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THE IMPACT OF THE SELECTED PARAMETERS OF FDM MANUFACTURING TECHNOLOGY ON TRIBOLOGICAL PERFORMANCE OF ABS–STEEL PAIR UNDER DRY FRICTION

WPŁYW WYBRANYCH PARAMETRÓW TECHNOLOGII WYTWARZANIA FDM NA CHARAKTERYSTYKI TRIBOLOGICZNE PARY ABS–STAL W WARUNKACH TARCIA SUCHEGO

Key words: FDM, ABS, 3D printing, tribology, dry friction, steel.

Abstract: The paper presents the result of tribological test of ABS and steel samples sliding under dry friction. Polymeric samples were manufactured of ABS material using FDM technology. Testing was carried out in unidirectional sliding in a ring-on-flat contact in a PT-3 tribometer. The scope of tested parameters included volumetric and mass wear, the friction coefficient, and polymeric specimen temperature. Polymeric specimens used in the study were manufactured at various settings of the 3D printing process such as the orientation of the specimen in print with respect to the printer building tray and the thickness of a single layer of the deposited material. Comparisons of the impact of these parameters on tribological performance of the sliding contact were analysed.

Słowa kluczowe: FDM, ABS, druk 3D, tribologia, tarcie suche, stal.

Streszczenie: Przedstawiono wyniki badań tribologicznych pary ABS – stal w warunkach tarcia suchego. Polimerowa próbka została wykonana z materiału ABS przy użyciu metody FDM. Testy jednokierunkowego tarcia w układzie pierścień – tarcza przeprowadzono na Tribometrze PT-3. Analizowanymi parametrami były zużycie masowe i objętościowe, współczynnik tarcia oraz temperatura próbki polimerowej. Próbki polimerowe zostały wyprodukowane przy różnych parametrach procesu druku 3D, takich jak: orientacja próbki w stosunku do platformy drukarki oraz grubość drukowanej warstwy. Przeprowadzono szczegółową analizę wpływu tych parametrów na charakterystyki tribologiczne badanego skojarzenia ślizgowego.

INTRODUCTION

The most common technology of Rapid Prototyping is 3D printing. The initial application as a tool to produce physical representations of virtual models was quickly transformed to the production of useable objects of difficult to manufacture shapes in various applications in medicine, aerospace, the automotive industry, and even architecture. 3D printing belongs to the additive manufacturing process group, which has several advantages, such as low cost of production, low weight, low waste, and high functionality, resulting from almost unlimited freedom of shaping the designed object. That technology is evolving toward the production of end-use parts. The direct link between the CAD design (a virtual solid shape) and the printer input file allows one to bridge the gap between the designer and the manufacturer, which results in the capacity for accelerated development of the final product **[L. 1]**. As additive manufacturing and 3D printing become increasingly popular for the production of polymeric components, it becomes apparent that the mechanical properties, manufacturing accuracy, and the tribological wear of new materials are unknown and must be determined by experimentation **[L. 2, 3]**.

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There is a rapidly growing base of research jobs related to wear measurements of polymeric – metal sliding combination under dry friction was presented, inter alia, in the papers **[L. 3–9]**. The paper **[L. 3]** presents an analysis of the impact of the FDM technology parameters on tribological parameters. The authors examined three deferent printing positions of ABS sample and concluded that the largest wear was noticed in the sample printed horizontally (specific angle Pd -0° against the construction platform). In the study [L4**]**, the authors investigated the tribological behaviour of ABS and PA6 polymer-metal sliding combination under dry friction and observed that frictional heat produces during sliding had a significant effect on the tribological behaviour of samples. The subsequent results show that the friction coefficient and specific wear rate were significantly influenced by the increase in load and sliding velocity in tribological tests. Despite the development of this field of research further knowledge on the impact of the manufacturing process parameters on the tribological performance of the printed object is needed.

FDM TECHNOLOGY

FDM technology translates to Fused Deposition Modelling and is the most common rapid prototyping technology, known as printing from plastic. Thermoplastic materials are used in FDM technology. In the case of the presented tests, ABS supplied by Zortrax Company was used for preparation of polymeric samples. The selected mechanical properties of ABS are presented in **Table 1**. While the printer operates, the material is melted by heating and deposited on a printer's working surface layer by layer in order to form a designed element. The printing head is driven by a biaxial mechanism in parallel to the working platform, movement in the Z-direction is determined by layer's thickness and thee movement of the working platform. FDM technology is schematically presented in **Fig. 1 [L. 10–12]**.

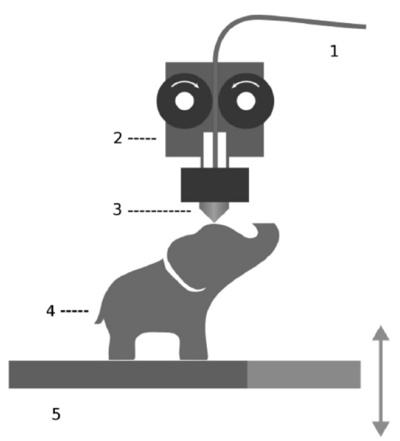

Fig. 1. Schematic of FDM technology: 1 – filament, 2 – head, 3 – nozzle, 4 – printing object, 5 – working platform [L. 10]
Rys. 1. Schemat technologii FDM: 1 – filament, 2 – głowica, 3 – dysza, 4 – drukowany obiekt, 5 – platforma robocza **[L. 10]**

Table 1. Mechanical properties of Z-ABS [L. 12]
Tabela 1. Właściwości mechaniczne materiału Z-ABS **[L. 12]**

Mechanical properties	Metric	Test Method
Tensile Strength	30.46 MPa	ISO 527:1998
Breaking Stress	25.89 MPa	ISO 527:1998
Flexural Modulus	1.08 GPa	ISO 178:2011
Izod Impact, Notched	8.93 kJ/m^2	ISO 180:2004
Shore Hardness (D)	69.2	ISO 868: 1998
Density	1.195 g/cm^3	ISO 1183-3:2003

SPECIMENS AND TEST CONDITIONS

Polymeric cuboid samples of 30x30x5 [mm] were printed in two positions: vertical and horizontal. Three different thicknesses of layers were chosen: 0.09, 0.19, and 0.39 [mm]. The models in print were positioned to achieve the orientation of layers in the final product either parallel or perpendicular to the face of the specimen (**Fig. 2**. – grey lines shows orientation of printed layers, red arrows indicates tested surface).

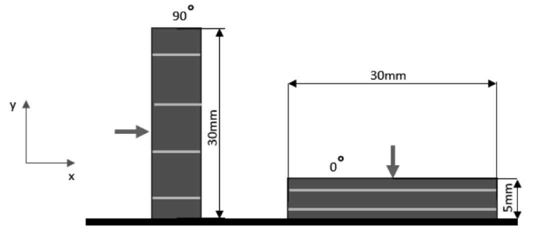

Fig. 2. Positions of printed samples and dimensions of samples
Rys. 2. Pozycje drukowanych próbek i ich wymiary

The steel NC6 (PN-86/H-85023) counter specimen had a ring shaped (annular) face with the outer diameter of 22 mm and inner diameter 15.2 mm. The overall surface area of the contact zone amounted to A ≈199 mm^2.

TEST METHODOLOGY

The tribological testing was carried out in unidirectional sliding in a ring-on-flat contact in a PT-3 tribometer. The machine enables axially loaded testing, and the polymeric sample is restrained from rotation by a friction measurement system. The counter-specimen is attached to the tribometer's spindle and is rotated with the spindle by an electric motor **[L. 13, 14]**. In **Fig. 3** the configuration of samples during tribological test is presented. The test was carried out under dry friction conditions. The polymeric samples were air-cured after printing for a minimum of 48h to obtain normal saturation with moisture and atmospheric gases. Moreover, a spontaneous relaxation of residual stress was thus allowed. The load applied was equal to F_N = 410 N which corresponds to a mean contact pressure of p_{av} = 2 MPa. The acting radius of the friction force was expressed as the mean radius of ring shaped contact area R_{av} = 0.0093 m. The rotational velocity of the spindle was set at 110 rpm. A single test run was 30 min long. The scope of tested parameters included volumetric and mass wear, the friction coefficient, and polymeric specimen's temperature. The mass of the polymeric sample was measured every 2 min during the first 10 minutes, then every 5 min during next 10 minutes, and at the end of the test.

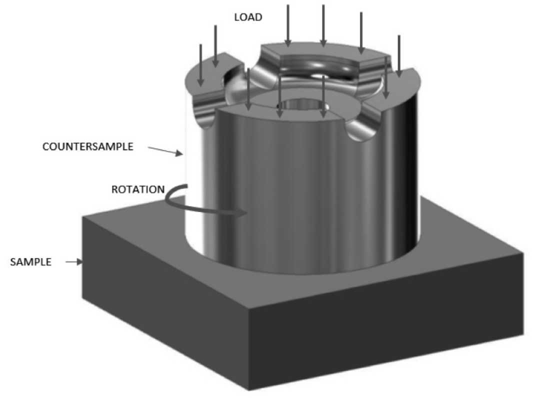

Fig. 3. Specimen setup geometry
Rys. 3. Geometria układu próbek

TEST RESULTS

The test results consist of comparisons of wear, friction moment, the friction coefficients, and temperature. The specimens printed in a vertical (**Fig. 2**, 90°) and horizontal (**Fig. 2**, 0°) position were marked as V and H, respectively. The capital letters are preceded by numbers, which correspond to the thickness of layers, e.g., 019H means a horizontal sample with a 0.19 mm layer thickness. The test results are presented in **Figs. 4 – 6** . The most critical parameter in this tribological test was wear. Figure 4 presents a comparison of mean wear of ABS samples and **Fig. 5** shows a comparison of mean wear values in each type of ABS samples.

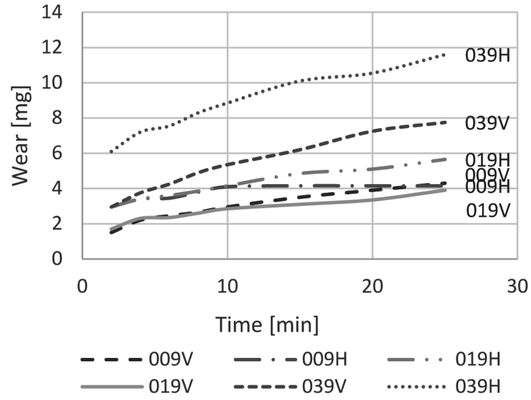

Fig. 4. Wear process comparison for each configuration of ABS sample
Rys. 4. Porównanie przebiegu zużycia masowego dla każdej konfiguracji próbki ABS

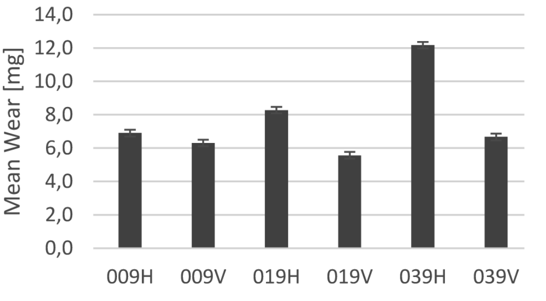

Fig. 5. Mean value of wear for each type of ABS sample
Rys. 5. Średnie wartosci zużycia masowego dla każdego typu probki ABS

For better analysis of the wear process, the friction forces, the friction coefficients, and temperatures were taken into account. A set of charts presenting the friction forces, the friction coefficients, and specimens' temperatures are presented in **Fig. 6**. Results from tests on specimens 019V and 039H are presented.

On the basis of the presented results, the sample with the highest layer shows the fastest wear, the slowest wear is observed in the middle thickness of the printed layer, which was intuitively obvious. The printing position also has an impact on wear. The mean value of wear is equal to 12.17 mg for 039H samples and 5.57 mg for 019V samples. The weight loss is 40% greater for horizontal samples than vertical ones. The difference in wear between the two extreme cases is equal to 218%. This means that the element manufactured with a 0.39 mm layer will be damaged 2 times faster than the same element printed with 0.19 mm layer. The progress of wear is a similar shape for each configuration of the polymeric sample. The fastest increase in wear is observed within the first 10 minutes of the test, after this time, the rate at which wear progresses decreases, which indicates a running in is taking place quickly. During that phase of the test, a stabilization of the friction moment is also observed. The 039H sample has the lowest friction coefficient, which is reflected in lowest temperatures during the tests; however, the wear rate in that specimen type is greatest of all. Comparatively, the 019V produces the greatest friction coefficient, and reaches the highest temperature, which, surprisingly, comes along with the smallest wear.

After the test run was competed, an examination of each specimen by optical microscopy was done. Vertical and horizontal samples were compared. **Figure 7** contains photographs of examined samples at 20x zoom. The printed structure can be clearly visible on the horizontal sample. When the layers are perpendicular to the friction force, black precipitate is formed in the intralayer zones on the examined surface. The black residue is probably formed from metal oxides produced on the face of the steel counter specimen. On the vertical sample, a clearly visible layer of pulverised polymeric material can be observed beside the wear track.

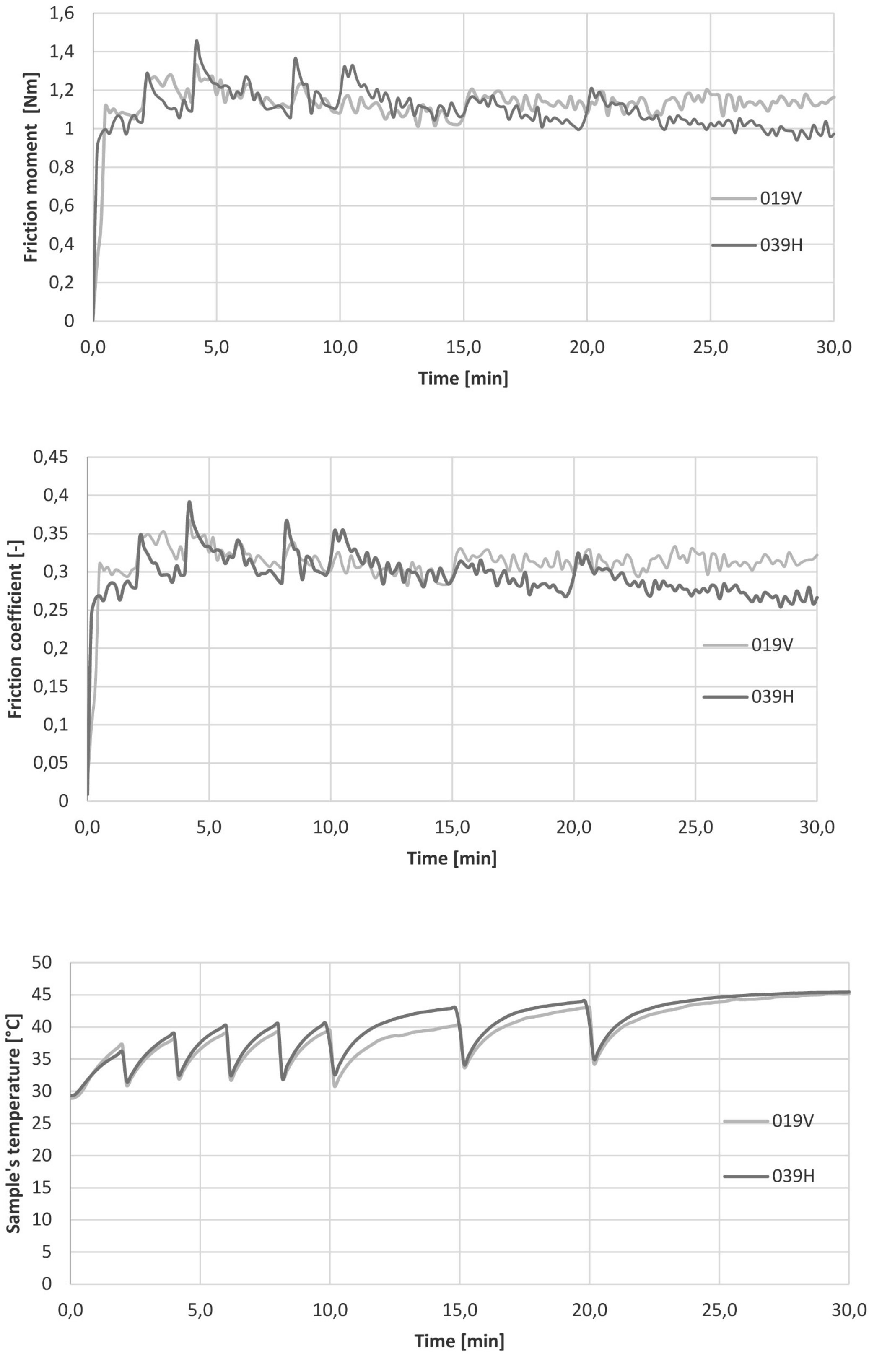

Fig. 6. Exemplary chart of friction moment, friction coefficient and sample's temperature

Rys. 6. Przykładowy wykres pomiarów momentu tarcia, współczynnika tarcia oraz temperatury próbki

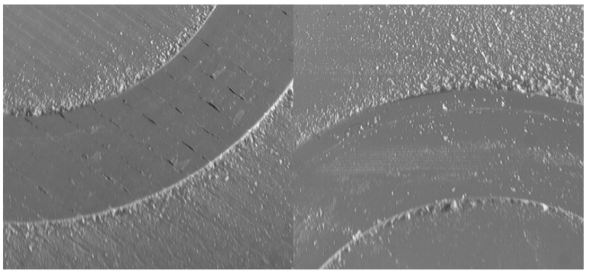

Fig. 7. Wear tracks on polymeric specimens
Rys. 7. Ślady zużycia na próbkach polimerowych

CONCLUSIONS

The tribological tests enabled us to observe the wear of ABS specimens in contact with steel counter specimens. The following general conclusions were formed:

– The printing position (the orientation of the print layers) has an impact on wear.
– The largest wear can be noticed in the sample printed horizontally with the greatest layer thickness.
– The structure of vertical samples is less robust. The specimens have a tendency to deform under load perpendicular to the work face.
– The stabilization of the frictional moment with the progress of the test may be related to the decrease in roughness of the polymeric specimen and the formation a pulverised polymeric as a wear product, which may act as a lubricant and decrease the frictional resistance.
– The next step of research should include tests of ABS samples manufactured with more grades in layer thickness and possibly using different layer orientation angles.
– Further research will include non-destructive testing to examine the internal structure of investigated samples.

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