Torsional strength tests of spline connections made of polymer materials (*Rapid communication*)

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Abstract: This work is a continuation of the publication [1], in which the torsional strength tests of samples made of polymer materials, loaded with torsional moment, which more and more often can be made with the use of incremental technologies, were carried out. The designed proprietary test stand, which was described in the publication [1], was used. A series of preliminary studies on the torsion of fittings with spline connections obtained using additive techniques were carried out. It was found, that a additive technologies have a clear impact on the torsional strength of the tested machine components, including the placement of the prototype relative to the 3D printing plane or the method of processing polymer material.

Keywords: torsion testing of polymeric materials, splined connections made of polymeric materials, incrementally produced machine elements, 3D printing.

Badania wytrzymałości na skręcanie połączeń wielowypustowych wykonanych z materiałów polimerowych

Streszczenie: Niniejsza praca jest kontynuacją publikacji [1], w ramach której przeprowadzono badania wytrzymałości na skręcanie próbek wykonanych z materiałów polimerowych obciążonych momentem skręcającym, które coraz częściej są wytwarzane z zastosowaniem technologii przyrostowych. Wykorzystano zaprojektowane do badań autorskie stanowisko badawcze opisane w publikacji [1]. Przeprowadzono serię badań wstępnych skręcania kształtek połączeń wielowypustowych otrzymanych przy użyciu technik addytywnych. Stwierdzono wyraźny wpływ zastosowanej technologii przyrostowej na wytrzymałość na skręcanie badanych elementów maszyn, w tym ułożenia prototypu względem płaszczyzny druku 3D i sposobu przetwarzania materiału polimerowego.

Słowa kluczowe: badania skręcania materiałów polimerowych, połączenia wielowypustowe z materiałów polimerowych, elementy maszyn wytwarzane przyrostowo, druk 3D.

Splined connections enable the transmission of significant torques with small dimensions and their own mass. Therefore, they are often used in the engineering industry. They are used to connect the hub to the shaft and to protect against relative rotation due to torque. The load-carrying element is a spline. Compared with keyed connections, splined connections may be more loaded, they also allow the centering of connected elements. In recent years, incremental technologies have been used more and more often to produce not only visual or technological prototypes but wholesome machine elements, including spline elements [1–7].

The study carried out research related to the extension of the scope of applications of incremental technologies in the construction of machines for the production of elements of spline connections.

EXPERIMENTAL PART

Materials

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

T a b l e 1. Polymer materials and incremental technologies used, from which the test samples were obtained

Incremental technology	Trade name of the material used for printing
FFF (Fused Filament Fabrication)	ABS in the form of a filament produced by Barrus Filaments
PolyJet (Polymer Jetting)	Full Cure RGD720 (FC) photopolymerization resin from Stratasys

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Fig. 1. View of the test samples: a) a sleeve clutch element with a splined sleeve and a hexagonal handle, b) a spline connection of a splined shaft with a gear hub

Preparation of test samples

The test samples (Fig. 1) were obtained using two machines: PRUS MK3 working in the FFF method and Stratasys Eden 260V working in the PolyJet method.

Methods of testing

Test of torsional strength of the samples obtained

The torsional strength test was carried out using a proprietary test stand whose operation and diagram were described in publication [1]. The tests were carried out to determine the strength parameters loaded with torsional moment in accordance with the recommendations of PN-EN 20898-7:1997.

Surface morphology studies of sample fractures after torsion tests

Morphology of fracture surfaces after torsion studies was performed using a Nikon SMZ1270 stereoscopic microscope. Magnification 10× and 50× were used.

RESULTS AND DISCUSSION

The tests carried out on samples made using the PolyJet and FFF methods have allowed the determination of torsional stresses for selected incremental technologies. The impact of the material used in a given technology and the type of splined connection were analyzed. The measurement results are shown in Fig. 2 and in Table 2.

Based on the obtained tests, a significant impact of the type of polymer and 3D printing method on torsional strength and the curve obtained from measurements were observed (Figs. 2a and 2b). It was observed that about 17% higher values of *Ms* were obtained for the samples (Table 2) prepared using PolyJet technology. However, in the case of connection samples obtained in FFF technology, we observe clearly higher values of the torsion angle, which is almost twice as large as α obtained for samples obtained using PolyJet. Unfortunately, in the literature, there are hardly any publications related to the testing of machine components manufactured incrementally and loaded with a torque, which is why the obtained test results could not be referred to the results presented in the world literature.

Figures 2c and 2d show a view of samples damaged after loading with a torsional moment. The location of the observed damage is outside the connection area, which indicates a very important aspect that the design of the shaft itself must be taken into account when designing. This parameter is closely related to the assumed strength, which, however, in the case of elements manufactured by incremental techniques is not constant for a given material and often depends on the 3D print structure, characteristic for a given additive method. The presented test results can be the beginning of creating a database of strength parameters for the design of machine elements loaded with torsional moment. Analysis of research results can be an element of new knowledge, the introduction of which to the methodology of designing machine elements will enable designing taking into account modern production techniques.

Analyzing the fracture surface after torsion of the sample obtained from ABS, a layered cellular structure with sharp edges (Figs. 3a and 3c) was obtained, which may indicate plastic-brittle fracture. However, in the case of connection samples obtained from FC (Figs. 3b and 3d), the view of the surface indicates a brittle fracture. These observations confirm the obtained test results presented in Figs. 2a and 2b, where the course of the relationship

T a b l e 2. Results of measurements of the torsional moment (*Ms*) and torsion angle (α) of the tested samples

Type of material	Splined connection		Sleeve clutch	
	Ms, N/mm^2	α, °	*Ms*, N/mm^2	α, °
ABS	36.3 ± 0.4	41.2 ± 0.2	35.4 ± 0.5	43.2 ± 0.2
Full Cure RGD720 (FC) photopolymerization resin	42.3 ± 0.3	21.5 ± 0.7	40.5 ± 0.1	22.3 ± 0.4

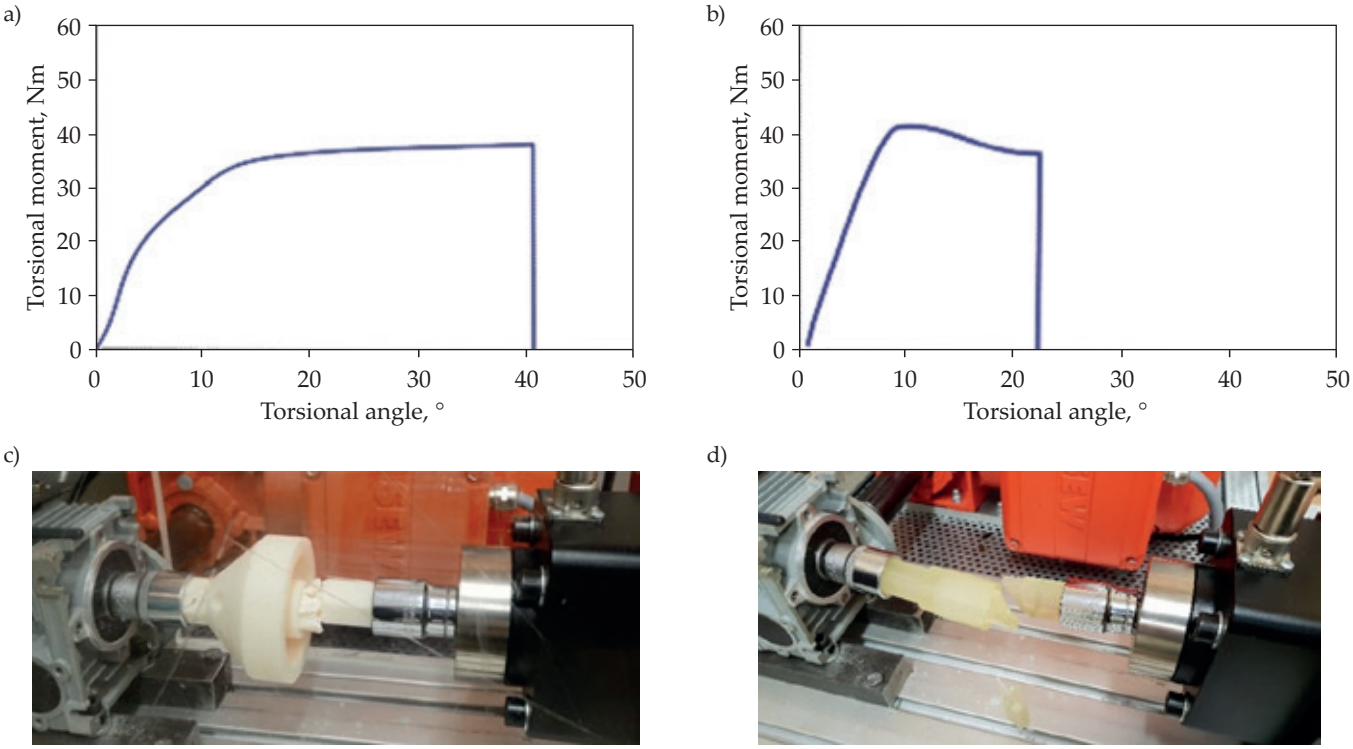

Fig. 2. Graphs of the dependence of the torsional moment and torsion angle for samples obtained by: a) the FFF method, b) the PolyJet method, and a view of the samples: c) spline connection made by the FFF method, d) a sleeve clutch made by the PolyJet method after the torsion test

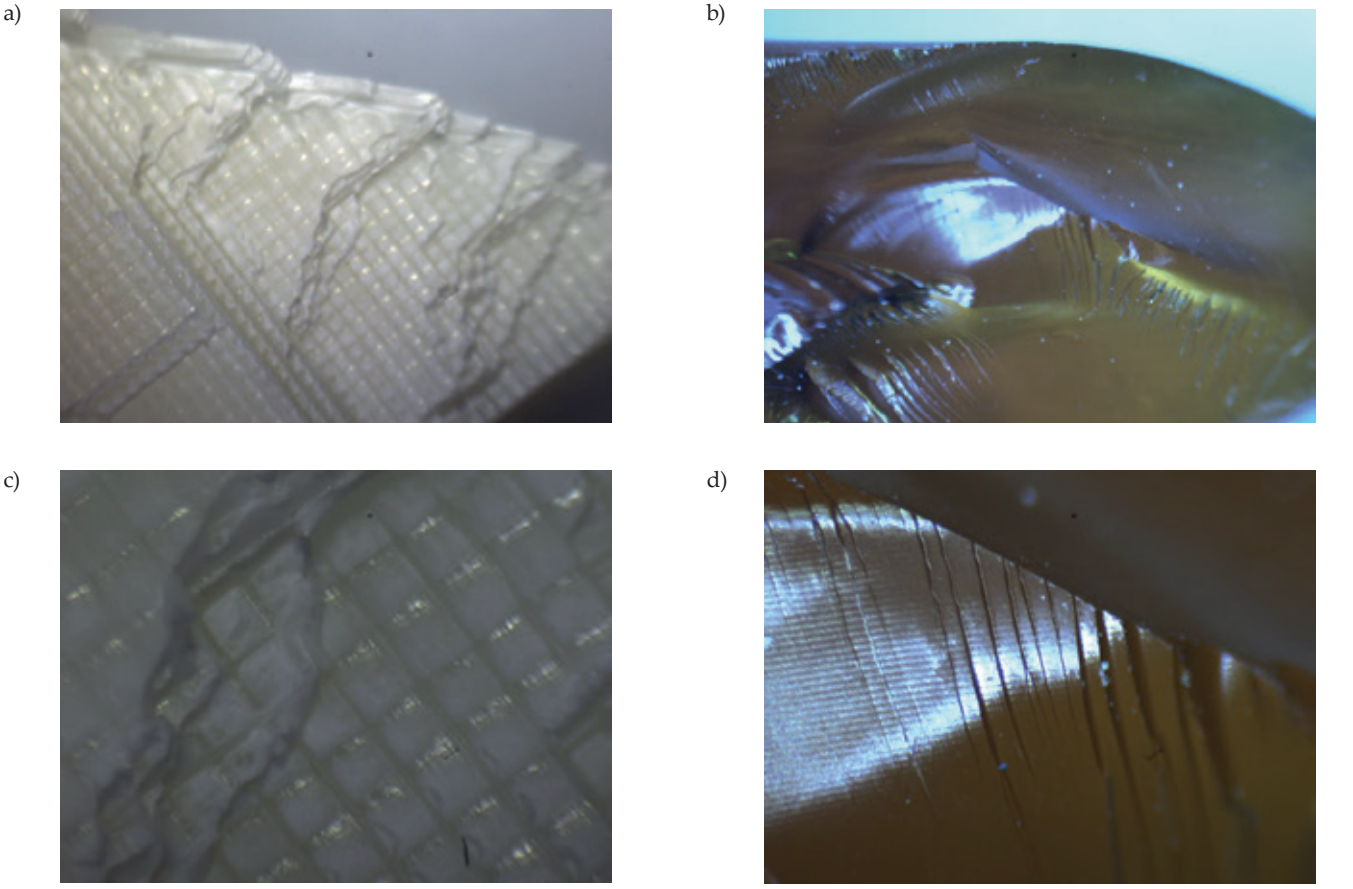

Fig. 3. View of the fractures after torsion samples: a) ABS at 10× magnification, b) FC at 10× magnification, c) ABS at 50× magnification, d) FC at 50× magnification

between the torsional moment and the torsion angle is characteristic for brittle fracture.

SUMMARY

Observing the process of torsion of connection elements used in the construction of machines working under load of torsional moment and incrementally made spline type connection and connection of the spline shaft with the gear hub, you can see the torsion of samples outside the connection area. These applications are useful when designing this type of connections, in this case, you can design, *e.g.* metal inserts to increase the strength of the connection, which can be incorporated into the carrier element by three-dimensional printing, pressing the insert or pasting the carrier element.

A significant impact on the torsional moment and torsion angle was also observed, type of polymer and 3D printing techniques.

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