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DETERMINATION OF WÖHLER FATIGUE CURVES FOR PEEK AND KIMYA PEKK-A MATERIAL

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Abstract: *As part of the work, tests were carried out to determine the mechanical properties of PEEK and KIMYA PEKK-A materials. The test samples were prepared using the incremental FDM method, it is a 3D printing involving the formation of a liquid thermoplastic. Two types of tests were carried out. The first test consisted in performing a uniaxial tensile test on an MTS Criterion Model 43 testing machine. During the test, the displacement was measured using two measuring devices - an extensometer and a digital image correlation system. Based on the test, Young's modulus, Poisson's number and maximum breaking force were determined. The value of the maximum breaking force was used to determine the load levels for the fatigue test, which was performed on the MTS Acumen model 12 dynamic testing machine. On the basis of the dynamic tests, the Wöhler fatigue curves were plotted.*

Keywords: Fatigue tests, image correlation, PEEK material, mechanical properties, Wöhler curves

1. Introduction

Polyetheretherketone (PEEK) due to its special properties has become a polymer that has found application in many industries, including the medical industry. This material belongs to the family of polyaryl ether ketones, a semi-crystalline thermoplastic characterized by a unique combination of high mechanical properties as well as resistance to chemical substances. An additional advantage of PEEK is the lack of cytotoxicity towards normal cells of the human body, thanks to which it can be successively used as a biomaterial. PEEK, due to its high mechanical strength, Young's modulus similar to bone, better load distribution compared to, for example, titanium biomaterials and lower stiffness compared to steel implants, has become an alternative to classically used solutions (Panayotov et al., 2016, Haleem et al., 2019, Kersten et al., 2015). Polytereroetherketone is also characterized by high thermal stability, and because its melting point oscillates around 340 ºC, PEEK is suitable for use at temperatures up to 260 ºC. An additional advantage of PEEK is its resistance to chemicals and hydrolysis. Resistance to UV, X and gamma radiation also makes it possible to sterilize the surface of the material. Thanks to the above properties, PEEK has become a material used in selective laser sintering technology. With the development of additive technologies that allow printing at high temperatures, PEEK began to be used in 3D printing of thermoplastics using the FDM method. Vapors released during the heating of the material in the 3D printing process are also characterized by negligible toxicity. Taking into account the above-mentioned advantages of PEEK material, especially its mechanical properties and the fact that its Young's modulus is similar to the properties of bone (Mrówka et al., 2021). This gives high hopes for the possibility of printing dedicated implants with better load distribution compared to steel implants. Determination of the mechanical properties of various materials is widespread in the field of biomedical engineering (Joszko et al., 2019, 2018, Wolański et al., 2020). Research is also conducted to determine

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the mechanical properties of biological materials (Gzik-Zroska et al., 2016). All these studies are conducted in order to better understand the functioning of the human body and, at the next stage, to develop various types of implants. In addition to the appropriate mechanical properties of the material intended for the implant, it is also necessary to check it for fatigue loads. Therefore, the purpose of the work was to determine the fatigue strength of PEEK and KIMYA PEKK-A materials.

2. Materials and Methods

The test material consisted of samples made with 3D printing in FDM incremental technology, i.e. the method of molding liquid thermoplastic. The printing parameters used are the speed of 30 mm/s, the layer thickness of 0.15 mm, the temperature of 425 °C and the degree of filling 100%. The samples were made in accordance with ASTM D790-02. In total, 40 samples were tested, 20 of each material (20 pcs. - PEEK, 20 pcs. - KIMYA PEKK-A). Two types of research were conducted. The first test is a static uniaxial tensile test, the second type of test is a dynamic fatigue test.

2.1. Static tensile test

The static uniaxial tensile test was carried out in accordance with the recommendations of ISO 527-2. The MTS Criterion Model 43 testing machine and the DIC digital image correlation system from Dantec Dynamics and the MTS extensometer were used in the study.

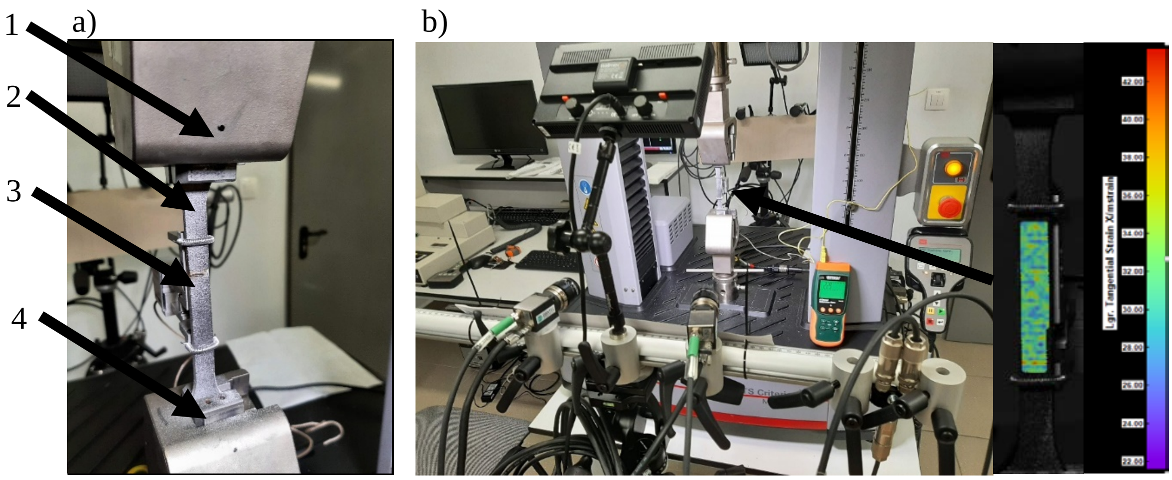

Fig. 1: a) measuring station: 1- upper handle, 2- test sample, 3 - lower handle, 4 - extensometer b) measuring station with a digital image correlation system

Each of the tested samples was mounted in a holder in such a way that the measuring distance between the holders was the same for each sample. The device holder ensures accurate and secure mounting in the axis of the test device without the possibility of moving during the test - Fig. 1a. During the test, an extensometer was placed on each test sample to continuously measure the strain. During the tests, the measurement of transverse and longitudinal deformation was also carried out using digital image correlation, which made it possible to determine the Poisson's number (Fig. 1b). Each sample was subjected to a static tensile test at a speed of 2 [mm/min].

2.2. Fatigue tests

Dynamic tests were carried out using the MTS Acumen model 12 dynamic testing machine (fig. 3). In total, 29 samples were tested for various stress levels calculated in relation to the maximum force Smax determined in static tests. The course of the load was sinusoidal from zero-ripple. The tests were carried out at a frequency of 10 Hz in constant temperature conditions from 22.5 to 22.9 °C, while the air humidity was maintained at 45 %. Prior to each test, the samples were measured by determining the width, thickness and length for each sample. The tests were carried out for four load levels, where for each load level there were specific numbers of samples listed in Table 1.

Fig. 2: Measuring station: 1- upper clamp, 2- test specimen and 3 – lower clamp

Tab. 1: Sets of specimens for fatigue test

Material PEEK	Material KIMYA PEKK-A
40 % Smax 3 specimens – 1.622 [kN]	40 % Smax 3 specimens – 1.570 [kN]
60 % Smax 4 specimens – 1.440 [kN]	60 % Smax 3 specimens – 1.396 [kN]
80 % Smax 4 specimens – 1.080 [kN]	80 % Smax 4 specimens – 1.047 [kN]
90 % Smax 4 specimens – 0.720 [kN]	90 % Smax 4 specimens – 0.698 [kN]

3. Results

The results of the static tensile test for the analyzed samples are presented in Table 2. Based on the measurements, the following were determined: the maximum force Smax [kN], Young's modulus [GPa], Poisson's number and the dimensions of the sample at the measurement site [mm].

Tab. 2: Static tensile test results – PEEK and KIMYA PEKK-A

Specimen PEEK	Young's modulus [GPa]	Poisson's ratio	Max Force S_{max} [kN]	Specimen KIMYA PEKK-A	Young's modulus [GPa]	Poisson's ratio	Max Force S_{max} [kN]
1A	2.21	0.35	1.758	**1B**	1.91	0.30	1.715
2A	2.04	0.33	1.745	**2B**	1.87	0.38	1.707
3A	2.01	0.32	1.741	**3B**	1.80	0.43	1.706
4A	2.05	0.33	1.745	**4B**	2.09	0.35	2.188
5A	2.02	0.34	1.736	**5B**	1.78	0.33	1.698
Mean	**2.066**	**0.33**	**1.745**	**Mean**	**1.89**	**0.36**	**1.803**

On the basis of the test results obtained from fatigue tests, Wöhler diagrams were determined for two types of tested materials (Fig. 3).

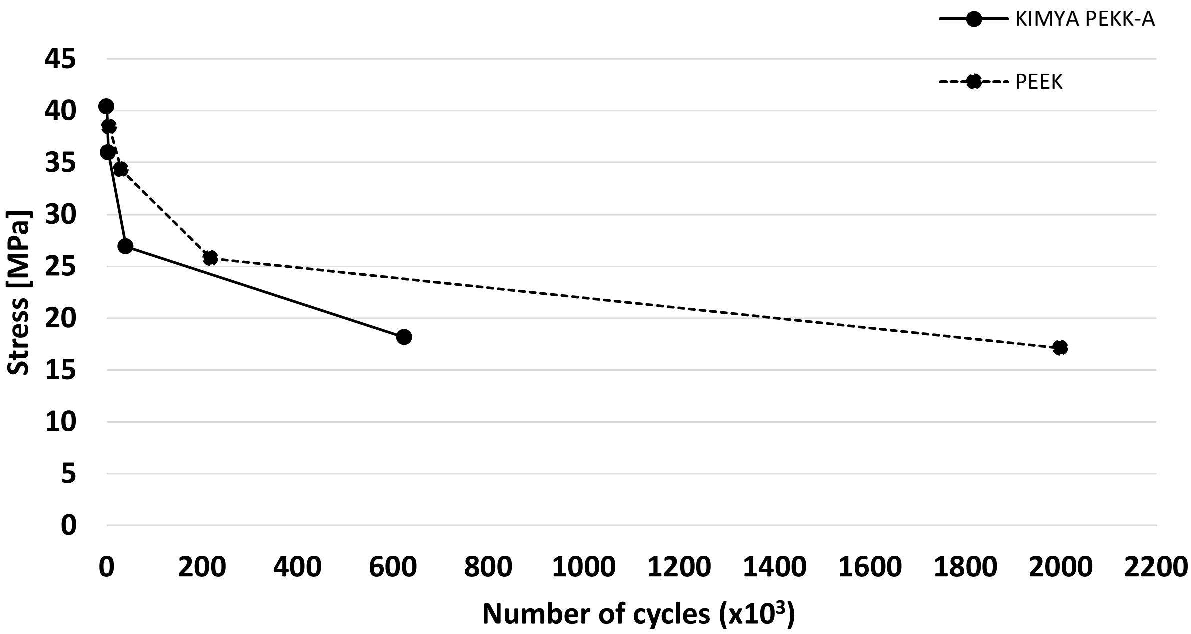

Fig. 3: Wöhler curve

4. Conclusions

On the basis of the tests carried out, it was observed that the PEEK type material is characterized by higher Young's modulus values than the KIMYA PEKK-A type material. The difference in the obtained values was 8.5 %. Differences were also observed for the value of Poisson's ratio. For the PEEK material, a value of 0.33 was obtained, while for the KIMYA PEKK-A material, a value of 0.36 was obtained. In addition, based on the dynamic tests, it was observed that the PEEK type material is characterized by a higher fatigue strength than the KIMYA PEKK-A type material.

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