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Influence of Additive Manufacturing Technology on Mechanical Properties of Glass-Filled Fine Polyamide PA3200GF

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Additive manufacturing is a very fast developing field of research and many parts with complicated geometry are now made using 3D printing. The injection molding, casting, milling and other processes have some limitations and low volume of production makes these processes quite expensive. 3D printing allows to fabricate parts with enough mechanical strength and without looking at the above mentioned limitations. Nowadays, designers are able to fabricate prototypes with not only optimized but also complex shape. Unfortunately, the parts made from thermoplastic materials by means of 3D technique have lower mechanical strength in comparison to the parts made by using injection molding process. The orientation of layers, thickness of a layer, porosity, and process parameters have a big influence on mechanical properties of the fabricated parts. In this paper, the experimental results from the static tensile tests, the compression tests and the dynamic three-point bending test are presented. The tests were performed for different orientations of printing specimens. It was shown that to assess the mechanical properties of printing parts (made by using selective laser sintering (SLS) technique)our own measurements need to be obtained. The available catalogue data are not sufficient for further investigations like in the finite element (FE) analyses.

Key words: additive manufacturing, tensile test, compression test, three-point bending, polyamide, PA3200GF, selective laser sintering, DMA.

1. General

Additive manufacturing, also known as 3D printing, is a rapidly developing field of research. Many parts with complicated geometry, which are very difficult to produce by standard techniques (injection molding process, casting, milling, turning processing and other), can be easily and inexpensively manufactured by using printing technology (FDM, SLS, MJP/PolyJet). The main problem in the additive manufacturing is that the printed structures do not have homogeneous topology and their mechanical properties cannot be treated as isotropic. The porosity, direction of printing, thickness of a layer and the used printing processes have a strong influence on the mechanical strength and the solid density [1, 2].

Generally, suppliers provide the information about the mechanical properties of the material, but their data are very poor and often do not describe the accurate stress/strain characteristics that take into account the direction of the printing. For better understanding of the mechanical properties of printed glass-filled (bubbles) thermoplastic materials, a series of mechanical tests were performed to extract the mechanical properties in different orientation of printing [3].

2. Selective laser sintering process

All the investigated specimens were made by using 3D printing process in SLS technology. SLS is a technique that uses a laser (CO_2) as the power source to sinter powdered material. The used laser pulses down on the platform according to the digital geometry converted to the STL format, where the layer of powder is distributed. The laser heats the powder either to just below its melting point or above its melting point, which fuses the particles in the powder together into a solid form. The part is built layer by layer. The created solid body does not require any support structure. The surrounding powder remains loose and serves as a support for subsequent layers, thus eliminating the need for the secondary supports that are necessary for vat photopolymerization processes [1, 2]. The reference schematic of SLS process is presented in Fig. 1.

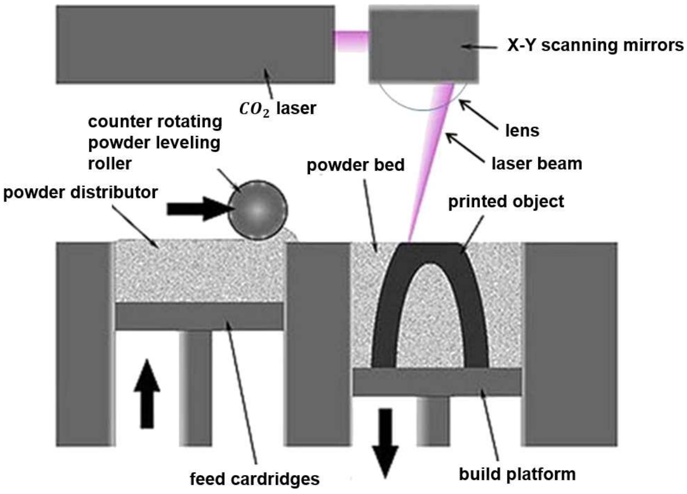

Fig. 1. Schematic of SLS process.

The SLS technique allows to obtain quite strong parts that are water and airtight, and heat resistant. It is recommended to create small parts with complicated geometry like in tools for grippers, small parts for airplanes, etc.

3. Measurement procedure and equipment

The mechanical properties of the manufactured parts made from the thermoplastic material polyamide using 3D printing technology strongly depend on the process parameters, thickness of a layer, grain size, and direction of printing. For this purpose, a series of specimens were produced in different orientations (see Fig. 2). Next, they were tested using two special machines: Instron 3367 and DMA 242 E Artemis [4, 5].

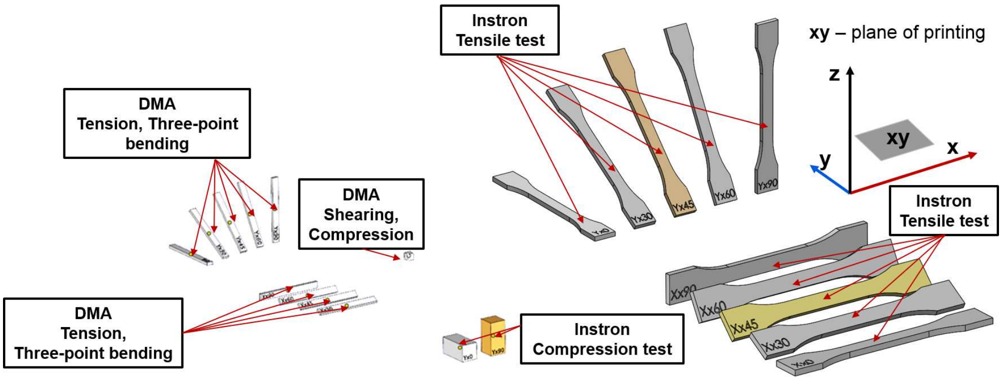

Fig. 2. Investigated specimens dedicated to tests [1].

Three main tests were performed to investigate mechanical properties for the structures made from polyamide PA3200GF. The tensile and compression tests were performed with the use of the strength testing machine Instron 3367, but the three-point bending test to investigate mechanical properties in different temperatures was performed using a dynamic mechanical analyzer DMA 242 E Artemis (see Fig. 3). The obtained results were compared and analyzed from the point of view of the effects of printing orientation of particular specimens. The visible influence of the orientation of printing was detected [4, 5].

The tensile tests of the printed specimens were performed using tensometric bridge and extensometer. The convergence between the results from a tensometric bridge and an extensometer was very good, so it was decided to perform the tests using a tensometric bridge for only three types of the specimens: Y0, Y90 and X90 (see Fig. 2). In this way, Poisson's ratio was also obtained. For the compression test the internal measuring system was applied. Each of the specimens was manufactured according to the specified standard dedicated to

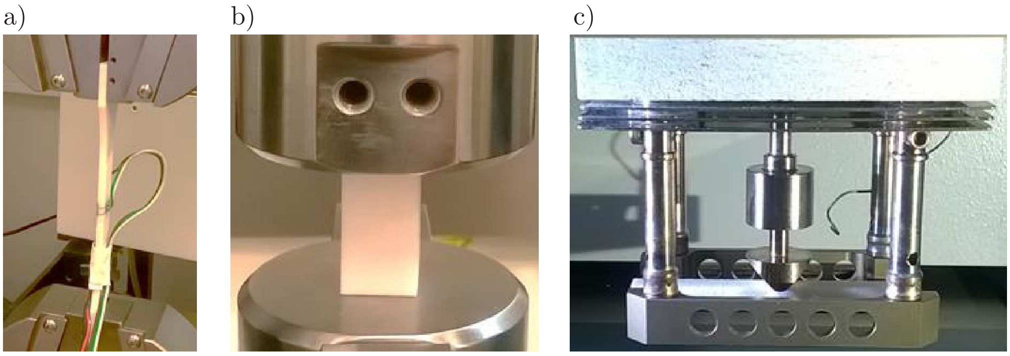

Fig. 3. The types of the performed tests: a) tensile test, b) compression test, c) three-point bending test.

performing the real tests. A three-point bending test was performed using the DMA machine in the range of the temperatures from −50° to 120° and for different frequency of analysis.

4. Measurement results

The results from the static tensile tests are presented in Figs. 4 and 5. The stress-strain curves show a strong dependence on the orientation of printing. The values of Young's modulus are different and oscillate in the range of 1800–2900 MPa. The difference is very big, which proves that the printed thermoplas-

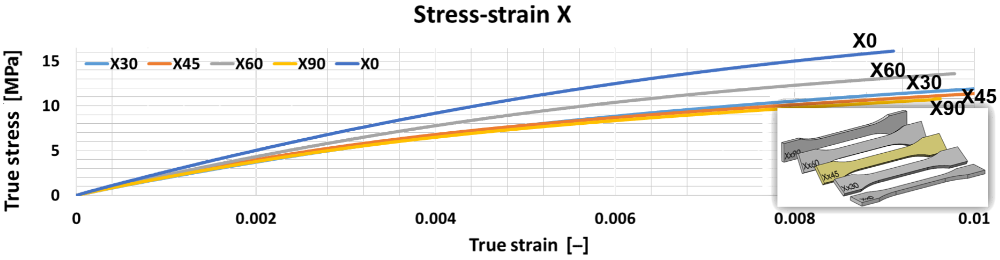

Fig. 4. Stress-strain curves for different orientation of printing – static tensile test.

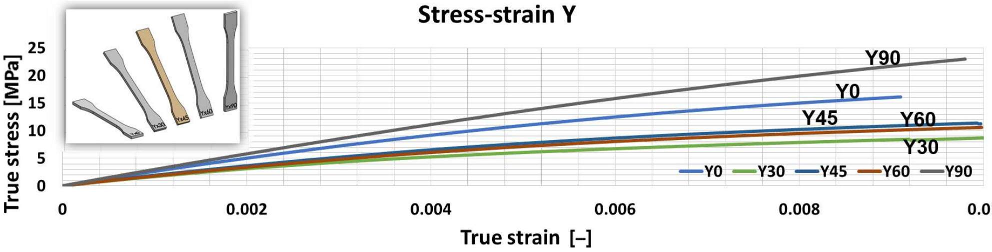

Fig. 5. Stress-strain curves for different orientation of printing – static tensile test.

tic parts cannot be treated as an isotropic structure. The Poisson ratio is in the range of 0.34–0.37. Based on the obtained results, it can be also concluded that the specimens printed in the parallel layers show axial symmetry. The results obtained from the static compression tests are presented in Fig. 6. The stress-strain curves are averaged from five tests for each of the type of specimen. Based on the compression tests, one can see that the specimen having the orientation of printing parallel to the direction of compression, is the strongest one when taking into account mechanical strength. The shape of the deformed specimen does not reveal barreling (see Fig. 7).

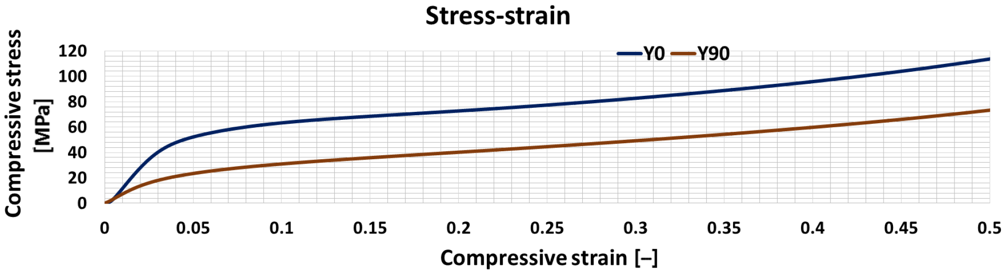

FIG. 6. Stress-strain curves for two different orientation of printing – static compression test.

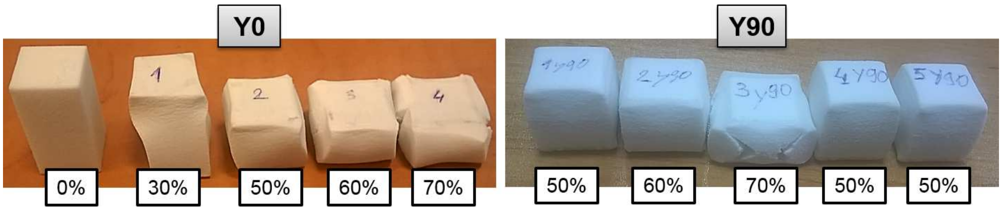

FIG. 7. Specimens after compression tests.

The results from the DMA tests in the range of −50° to 120° and with different frequency of excitation are presented in Fig. 8. The presented results are for storage modulus (E′) and loss modulus (E″). The storage modulus represents the material stiffness and is proportional to the maximum stored work during stress, whereas the loss modulus is proportional to the work dissipated from the material during stress. It is measured for the oscillation energy transferred into heat [5, 6].

After the performed series of tensile, compression and three-point bending tests, the obtained results were compared with the available catalogue data [3] (see Fig. 9). Based on our own and available parameters, one can see that there are some differences for Young's modulus. The results obtained from our own tests show lower values in the temperature domain, but the trend and the point of the glass transition temperature (T_g) are the same. One can suppose that the

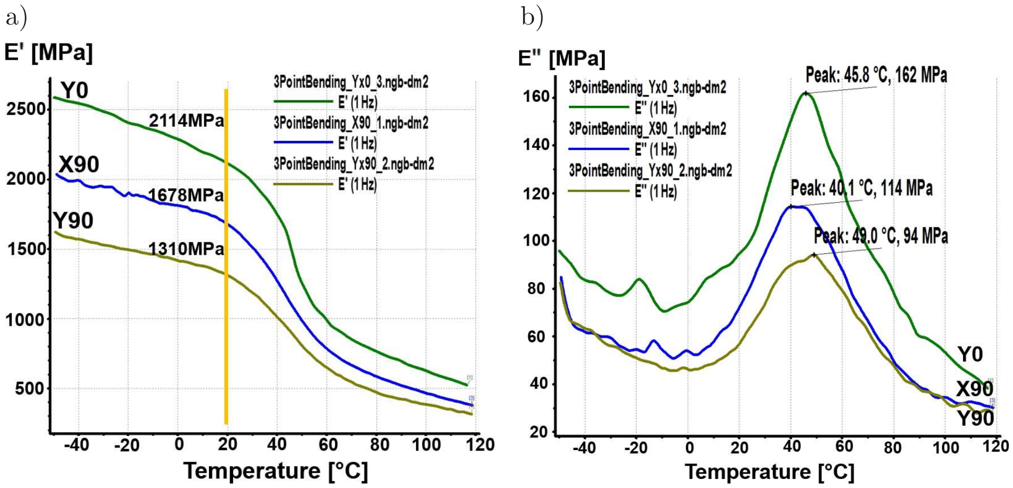

FIG. 8. Storage (a) and loss (b) moduli for different temperatures – DMA three-point bending test.

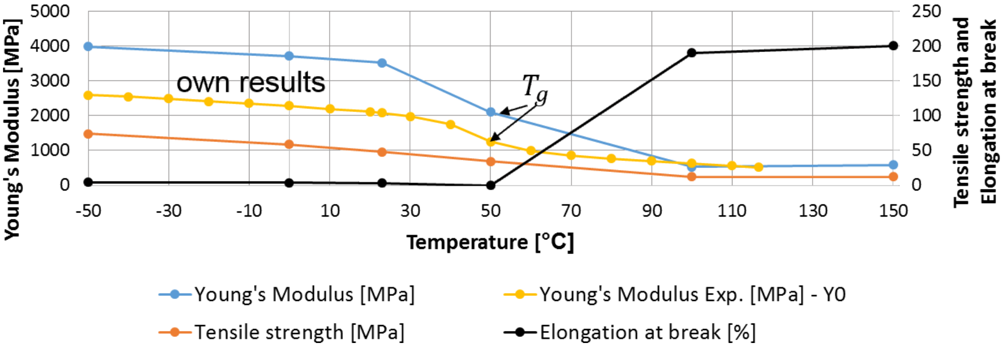

FIG. 9. Material properties – comparison of our own results with the catalogue values [3].

differences are due to the lack of information about the orientation of printing of the specimens used to obtain the catalogue data. This shows that further investigations are necessary to be performed in order to assess the exact parameters for the studied structure.

5. CONCLUSIONS

Commonly available mechanical properties of the printed parts made from the thermoplastic materials (e.g., PA3200 GF) are inadequate and they do not include information about Poisson's ratio, and Young's modulus in different orientation of printing and the manufacturing process.

Based on the performed experiments, one can conclude that the mechanical properties of the printed specimens strongly depend on the process parameters, layer thickness and orientation of printing. Furthermore, the characteristics of tensile and compression tests showed the dependency on the orientation of printed specimens with respect to the printed layer. In addition, the specimens printed in parallel layers showed axial symmetry.

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