Torsional strength testing of machine elements manufacture by incremental technology from polymeric materials

(*Rapid communication*)

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Abstract: In this article the research related to the scope increase of incremental technology in machine industry is presented. Those technologies were used for the manufacture of components from polymeric materials with torque loaded such as: shafts, clutches of gear hubs and other elements of the propulsion system in which torque is transferred. To analyze the properties of the manufactured elements the original testing stand was designed and a series of preliminary torsional strength tests of the gear shaft fittings obtained using additive techniques have been carried out. On the basis of the obtained results it was stated that there is a clear influence of the printing plane in the applied incremental technologies [SLS (selective laser sintering) and FFF (fused filament fabrication)] on the torsion resistance of the obtained elements. The properties of the shafts also depend on the type of polymeric materials which they were made of.

Keywords: torsional strength testing, polymeric materials, machine elements, incremental technologies.

Badania wytrzymałości na skręcanie elementów maszyn wytwarzanych przyrostowo z materiałów polimerowych

Streszczenie: Przedstawiono badania związane ze zwiększaniem zakresu wykorzystania technologii przyrostowych w budowie maszyn. Technologie te zastosowano do wytwarzania z materiałów polimerowych elementów obciążonych momentem skręcającym, takich jak: wały, sprzęgła piasty kół zębatych i inne elementy układu napędowego, w których jest przenoszony moment obrotowy. W celu przeanalizowania właściwości wytwarzanych elementów zaprojektowano autorskie stanowisko badawcze, za pomocą którego przeprowadzono serię badań wstępnych skręcania wałków przekładni wytworzonych z wykorzystaniem technik addytywnych. Na podstawie uzyskanych wyników stwierdzono, że właściwości elementów poddanych skręcaniu wyraźnie zależą od płaszczyzny wydruku w zastosowanych technologiach przyrostowych (SLS i FFF) oraz od rodzaju materiałów polimerowych użytych do wykonania badanych elementów.

Słowa kluczowe: badania skręcania, tworzywa polimerowe, elementy maszyn, technologie przyrostowe.

Dynamic development of additive manufacturing technique causes that there are often competitive to traditional production methods. Based on the 3D-CAD model (including data processing), the parts created in incremental process are characterized by a layered structure. Incremental technology gives the possibility of manufacturing products with complex shapes and internal structures of the model, which were previously unavailable for the conventional production methods from the automotive, aerospace, railway or orthopedic industries [1].

In recent years, incremental technologies have been used more and more often to produce not only visual or technological prototypes but also primary machine components based on rapid manufacturing (RM) processes [2–8].

Therefore, the development of designing and manufacturing methodologies of production and data for calculation of the strength of machine parts, especially those in torsional and multiple loads working are very important.

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The objective of this study was to extend the range of incremental technology applications in the construction of machines for the production of components loaded with torque such as shafts, clutches of hubs.

EXPERIMENTAL PART

Materials

In the study, the specimens were made from materials listed in Table 1.

Preparation of specimens

The specimens whose view and dimensions are shown in Fig. 1, were obtained using two machines: Prusa MK3 working with FFF (fused filament fabrication) method and TPM Elite P 3200 working with incremental technology SLS (selective laser sintering). The samples were obtained for 45° print angle and in horizontal and vertical orientation.

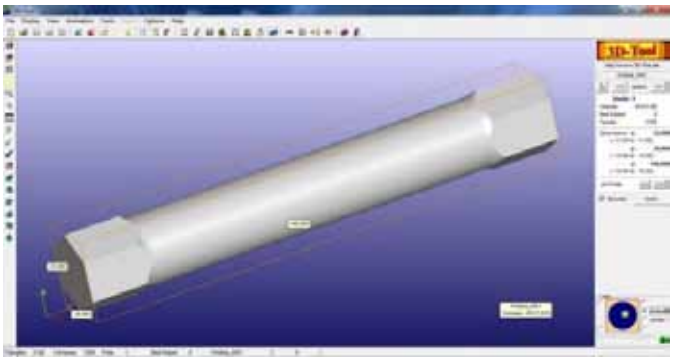

Fig. 1. Torsion test model (gear shaft) – STL file

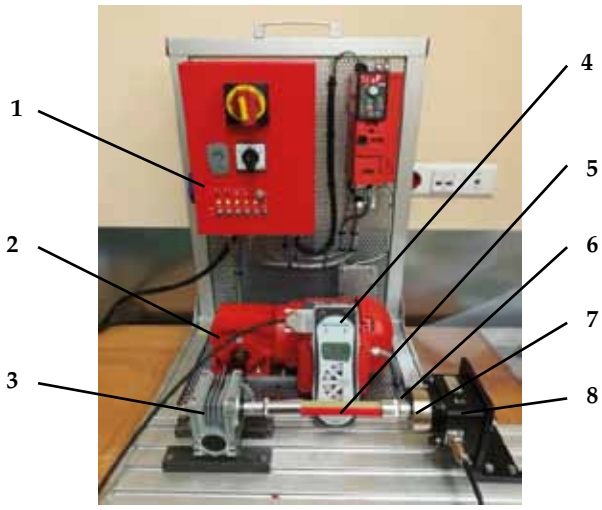

Fig. 2. Torsion test stand: 1 – control panel, 2 – electric engine, 3 – shaft, 4 – torque recorder display, 5 – specimen, 6 – sample movement sensor, 7 – torque sensor, 8 – measuring system

T a b l e 1. Polymeric materials and incremental technologies used to prepare the specimens

Incremental technology	Polymeric materials	Trade name
SLS (selective laser sintering)	Powdered polyamide 6 (PA6)	Precimid 1171 – manufactured by ShuoWei 3D printing technology (Shanghai) Co., Ltd
FFF/FDM (fused filament fabrication/ fused deposition modeling)	Polylactide (PLA)	Maker Bot Tough PLA Bundle – manufactured by DAEMON 3D Print

Methods of testing

Torsional strength

The torsional strength test was carried out *via* the submitted for patenting designed original testing stand. The stand diagram is presented in Fig. 2.

Accelerated aging test

In order to investigate the atmospheric conditions resistance of samples, the aging test in accelerated aging chamber KK-1000 CHULT from Pol-Eko-Aparatura was performed. The chamber was equipped with a filtered Xenon lamp (λ ~ 300–400 nm) with intensity of 60 W/m^2. In each cycle the samples were exposed to UV lamp for 2 h, in which time for 18 minutes the samples were additionally subjected to a shower with distilled water. The temperature in the chamber was in the range from -50 ± 3 °C to +50 ± 3 °C. The total degradation time was 50 h for each cycle.

RESULTS AND DISCUSSION

Due to the applications in machine construction the aging resistance of polymeric materials produced incrementally is very important. Therefore, the accelerated aging test of samples in the aging chamber according to the procedure described above was carried out.

In order to conduct strength test of the obtained machine elements (Fig. 1), the concept of the test stand was developed. The test stand allows the loading of samples and the registration of test results (Fig. 2). The tests to determine the strength parameters of the gear shaft loaded with torque in accordance with the recommendations of PN-ISO 898-7:1996 were carried out. On the basis of the tests, the allowable torsional stress for samples made by SLS and FFF methods was determined. The effects of the material used in selected technologies, the internal structure of the sample and the orientation of the sample relative to the layering direction in the incremental process on the values of allowable stresses were studied. The

results presented in Fig. 3 indicate, that the orientation of the model layers has a significant impact on torsional strength. Furthermore, it was found that the best results were obtained for the samples printed horizontally using FFF technology (Fig. 3). For the samples obtained in the same printing plane by the SLS method, the clear yield strength was observed. As a result of this, the torsion angle is very large and amounts to about 160°. The remaining curves indicate brittle cracking of the tested samples. Moreover, the samples obtained for 45° print angle in SLS technology were characterized by the worst strength (Fig. 3). Unfortunately, there are no publications related to the tests of incremental manufactured machine elements and torque loaded. Therefore, the results of the study could not be referred to the results presented in the world literature.

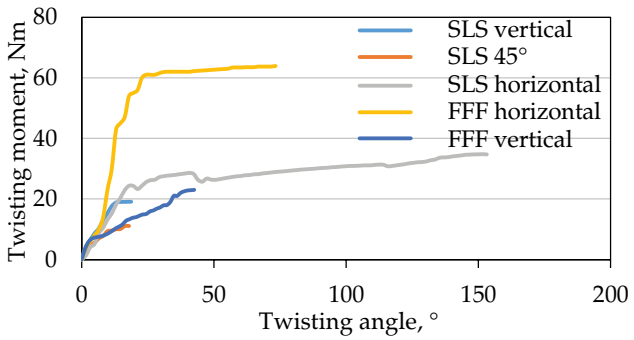

Fig. 3. Relations of the torque in the function of the angle of twisting of the tested samples obtained by SLS and FFF technologies

After aging process, on the other hand, the samples prepared using SLS method had significantly lower, about 30 %, torque moment compared to the unaged, regardless of the printing plane. A similar unfavorable effect for samples obtained by FFF was observed. The torque moments decreased by 15 and 22 % for horizontal and vertical printing direction, respectively.

CONCLUSIONS

On the basis of the review of the literature and the obtained results it was found that there is a need to develop a designing and modeling methodology, and manufacturing incrementally produced elements of machines designed to work under torque load. The implementation of subsequent tests using the developed methodology and analysis of the results will constitute the original material that can be used to develop a database of material properties and their structures as input data used for designing and calculation of incremental machine components.

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