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AN ANALYSIS OF THE IMPACT OF THE FDM TECHNOLOGY PARAMETERS ON TRIBOLOGICAL PROPERTIES

ANALIZA WPŁYWU PARAMETRÓW TECHNOLOGII FDM NA WŁAŚCIWOŚCI TRIBOLOGICZNE

Key words: FDM, ABS, additives technology, 3D printer, tribology.

Abstract The paper presents the results of tribological tests for sample models made by FDM technology. The ring-shaped samples were made of the ABS P430 material using the Dimension 1200es machine. Disc-shaped counter-samples were made of C45 steel. The analysed technological parameter of the process of building sample models was the "printing" direction (between the friction surface of the sample and the building platform), determined at three degrees of variability (0°, 45°, and 90°). Using the T-15 tribological tester of the ring-on- disc type, a study was carried out to determine the effect of printing direction on the friction force and the total friction wear. In addition, metrological measurements of the tested surfaces were carried out.

Słowa kluczowe: FDM, ABS, technologia przyrostowa, drukarka 3D, tribologia.

Streszczenie Przedstawiono wyniki badań tribologicznych modeli próbek wykonanych w technologii FDM osadzania topionego materiału. Próbki w kształcie pierścieni wykonane zostały z materiału ABS P430 przy wykorzystaniu maszyny Dimension 1200es. Przeciwpróbki wykonane zostały ze stali C45 w kształcie tarczy. Analizowanym parametrem technologicznym procesu budowy modeli próbek był kierunek „wydruku" (pomiędzy płaszczyzną tarcia próbki a platformą budowania), ustalony na trzech stopniach zmienności (0°, 45° i 90°). Wykorzystując tester tribologiczny T-15 typu pierścień–tarcza, przeprowadzono badania polegające na wyznaczeniu wpływu kierunku rozmieszczenia modeli na platformie budowania na wartość siły tarcia oraz sumaryczne zużycie pary ciernej. Ponadto przeprowadzone zostały pomiary metrologiczne badanych powierzchni.

INTRODUCTION

Prototype production with use of plastic-based materials is currently one the most often used methods of rapid manufacturing of single models [**L. 13**]. Conventional manufacturing technologies with use of injection moulding or casting require design and construction of costly and time-absorbing technological processes. After conducting various tests, this hardware may require the introduction of structural changes that increase production costs and lengthen the duration of the implementation of models into serial production, thus decreasing the product's competitiveness in the market. These problems can be challenged by additive production technologies allowing for construction of physical, durable prototype models directly from three-dimensional CAD models. The development of new technologies and the application of machines and devices equipped with control systems have resulted in enormous progress in the field of rapid prototyping in recent years. It refers both to greater interest in the application of additive technologies in such fields like casting [**L. 7**] or medicine and the development of measuring systems (procedures, programs) used to assess the properties of manufactured models, for example, the wear process. In case of various technologies, mechanical properties [**L. 6**], manufacturing accuracy [**L. 11**], and tribological wear of models produced with use of new materials

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are unknown and must be determined in experiments. Research related to the use of additive technologies in the construction of elements exposed to wear was presented in several scientific studies [**L. 3, 4, 5, 8**]. Additionally, research related to wear measurements of plastics for friction wear as a part of polymer-metal hybrid materials was presented, inter alia, in the studies [**L. 1, 9, 10, 18**]. In the study [**L. 3**], the authors tested drivetrain elements (gears) manufactured with use of the Fused Deposition Modelling (FDM) technology. Prototypical elements of gears were manufactured with use of the selected PLA and ABS materials that were subsequently subject to wear tests and friction coefficient measurements. The tests proved that tribological parameters differed, depending on FDM technology material hardness. These tests were conducted for three load values for sample models: 20 N, 40 N, and 60 N.

In the studies [**L. 4, 5**], the authors tested sample models manufactured with use of the selective laser sintering (SLS) technology, two types of powders, and photo-curing of PJM polymer liquid resins. In case of the SLS technology, samples were made of non-modified PA 2200 polyamide and glass fibre-hardened PA 3200 polyamide, and the VeroWhite (trade name) polymer resin was used for the PJM technology. The test results proved that printing direction had an impact on both the wear value measured with the linear method and the friction coefficient.

The selected rheological properties of the materials used with the FDM technology were presented in the papers [**L. 6, 12**] in which the main analysed technological parameter was the printing direction of models on the construction platform.

This paper presents initial friction tests performed at the butt joint of the fixed ring with the rotating disc. The rings (discs) used in tests were made of the well-known ABS constructional material, and the test results were compared with those obtained for pure PA 2200 polyamide [**L. 4**], glass-fibre PA 3200 GF polyamide [**L. 5**], and the VeroWhite polymer resin [**L. 4**]. The test purpose was to determine the impact of the technological parameter, namely, the "printing direction," on wear measured by the linear method and friction force in a polymer-steel slide joint.

FDM TECHNOLOGY

Fused Deposition Modelling is one of the most popular rapid prototyping technologies because of low production costs and the significant variety of used materials. In this technology, rod-shaped material is delivered to a printhead in which it is heated to the temperature slightly lower than the melting temperature of a given material. The heated material is extruded by printing nozzles and distributed on the machine work platform in the location of the currently constructed cross section of a model. After construction completion, the work platform is lowered by the value of the thickness of the currently constructed layer, and the process is repeated until construction of a model is finished. The supporting material is delivered in the same way, but only in places where it is necessary to construct supports. *Modus operandi* for model building with the use of the FDM technology is schematically presented in **Figure 1**. The selected mechanical properties of the ABS P 430 material are presented in **Table 1**. For this technology, it is possible to construct models on the already existing objects, and it was presented in the research study [**L. 2**].

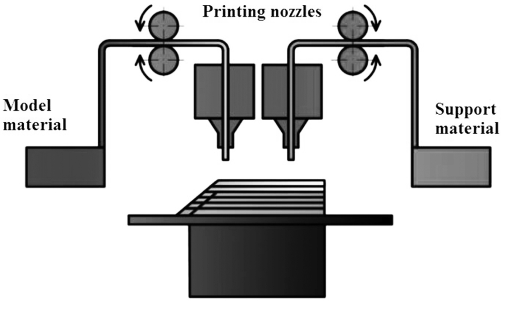

Fig. 1. The principle of building models by the FDM technology

Rys. 1. Zasada budowy modeli przy wykorzystaniu technologii FDM

Table 1. Mechanical properties of ABS P 430 [L. 15]

Tabela 1. Właściwości mechaniczne materiału ABS P 430 [**L. 15**]

Mechanical properties	Young's modulus	Tensile strength, Rm	Charpy notched impact strength	Shore hardness	Density
ABS P430	2320	37	106	75	1.040
Unit	MPa	MPa	kJ/m^2	Scale D	kg/m^3
Standard	EN ISO 527	Method A	ISO 180/1A	ISO 868	ASTM D792

SAMPLES FOR TESTS

The samples for tests were manufactured according to the T-15 tester instruction manual [**L. 14**] (**Figure 2**). Approximation of solid models by means of a triangle mesh was conducted for the deviation tolerance of 0.01 mm and the angular deviation of 10°. The defined model was mapped using 1.220 triangles. The samples were manufactured in 3 variants, namely 1 – 0°, 2 – 45°, and 3 – 90° (**Figure 3**), 5 pieces for each. In case of all sample models thickness of the layer being built was 0.25 mm.

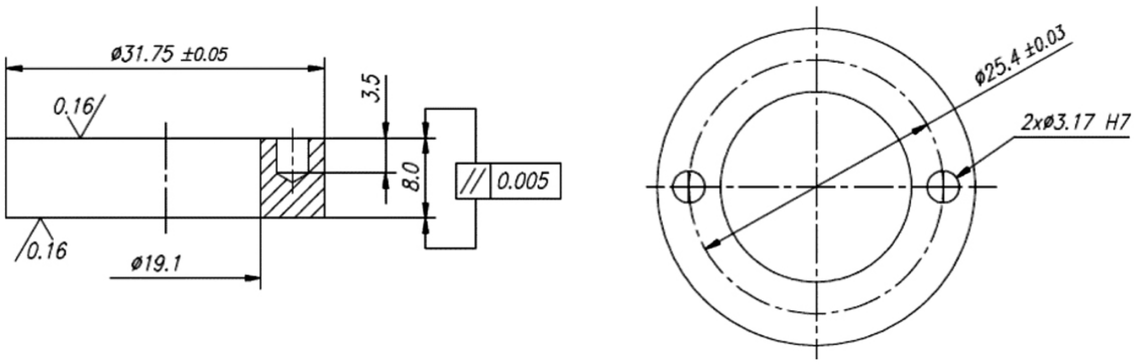

Fig. 2. Sample dimensions
Rys. 2. Wymiary próbek

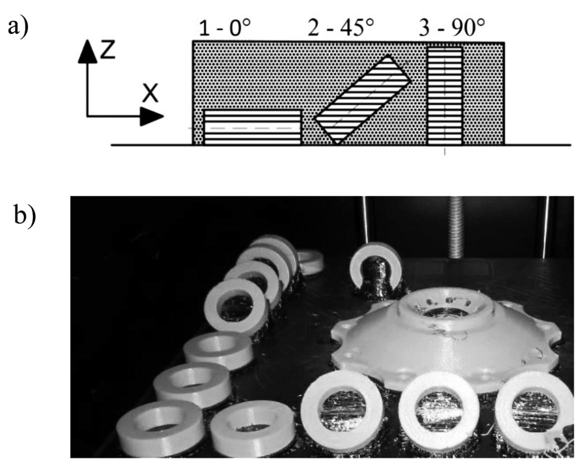

Fig. 3. Samples on the construction platform: a) placement, b) printed models
Rys. 3. Próbki na platformie budowania: a) rozmieszczenie, b) wykonane modele

TEST METHODOLOGY

Tribological tests were performed by means of a T-15 tribological tester consisting of a testing device, a measuring and controlling system, and a computer with software to conduct tests and record their results. The station operation details are presented in **Figure 4**.

For the disc, the rotational velocity was set at 150 rpm, test cycle time to be 3600 seconds, and the sample was subject to the load of 75 N. Considering the calculated area of the joint between the sample and the counter-sample being 505.21 mm^2 and the above mentioned force, the value of pin pressure at the joint is 0.148 MPa. This is a very small value regarding compressive strength of polyamide materials being at the level of 30–70 MPa. During the tests, friction force, summarized displacement of the friction pair, and temperature were measured near the joint of wearing surfaces, as well sample wear after completion of the test cycle and the cooling of the tribological system. Then, metrological measurements of the top layer were conducted with use of an optical Talysurf CCI Lite profilometer, determining surface roughness parameters in the spatial arrangement.

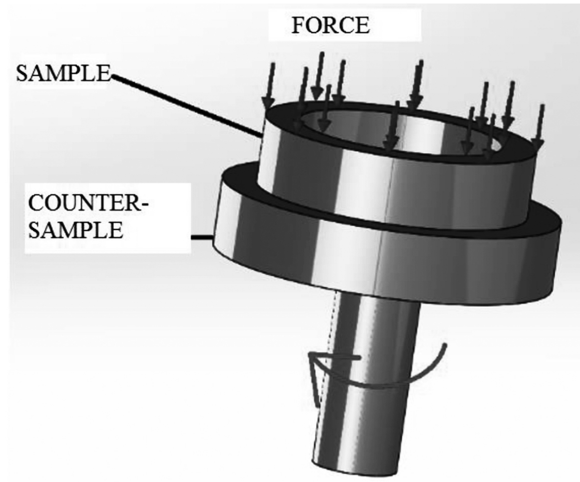

Fig. 4. Test station model, tester T-15 [L. 14]
Rys. 4. Stanowisko badawcze T-15 [**L. 14**]

Table 2. Test cycle parameters
Tabela 2. Parametry cyklu badawczego

Parameter	Value
Load	75 N
Test time	3600 sec.
Pin pressure between ring and disc	0.148 MPa
Disc Roughness	Ra ~ (0,1)
Velocity of the disc	0.16 m/s
Length of the pin path	594 m
Friction	Dry
Temperature of environment	24°C

TEST RESULTS

The test results are presented in **Fig. 5–8** and **Table 3**. The wear measurements are presented just upon completion of the test cycle (time t1), i.e. after 3600 sec. **Fig. 8** shows only some parts of the test cycle, because three of five tested sample models were damaged during the test cycle. A sample model damaged at the test station is shown in **Fig. 9**. Comparisons of the test results to the tests previously performed for the SLS technology (non-modified polyamide 12 (PA 2200) and glass-fibre 12 polyamide (Pa 3200 GF)) and the VeroWhite liquid polymer resin are presented in **Fig. 5** (where 0.1, 0.2, 0.03 – thickness of built layers). 3D views of the sample models after completing the measurement cycle and the graphic interpretation of the volumetric parameters were presented in **Fig. 10** and **11**.

Table 3. Mean value of tribological tests, ABS material
Tabela 3. Średnie wyniki pomiarów tribologicznych, materiał ABS

Sample number	Friction force, N	Displacement – t_1, μm
1 - 0°	7.74	51.67
2 - 45°	7.58	43.1
3 - 90°	7.41	29.81

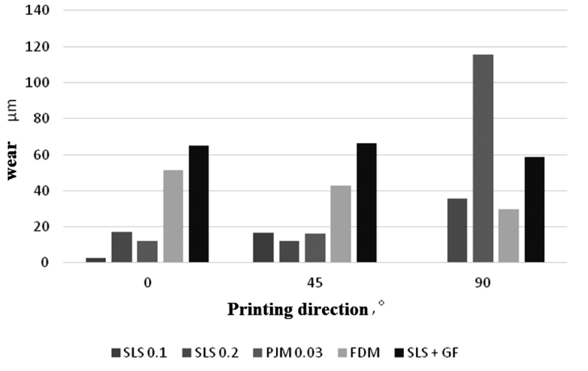

Fig. 5. Comparison of test results for three technologies [L. 4, 5]
Rys. 5. Porównanie wyników badań dla trzech technologii [**L. 4, 5**]

On the basis of the presented test results, we can conclude that wear of samples manufactured with use of the FDM technology decreases along with the increase of the angle value for model distribution on the construction platform. The test results proved that

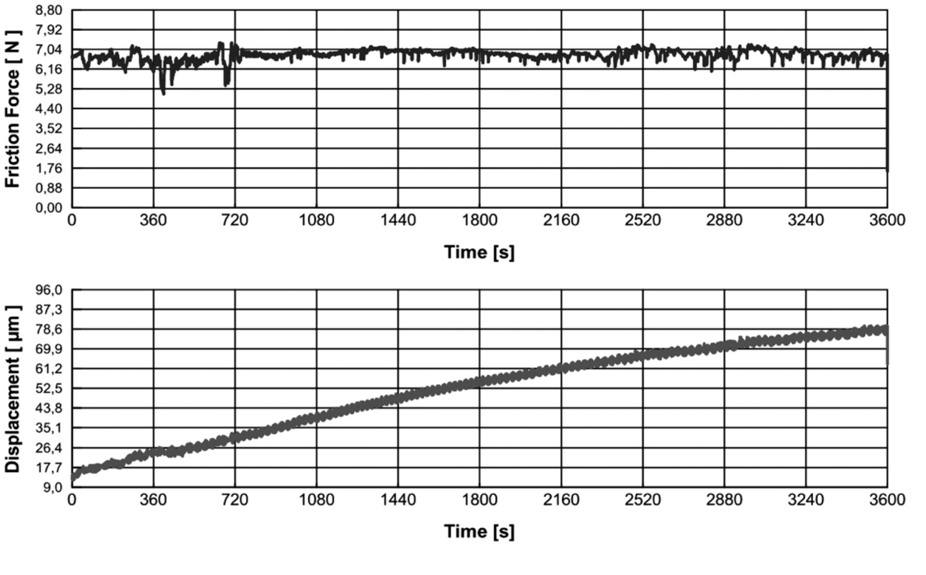

Fig. 6. Exemplary chart of friction force and displacement measurements for the ABS P430 material, Pd – 0°
Rys. 6. Przykładowy wykres pomiarów siły tarcia i zużycia liniowego dla materiału ABS P430, Pd – 0°

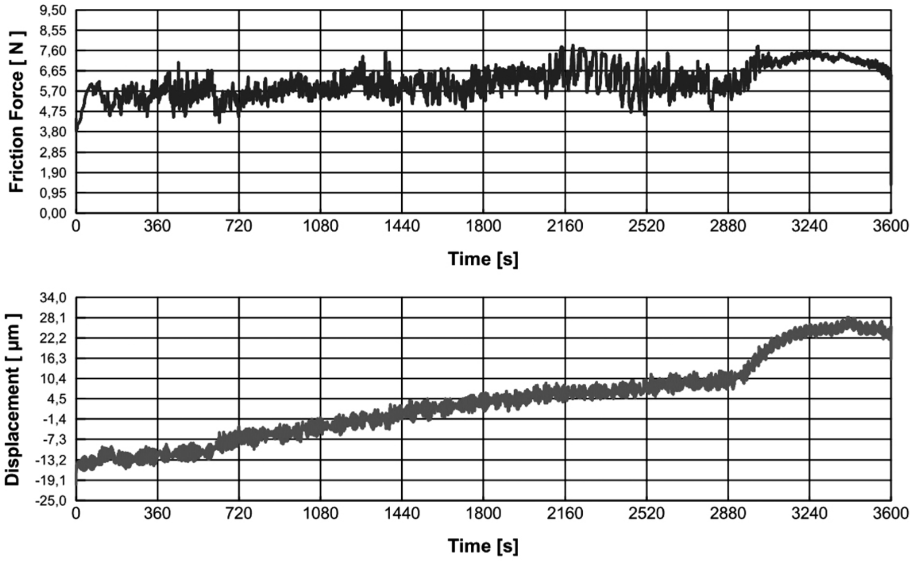

Fig. 7. Exemplary chart of friction force and displacement measurements for the ABS P430 material, Pd – 45°
Rys. 7. Przykładowy wykres pomiarów siły tarcia i zużycia liniowego dla materiału ABS P430, Pd – 45°

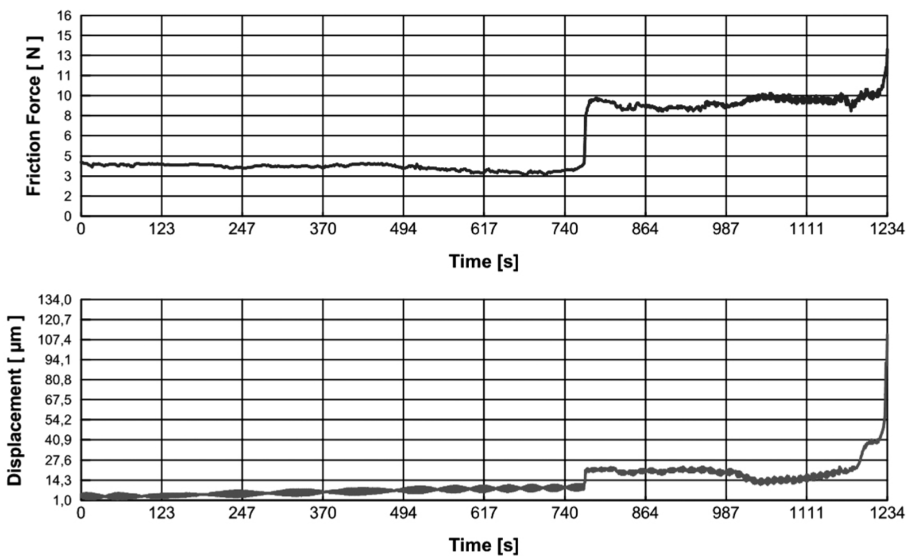

Fig. 8. Exemplary chart of friction force and displacement measurements for the ABS P430 material, Pd – 90°
Rys. 8. Przykładowy wykres pomiarów siły tarcia i zużycia liniowego dla materiału ABS P430, Pd – 90°

Fig. 9. Example of a sample destroyed during testing, Pd – 90°
Rys. 9. Przykład próbki zniszczonej podczas badań, Pd – 90°

a wear value measured by means of the linear method for the angles of 0°, 45°, and 90° were 51.67 μm, 43.1 μm, and 29.81 μm, respectively. Despite the smallest wear value for Sample 3, it turned out that this type of distribution was characterized with the lowest strength of built models. During the test cycle, the models were destroyed, making it impossible to conduct further tests. The wear measurement conducted after time t2, i.e. after cooling of the tribological system, proved that the largest wear also occurred in the case of the samples manufactured at the specified Pd angle of 0°, and it was 17.58 μm. While comparing the test results to those

Table 4. Mean values of volumetric roughness parameters

Tabela 4. Średnie wartości parametrów objętościowych chropowatości

Sample number	Vm	Vv	Vmp	Vmc	Vvc	Vw
1 - 0°	0.00004	0.00356	0.00004	0.00286	0.00271	0.00085
2 - 45°	0.00017	0.00444	0.00017	0.00253	0.00411	0.00033
3 - 90°	0.00003	0.00060	0.00003	0.00039	0.00051	0.00009

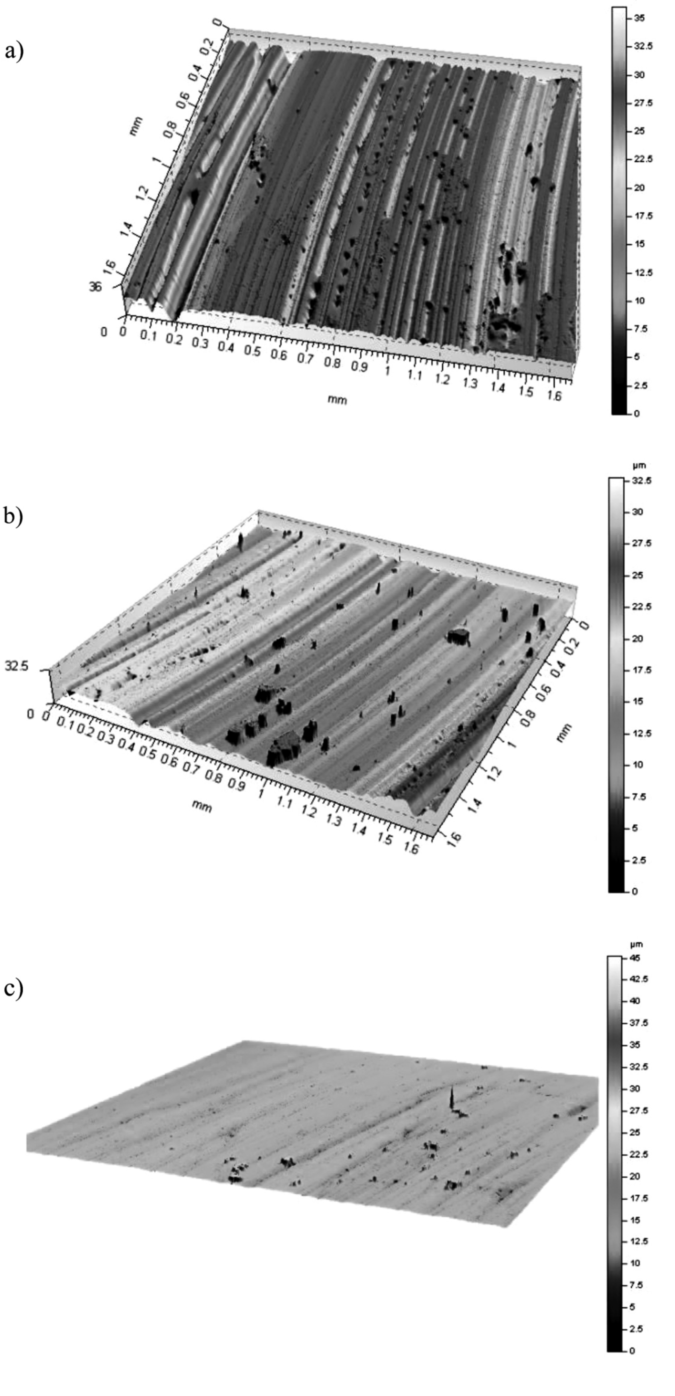

Fig. 10. View of the sample surface after completing the measuring cycle: a) Pd – 0°, b) Pd – 45°, c) Pd – 90°

Rys. 10. Widok powierzchni próbki po zakończeniu cyklu pomiarowego: a) Pd – 0°, b) Pd – 45°, c) Pd – 90°

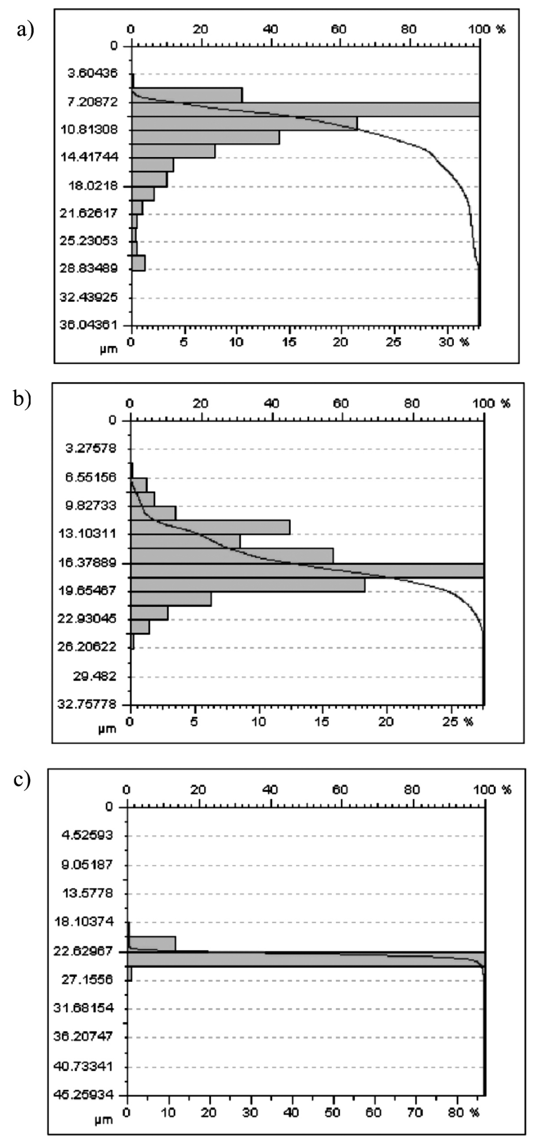

Fig. 11. Material ratio curve: a) Pd – 0°, b) Pd – 45°, c) Pd – 90°

Rys. 11. Krzywa udziału materiału: a) Pd – 0°, b) Pd – 45°, c) Pd – 90°

obtained for the SLS and PJM technologies (**Fig. 5**), we can conclude that other technologies showed similar tendencies (significant differences in test results, depending on a distribution direction). The samples manufactured with use of the SLS technology with specified thickness of a built layer of 0.2 mm were also destroyed during tests. The analysis of the 3D sample view presented in **Fig. 10** clearly shows the largest wear of samples manufactured at the specified Pd angle of 0°, and longitudinal wear traces with the largest depth are clearly visible. On the basis of the volumetric surface roughness parameters shown in **Table 4** and the previous test results and analysis of bibliography [**L. 16, 17**], we can conclude that quality of a top layer has the significant impact on the wear process. In the case of the distribution of models on the platform at the specified angle of 90° after completing the wear process, the smallest value of the Vvc parameter, standing for core void volume, was measured. Nonetheless, these samples were destroyed. While comparing the models manufactured at the specified Pd direction of 0° and 45°, we can conclude that sample wear decreases, while values of volumetric parameters of Vvc, Vv, Vm, and Vmp increase. On the basis of **Fig. 11** showing the graphic interpretation of a material ratio in the top layer, just upon completing the test cycle, we can conclude that a friction surface inclination angle against the construction platform increases, while a number of peaks and valleys in the sample surfaces being tested decreases.

CONCLUSIONS

While analysing the results of tribological tests, we can formulate the following general conclusions:

– In case of samples manufactured with use of the FDM technology, the largest wear can be noticed in the sample models manufactured at the specified angle Pd – 0° against the construction platform.
– No significant impact of a printing direction of ABS samples manufactured with use of the FDM technology on a value of friction force between them and C45 steel was found.

The distribution of samples at the specified Pd angle of 90° does not allow performing measurements in the correct way, because of the very poor strength of models that were destroyed during tests.

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