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Strengthening of tribocoupling parts of transport and agricultural machines with fullerene materials

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Abstract

The aim of this work is a comparative study of tribological properties and tribotechnical characteristics of polymer nanocomposites based on polyamide 6, modified with nanosized fillers. The work investigates polyamide 6 as a matrix modified with the following fillers: fulleroid materials (carbon fibers), microsized fillers containing nanoparticles (fullerene carbon black), nanoparticle fillers (fullerene C60).The influence of fulleroid modifiers and carbon fibers on the tribological properties of samples and parts made of polymer nanocomposites based on thermoplastic (polyamide 6) polymer matrices was studied. It was shown that the introduction of fulleroid modifiers allows to significantly reduce the friction coefficient of polymer compositions while increasing their mechanical characteristics. It was found that the use of carbon fibers for modification of polyamide 6 with an increase in mechanical characteristics during operation leads to an increase in the friction coefficient of the conjugated steel sample by more than two times compared to the original polymer matrix.

Key words : transport vehicles, agricultural machinery, parts, fulleroid modifiers, polymer matrix.

Introduction

The durability of parts, assemblies, systems and units of transport and agricultural machines is largely determined by the phenomena of friction and wear. The use of new progressive structural materials ensures the creation of tribocoupling of machine parts with a high level of specified operational characteristics. An important place among these materials has recently been occupied by polymer nanocomposites . The main advantage of polymer nanocomposites as materials for tribocoupling of parts is their increased strength characteristics and tribotechnical indicators. This is due to the peculiarities of the interaction in the system "polymer matrix-filler nanoparticle" [1-3].

Literature review

Increasing the strength of polymeric materials leads to a decrease in the coefficient of friction and wear in triboconjugates of samples and parts [4,7,8]. At the same time, this pattern is not observed for polymer composites filled with micro-sized fillers in the form of fibers [5,6]. This can be explained by the fact that during the wear process, micro-sized fillers are torn out of the polymer matrix, which leads to an increase in the abrasive properties of the conjugated surfaces [9,11,14]. This causes an increase in the coefficient of friction [10,12]. This problem can be solved using polymer nanocomposites [13]. In such materials, nanoparticles are more firmly held in the matrix, and their detachment does not lead to a change in the properties of the microsurface [15].

Purpose

The aim of this work is a comparative study of the tribological properties and tribotechnical characteristics of polymer nanocomposites based on polyamide 6 (PA-6) modified with nanoscale particles.

Results

The work investigates polyamide PA-6 as a matrix modified with the following fillers: fulleroid materials (carbon fibers), micro-sized fillers containing nanoparticles (fullerene carbon black), and nanoparticle fillers (fullerene C60).

Polymer nanocomposites were obtained by polymerization in in situ according to the method [2] after mixing the filler and monomer, and mixing the finished PA-6 with the filler in an extruder. C60 fullerenes (purity 99.0%) and fulleroid carbon black (fullerene content 10.5%; 68% C60 fullerene, 30% C70 fullerene by weight, the sum of higher fullerenes about 2%) were used as fillers. Fulleroid carbon black is an ultrafine carbon - a product of burning graphite electrodes in an arc in an inert gas atmosphere with an average particle size of 0.5...2.0 microns. Fulleroid carbon black is the main raw material for producing fullerenes . Fractionated chopped viscose carbon fiber (average length 400 μm) was used as a filler. Tests on the МТУ-01 friction machine were carried out according to the "roller-plate" scheme. The roller with a diameter of D = 19 mm is made of 40X steel, heat-treated to a hardness of approximately 58 HRC. The roller rotated at a frequency of n = 60 rpm. This corresponded to a linear sliding velocity of 0.06 m/s. The roller was pressed against a plate measuring 40×40×5 mm with a force of 400 N. Young's modulus and tensile strength were determined on a UTS 10 tensile testing machine (UTStestsysteme , Germany) during compression for samples in the form of a half-cylinder with a diameter of 8...9 mm and a height of 9...12 mm in the load range from 0.001 N to 10 kN . In this case, the range of deformation rates of the samples was from 1 μm/ min to 1 m/min. All measurements were performed for series of samples of at least five obtained by different methods of forming nanocomposites.

As already noted, PA-6 was chosen as the thermoplastic matrix as a polymer that is widely used for the manufacture of sliding bearings of transport and agricultural machines. It is known that the optimal method for obtaining nanocomposites is polymerization in situ [6]. All other methods of their production are associated with problems of aggregation of filler particles. In which they are difficult to overcome. This problem complicates the uniform distribution of filler particles in the polymer matrix. Mixing the finished polymer with a filler in an extruder is the most common method of preparing polymer composites. In this work, both methods of obtaining polymer compositions were considered. The PA-6 matrix material is obtained by anionic polymerization using metallic sodium as an initiator and toluene diisocyanate as a cocatalyst . Fullerene C60 is chemically unstable under these conditions. Therefore, polymer composites obtained by polymerization in situ are chemically modified. In them, nanoparticles are chemically bound to a polymer matrix. In addition, the comparative nature of the tribological properties of compositions obtained by different methods is interesting. Introduction of fullerene C60, at a filling level of 0.01...0.1 wt.%, into the PA-6 matrix during synthesis by polymerization in In situ , the Young's modulus and strength increase by approximately 18...20%. Nanocomposite samples obtained by mixing the polymer melt with other components in an extruder were tested [7,8] . The test data are given in Table 1. As can be seen from the data presented, the melt mixing method does not lead to a significant increase in the strength characteristics of PA-6 at a fullerene C60 content of 0.01 wt.% (an increase of 3%). The introduction of both fullerene C60 and fullerene carbon black in amounts of 1 wt.% leads to a decrease in mechanical properties. The sharp drop in the mechanical characteristics of PA-6 filled with 1 wt.% fullerene C60 is due to the fact that the insufficiently uniform distribution of fullerene C60 in the polymer matrix necessitates the introduction of a co-solvent (Erucamide 0.05 wt.%) , which simultaneously acts as a plasticizer and prevents crystallization of PA-6, which leads to a decrease in mechanical characteristics. The decrease in the mechanical properties of nanocomposites at high filling degrees is due to the uneven distribution of the filler in the polymer matrix.

Table 1 – Mechanical properties and characteristics of nanocomposites based on PA-6 obtained by extrusion

Modifier content	Young's modulus E, MPa	Destructive force σ_u MPa	Elongation ε, %	Friction coefficient f_{tr}
PA-6 without additives	673 ±15	64 ±1	285 ±5	0.26...0.30
C60 – 0.01 wt.%	702 ±12	66 ±1	302 ±5	0.187...0.19
C60 – 1 wt.%; Erucamide 0.05 wt.%	258 ±14	12 ±1	289 ±5	0.28...0.30
Fullerene carbon black – 1 wt. %	618 ±15	63 ±1	276 ±5	0.29...0.30

In this work, the tribotechnical characteristics of polymer nanocomposites were investigated (Fig. 1–3). For the PA-6 nanocomposite 0.01 wt.% fullerene C60, obtained by polymerization in In situ , a significant decrease in the friction coefficient (from 0.28±0.02 to 0.18±0.05) is observed compared to pure PA-6. This can be justified by the increase in the mechanical strength of the polymer nanocomposite. At the same time, for the PA-6 polymer matrix filled with 10 wt.% carbon fiber, an increase in the friction coefficient (up to 0.5 2±0.05) is observed. To explain the obtained result, we studied the materialography of wear spots on the material of the samples and parts (Fig. 4).

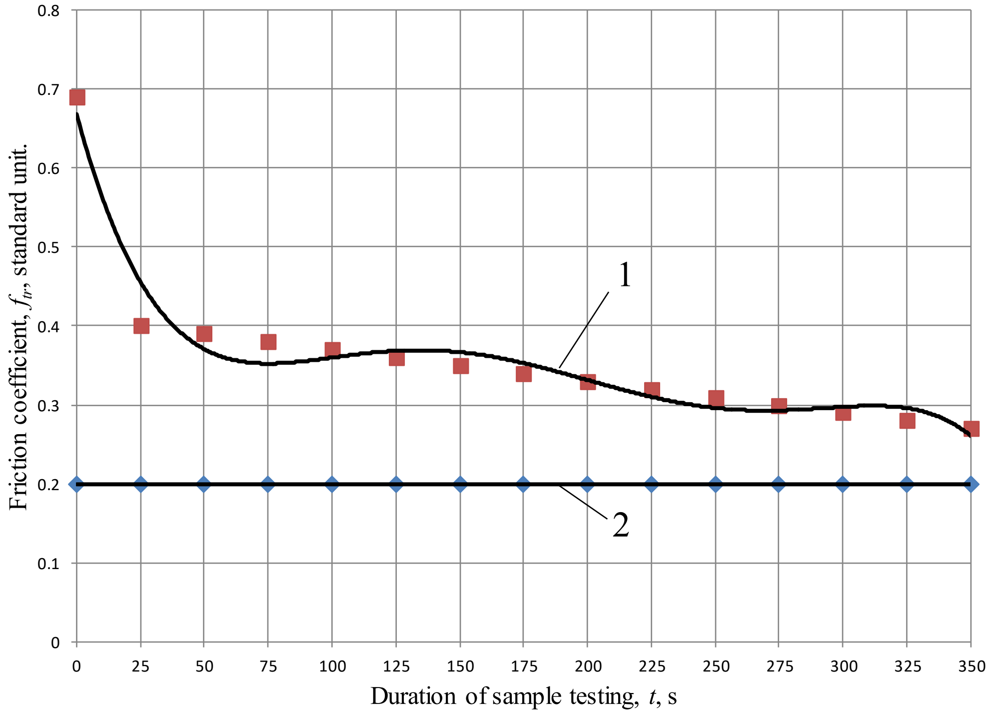

Fig. 1. Dynamics of changes in the friction coefficient for samples of PA-6 (1) and PA-6 with 0.01 wt.% of C60 fullerenes (2), obtained by the polymerization method in situ

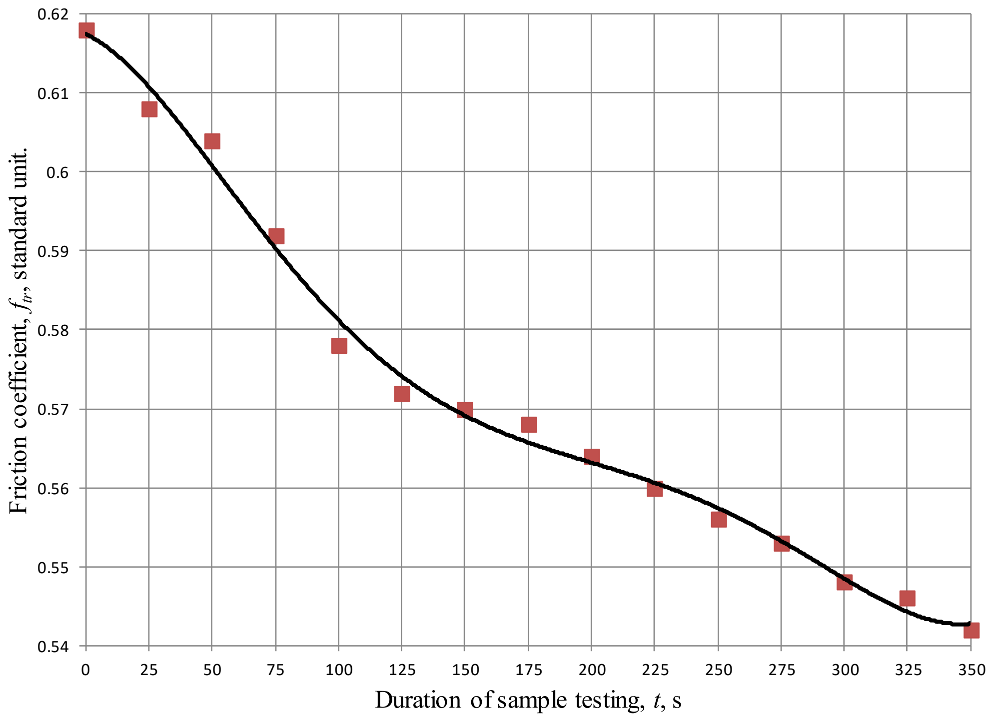

Fig. 2. Dynamics of changes in the coefficient of friction for samples of composite material: PA-6 filled with 10 wt.% carbon fibers, obtained by polymerization in situ

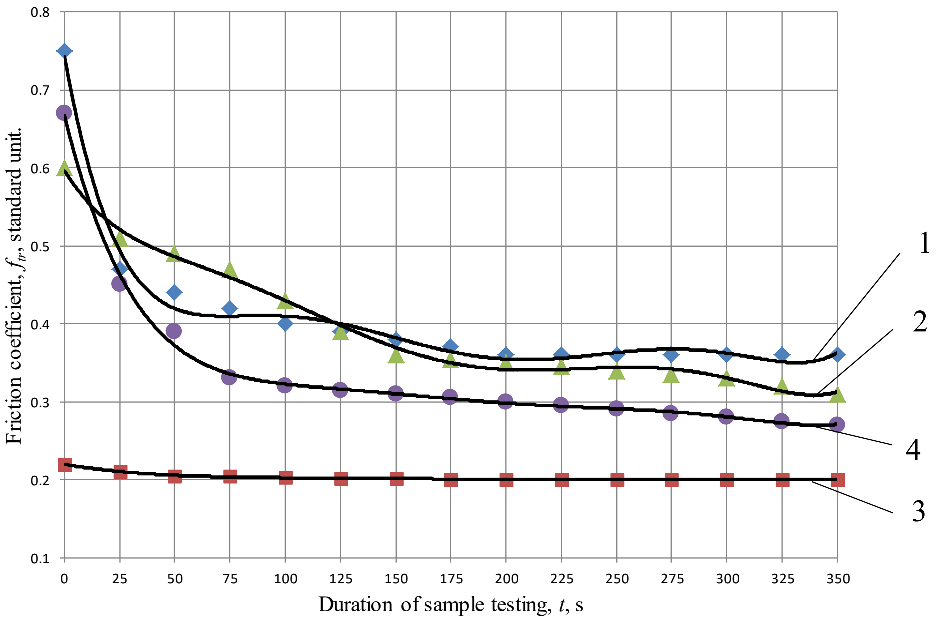

Fig. 4. Dynamics of changes in the friction coefficient for pure PA-6 (1) and polymer nanocomposites obtained by extrusion and containing: 1 wt.% C60 fullerenes and 0.05 wt.% Erucamide (2); 0.01 wt.% C60 fullerenes (3); 1 wt.% fullerene carbon black (4)

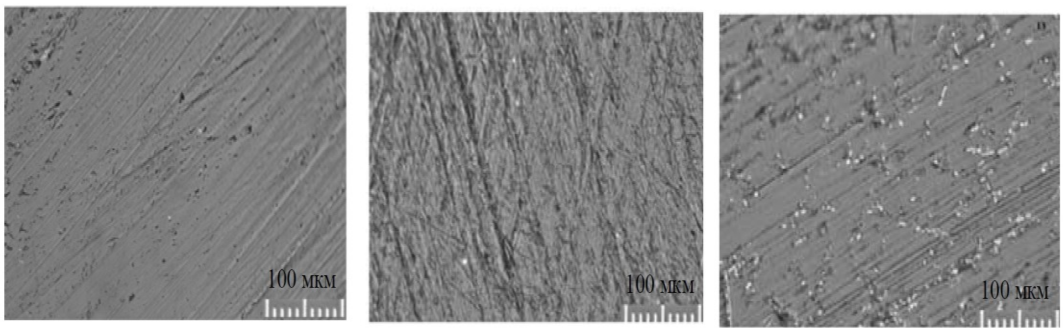

Fig. 4. General view of friction surfaces for pure PA-6 (a), PA-6 with 0.01 wt.% C60 fullerenes (b) and for PA-6 with 10 wt.% carbon fibers (c), obtained by polymerization in in situ , x400

The study of the surfaces of the samples after testing (Fig. 4, a, b) shows that chemically incorporated fullerene C60 does not change the sliding properties of the surface compared to pure PA-6. It was found that in samples reinforced with carbon fibers, fiber particles break away from the polymer matrix and become burrs , which worsen the sliding properties of the surface. Such an effect of fibers in polymer compositions is observed in [9]. For nanocomposites obtained by extrusion (Fig. 3), a decrease in the friction coefficient is also observed. In this case, the value of the friction coefficient is lower than for the polymer synthesized by polymerization in in situ with the introduction of 0.01 wt.% fullerene C60. The friction coefficient changes from 0.30±0.2 to 0.25±0.02. It was found that the most effective modification of PA-6 is 1 wt.% fullerene carbon black. In this case, the friction coefficient decreases to 0.20±0.01. The increase in the friction coefficient for the nanocomposite filled with 1 wt.% fullerene C60 in the presence of Erucamide 0.33±0.02 is associated with an increase in the viscosity of the composite during friction. This is due to the fact that the surface heats up and the glass transition temperature decreases in the presence of the additive. This is confirmed by the study of friction spots (Fig. 5).

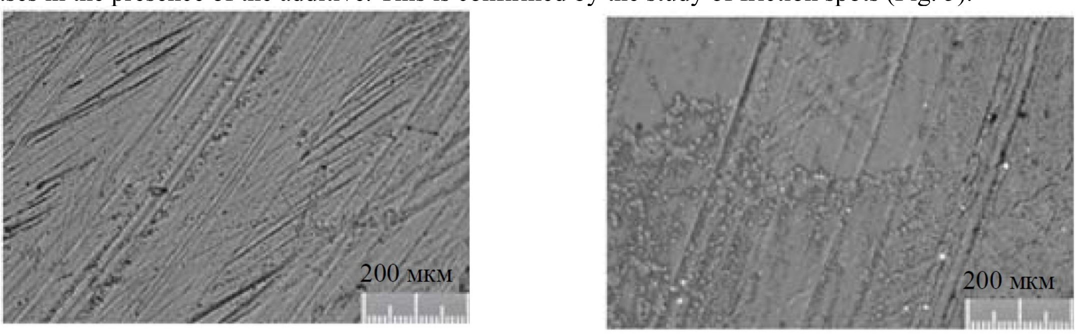

Fig. 5. Photographs of friction surfaces of polymer nanocomposites obtained by extrusion and containing 0.01 wt.% of C60 fullerenes (a); 1 wt.% C60 fullerenes and 0.05 wt.% Erucamide (b), x200

It was found that for a nanocomposite filled with 1 wt.% fullerene C60 in the presence of Erucamide, leakage is clearly visible.

Conclusions

1. As a result of the research, the possibility of creating polymer nanocomposites based on polyamide 6 matrices modified with fullerene materials has been shown.

2. It has been shown that the introduction of fullerene materials significantly (by half) reduces the friction coefficient of nanocomposites compared to pure polyamide 6.

3. The decrease in the friction coefficient of polymer nanocomposites can be justified by the increase in the mechanical strength of the composites in the absence of the removal of nanoparticle aggregates to the conjugate surfaces of the samples being lapped.

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Аулін В.В., Тихий А.А., Деркач О.Д., Лисенко С.В., Макаренко Д.О. Зміцнення трибоспряження деталей транспортних і сільськогосподарських машин фулероїдними матеріалами.

Метою даної роботи є порівняльне дослідження трибологічних властивостей і триботехнічних характеристик полімерних нанокомпозитів на основі поліаміду 6, модифікованих нанорозмірних. В роботі досліджуються поліамід 6 як матриця, модифікована наступними наповнювачами: фулероїдними матеріалами (вуглецеві волокна), мікророзмірними наповнювачами, що містять наночастинки (фулеренова сажа), наночастинками-наповнювачами (фулерен С60). Досліджено вплив фуллероїдних модифікаторів та вуглецевих волокон на трибологічні властивості зразків і деталей з полімерних нанокомпозитів на основі термопластичних (поліамід 6) полімерних матриць. Показано, що введення фуллероїдних модифікаторів дозволяє значно знизити коефіцієнт тертя полімерних композицій при підвищенні їх механічних характеристик. Виявлено, що використання вуглецевих волокон для модифікації поліаміду 6 при зростанні механічних характеристик в процесі експлуатації призводить до зростання коефіцієнта тертя спряженого сталевого зразка більш ніж удвічі порівняно з вихідною полімерною матрицею.

Keywords: транспортні машини, сільськогосподарські машини, деталі, фуллероїдні модифікатори, полімерна матриця.