield stress and elongation at break are displayed, respectively. These values are depicted as mean value together with its standard deviation for the given set of the specimens. Due to the fact that yielding limit was not reached in the case of best surface orientation, the quantity is substituted with maximal achieved stress. As it can be seen, lowest values of the stress and elongation at break show specimens which were positioned in best surface orientation.

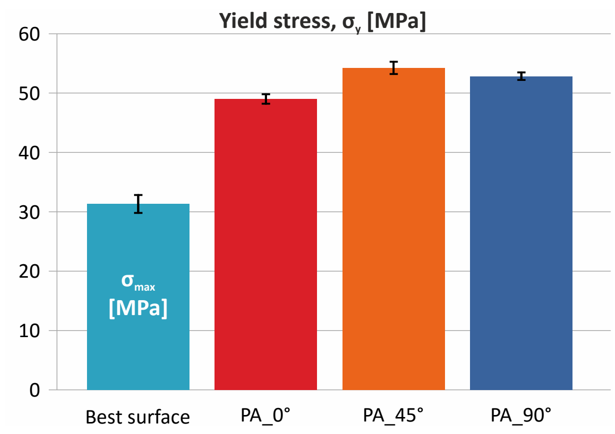

Figure 10. Tensile strength [MPa]; Mean (SD)

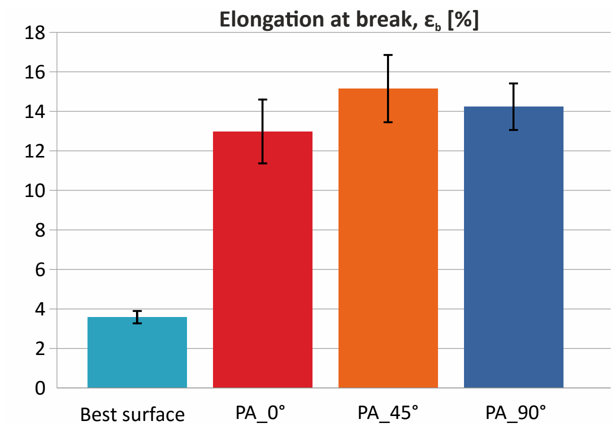

Figure 11. Elongation at break [%]; Mean (SD)

Last diagram (Fig. 12) maps Young's modulus of the material for individual groups of specimens. Once again, lowest value can be found in the case best surface orientation. For all the other orientations of the samples, the value of Young's modulus varies only in a small interval of MPa.

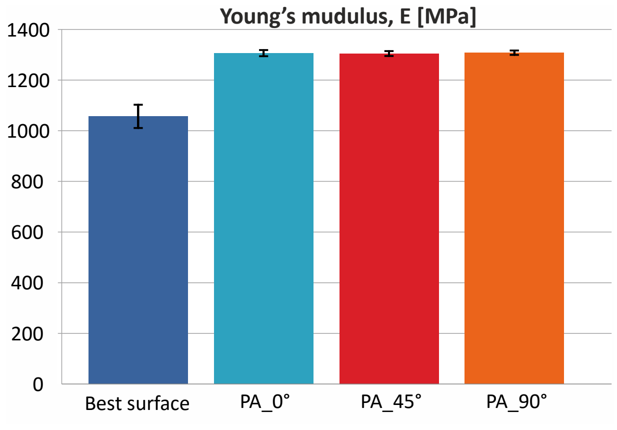

Figure 12. Tensile strength [MPa]; Mean (SD)

Apart from displayed stress-strain diagrams, the shape and form of specimen's rupture was evaluated. In the Fig. 13 it can be seen that specimens which were built in 45° and 90° position show distinct necking of the cross-section. These samples also show highest values of tensile strength. As it was mentioned in previous sections, best surface specimens do not even reach yielding limit of the material and it breaks due to unsufficient bond between individual layers. Consequently, the form of the specimen rupture corresponds with such damage which can be found in the case of brittle materials.

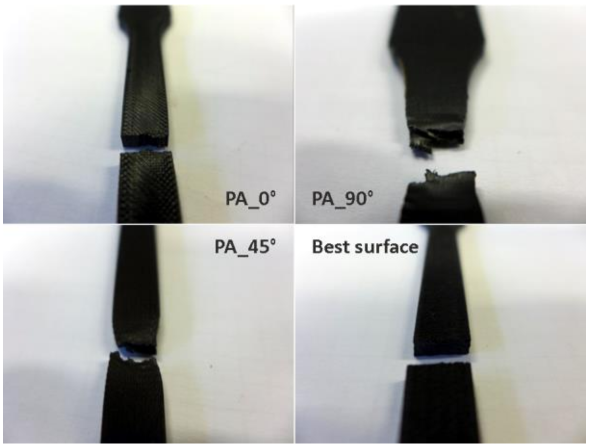

Figure 13. Typical fracture surfaces for individual orientations

4 DISCUSSION

As apparent from the tensile test diagrams, the specimens which were positioned in angles 0°, 45° and 90° show standard behavior during mechanical loading. Diagram starts with linear part which is followed by nonlinear response to loading. After the tensile strength of the material is reached, value of stress begins to decrease with increasing elongation. Such decrease in stress – strain characteristics is present until rupture of the specimens occurs.

On the other side, specimens which were positioned to obtain best surface quality broke earlier than it could reach yielding limit of the material. Such condition is most probably not caused by behavior of the material but due to the inner structure of the specimens. Individual layers are likely to be insufficiently connected and thus the structure cannot withstand increased loading. Similar observation is published in the work of Knoop and Schoeppner [Knoop 2015] for specimens which were built in the upright orientation, i.e. perpendicularly to the building plate. Such orientation was not contained in presented study because main interest was focused on best surface alignment.

Another comparison can be made for the quantities which were extracted from tensile test data. In the publication of M. Ghahremanpour et al. [Ghahremanpour, 2013], the authors report value of yield stress and Young's modulus for injection molded PA 12 specimens. The average values are 36,5 MPa for yield stress and 940 MPa for Young's modulus. In this case, PA 12 processed with use of FDM technology shows better mechanical performance than molded material. On the other hand, its elongation at break is considerably lower than in materials processed with use of conventional technologies (120 – 300% [Matbase.com 2015]).

5 CONCLUSION

In this paper, the influence of part orientation during 3D printing with use of Fused deposition modelling method was studied. Results show that mechanical performance of the material is strongly dependent on the model orientation. Before each building job, the position of the model should be placed in such direction that the inner structure is loaded parallel to the filament building paths.

Worst mechanical performance was observed in the case of specimen which was positioned in "best surface" orientation, i.e. tilted in 45° and 45° in horizontal axis. Individual layers are insufficiently connected and resulting structure causes premature rupture of the specimen during mechanical loading.

In comparison with injection molded specimen, the PA 12 processed via FDM technology show higher mechanical performance (Young's modulus and yield stress). On the other hand, elongation at break is considerably lower.

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CONTACTS:

Ing. Jiri Safka, Ph.D.
The Institute for Nanomaterials, Advanced Technology and Innovation
Technical University of Liberec
Studentska 2, 461 17 Liberec 1, Czech Republic
Tel.: +420 485 353 801
e-mail: jiri.safka@tul.cz
https://cxi.tul.cz