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MECHANICAL PROPERTIES OF MATERIALS OBTAINED BY 3D-PRINTING TECHNOLOGY

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Abstract: *This paper discusses the results of the static compression tests of cylindrical samples made from ceramic powders using incremental forming method with application of 3D-Printing technology. The analysis of tests results has been conducted. Anisotropy of the mechanical properties of the material, depending on the direction of the elements on the build tray of 3D printer, has been observed.*

Keywords: Additive technologies, Compressive strength, Mechanical properties of materials.

1. Introduction

Building a model with an incremental technique involves additions of layers of the material, where each subsequent layer is an exact reflection of the model cross-section in a given plane. The resulting model assumes a predetermined shape, which is designed using a CAD computer program for three-dimensional designing. The materials from which the models are made differ from materials used in other technologies. Usually in such technologies as waste or plastic machining etc., we use semi-finished products, which were produced previously in other processes, e.g. in the ironworks (Nowakowski et al., 2016). Additive technology is used both for shaping the model geometry and the properties of the material created. Therefore, it is reasonable to perform tests of the properties (Adamczak and Bochnia, 2016) of the produced materials. The characteristics of 3D-printing technology and the materials used are shown in the works of (Brett et al., 2014), (Goulas et al., 2016). With the development of the materials used in additive technologies, there are more and more studies on their properties (Lee et al., 2007), (Pilipović et al., 2009).

One of the incremental technologies is the adhesive bonding of ceramic powders referred to as 3D-printing. For the execution of this method, machines with printing nozzles can be used, similar to those in the inkjet printers. The binder is applied by the nozzles onto the powder spread on the build tray of the machine. The build tray changes its position down in the Z axis direction by increments of the value of thickness of distributed powder. The binder initially joins the powder building so called uncured model, which in order to achieve performance after printing is cured by for example an epoxy resin.

This paper presents the results of the compression tests of samples produced with 3D-Printing technology, in different directions of print. The results may be useful for engineers who design various models. Moreover, molds obtained with this technology can also be used in various types of modeling of engineering calculations (Bochnia, 2012) and construction works (Takosoglu et al., 2016) or research works (Blasiak, 2015).

2. Methods

Solid model of the sample was drawn using CAD 3D program and saved in a digital file with *.stl* extension using triangulation parameters in the export options: resolution – adjusted, deviation - tolerance 0.016 mm, angle - tolerance 5^0. Using a computer program that comes with the 3D printer, the sample models were placed (virtually) on the build tray in two different orientations, in order to enable horizontal and vertical printing.

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Samples for the research were made of ceramic powders with 3D-Printing technology, using ZPrinter 650 (current name ProJet 660) and materials from 3D Systems. Cylindrical samples of the following dimensions were made: height 15 mm and diameter of 10 mm.

Samples were printed in the orientation:
- horizontal, print direction X – 20 pcs.
- vertical, print direction Z – 20 pcs.

Then, after cleaning the samples from the remaining powder, 10 pieces from each of the printing directios were selected, and cured with the epoxy resin. In this way, there were obtained four series of samples, 10 pcs each. In each series: printed horizontally - cured and uncured by the resin, and printed vertically - cured and uncured by the resin. The samples were prepared to perform the compression tests by appropriate markings.

The test was made using the Ispect mini (Hegewald & Peschke MPT GmbH) testing machine with range of 3 kN, equipped with a flat compression plates. Measurement, data acquisition and setting the parameters of the test was performed in the LABMASTER program (Version 2.5.3.21), which is supplied with the Inspect mini machine.

3. Results

Examples of collective graphs compressive force versus displacement obtained directly from the computer of testing machine were shown in Figs. 1, 2, 3 and 4.

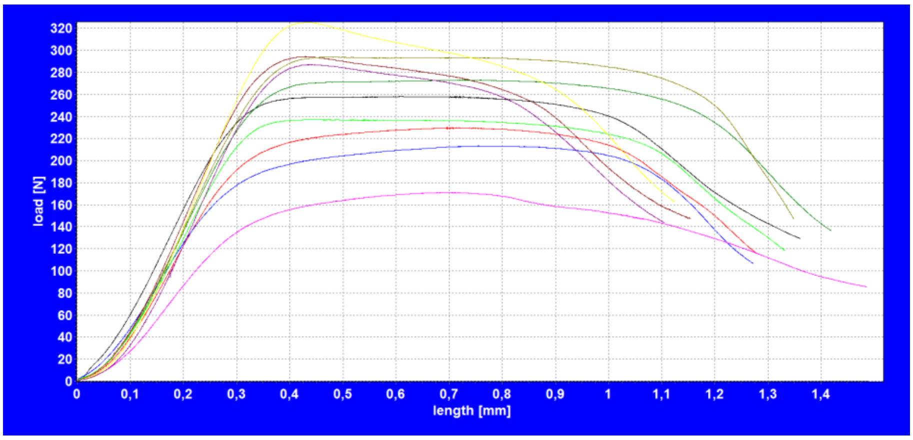

Fig. 1: The stress-strain dependency for the uncured samples of 10 mm diameter printed in a horizontal position - direction X.

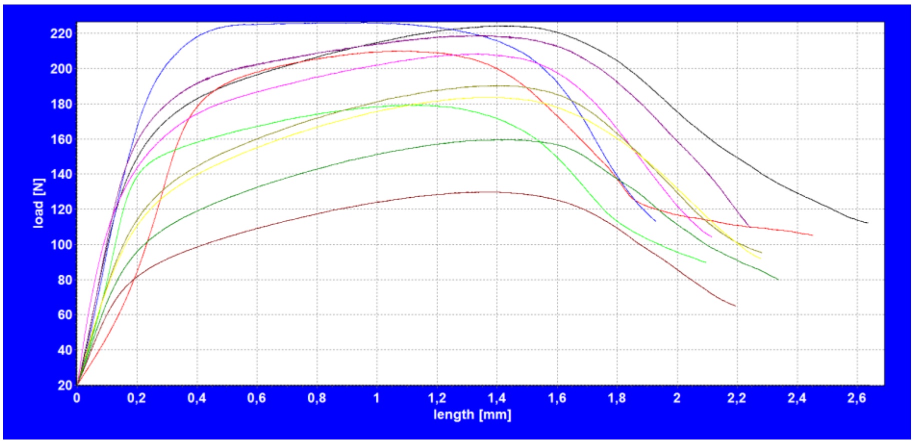

Fig. 2: The stress-strain dependency for the uncured samples of 10 mm diameter printed in a vertical position - direction Z.

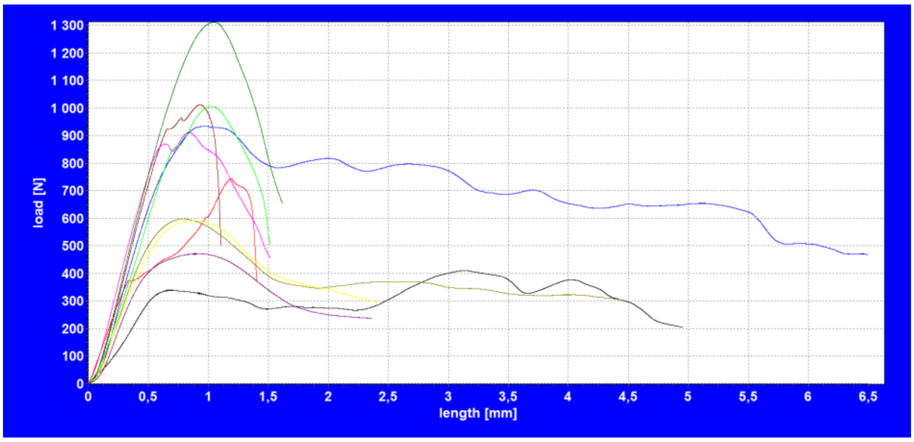

Fig. 3: The stress-strain dependency for the samples cured with epoxy resin having a diameter of 10 mm printed in a horizontal position - direction X.

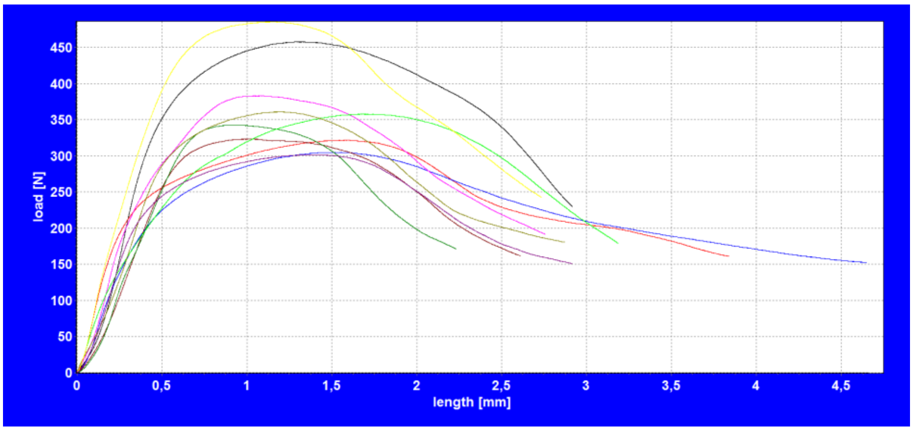

Fig. 4: The stress-strain dependency for the samples cured with epoxy resin having a diameter of 10 mm printed in a vertical position - direction Z.

Compressive strength was calculated with the formula:

$$\sigma = \frac{F_m}{S} \qquad (1)$$

where: F_m – the maximum compressive force,
S – surface area of the sample onto which the compressive force is applied.

The deformation of individual samples was calculated using the following formula:

$$\varepsilon = \frac{L_0 - L}{L_0} \cdot 100\% \qquad (2)$$

where: L_0 – initial height of the roll sample,
L – sample length after compression.

Test results: compressive strength σ and deformation of individual samples ε was presented in table 1. The table presents average values calculated for each measurement series.

Tab. 1: Results of compressive strength tests.

	Direction X, uncured samples	**Direction X, cured samples**	**Direction Z, uncured samples**	**Direction Z, cured samples**
Average compressive strength σ [MPa]	$\overline{\sigma} = 3.29$	$\overline{\sigma} = 9.95$	$\overline{\sigma} = 2.46$	$\overline{\sigma} = 4.64$
Average deformation ε [%]	$\overline{\varepsilon} = 8.6$	$\overline{\varepsilon} = 18.6$	$\overline{\varepsilon} = 15.1$	$\overline{\varepsilon} = 20.5$

Based on the presented compression graphs 1 ÷ 4 one may state a large dispersion of results. Although curing the samples with the resin has increased the average compressive strength, it has not improve the reproducibility of the results. This type of phenomenon can be observed in the majority of composite materials.

4. Conclusions

The conducted research shows that the material built with additive technology 3D-Printing has clear anisotropic properties determined by the orientation of the element on the build tray of the machine, thus by the printing direction. The samples printed in vertical direction, both uncured and cured with resin, have a respectively smaller compressive strength than the samples printed in the horizontal direction. Curing with resin increases the compressive strength from two to three times. The tests of the compressive strength showed a large dispersion of results which may indicate a considerable heterogeneity of materials received with this technology.

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