Selected mechanical properties of MED610 medical resin used in PolyJet Matrix additive technology

Wybrane właściwości mechaniczne medycznej żywicy MED610 stosowanej w technologii przyrostowej PolyJet Matrix

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This paper presents the results of static strength tests carried out, i.e. tensile, bending and compression tests. The tests were performed on the basis of ISO 527, ISO 178 and ISO 604 standards. The study used a photo-curable resin with the trade name MED610, which meets a number of biocompatibility requirements and can be used for medical applications. PolyJet Matrix 3D printing technology was used to produce the test samples. The study showed a clear anisotropy of mechanical properties due to the printing orientation, particularly noticeable for the tensile and bending tests.
KEYWORDS: MED610, PJM, mechanical properties, 3D printing

W artykule przedstawiono wyniki przeprowadzonych statycznych prób wytrzymałościowych, tj.: próby rozciągania, zginania i ściskania. Badania wykonano w oparciu o normy ISO 527, ISO 178 oraz ISO 604. W badaniu zastosowano żywicę fotoutwardzalną o nazwie handlowej MED610, która spełnia wiele wymagań dotyczących biokompatybilności i może być stosowana w aplikacjach medycznych. Do produkcji próbek wykorzystano technologię druku 3D PolyJet Matrix. Badanie wykazało wyraźną anizotropię właściwości mechanicznych, zauważalną zwłaszcza w testach rozciągania i zginania.
SŁOWA KLUCZOWE: MED610, PJM, właściwości mechaniczne, druk 3D

Introduction

Currently, additive technology is gaining importance and popularity, with applications in many areas such as aerospace industry, automotive industry, electric and electronic industries, functional energy devices, architecture and construction, healthcare and medical industry including the production of tissues and organs [1]. In the case of medical applications, a remarkable advantage of additive technology is its personalization, meaning that components are individually manufactured based on the patient's body geometry to achieve the best possible fit [2]. Unfortunately, additive technology is not without its disadvantages, one of which is the anisotropy of mechanical properties. This aspect is extremely important, as designers and manufacturers of 3D printed parts that are expected to function under certain loads must choose the right printing parameters to achieve the highest possible strength and thus longer product life [3].

The paper [4] investigated the effect of printing orientation on the tensile strength and geometric accuracy of 3D printed Digital Light Processing samples using dental resin. The study showed that printing layer direction influences the accuracy of the final product, and in the case of 45° orientation leads to the biggest deviations. In addition, samples produced flat, i.e. printed in 0° orientation, had the highest tensile strength. Anisotropic behavior is particularly noticeable in technologies from the material extrusion group, where the thermoplastic material is extruded into a fiber layered according to a preset path. In this case, not only the orientation of the print affects the anisotropy of the mechanical properties but also the raster angle direction in the infill pattern [5]. Methods are being sought to reduce anisotropy, one of which is the use of heat treatment in the case of technologies from the material extrusion group, for example, the warm isostatic pressure process [6].

The purpose of this study is to investigate the tensile, bending and compressive strength of MED610 resin using PolyJet Matrix 3D printing technology in relation to three different printing directions: 0°, 45°, 90°.

Materials and methods

MED610 (Stratasys Corp., Minneapolis, United States) material was used in an additive process to produce samples. The MED610 photo-curable resin changes its state from liquid to solid (photopolymerization) due to UV light during the additive manufacturing process. After printing, this material is approved for medical applications such as dental applications. According to the manufacturer, a component made of this material can be approved for permanent contact with the skin and limited mucosal membrane contact, i.e. up to 24 hours. MED610 is a biocompatible material and meets many normative requirements (ISO 10993) for: cytotoxicity, irritation, delayed-type hypersensitivity, genotoxicity, chemical characterization [7]. The support material used in the additive manufacturing process was SUP705 resin (Stratasys Corp., Minneapolis, United States), a unique benefit of this material is the ease of clearance during the support removal process. The chemical composition of both resins is shown in table I and selected properties of the MED610 resin are shown in table II.

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Table I. Chemical composition [8, 9]

MED610							
Component	Isobornyl acrylate	Acrylic monomer	Urethane acrylate	Acrylic monomer	Epoxy acrylate	Acrylate oligomer	Photo initiator
Weight %	15÷30	15÷30	10÷30	5÷10 10÷15	5÷10 10÷15	5÷10 10÷15	0.1÷1 1÷2

SUP705						
Component	Acrylic oligomer	1,2-Propylene glycol	Polyethylene glycol	Glycerin	Photo initiator	Acrylic acid ester
Weight %	< 50	< 35	< 30	< 25	< 0.5	< 0.3

Table II. MED610 properties [7]

Property	Standard ASTM	Value
Tensile strength	D638	50÷65 MPa
Elongation at break		10÷25%
Flexural strength	D790	75÷110 MPa
Notched Izod impact	D256	20÷30 J/m

The samples (fig. 1*a*, 1*b*, 1*c*) were designed in the CAD (computer aided design) software SolidWorks (Dassault Systemes SolidWorks Corp.,Waltham, MA, USA) then the virtual models of the samples were saved to STL format i.e. their geometry was described using a triangle mesh. The STL files were then imported into the Objet Studio 3D printer software and placed on the virtual platform (fig. 1*d*, 1*e*, 1*f*). The samples were produced

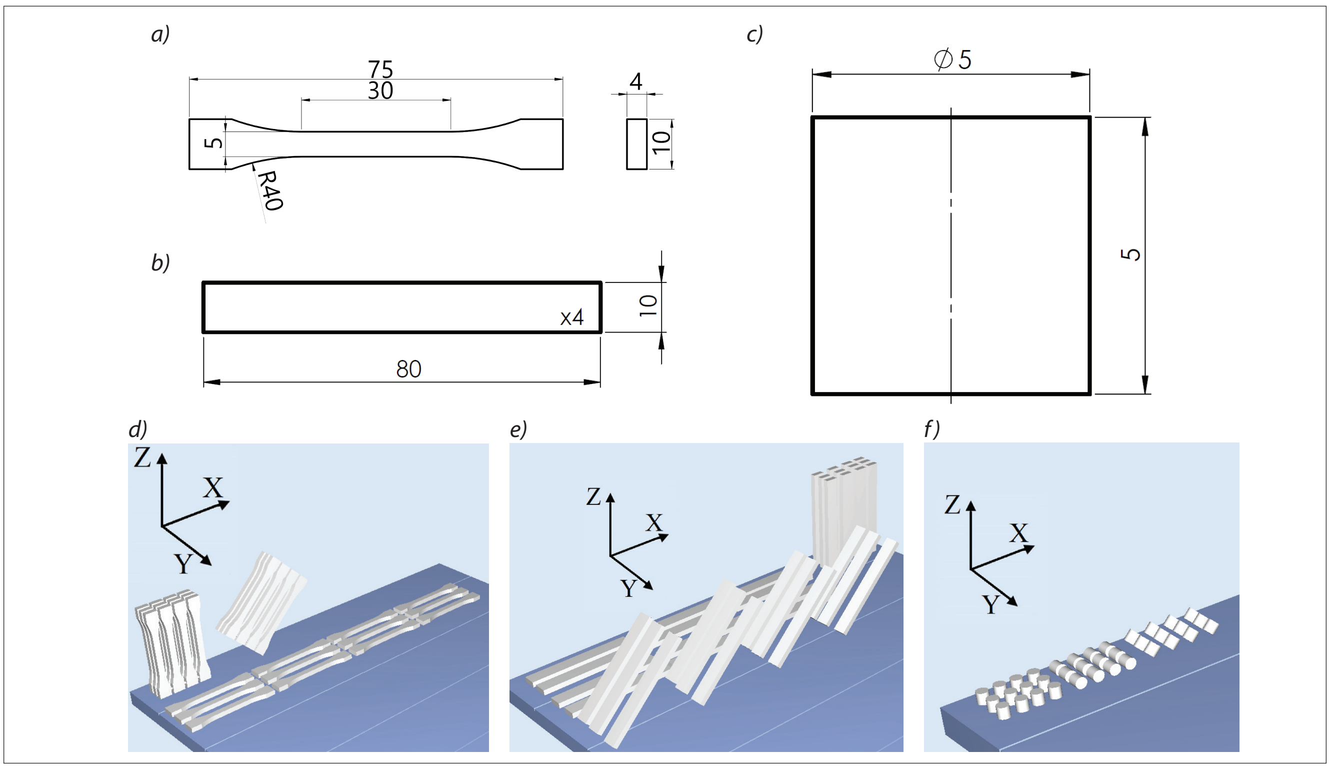

Fig. 1. Test samples: (*a*) dimensions of tensile test samples, (*b*) dimensions of bending test samples, (*c*) dimensions of compression test samples, (*d*) arrangement of tensile samples on the virtual platform, (*e*) arrangement of bending samples on the virtual platform, (*f*) arrangement of compression samples on the virtual platform

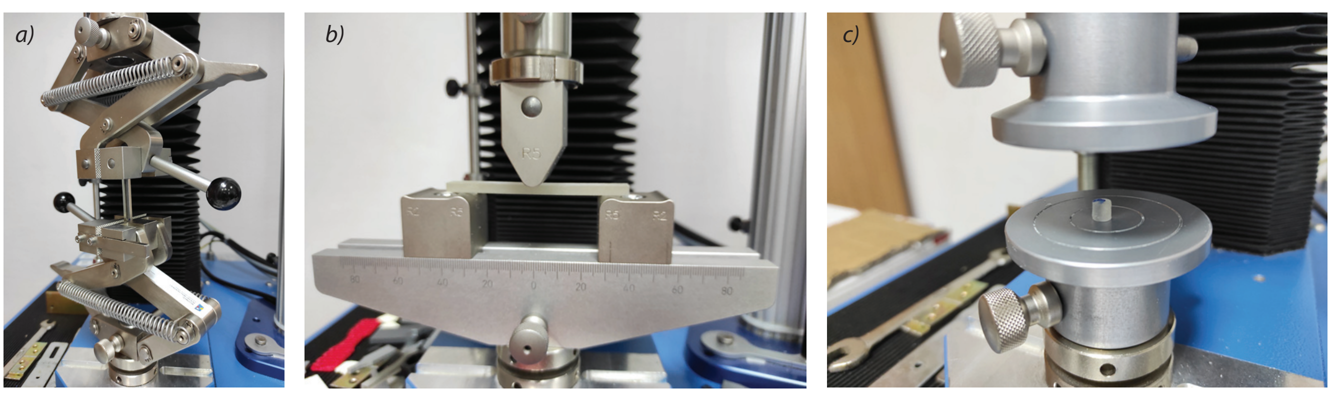

Fig. 2. Position of the sample during: (*a*) tensile test, (*b*) bending test, (*c*) compression test

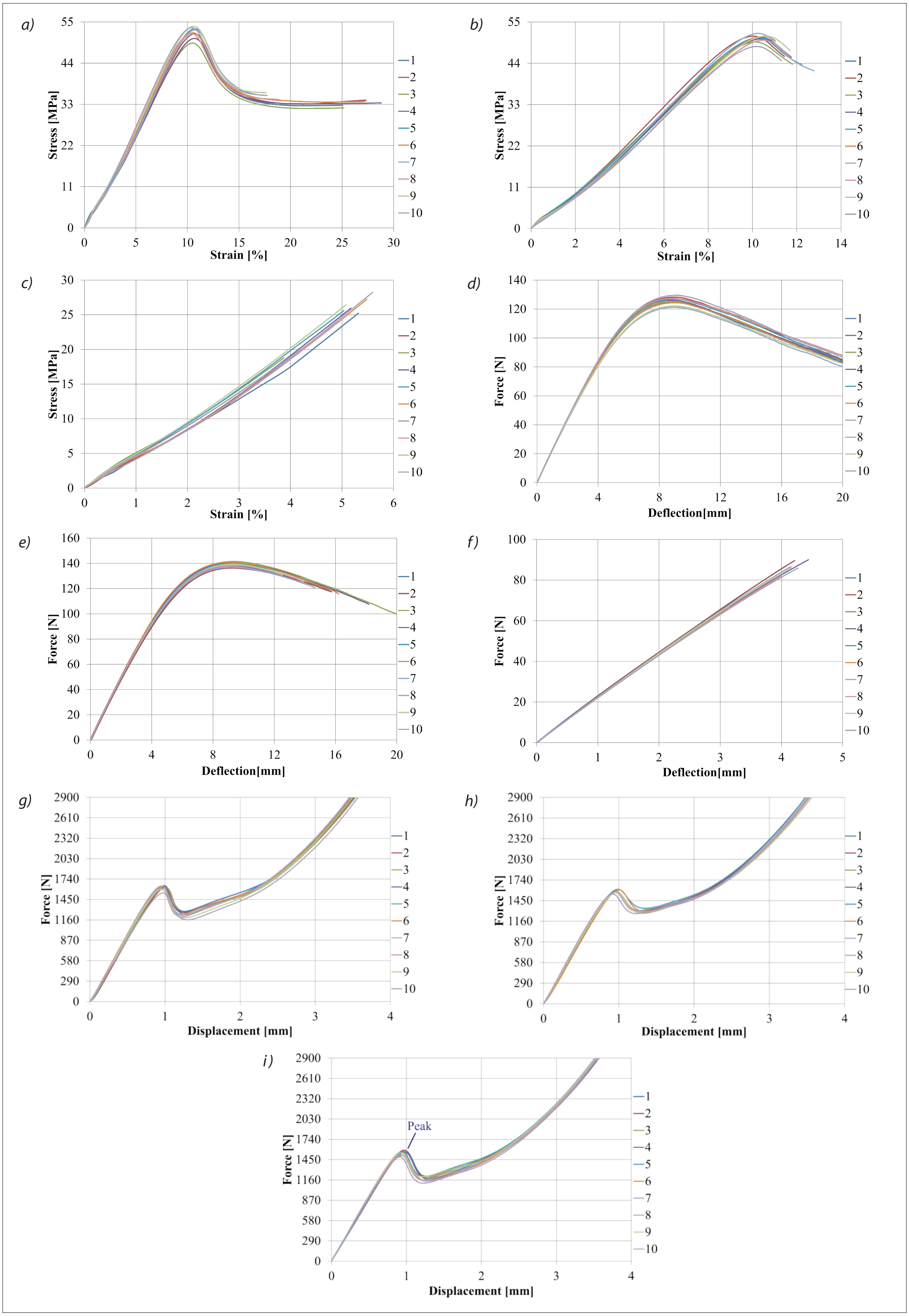

Fig. 3. Test results of: (*a*) 0° tensile, (*b*) 45° tensile, (*c*) 90° tensile, (*d*) 0° bending, (*e*) 45° bending, (*f*) 90° bending, (*g*) 0° compression, (*h*) 45° compression, (*i*) 90° compression test

on a Connex 350 printer (Stratasys Corp., Minneapolis, United States) in High Quality printing mode, which is characterized by a layer height of 0.016 mm and with a matte surface finish, meaning that the samples were entirely covered with support material. The PolyJet Matrix (PJM) technology used involves applying liquid resin through the print head to the 3D printer's work table in the form of tiny droplets mapping the cross section of the part being made. UV lamps are placed in the print head, as a result of UV light, the photopolymerization process takes place, i.e. the transition from the liquid to the solid state of the resin. The process is repeated layer by layer until a full-sized 3D object is obtained. The test samples were fabricated in three printing directions of 0°, 45° and 90°. After the samples were produced by the additive process, the support material was removed using a water pressure washer.

The Inspekt Mini strength testing machine (Hegewald and Peschke, Nossen, Germany) with the LabMaster software (Hegewald and Peschke, Nossen, Germany) was used to perform tests. The maximum load range of the machine was 3 kN. An example of samples during tensile, compression and bending testing is shown in fig. 2. The tests were performed in accordance with ISO 527 (sample type 1BA), ISO 178 and ISO 604. The values of the individual quantities were calculated from the following formulas:

- mean value

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \quad (1)$$

where: n – group size; x_i – single test result

- standard deviation

$$SD = \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2} \quad (2)$$

Results

Nine types of tests were performed, i.e. static tensile, bending and compression at three different printing orientations of 0°, 45°, 90°. Each test was repeated ten times, giving a total of ninety samples. Figure 3 shows the curves obtained from the strength testing machine data. In the case of the tensile test (fig. 3*a*, 3*b*, 3*c*), it can be seen that samples printed flat (0°) lasted the longest reaching the highest strain compared to samples printed at 45° and 90°. Samples printed at printing directions of 0° and 45° reached maximum stress at about 10% strain while the crack of the 90° samples occurred in ranges of 5÷5.5% strain.

The course of the graphs shows a clear anisotropy. A similar trend is noticeable for the bending graphs (fig. 3*d*, 3*e*, 3*f*). The bending samples printed at 0° did not crack during the test. The samples printed at an angle of 45° mostly cracked before the 20 mm deflection. The samples printed at 90° were destroyed relatively quickly at about 4 mm deflection. In the case of the compression test, the graphs (fig. 3*g*, 3*h*, 3*i*) show almost identical trends. Tests were limited due to the machine's range of operation, but it is worth noting that in this type of load operation, anisotropy is negligible.

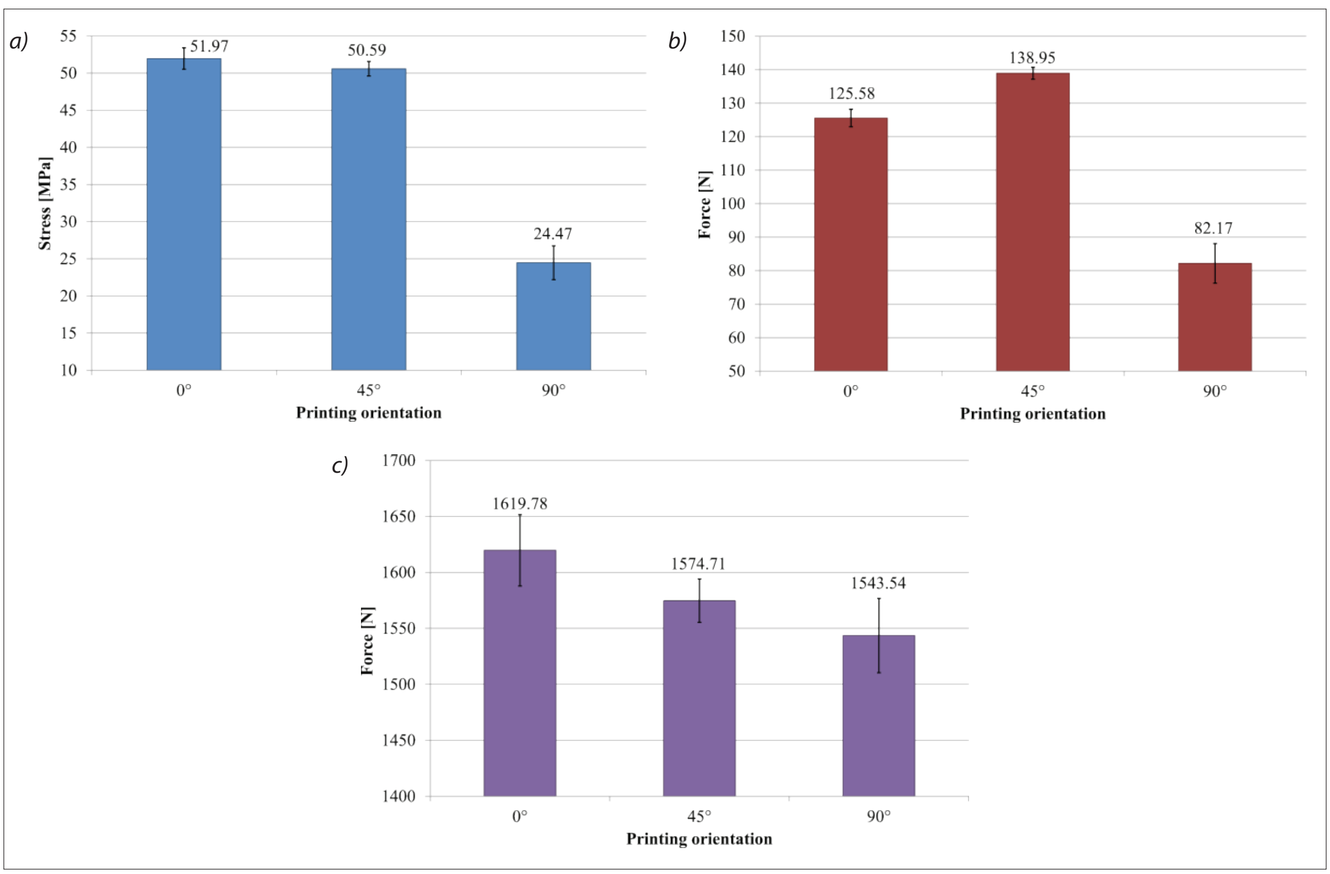

Fig. 4. Mean values of: (*a*) tensile test, (*b*) bending test, and (*c*) compression test results

Figure 4 shows bar graphs presenting the mean values (maximum stress or force) calculated from each series of samples, with the standard deviations indicated. It can be observed that the mean value of the tensile strength (fig. 4*a*) for the 0° samples is only 3% greater than the mean value of the tensile strength for the 45° samples. The greatest difference is seen when comparing the mean value of the tensile strength of 0° or 45° samples to the mean value of the tensile strength of 90° samples. The difference reaches 112% compared to 45° samples and 107% compared to 0° samples.

In the case of the bending test (fig. 4*b*), it can be observed that the mean value of the maximum force for the 45° samples is only 11% greater than the mean value of the maximum force for the 0° samples. The 90° samples crack relatively quickly at the mean force of 82.17 N. The standard deviation takes on the highest value for sample 90°. For the compression test, the location of the first peak on the compression graph was analysed (fig. 3*i*). At this location, the highest mean value of the load was registered for samples made in 0° orientation (fig. 4*c*). However, it should be noted that the standard deviations take high values regardless of the orientation of the print.

Conclusions

Analysis of the results allows to draw the following conclusions:

- the study showed that the anisotropy is notably visible in the static tensile and bending tests performed;
- the highest tensile strengths was achieved by samples produced with the 0° print orientation used, but the 45° samples had a slightly lower result – by about 3% (fig. 4*a*), but it is worth noting that the 45° samples cracked much earlier than the 0° samples (figs. 3*a*, 3*b*), while the 90° samples were the weakest (fig. 3*c*);
- the highest bending force registered for 45° samples, but most samples cracked while 0° samples did not crack (figures 3*d*, 3*e*), during the bending test 90° samples were the weakest (fig. 3*f*);
- in the case of the compression test, the anisotropy is not clearly visible, but by analyzing the first peak in the graphs (fig. 3*g*, 3*h*, 3*i*), it can be seen that the highest compressive force was registered for samples made with the 0° print orientation used. Nevertheless, the highest standard deviations were obtained in this study (fig. 4*c*).

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