MICROSTRUCTURE PROPERTIES OF PARTICLES REINFORCED POLYTETRAFLUOROETHYLENE COMPOSITE BEARINGS AFTER WEAR

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High-performance engineering polymers that ensure the desired properties for journal bearings and give good wear results are investigated. In this study, microstructure properties of polymer-based particle reinforced PTFE composite bearings have been determined by optical and SEM wear surface images.

Keywords: *wear, microstructure, polytetrafluoroethylene composite, bearing.*

For the past few decades, polymeric materials have been widely used in industry. Some of these materials are thermoplastics (polypropylene (PP), polyethylene (PE), polyoxymethylene (POM), polytetrafluoroethylene (PTFE) and polyamide (PA) etc.). The main advantage of these polymers is high wear and corrosion resistance. These materials (PTFE) are especially used due to their good tribological properties and solid lubricant properties in the food industry and due to their good performance in non-lubricated dry conditions in journal bearings. PE has low density, high elasticity, and strength. PA, POM and PTFE have good sliding and wear properties at low frictions. Polyoxymethylene is a material which is generally used in engineering applications and is highly self-lubricating [1–7].

PTFE bearings are frequently used in various machines due to their low friction coefficients in boundary lubrication conditions. The major problems in designing polymer bearings are selecting optimal dimensions and material type for a long life and obtaining lower friction and wear losses. Tribological properties of polymer radial bearings are affected by the adhesion on the surfaces of steel-polymer, cohesive characteristics of the polymers used and thermal effects in the friction area at high p–v (pressure.velocity) values [8–10]. These (p.v) value are not valid for polymeric materials. Velocity is affected by applied pressure in these materials [11, 12]. Even though some filler materials are added to the polymers, their effects on tribological properties are not clearly known. There are different opinions in literature on how fillers affect the polymer wear. These filler materials decrease wear by modifying the opposite surface and supporting the load. This increasing effect on wear is due to increased adhesion. They also reduce wear of the PTFE composites and can induce abrasive wear of the counterface [13–15]. If polymeric materials are worn in abrasive conditions, wear rate decreases with an increase in grit grade number [16].

Polymer-based PTFE materials can be used as journal bearings at low speeds [17]. The objective of this study is to determine the wear surface properties of the pure PTFE, 35% Graphite (C-PTFE), 60% CuSn10 (B-PTFE), and 25% glass-fiber (G-PTFE) particle reinforced PTFE journal bearings at low speeds (v = 0.13 m/s).

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Experimental studies. ***Preparation of experimental materials.*** In this study, the pure PTFE, C-PTFE, B-PTFE and G-PTFE particle reinforced materials have been used as journal bearing and SAE 1050 material as a shaft. The chemical compositions of the journal material used in the experiments are (%): 0.51 C; 0.3 Si; 0.7 Mn; 0.04 P; 0.05 S; balance Fe. Dimensions of bearing specimens were as follows: inner diameter ($d = 10^{+0.05}$ mm), width (B = 10 mm), outer diameter (D = 15 mm).

The specimens have been worn and friction coefficients have been measured on radial journal bearing wear test rig in dry conditions as described by Atik et al. [18] and Ünlü and Atik [19]. The wear losses have been measured in dry conditions with 20 N loads, 250 rpm (v = 0.130 m/s) and every 30 min for 2.5 h (1177.5 m sliding distance). The specimens were cleaned by acetone. The microstructures of the specimens wear surfaces have been photographed using the optical microscope (Hund Wetzlar CCD-290) and scanning electron microscope (Jeol JSM-6060).

Radial journal bearing wear test rig. Bearings materials in journal bearings are generally selected from materials which have lower wear strength than the shaft material, thereby lowering the shaft wearing significantly. For this reason, journal bearing wear test apparatus are designed to examine the wear of bearing materials. In this study, a special bearing wear test apparatus has been designed to examine the wearing of the bearing material and the shaft together. Therefore, it is possible to investigate different bearing and shaft materials and also the effects of heat treatments on these materials. Such a mechanism provides wear of bearings rather than using standard methods as this is a more appropriate direction [18]. The system is formed by a weight applied by a rigid bar, a steel bar connected to the bearing from a distance and a comparator. Friction coefficient is determined from the friction force formed along the rotating direction of the bearing and the movement of the steel bar connected to the bearing [19]. Radial wear test rig is illustrated in Fig. 1.

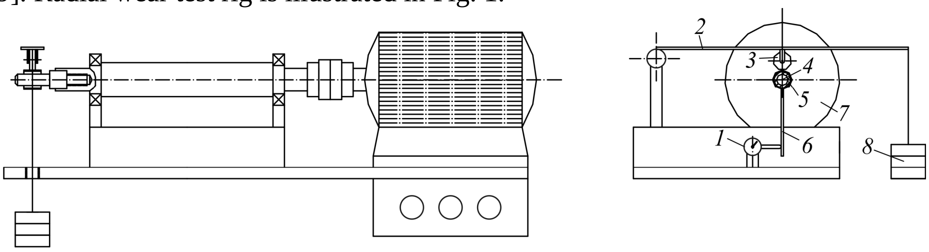

Fig. 1. Radial journal bearing wear test rig: *1* – comparator; *2* – rigid bar; *3* – load contact point (rolling bearing); *4* – journal sample; *5* – journal bearing samples; *6* – plate bar; *7* – motor; *8* – loads.

Results and discussion. Hardness values, surface roughness, friction coefficient, bearing temperature, bearing weight loss, and bearing wear rate of PTFE bearings were determined in our previous study [20]. These values are as follows hardness – 51; 61; 65 and 54 Share-D for PTFE, C-PTFE, B-PTFE and G-PTFE, respectively. Surface roughness values are 1.59; 0.71; 1.1 and 3.95 μm for PTFE, C-PTFE, B-PTFE and G-PTFE, respectively, before wear. Surface roughness values are 2.26, 0.78, 0.92 and 3.52 μm for PTFE, C-PTFE, B-PTFE and G-PTFE respectively after wear. Friction coefficients were obtained between 0.2 and 0.3, bearing temperatures were measured between 36 and 37 °C in all journal bearings. Bearing wear rate of pure bearing is (mm^3/Nm): $7.2 \cdot 10^{-6}$; $4.7 \cdot 10^{-6}$; $8.5 \cdot 10^{-6}$, and $2.86 \cdot 10^{-6}$ for PTFE, C-PTFE, B-PTFE and G-PTFE, respectively [20].

After wear tests, the roughness of pure and C-PTFE bearings have increased, but roughness values of B-PTFE and G-PTFE bearings decreased. Similarity between the friction coefficient and bearing temperature of pure and filled PTFE bearings is the result of PTFE coating on the filled materials surface and thus forcing this bearing to act as pure PTFE bearing. Wear resistance of particle filled PTFE bearings increased about 2…3 times because of particle reinforcement. Graphite, bronze, and glass reinforcement grains and wear surfaces were shown in the microstructure. These results are supported by wear surface optical and SEM images (Figs. 2, 3). In this study, few adhesive wear occurred for particle filled bearings, due to better wear resistance significance of bronze, glass, and graphite solid lubrication property (Figs. 2, 3*b–d*), corresponding properties for pure PTFE bearing (Figs. 2, 3*a*). In our previous studies [21, 22], we examined polymer based PE, PA, POM, pure PTFE, graphite, bronze and glass-fiber reinforced PTFE, pure Bakelite and bronze and ferrous reinforced Bakelite bearings [21]. We reported that particle reinforcement increased the wear resistance of polymer bearings.

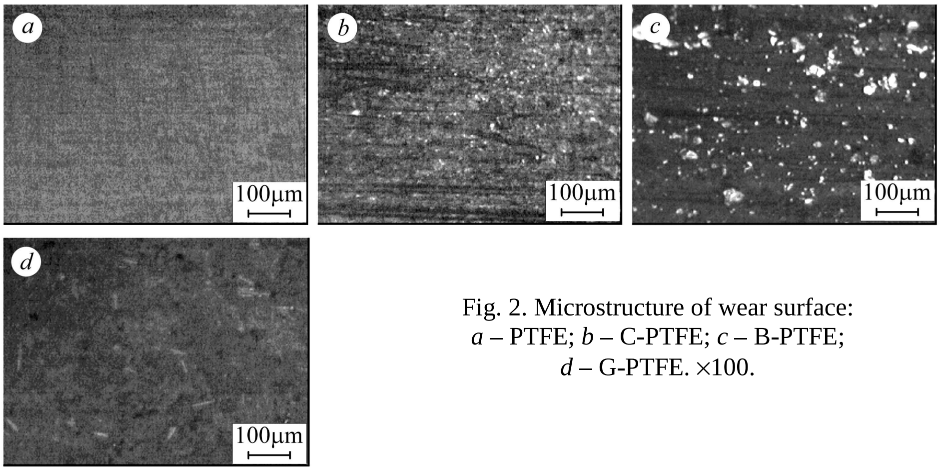

Fig. 2. Microstructure of wear surface:
a – PTFE; *b* – C-PTFE; *c* – B-PTFE;
d – G-PTFE. ×100.

Authors [23, 24] have investigated wear properties of PTFE composites. They observed the less abrasive and adhesive wear in particle reinforced PTFE composites. They reported that some materials, such as graphite and bronze powder as fillers could effectively increase the wear life of PTFE-based composites. Also, graphite was a potential of lubricants, which could also form a transfer film on the sliding surface. The PTFE-filled composites showed much smoother surfaces than the same composites filled with graphite.

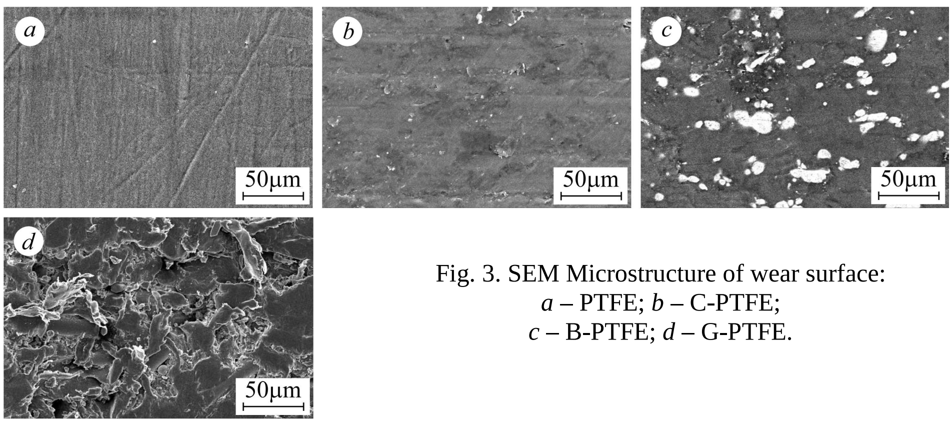

Fig. 3. SEM Microstructure of wear surface:
a – PTFE; *b* – C-PTFE;
c – B-PTFE; *d* – G-PTFE.

Xiang et al. [25] have investigated friction and wear properties of PTFE composites. They reported that PTFE fabric composite exhibits a very low coefficient of friction, high wear resistance and less wear as compared to C86300 composite under similar testing conditions due to the solid lubricant structures of the two PTFE composites.

Khoddamzadeha et al. [26] have investigated bronze, carbon fiber and graphite reinforced PTFE composites for sliding bearing applications. They found that these fillers significantly improve the hardness and the wear resistance of PTFE. The hardness of the PTFE composite is affected by the content level of the fillers and the fillers hardness as well. They say: “The wear behavior of PTFE composites is a complex phenomenon, which depends on the nature of the fillers, the content level of the fillers present, and their morphology. The PTFE composites have friction coefficients similar to pure PTFE. This may be attributed to the presence of a thin transfer film of PTFE on the counter surface that enables the PTFE composites to maintain almost the same frictional properties as pure PTFE”. They also observed that the adhesive wear of the reinforced PTFE composites are less than that of pure PTFE.

Khan et al. [27] wrote that the physical and tribological properties were improved by the use of PTFE micropowder in ethylene–propylene–diene–rubber (EPDM). They observed agglomerated particles having a particle size even less than 0.5 mm in microstructure.

Authors [28–30] have investigated carbon nanoparticle reinforced, carbon fibers reinforced, and PA6 filled PTFE composites respectively. They reported that these reinforcement materials decrease adhesive wear and improve wear resistance in PTFE materials. In our study, we obtained similar adhesive wear surfaces in PTFE bearings.

In addition, in previous studies the authors [23–30] reported that these reinforced polymer materials and bearings could be used in industry applications. This situation is important for less bearing wear. The differences in our results and those of other previous studies may be attributed to the fact that their materials were different from the materials, used by us.

CONCLUSIONS

When wear surfaces of samples were examined by optical microscope and scanning electron microscope, the adhesive wear of pure PTFE bearing sample were obtained higher than those of the other filled PTFE bearings. Adhesive wear decreased in particle filled bearings, because bronze, glass and graphite had better wear resistance property and graphite solid lubrication properties. Consequently, surface wear properties of particle filled PTFE bearings were significantly improved.

РЕЗЮМЕ. Вивчено спеціальні полімери підвищеної довговічності, які можуть забезпечити бажані властивості для буксових підшипників, зокрема, зносотривкість. За допомогою оптичної та електронної мікроскопії досліджено мікроструктурні властивості матеріалів на політетрафторетиленовій основі після зношування.

РЕЗЮМЕ. Изучены специальные полимеры повышенной долговечности, которые могут обеспечить желаемые свойства для буксовых подшипников, в частности, износостойкость. С помощью оптической и электронной микроскопии исследованы микроструктурные свойства материалов на политетрафторэтиленовой основе после износа.

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