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MECHANICAL AND TRIBOLOGICAL PROPERTIES OF SELF-LUBRICATING NANOCOMPOSITES BASED ON POM

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Abstract: Self-lubricating polymer composite are used more and more in tribological applications. Parts from these composite are good alternatives where conventional elements cannot be employed easily, for example in medical equipment, food industry. They have several advantages in comparison to metal ones: low weight, often no lubrication is required, low noise level, excellent mechanical damping effect, favorable friction etc. Self-lubrication is characterized by ability to transfer microscopic amounts of material to the mating surface. This transfer process creates a film that provides lubrication and reduces friction over the length [1-2]. This paper focuses on mechanical properties: tensile strength, flexural strength, impact resistance, hardness, density and tribological properties results derived by bloc-on-ring tests. Investigations of friction and wear resistance of polymers and polymers with additives, using the SMC-2 device has been carried out in the present work. Used basic material (POM) and two types of nanoparticles (copper oxide and expanded graphite) by mixing them with five different concentrations (0 %; 0.5 %; 3 %; 7.5 % and 15 %) by volume. The influences of parameters like normal load, speed and time were considered variable value in the wear tests.

Keywords: self-lubricating, tribology, wear, friction, nanoparticles, POM

1. INTRODUCTION

The aim of this thesis is study of the mechanical and tribological behavior of the self-lubricating polymer nanocomposites. A self-lubricating polymer composite is a material that consists of reinforcing fibers, solid lubricant additives, and a polymer matrix. Briefly, self-lubricating polymer composites combine the self-lubricating properties of the polymeric materials with the better mechanical properties of additives.

For investigation, has been made the polyoxymethylene (POM) nanocomposites with different copper oxide and expanded graphite nanoparticles concentrations (0 %, 0.5 %, 3 %, 7.5 % and 15 %) by volume. POM used mostly for moving parts and it is one of the most versatile engineering thermoplastic with excellent friction and wear properties, high strength, and good chemical stability is widely employed to replace the traditional metals and ceramics in microelectronic packaging, aerospace, automotive, and biomedical applications [3-5]. However, the pure POM resin can not necessarily satisfy the requirements as sliding parts.

Even though the self-lubricating composite are rapidly emerging in the industrial applications, yet by now, their tribological behavior is not highly predictive because the available theoretical knowledge is rather limited. Moreover, investigation of the relevant literature indicates that compared to experimental studies, fewer efforts have been made to simulate the tribological behavior of these composites.

The work contains two parts. The first part of studies is including production of samples, research of mechanical properties, deformation, thermal parameters, and condition monitoring of the thermoplastics. The aims of second part are investigations of scratch, friction properties and wear resistance. It is also important to figure out nanoparticles additives operating principles, which would reduce the friction surface wear and friction losses, extend the theoretical and practical knowledge

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about the potential application of nanoparticles, polymer properties when they are added to the organic and inorganic nanoparticles.

2. MATERIALS AND METHODS

The first part of the project was started at Riga Technical University (RTU), with the design and manufacturing of the POM-C composites with different copper oxide (30-50 nm) and expanded graphite nanoparticles concentrations. Also, at RTU, were investigated the mechanical properties: tensile strength, flexural strength, impact resistance, hardness, density and thermal characterization including: DSC, TGA, FT-IR. Thermal analysis methods are important in assessing the various polymers indicators: glass transition, melting and crystallisation temperature, degree of crystallinity, moisture, volatile additives and fillers [6].

Mixing process of polymer pellets and nanoparticles has been made used (two rolls mill) device, carefully controlling the temperature, nip gap, mixing time, and uniform cutting operation. After mixing, the polymer compositions were molded in an electrically heated Mini – Jector device. The temperature range for molding was maintained by circulating water.

2.1. Measurement Mechanical Property

Hardness of polymer nanocomposites was measured with an instrument called Durometer, by Shore D scale. Measured hardness was determined by the penetration depth of the indenter under the load.

The tests of tensile and flexural strength were performed on a Zwick/Roell tester. Five samples of flexural and ten samples of tensile tests, of each material, were tested and the results are average values. Also DSC and TGA experiments showed the thermal conductivity, melting and crystallization zones temperatures of the polymer nanocomposites.

2.2. Investigate of tribology

Tribological investigations of dry sliding friction pairs were made at the upgraded friction tribotester SMC - 2, using the block on ring simulation model of the friction pair Fig. 1. Through device software loading force, the rotation speed and testing time are controlled. Measuring parameters - temperature, friction coefficient, torque and wear rate. The geometry of the frictional couple is given in Fig. 2.

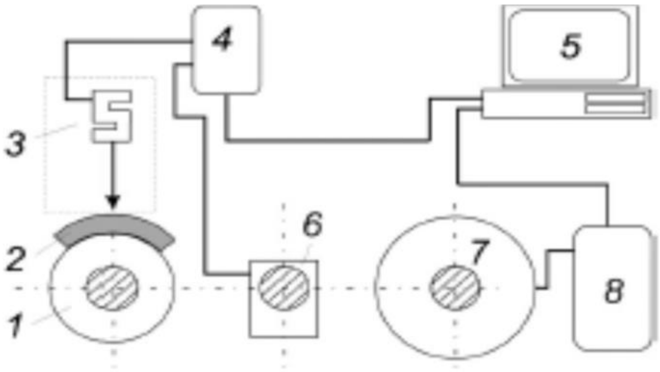

Figure 1. Schematical diagram of the tribological tests: 1 - roler; 2 - block; 3 - loading drive with load sensor ; 4 - data interface panel ADC-200/20; 5 - data acquisition PC; 6 - torque sensor; 7 - electromotor; 8 - servo-motor driving system.

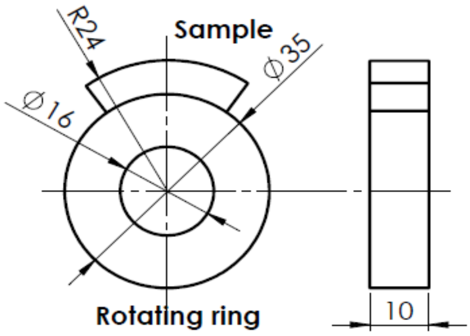

Figure 2. The shapes and dimensions of the friction pair block-on-ring.

The characteristics of the friction pair "block on ring": metal ring dimensions - Ø35 mm × 10 mm, material - steel 45; hardness 40 HRC; surface roughness Ra= 0.08 - 0.1 μm; polymer roughness Ra= 0.25 μm.

There were selected the following test parameters: three sliding speeds (v = 0.5 m/s, v = 1 m/s, v = 1.5 m/s), (rotation speed – 270 rpm, 550 rpm and 825 rpm), two applied loads (F = 125 N, F = 150 N), the sliding distance being L = 3000 m, for each test done at room temperature and in a laboratory environment.

3. EXPERIMENTAL RESULTS

The mechanical properties results of POM nanocomposites at different copper oxide and expanded graphite content was displayed in Table 1. Mechanical properties of polymer nanocomposites changed compared to the pure matrix material.

In the case of hardness and density tests, it was clear that with increasing the copper oxide content the results of POM nanocomposites increased. At biggest copper oxide concentration (15 vol. %), the addition of copper oxide particles had significant effect on the hardness and density values of composites. Compared this results of polymers composite with expanded graphite, can be observed that value changed very slightly.

By analyzing the impact resistant influence, it can be observed a different effect of nanoparticles. In case of POM and expanded graphite composite, the impact resistant values increase with particle content. The biggest value of POM and copper oxide composite was by 3 vol. % (13.14 kJ/m^2) and it goes down in case with 7.5 vol. % and 15 vol. %. Moreover, it was observed, that these concentrations increase in porosity and air bubbles inside polymer composite. The interface between POM and copper oxide phase was very clear, which indicates the poor compatibility between POM and copper particles in concentrations 7.5 vol. % and 15 vol. %. The porosity occurred with increasing the copper oxide content in composite.

Compared POM nanocomposites, it can be observed that modulus of elasticity and hence the strength increases with particle content. An exception is only POM and expanded graphite composite results of flexural strength experiment.

Received thermal analysis results showed different melting and crystallization temperature values of composites. Intensity temperature in melting zone decreases in the case where the particles concentration content increases. And there is reverse process in crystallization zone. Temperature is growing up together with particles concentration.

Table 1. Mechanical characteristics of POM nanocomposites.

Mechanical properties Material	Hardness (Shore D)	Density (g/cm^3)	Impact resistant (kJ/m^2)	Tensile strength (modulus of elasticity E MPa)	Flexural strength (modulus of elasticity E MPa)	Temperature of max. intensity in melting zone °C	Temperature of max. intensity in crystallization zone °C
POM	76	1.405	10.48	2125	1758.9	168.35	144.85
POM + 0.5% exp. graphite	75.8	1.403	15.67	2365.2	2035.6	168.87	144.42
POM + 3% exp. graphite	75.5	1.403	15.48	2438.3	2006.7	168.65	144.70
POM + 7.5% exp. graphite	74.5	1.405	15.43	2480.2	1992.7	167.41	145.15
POM + 15% exp. graphite	74.1	1.405	17.44	2459	2031.2	166.33	145.64
POM + 0.5% copper oxide	76.3	1.408	12.15	2213	1826.2	168.98	144.72
POM + 3% copper oxide	76.4	1.423	13.14	2237	1928.3	168.65	144.45
POM + 7.5% copper oxide	76.8	1.451	11.16	2236	1934.2	168.33	145.20
POM + 15% copper oxide	80.7	1.498	10.26	2369	2027.8	167.56	146.19

3.1. Friction and Wear Behaviour

All received tribological data were analysed through the influence of testing parameters and through the concentration of nanoparticles. Figure 3 shows the friction coefficient of polymer block sliding against ring of steel 45, at 0.5 m/s speed under a 125 N load. It was showed that the POM with

0.5 vol. % expanded graphite nanoparticles represented better properties in friction reduction than that with other concentrations. Higher nanoparticles contents over 3 vol. % led to an increase in the average of friction coefficient. The influence of nanoparticles content on the average wear rate was almost correlative to the change in friction coefficient. The POM samples with additives represented low wear rate. Polymer samples loses a small part of the mass, about 0.7 wt. %.

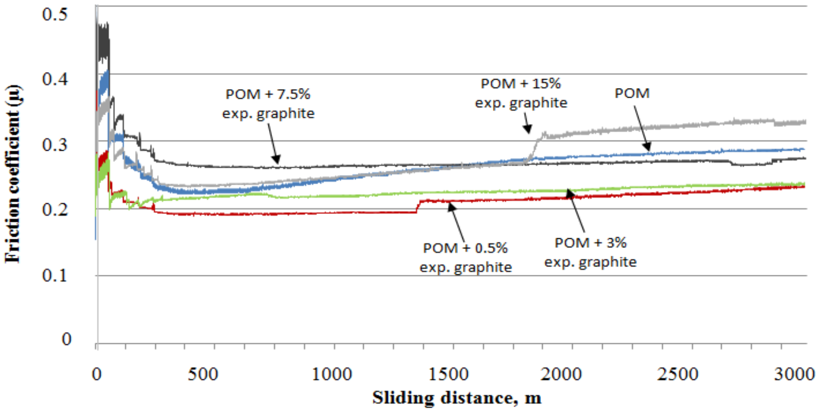

Figure 3. Frictional coefficient curves; Load 125 N; Velocity 0.5 m/s; Distance 3000 m.

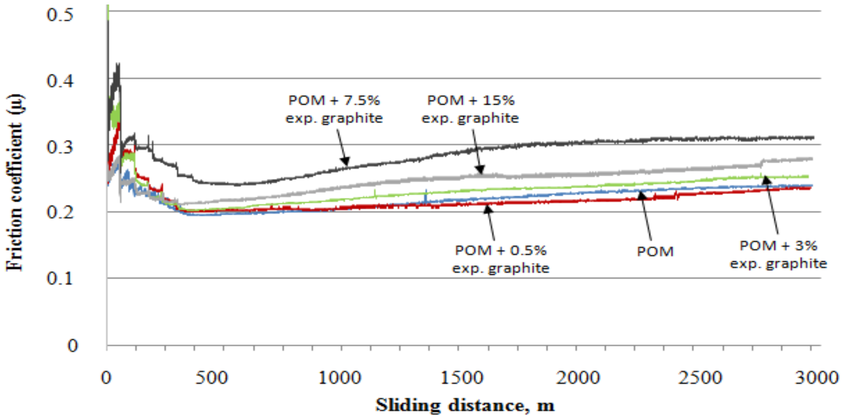

Figure 4. Frictional coefficient curves; Load 125 N; Velocity 1 m/s; Distance 3000 m.

In case of normal load = 125 N and v = 1 m/s the lowest friction coefficient value was obtained for POM and 0.5 vol. % expanded graphite nanocomposite (Figure 4). After that, line up by pure POM and POM with 3 vol. % expanded graphite nanocomposite, with very similar development. The highest values were obtained for 7.5 vol. % and 15 vol. % nanocomposite.

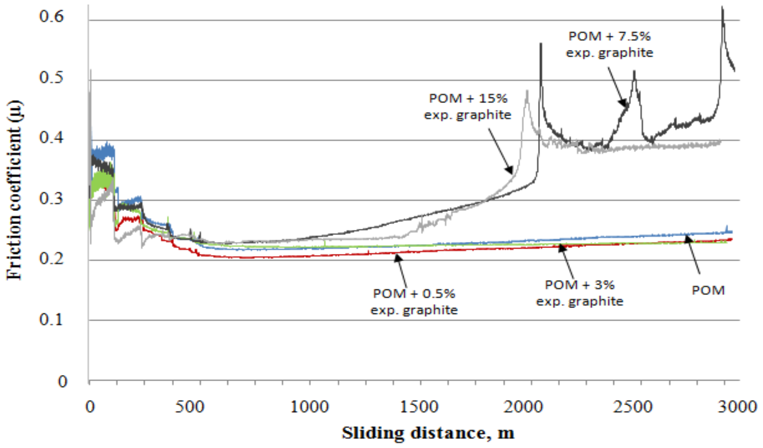

Figure 5. Frictional coefficient curves; Load 150 N; Velocity 0.5 m/s; Distance 3000 m.

In case of normal load = 150 N and v = 0.5 m/s the lowest friction coefficient value was obtained for POM and 0.5 vol. % expanded graphite nanocomposite (Figure 5). After that, line up by pure POM and POM with 3 vol. % expanded graphite nanocomposite, with very similar development. The highest values were obtained for 7.5 vol. % and 15 vol. % nanocomposite. After 2000 m these values raised up dramatically. Temperature in these contact zones was about 130 °C.

When velocity was 1.5 m/s, after a few minutes polymer nanocompozites started to melt (Figure 6). Temperature in these contact zones reached 160 °C. It was very clear, that we cannot use this sliding speed for tribological investigations.

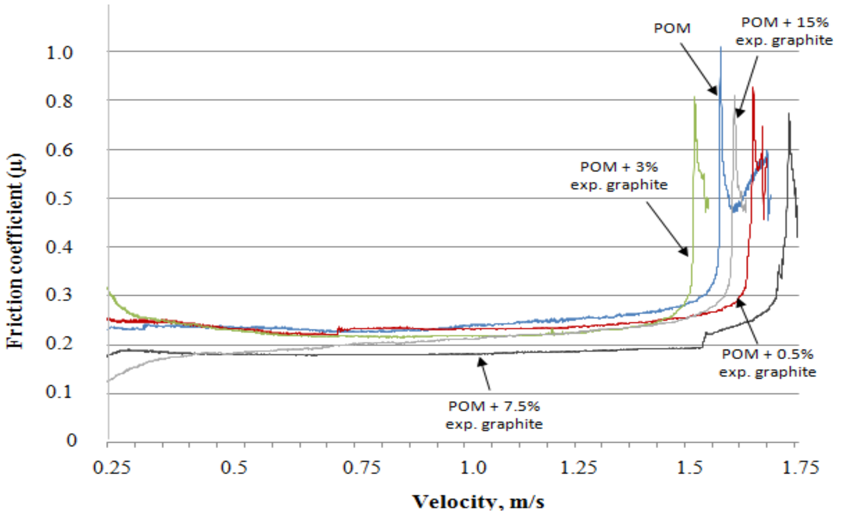

Figure 6. Frictional coefficient curves; Load 125 N; Varying velocity 0.25 - 1.75 m/s.

In case of normal load=150 N and v=1 m/s sliding speed, a few minutes after start polymer nanocompozites started to melting. We cannot use this parameters combination for tribological investigations.

Figure 7 show the friction coefficient of POM and copper oxide nanocomposite. The pure POM represented best properties in friction reduction than that with other concentrations. After that, followed by POM with 0.5 vol. % nanoparticles. Higher nanoparticles contents over 3 vol. % led to an increase in the average of friction coefficient.

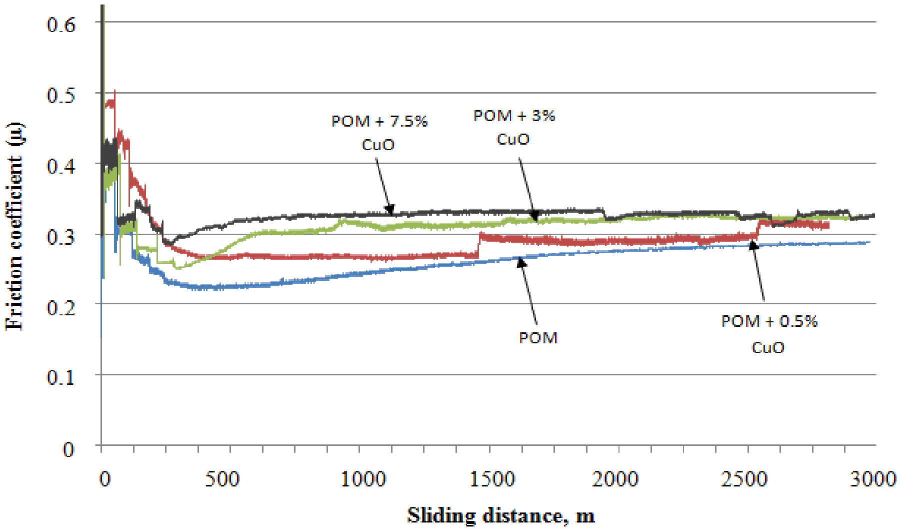

Figure 7. Frictional coefficient curves; Load 125 N; Velocity 0.5 m/s; Distance 3000 m.

The lowest friction coefficient in Figure 8 is of pure POM. After that, followed by POM with 0.5 vol. % CuO nanoparticles, but after 2000 m it began to rising up. Higher nanoparticles contents, 3 vol. % and 7.5 vol. %, led to an increase in the value of friction coefficient.

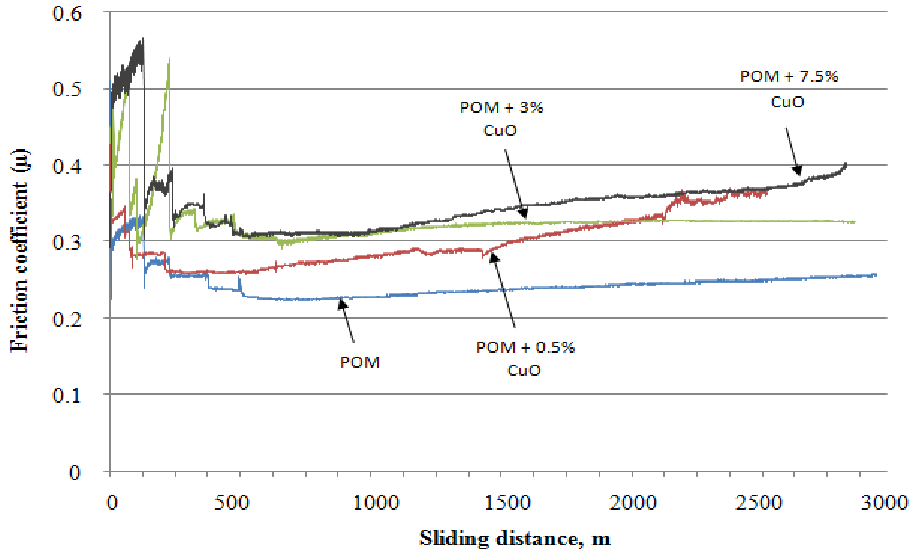

Figure 8. Frictional coefficient curves; Load 125 N; Velocity 1 m/s; Distance 3000 m.

In case of normal load = 150 N and v = 0.5 m/s, the lowest friction coefficient value was obtained for pure POM (Figure 9). After that, line up by POM with 3 vol. % expanded graphite nanoparticle. The highest values were obtained for 0.5 vol. % and 7.5 vol. % nanocomposite, with very similar development.

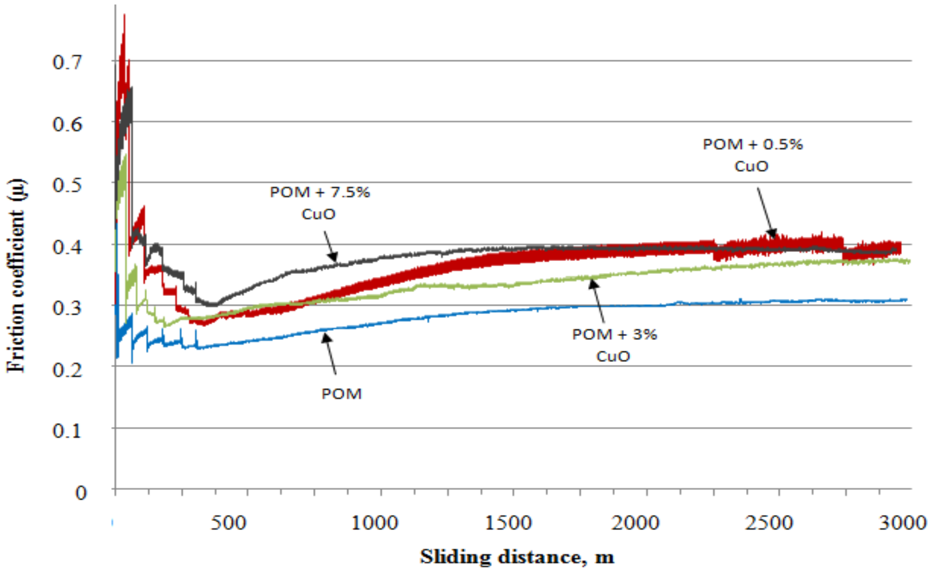

Figure 9. Frictional coefficient curves; Load 150 N; Velocity 0.5 m/s; Distance 3000 m.

3.2. Microscopic observation of the polymer surfaces

The surface morphology of POM composites observed by optical microscopy. Several pictures showed in Figure 10. Normal load was 125 N; speed 270 rpm (v = 0.5 m/s), temperature in contact zone 60 °C. Sliding against high alloy steel, there is no film formation onto the polymer sliding surface but separate particles are embedded into the polymer.

Many apparent signs of ploughing along the sliding direction could be observed in the worn surface of POM nanocompozite. The heating at the interface may be high enough to cause melting or softening of the wear debris and the adhesion of debris to the worn surface of composites (Figure 10 b, d). It can be seen that the wear debris was in the form of lamellar, their uneven edges and molten surface suggested that they underwent plastically stretching and melting [7].

The worn surface of POM and 7.5 vol. % CuO was the smoothest of these composites, and there were only some scratch grooves and little debris on it (Figure 10 f). This was because the copper particles enhanced the surface hardness of POM composites, which led to better resistance to scuffing and the lowest wear rate.

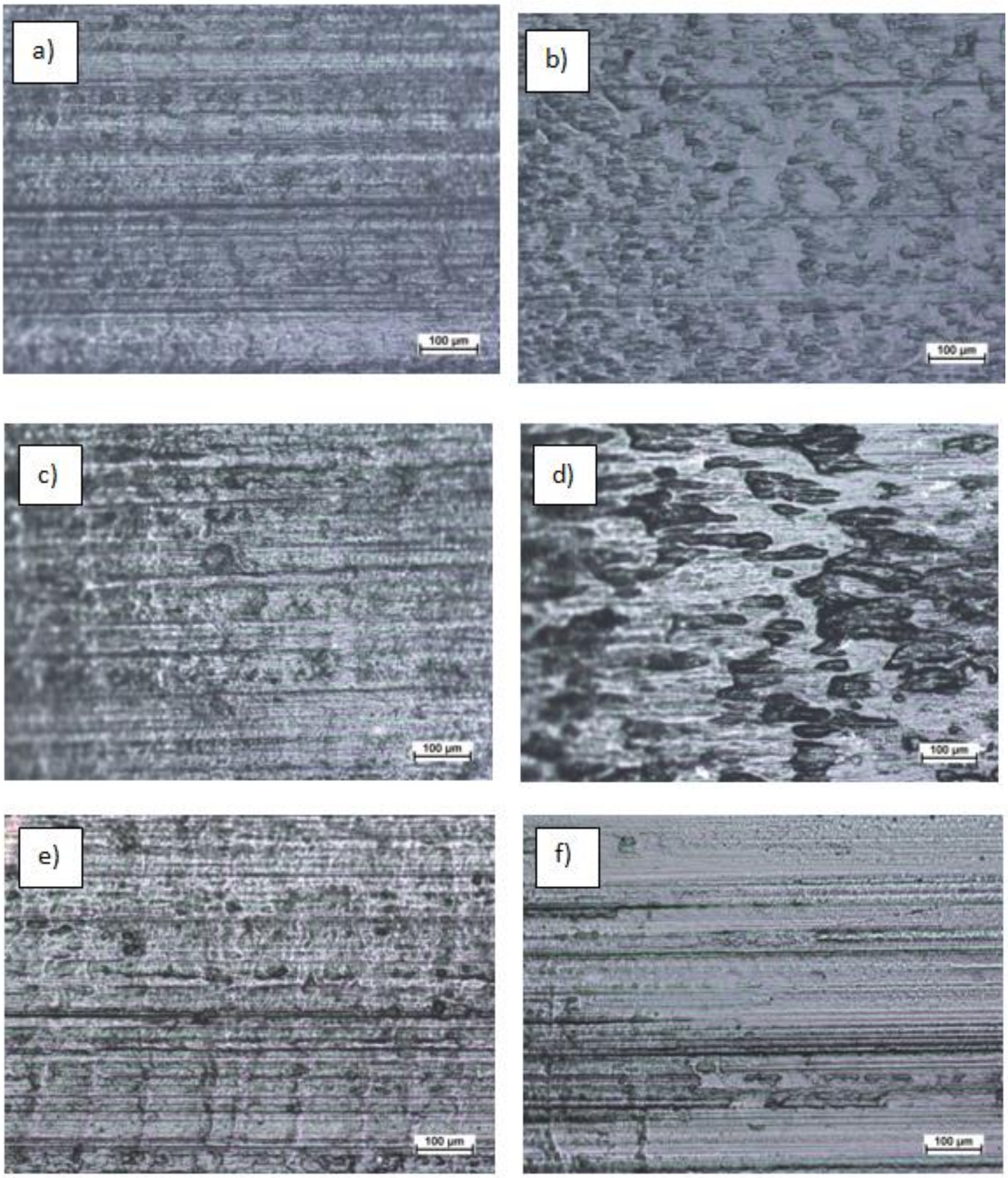

Figure 10. Microscopy of POM nanocomposite sliding surfaces before and after sliding against steel POM surfaces before sliding; (b) POM surfaces after sliding; (c) POM + 7.5 % graph. surfaces before sliding (d) POM + 7.5 % graph. surfaces after sliding; (e) POM + 7.5 % copper oxide surfaces before sliding; (f) POM + 7.5 % copper oxide surfaces after sliding.

4. CONCLUSIONS

Investigations of mechanical and tribological properties of polymers and polymers with additives, has been carried out in the present work. Mechanical properties of polymer nanocomposites changed compared to the pure matrix material. Compere POM with POM-CuO composites, particles increased values of hardness, density, flexural strength, however CuO particles decrease values of impact resistance. Compared this results of polymers composite with expanded graphite, can be observed that value changed very slightly.

Received thermal analysis results showed different melting and crystallisation temperature values of composites. Intensity temperature in melting zone decreases in the case where the particles concentration content increases. And there is reverse process in crystallization zone. Temperature is growing up together with particles concentration.

POM and 0.5 % expanded graphite is most suitable sliding material, because their friction coefficient is lowest and their wear resistance is higher. In case of POM and CuO nanocomposite, the lowest friction coefficient value was obtained for pure POM.

Some melting was observed in case of normal load = 150 N and sliding speeds v = 1 m/s and 1.5 m/s. during the tests under higher load, which refers to the overload situation of polymers. Temperature in these contact zones reached 160 °C. It was very clear, that we cannot use this sliding speed for tribological investigations.

Moreover, it was observed, that copper particles in concentrations 7.5 vol. % and 15 vol. % increase in porosity and air bubbles inside polymer composite. The interface between POM and copper oxide phase was very clear, which indicates the poor compatibility between POM and copper particles.

ACKNOWLEDGEMENT

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