DESIGN OF THE GRIP AND THE SPECIMEN FOR TENSILE TESTING OF 3D PRINTED MATERIALS

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ABSTRACT
A novel design for a specimen and a grip for tensile testing of 3D printed materials is proposed and investigated in the paper. The specimen design is based on ISO 527-2 standard and it is intended for the upright 3D printing and investigation of influence of the 3D printing orientation on the mechanical properties of the 3D printed material. Two specimens were 3D printed from PLA material and successfully tested in a tensile testing machine. Grips, made from 3D printed composite materials (onyx reinforced with graphite fibers), were designed and used for fixation of the specimen in the machine jaws. Obtained results for ultimate tensile strength were in the expected range for PLA material.

Keywords: 3D printing, FDM, tensile properties, tensile specimen, tensile testing grip

1. INTRODUCTION
Recent advances in additive manufacturing technologies (or as it is also popularly known, 3D printing) have led to their application in numerous fields of science and technology [1,2]. One of the most wide-spread 3D printing technology in recent years is FDM (Fused Deposition Modelling) thanks to its cost-effectiveness, a wide range of usable materials and possibility of relatively simple production of parts with complex shape. FDM process is based on the extrusion and melting of thermoplastic material (filament) through a heated nozzle and depositing it along a previously defined path, layer by layer on a build plate, thus forming a 3D part after cooling and solidification of filament. Different thermoplastics materials are used in FDM printers where polylactic acid, more commonly known as PLA, is the most widely used because of its ease of use, a low extrusion temperature and a low price.
In order to implement components made with 3D printing from PLA or other filament material in different structures or mechanisms, mechanical properties data of the material obtained after the additive manufacturing process could be needed. Tensile testing is the basic procedure for obtaining mechanical properties of various materials that provides fundamental information about the mechanical behavior of materials needed by designers. As FDM 3D printing is a relatively new technology, the mechanical properties of the obtained material and its testing

still have a lot of unknowns and are the subject of various researches [3-6]. FDM 3D printing process has a large number of parameters such as: infill density, layers height, print speed and temperature, etc. All these parameters could have an influence on the final characteristics of the product, and therefore also on its mechanical properties. Due to FDM printing procedure, anisotropy occurs in the components and influence of material orientation regarding to the printing orientations is very important feature of mechanical properties. However, there are some problems in manufacturing specimens for investigating different 3D printing orientation because a specimen has to be printed at different angels, and even in an upright position to the build plate (see Figure 4 and 5). As reported in [3], the vibrations of the part and the adhesion to the build plate are issues when specimens are positioned upright. In this paper, a new design of specimen and accessory grip is proposed, the design which makes easier printing of a specimen in an upright position.

2. DESIGN OF THE GRIP AND THE SPECIMEN

The design of the specimen was based on EN ISO 527-2 standard for tensile testing on plastics. The specimen from the standard was changed at the ends (tabs), that are used for fixation in a test machine. A wedge was added (Figure 1) to the tabs, that fulfils two functions. Its lateral surfaces provide the surfaces for the fixation in the grip, and the end surface provide a larger contact surface and better adhesion with a 3D printer build plate. The wedge also avoids the need for long tabs on specimen for better grip in a machine, thus making the specimen shorter, which is more appropriate for the upright printing. The other features and dimensions of the specimen are as defined in standard.

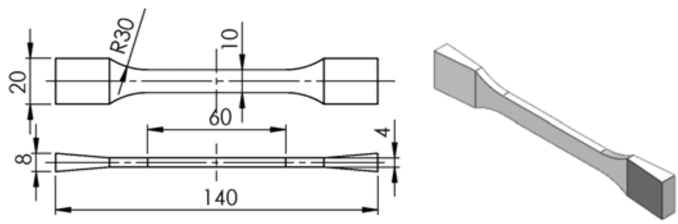

Figure 1. The specimen designed for the tensile testing.

The wedge grip, designed for fixation of specimen in the machine jaw is shown in Figure 2, with all dimensions. The grip was designed to match the specimen wedge tabs, with larger length for secure fixation. The grip for the one end of a specimen has two parts. There are two cylinders and holes for the connection and alignment of the grip parts.

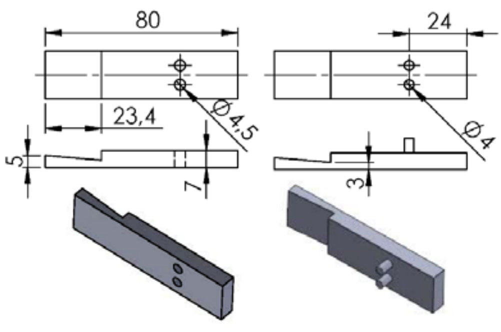

Figure 2. The two-part grip for specimen.

3. MANUFACTURING OF SPECIMENS AND GRIP'S PARTS

Ultimaker S5 Pro Bundle [7] 3D printer was used for creation of the specimens (Figure 3). The G-code for 3D printing process was prepared in open source software from manufacturer, Ultimaker Cura [8], using CAD models in .stl format made in commercial software Solidworks. In the 3D printing preparation, a specimen was positioned in the upright position (Figure 4). Two specimens were successfully made from PLA material. Only a slight surface imperfection was observed on the top part of the specimen in the printing, at the transition radius from narrow to the wide part. The two specimens were made with two different infill density: 80% (specimen 1) and 40% (specimen 2), and with triangle infill pattern. Both specimens were printed in fine quality with 0,1 mm layer height. For other 3D printing settings, the default values in Ultimaker Cura were selected.

Figure 3. 3D printing of a specimen.

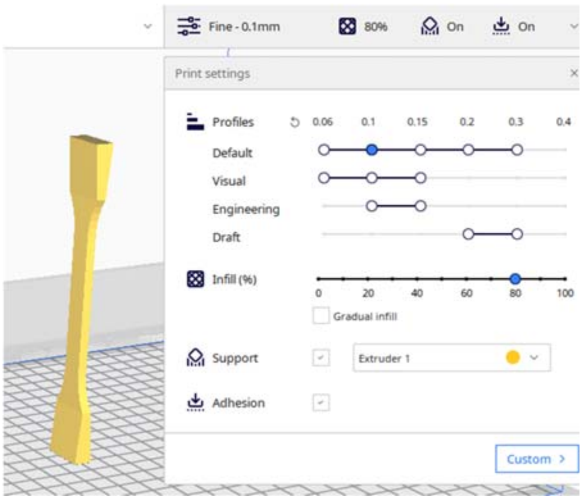

Figure 4. Set-up for 3D printing in Ultimaker Cura.

The grip for specimen was created on Markforged Mark Two printer [9], using onyx material as a filament [10] and carbon fiber [11] as a reinforcement, Figure 5. The Mark two printer has an additional nozzle for different reinforcement fibers, hence facilitating 3D printing of composites. This printer and materials were selected with the goal of having the grip made from material with greater strength and resilience. Online software of the manufacturer, Eiger [12], was used for printing preparation. The solid fill for infill pattern was selected (in order to achieve greater strength) with the default software value for layer height of 0,125 mm. Eight layers in two group of four of outer shell fiber reinforcement, with three concentric fiber rings, were manually set in the software (Figure 6). In order to prevent slipping of grips in machine jaws, the grinding paper was glued on the surfaces of the grip that come in contact with jaws after printing (Figure 7).

Figure 5. Markforged mark Two 3D printer

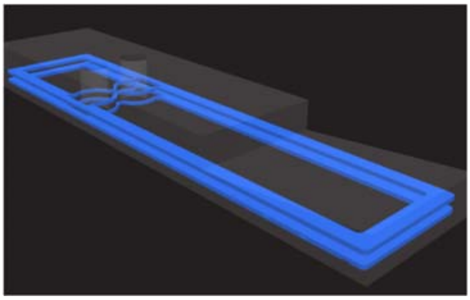

Figure 6. The model of a grip part in Eiger software – carbon fiber reinforcement

Figure 7. The specimen positioned into the grips with glued sanding papers.

4. TENSILE TESTING

The testing of the design of the grips and specimen is conducted on the universal tensile testing machine "Amsler" (Figure 8). The tensile tests of the both prepared specimens were successful, i.e. the grips successfully fixated specimens during tests (Figure 9). Figure 10 shows the fractured specimens after testing. The registered ultimate force and calculated ultimate stress for the two specimens are given in table 1. The results are in the expected range for PLA material [3-6]. It is not possible to conclude that there is a deterioration of the mechanical properties in vertical direction of 3D printing. The measured ultimate stress values are similar as the values registered for the horizontally printed specimens in [3]. This could be result of avoiding the vibration of the specimen during the printing and obtaining good quality of the 3D printing on the upper part, as a result of the specimen design. Also, used fine quality of 3D printing with 0,1 mm layer height could also had influence on the results. However, the focus in this paper was on the design of the grip and specimen for vertical position during 3D printing, therefore to evaluate the influence of the specimen orientation in 3D printing on mechanical properties further investigations are needed.

Figure 8. Tensile testing machine.

Figure 9. A specimen in the machine fixtures.

Figure 10. Fractured specimens after tensile testing.

Table 1. Tensile test results

Specimen	Infill density	Ultimate force / kN	Ultimate stress / MPa
1	80%	1,945	48,6
2	40%	1,555	38,9

5. CONCLUSION

The design for a tensile specimen, proposed in the paper, was successfully used for 3D printing of the specimen in an upright position. The design of the grip for the fixation of the specimen, also proposed, was successfully tested on a tensile testing machine. The specimen with the grips can be used for further research of influence of the 3D printing orientation on the mechanical properties of the 3D printed material. The influence of the other 3D printing parameters could also be investigated using the proposed specimen and grips.

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