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ANISOTROPHY OF MECHANICAL PROPERTIES OF A MATERIAL WHICH IS SHAPED INCREMENTALLY USING POLYJET TECHNOLOGY

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Abstract: *This paper discusses the results of static tensile test of rectangular cross-section specimens made of a photo-curable material – FullCure 720. The specimens were prepared applying an incremental shaping method with the use of PolyJet technology. An analysis of the results was conducted and uncertainty in the measurements of tensile strength was estimated. Direction of specimens on a working platform of the machine was taken into account. The occurrence of anisotrophy of mechanical properties of the materials depending on the direction of the elements on the working table of a 3D printer was confirmed.*

Keywords: Additive technologies, tensile strength, anisotrophy of mechanical properties of materials.

1. Introduction

More than thirty years ago, appearance of the first 3D printing technology gave rise to new technologies, initially known as Rapid Prototyping, which found their application in the production of solid models of prototypes. Currently, more and more often we use the term 'incremental technologies' (additive manufacturing technology), since creation of models using incremental technologies involves adding material in layers where each subsequent layer is an exact reflection of any section of a model in a given plane. The current state and the prospects for development of incremental technologies was discussed, inter alia, in the study by Campbell (Campbell et al., 2012), presenting the possibilities of industrial applications, material development and design intentions. A body (solid), having substantially different properties from those of a semi-finished product is produced during a technological process of building a model on the working platform of a 3D printer. During the manufacturing (printing) process of a model, mechanical properties of a material are shaped as well (Adamczak et al., 2014, 2015; Bochnia & Kozior, 2014).

With the development of materials used in incremental technologies, there are more and more studies on their properties. It is worth quoting the study (Puebla et al., 2012), which presents the results of studies on the effects of environmental conditions (ageing) and orientation (i.e. arrangement on the working platform of the printer) on mechanical properties of the specimens made with the use of stereolithography. The studies have shown anisotrophy of materials manufactured using stereolithography as well as a reduction in mechanical properties under the influence of environmental conditions. The study (Bassoli et al., 2012) discussed the effect of the direction of deposition of layers (virtual arrangement of an element on the working platform) and laser sintering of polyamide powders on mechanical properties of produced materials of specimens for the tests. Significant differences were found, indicating anisotrophy of materials obtained using this technology. Many researchers used 3D materials for modeling various elements, e.g. sealing rings, membranes, viscoelastic elements, cable guides, muscle models and other structural components (Laski et al., 2015; Miko & Nowakowski, 2012; Takosoglu et al., 2012, 2014). The authors of this work, taking into consideration the issues outlined above as well as the possibility of using both incremental materials and technologies to build the models of mechanical seals (Blasiak et al., 2014; Blasiak, 2015a, 2015b), tried to estimate tensile strength on the

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basis of static stretching of specimens shaped incrementally using photo-curable rosin FullCure720, taking into account the directions of printing. Further considerations involved the preparation of specimens, static tensile test and an analysis of the results.

2. Methods

Test specimens were made of photo-curable rosin FullCure 720 using PolyJet technology (http://objet.com/3d-printing-materials), with the use of the printer Connex350 by Objet. Specimens with the size according to the (ASTM, 2013) standard with the following dimensions: width of the narrow section of the specimen 13±0.02 mm, length of the narrow section 57±0,02 mm, thickness of the specimen 4±0.4 mm, width of the handle 19±0.025 mm, total length of the specimen 165 mm were used to conduct the static tensile test.

Solid model of the specimen was drawn in CAD 3D and saved in a digital file with the extension *.stl*, using triangulation parameters in export options: resolution – adjusted, deviation – tolerance of 0.016 mm, angle – toleration of 5^0. Then, using the program Objet Studio, models of specimens were placed on the working platform of a machine Connex350 in three different positions in accordance with longitudinal movement of printhead:

- direction X – specimen placed sidewise on the working platform,
- direction Y – flat side of the specimen placed on the working platform,
- direction Z – specimen placed vertically on the working platform.

Specimens were prepared in the mode Glossy in order to obtain a smooth surface.

Models arranged virtually on the working platform with the use of the program Objet Studio are shown in Fig 1.

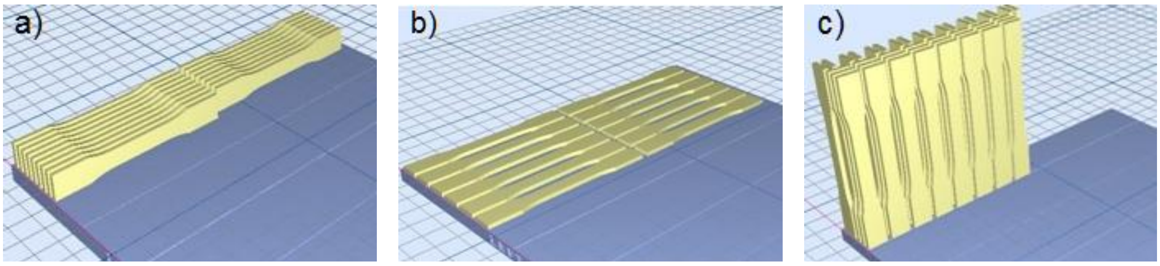

Fig. 1: Arrangement of specimens on the working platform; a) sidewise – direction X, b) flat side – direction Y, c) vertical – direction Z.

After printing, the specimens were carried away from the machine's working platform and then the supporting material was removed. They were then prepared for carrying out the static tensile test. The test was conducted with the use of a testing machine Inspect mini and an extensometer for strain measurement. In the program Labmaster, which is supplied with the machine Inspect mini, the test speed was set at 5 mm/min.

3. Results

Specimen all-in-one charts illustrating loading forces applying to specimens in displacement function obtained directly from the testing machine's computer are shown in Fig. 2, 3 i 4.

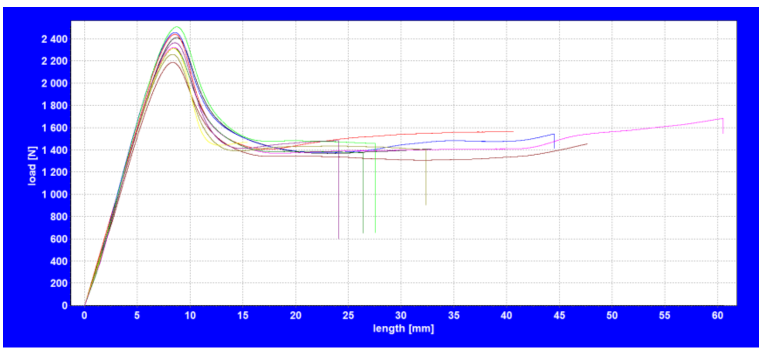

Fig. 2: Graph illustrating specimens placed sidewise in direction X on the working platforms undergoing tensile tests.

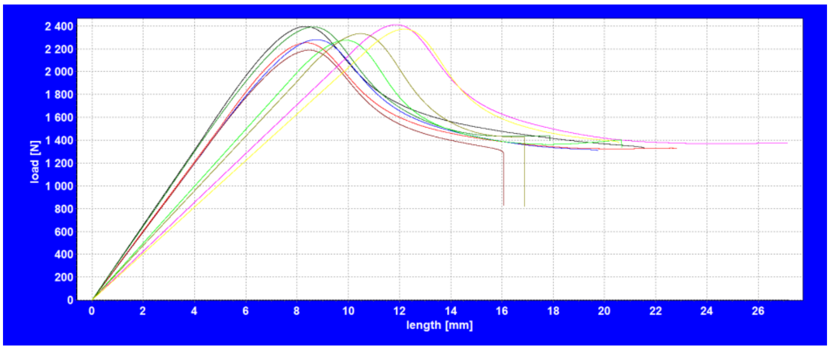

Fig. 3: Graph illustrating specimens placed with the flat side in direction Y on the working platforms undergoing tensile tests.

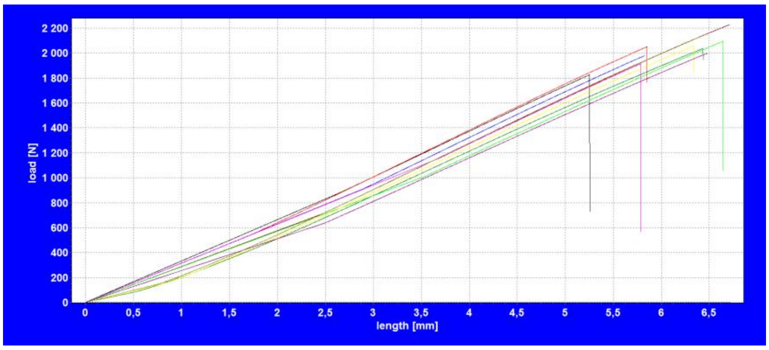

Fig. 4: Graph illustrating specimens placed vertically in direction Z on the working platforms undergoing tensile tests.

The program Labmaster, after entering data, such as width and thickness of the specimen, while recording the maximum tensile force, calculates tensile strength Rm. Standard results uncertainty regarding tensile strength *Rm* for specimens made in individual positions was calculated using the formula (1) (Adamczak et al., 2011).

$$u_{R_m} = \sqrt{\left(\frac{1}{\bar{a}_0 \bar{b}_0}\right)^2 u_{F_m}^2 + \left(\frac{-\bar{F}_m}{\bar{a}_0^2 \bar{b}_0}\right)^2 u_{aA}^2 + \left(\frac{-\bar{F}_m}{\bar{a}_0 \bar{b}_0^2}\right)^2 u_{bA}^2} \quad (1)$$

where: – $\bar{F}_m$ – the average value of the maximum tensile force calculated for individual directions of printing (Table 1),

u_{F_m} – uncertainty of an average value of the maximum tensile force,

$\bar{a}_0$ – average thickness of specimens,

u_{aA} – uncertainty of an average thickness of specimens,

$\bar{b}_0$ – average width of specimens,

u_{bA} – uncertainty of an average width of specimens.

Values of tensile strength obtained in individual tests and uncertainties of measurements are listed in Table 1.

Tab. 1: Results of tensile strength tests.

Orientation of specimens (Fig. 1)	**Average value of tensile strength** $\bar{R}_m$ **[MPa]**	**Values of uncertainties of measurements** u_{R_m} **[MPa]**
X direction	45.17	0.591
Y direction	44.28	0.450
Z direction	37.79	0.657

The studies have shown that tensile strength *Rm* of specimens made in vertical position is 19.5% lower than the strength of specimens made in direction X and 17.2% lower than the strength of specimens made in direction Y. The lack of a typical plastic deformation comes as a surprise, as shown in Fig. 4. Uncertainty of measurements u_A for specimens placed on the working platform vertically is 11.1% higher than for specimens printed in direction X and 46% higher than for specimens printed in direction Y. These results show marked anisotrophy of material properties in relation to the directions of printing.

4. Conclusions

The studies have proven, as shown in the all-in-one graphs (Fig. 2, 3) illustrating tensile tests of specimens made in horizontal position, a good reproductivity of results in terms of tensile strength and, when exceeded, in the field of plastic deformations, specimens broke up in the case of longer elongations. Specimens made in vertical positions have shown poorer properties, as shown in an all-in-one graph (Fig. 4). Material of specimens built incrementally in direction Z (vertical) have not shown plastic properties, its tensile strength was lower than the strength of specimens built in horizontal direction. Uncertainty of tensile strength measurements was also lower than uncertainty of specimens built horizontally, which indicates greater dispersion of results. The studies have shown that material built using incremental technology has marked anisotropic properties determined by the directions of consecutive layers.

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