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Tensile Strength Testing of Samples made of ABS-M30 Polymer Using FDM Technology

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Abstract. The article details the principle behind Fused Deposition Modelling (FDM) technology. Strength tests were carried out on a Stratasys FORTUS 400mc industrial 3D printer. Prints of the strength specimens were made in different orientations in the working chamber of the machine.
Keywords: rapid prototyping, FDM/FFF technology, tensile strength, rapid prototyping

1. INTRODUCTION

Additive manufacturing is one method of producing physical three-dimensional objects from a digital computer model. The first incremental technologies were developed in the 1980s. These techniques were based on building an object by applying layer upon layer of material [1]. Depending on the type of additive technology, the build material can be plastic, light-cured resins, metal alloys, ceramics or biochemicals. Incremental technologies can be thought of as the opposite of cavity machining (machining, erosion, friction). Additive manufacturing technologies have mainly found their way into prototyping due to the short manufacturing time and ease of modification.

The most common additive manufacturing technology is Fused Deposition Modelling (FDM)

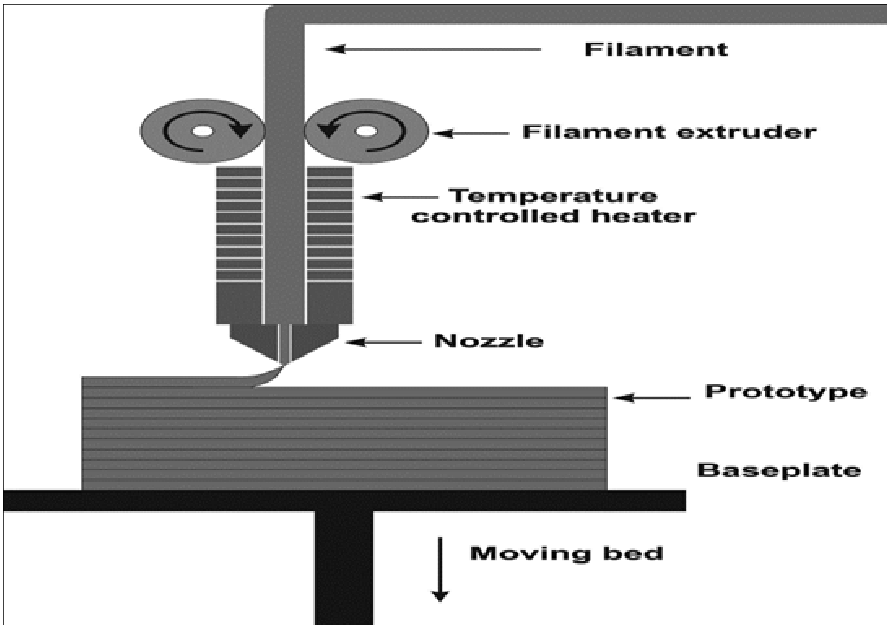

Fig. 1. Principle of FDM technology [5]

The method was developed in the 1980s through Scott Crump and was patented by Stratasys [2]. There are other names in the literature for incremental technologies that work in analogy with FDM. These can include:

– Fused Filament Fabrication (FFF),
– Modelling Extrusion (ME),
– Fused Layer Manufacturing (FLM).

The operating principle is to produce spatial objects layer by layer by applying molten plastic on top of each other [3]. The material for the head is usually supplied in the form of wire wound onto a spool (filament) or in pellet form. Inside the print head, the material is heated to a suitable temperature, after which it is converted to a semi-fluid state [4]. The material thus prepared is extruded through the head nozzle in the form of a thin path, the width of which is determined by the nozzle diameter. The material thus prepared is spread layer by layer on the machine's working platform until the full height of the printed workpiece is reached. The layers of the current filament connect to the previous layers. For some materials, the solidification process of the molten layers is accelerated using additional fans located on the print head.

The components manufactured using FDM technology are characterised by a distinctive stripe-like outer wall structure. As with other incremental methods, the manufactured parts can be subjected to additional finishing, which can produce a surface that does not deviate from traditional manufacturing methods. The basis of post-processing is the removal of additional support structures. The use of additional finishing methods (mechanical, chemical) allows for the removal of the characteristic joining lines of the material layers, hence producing a smoother model surface [6]. FDM is one of the most cost-effective methods for manufacturing thermoplastic components. This is due to the rapid rate of detail construction, low material losses and the relatively low operating cost of the machine. Printed components using FDM technology are characterised by high anisotropy. The strength properties in the Z-axis direction are significantly lower than those obtained in the XY plane.

2. PREPARATION OF MATERIAL SAMPLES FOR TESTING

The tensile test method for plastics is described in EN ISO 527: 1998 'Plastics, Determination of mechanical properties in static tension' (according to which the tests were performed). The spatial 3D model for the strength tests was modelled in the SolidWorks environment. Figure 2 shows the appearance of the ripped sample, while Table 1 shows all its geometric dimensions:

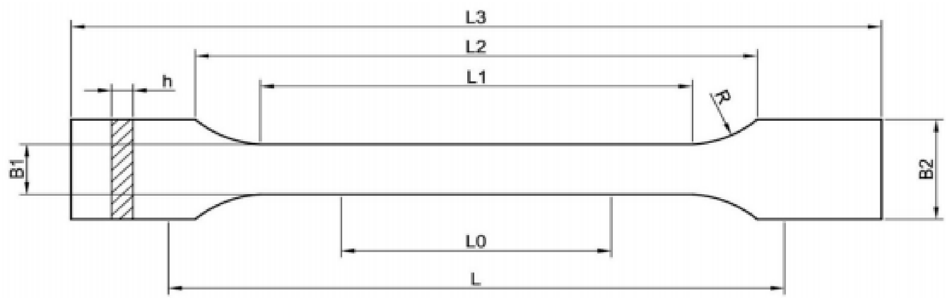

Fig. 2. The specimen is designed for strength testing [7]

Table 1. Dimensions of the test specimen [8]

Sample dimensions	Dimension
L3 – overall length	150 mm
L1 – length of the part bounded by the lines	40 mm
R – radius	60 mm
L2 – distance between wide parallel parts	106 mm
B2 – width at the ends	20 mm
B1 – width of narrow section	10 mm
H – thickness	4 mm
L0 – measurement length	50 mm
L – initial distance between handles	115 mm

Samples for testing were manufactured from the ABS-M30 IVORY material. The material is very widespread in various industries. The ABS-M30 thermoplastic material retains all the advantages of this material, while having an increased strength level of between 25% and 70% compared to standard ABS. A selection of material features is shown below in Table 2.

Printing of the samples was carried out on a Stratasys Fortus 400MC industrial 3D printer equipped with an enclosed, heated work chamber (visible in Fig. 4). Due to their orthotropic nature, the samples were produced in different orientations in the working area. Due to the high repeatability and accuracy of additive technologies, the number of sample batches was limited to five. Figure 3 shows the orientation of the print:

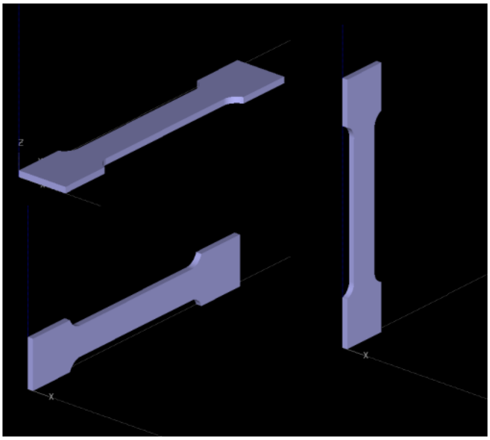

Fig. 3. Orientation of samples in the 3D printer during printing [own development]

Fig. 4. Stratasys FORTUS 400mc industrial 3D printer [own development]

Parameters characterising the printed strength samples:

– degree of filling: 100%,
– laying of paths: 1 outline, filling at 45° and 90°,
– print orientation: XY, ZX, YZ
– temperature of the extruded plastic: 320°C
– working chamber temperature: 95°C [for Fortus 400MC printer].
– Applied print nozzle: T16,
– height of model layer: 0.254 mm.

The 3D model of the strength specimen was prepared for printing using Insight 14.2 software.

3. ANALYSIS OF THE RESULTS

The results from the trials are shown below:

Table 2. Research results [own study]

Stretching						
Print orientation	Sample no. 1 [tensile strength in kN]	Sample no. 2 [tensile strength in kN]	Sample no. 3 [tensile strength in kN]	Sample no. 4 [tensile strength in kN]	Sample no. 5 [tensile strength in kN]	Test mean value [kN]
XY [45°]	1.4	1.45	1.45	1.45	1.4	**1.43**
XY [90°]	1.5	1.45	1.45	1.45	1.45	**1.46**
YZ [45°]	1.45	1.5	1.5	1.5	1.5	**1.49**
YZ [90°]	1.6	1.5	1.55	1.55	1.55	**1.55**
ZX [45°]	1.2	1.2	1.25	1.25	1.2	**1.22**
ZX [90°]	1.25	1.25	1.25	1.25	1.25	**1.25**
Print orientation	Sample no. 1 [MPa]	Sample no. 2 [MPa]	Sample no. 3 [MPa]	Sample no. 4 [MPa]	Sample no. 5 [MPa]	Mean value of tests [MPa]
XY [45°]	35	36.25	36.25	36.25	35	**35.75**
XY [90°]	37.5	36.25	36.25	36.25	36.25	**36.5**
YZ [45°]	36.25	37.5	37.5	37.5	37.5	**37.25**
YZ [90°]	40	37.5	38.75	38.75	38.75	**38.75**
ZX [45°]	30	30	31.25	31.25	30	**30.5**
ZX [90°]	31.25	31.25	31.25	31.25	31.25	**31.25**

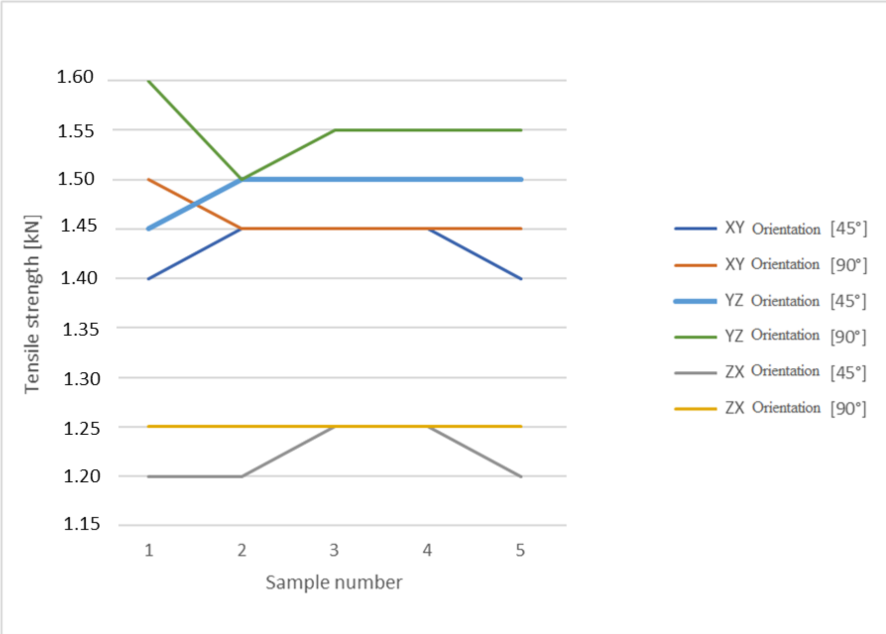

Fig. 5. Diagram of the dependence of the bursting force values for the test specimens [own work]

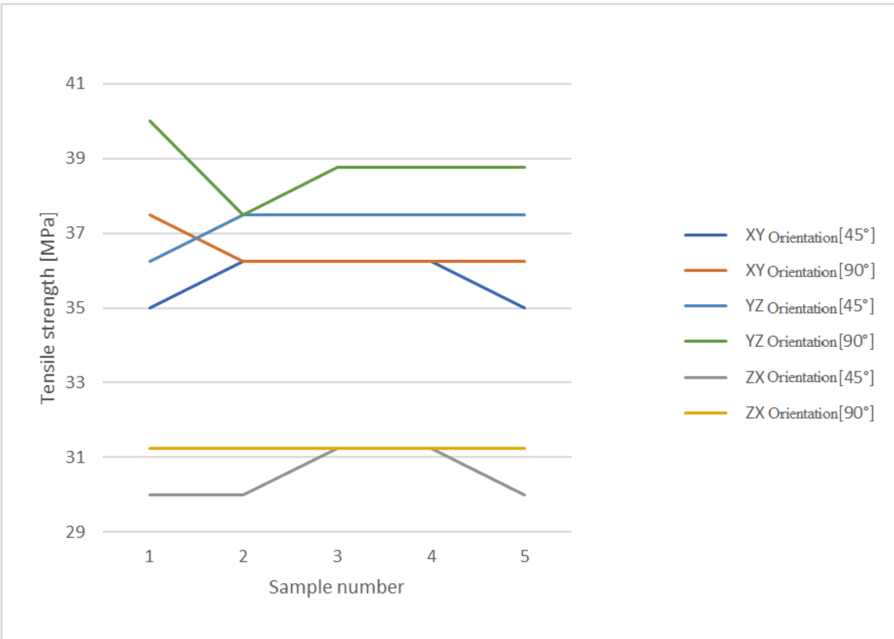

Fig. 6. Tensile strength dependence diagram for the test specimens [own work]

Below you can see the samples after the strength tests:

Fig. 7. Samples after strength testing [own development]

4. CONCLUSIONS

After testing the specimens, it can be concluded that the tensile strength and tensile strength values are different for the different print orientations. The biggest difference can be seen in the production of samples in the vertical position. The results obtained confirm the orthotropic nature of 3D printing using FDM/FFF technology. The internal infill of the models used (at 45° and 90°) has an impact on the results obtained. It can be seen that the use of internal filling produced perpendicular to the model walls (90°) has a positive effect on the strength parameters of the specimens obtained.

Printing workpieces in an industrial printer with a heated work chamber has an equally positive effect on the reproduction of the structure of the components and their dimensional tolerances. The specimens produced, irrespective of the print orientation, had no larger dimensional deviations than +/-0.03 [mm].

The results obtained from the strength tests indicate the need to continue this type of research in the context of changing more specific parameters characterising the 3D printing process. The research was carried out due to the creation of material profiles in ANSYS. The tests were successively carried out in the Rapid Prototyping and Numerical Computing Laboratory at the Łukasiewicz Research Network – Industrial Institute for Automation and Measurements PIAP (Warsaw, Poland).

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Badania wytrzymałości na rozciąganie próbek wykonanych z polimeru ABS-M30 w technologii FDM

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Streszczenie. W artykule szczegółowo przedstawiono zasadę działania technologii FDM (Fused Deposition Modeling). Zostały przeprowadzone badania wytrzymałościowe na przemysłowej drukarce 3D Stratasys FORTUS 400mc. Wydruki próbek wytrzymałościowych zostały wykonane w różnej orientacji w komorze roboczej urządzenia.
Słowa kluczowe: szybkie prototypowanie, technologia FDM/FFF, wytrzymałość na rozciąganie, szybkie prototypowanie