Tribological properties of polyethylene based composites with fillers on iron based

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Abstract. This work is devoted to identifying patterns of influence of powders of carbonyl iron and magnetic alloy Fe – Cu – Nb – Si – B, on the tribological properties of polymer composites based on ultra high molecular weight polyethylene (UHMWPE) and high pressure polyethylene (LDPE). It has been established that the introduction of a magnetically soft alloy powder into a polymer matrix based on LDPE significantly reduces the coefficient of friction. The best results are achieved at concentrations of 2.5 and 5.0%. The introduction of carbonyl iron in the matrix LDPE increases the coefficient of friction. The introduction of both carbonyl iron and soft magnetic powder into the UHMWPE polymer matrix leads to a significant increase in the friction coefficient. The wear rate of samples based on LDPE filled with carbonyl iron decreases by 53% at a concentration of 2.5% and continues to decrease to 74% at a concentration of 10.0%. When the LDPE matrix is filled with a powder of a magnetic alloy, this indicator decreases by more than 80%. The wear rate of UHMWPE-based composites when the matrix is filled with a magnetically soft alloy with a concentration of up to 10.0% decreases by 70%, while when filled with carbonyl iron to 10.0% it increases by 60%.

1. Introduction
Wear-resistant polymer composite materials are promising for use in various fields of technology, primarily in the friction units of parts. Composites based on a polymer matrix are rather inert, have high chemical resistance, durability and have not a sufficiently low friction coefficient. The filler, parameters and production technology [1-3] have a great influence on its values.

One of the common thermoplastics that is actively used under deformation loads is high pressure polyethylene (LDPE) [4]. In addition to high plasticity, this polymer is well mixed with various fillers, which makes it possible to create composites with desired properties [5].

Another promising material is ultrahigh molecular weight polyethylene (UHMWPE) [6,7]. Its high molecular weight gives the composite improved elastic-strength properties, increased wear resistance and the ability to operate in extreme conditions [8]. The use of such composites in the nodes of friction and intense load facilitates the design and improves its reliability, which contributes to reducing the cost of repair and maintenance of parts [9,10].

Carbon black, various minerals, metal-filled powders and other substances are used as fillers of polymer composites. All this is done in order to reduce the cost of the final product, impart certain properties to it and to obtain new compounds [11]. The use of the spherical joint system metal-polymer is a more alternative option than inert ceramics [12]. In the new special-purpose functional materials, the use of iron-based fillers is promising [13], since it is well dispersed in the polymer and gives the composite a number of special properties.
Depending on the fractional composition, shape and particle size of the ferrite filler, the operational properties of the material change. Therefore, studies of the effect of carbonyl iron and metallic powders of magnetically soft alloys on the tribological properties of the polymers mentioned above are relevant [14, 15]. At the same time, the effect of such fillers in UHMWPE and LDPE on friction and wear indicators has not been studied enough.

2. Formulation of the problem
The aim of the work is to identify patterns of influence of powders of carbonyl iron and magnetic soft alloy Fe-Cu-Nb-Si-B, on the tribological properties of polymer composites of ultrahigh-molecular polyethylene and high-pressure polyethylene.

3. Theory
The objects of study were polymer composite materials based on matrices of ultra high molecular weight polyethylene of the brand GUR 4150 and high pressure polyethylene of the brand 10803-020. Characteristics of polymer matrices are presented in table 1.

| Grade of polyethylene | Melt flow index, g / 10 min | Bulk density, g / cm³ | Strength at break, MPa | Molecular weight, g / mol |
|-----------------------|-----------------------------|-----------------------|------------------------|--------------------------|
| UHMWPE GUR 4150       | < 0.1                       | 0.93                  | 17                     | 9 200 000                |
| LDPE 10803-020        | 2.0                         | 0.92                  | 12.2                   | 500 000                  |

For the filling of the polymer, carbonyl iron of the P 10 grade with a particle size of 25 μm was chosen, as well as AMAG - 200 magnetically soft powder based on Fe-Cu-Nb-Si-B with a size not exceeding 50 μm.

Preliminary compounding of LDPE with a filler was carried out on laboratory rollers of the type LRMR-SC-150 / O with roll friction of 1: 1.1, at their temperature 115°C. Since the powder with UHMWPE is fine, it was mechanically mixed with fillers for 10 minutes.

The resulting mixtures were pressed at a pressure of 3.5 and 7.5 MPa and temperatures of 130 °C and 230 °C, for LDPE and UHMWPE, respectively. In the manufacture of products for tribological tests used press brand Joo-Quality-Press.

Control samples were made of thermoplastics based on the corresponding polymer matrices without fillers.

Tribological properties were determined using an UMT 2168 friction machine, in accordance with the method [16]. Test scheme - "finger-disk": the sample - a cylinder with a diameter of 10 mm and a height of 20 mm; counterbody - shaft made of steel 45, hardness 45 HRC, surface roughness Ra < 0.32 μm, load 70 N, rotation frequency 31.8 rpm, test time - 30 minutes.

4. Results of experiments and discussion
The results of the influence of concentrations of fillers on the tribological properties of the composites under study are shown in Table 2.
Table 2. Tribological properties of composites based on ultra high-molecular polyethylene and polyethylene of high pressure.

| Composite material | Friction coefficient | Wear rate, g / h |
|--------------------|----------------------|-----------------|
|                    | LDPE | UHMWPE | LDPE | UHMWPE |
| Polymer matrix     |      |        |      |        |
| Properties of the matrix |      |        |      |        |
| Carbonyl Fe        |      |        |      |        |
| 2.5%               | 0.676 | 0.093  | 0.0186 | 0.0026 |
| 5.0%               | 1.021 | 0.569  | 0.0083 | 0.0008 |
| 7.5%               | 0.685 | 0.495  | 0.0073 | 0.0012 |
| 10.0%              | 0.651 | 0.248  | 0.0048 | 0.0042 |
| Filler             |      |        |      |        |
| Carbonyl Fe        |      |        |      |        |
| 2.5%               | 0.396 | 0.495  | 0.0057 | 0.0018 |
| 5.0%               | 0.408 | 0.295  | 0.0046 | 0.0024 |
| 7.5%               | 0.644 | 0.475  | 0.0035 | 0.0006 |
| 10.0%              | 0.632 | 0.495  | 0.0035 | 0.0006 |
| Fe-Cu-Nb-Si-B      |      |        |      |        |
| 2.5%               | 0.396 | 0.495  | 0.0057 | 0.0018 |
| 5.0%               | 0.408 | 0.295  | 0.0046 | 0.0024 |
| 7.5%               | 0.644 | 0.475  | 0.0035 | 0.0006 |
| 10.0%              | 0.632 | 0.495  | 0.0035 | 0.0006 |

The friction coefficient in LDPE-based composites with the addition of a powder of a magnetically soft alloy based on Fe-Cu-Nb-Si-B significantly decreases (Figure 1). At concentrations of the filler of 2.5 and 5.0%, a decrease of more than 40% is observed. A further increase in concentration only approximates the values of the index to a composite of pure LDPE polymer, without additives.

The coefficient of friction in composites based on LDPE with the introduction of carbonyl iron increases. When the concentration of carbonyl iron filler is up to 5.0%, it increases by more than 50%, and with further increase the concentration decreases to values close to the matrix of the original LDPE.

![Figure 1. Coefficient of friction LDPE with fillers](image)

The absolute values of the friction coefficient in UHMWPE based composites with the introduction of both carbonyl iron and powder of the Fe-Cu-Nb-Si-B magnetic base alloy, depending on the concentration, increase respectively in the range from 0.248 to 0.569 and from 0.248 to 0.495 (Figure 2). Moreover, when adding a soft magnetic powder, the values of the friction coefficient gradually increase in proportion to its concentration. When carbonyl iron is added, the values of the friction coefficient abruptly decreases from 0.547 at a concentration of 2.5% and then gradually decrease to 0.248 at a concentration of 10.0%.
Figure 2. Coefficient of friction of UHMWPE with fillers

The wear rate of LDPE-based composites with the introduction of carbonyl iron gradually decreases from 0.0088 g/hour at a concentration of 2.5% to 0.0048 g/hour at a concentration of 10.0%, and when introducing powder of a soft magnetic alloy, decreases from 0.0047 g/hour at a concentration of 2.5% to 0.0035 g/hour at a concentration of 10.0% (Figure 3). The best performance was achieved when filling with a magnetically soft alloy with a concentration of 10%. In this case, the wear rate is reduced by more than 80%.
The wear rate of composites based on UHMWPE filled with both carbonyl iron and powdered magnetic alloy from Fe – Cu – Nb – Si – B is mainly reduced (Figure 4). At the same time, with the addition of 10.0% carbonyl iron, this indicator increased by more than 60%.

From the obtained results, it follows that the introduction of a magnetically soft powder with a concentration of 2.5% in UHMWPE makes it possible to reduce the wear rate by almost 70%.

From the analysis performed, it can be seen that the concentration and particle size of the filler significantly affect the tribological properties of the produced polymer composite materials. At the
same time, LDPE-based samples, due to the good plasticity of the polymer matrix, are better dispersed with iron-based fillers, especially with larger powders of 50 microns in size. The lowest values of the friction coefficient and wear rate in LDPE-based composites are achieved with the addition of a soft magnetic powder. In composites based on UHMWPE, with the introduction of both carbonyl iron and powder of a soft magnetic alloy, the values of the friction coefficient increase significantly. The smallest values of wear rate in UHMWPE based composites were obtained with the introduction of a powder based on a magnetic soft alloy. Therefore, for composites based on UHMWPE filled with both carbonyl iron and soft magnetic powder, it makes sense to add binding components or optimize the manufacturing technology of composites.

5. Conclusions
It has been established that the introduction of a magnetically soft alloy powder into a polymer matrix based on LDPE significantly reduces the coefficient of friction. The best results are achieved at concentrations of 2.5 and 5.0%. The introduction of carbonyl iron in the matrix LDPE increases the coefficient of friction. The introduction of both carbonyl iron and soft magnetic powder into the UHMWPE polymer matrix leads to a significant increase in the friction coefficient.

The wear rate of samples based on LDPE filled with carbonyl iron decreases by 53% at a concentration of 2.5% and continues to decrease to 74% at a concentration of 10.0%. When the LDPE matrix is filled with a powder of a magnetic alloy, this indicator decreases by more than 80%. The wear rate of composites based on the UHMWPE matrix decreases by 70% when the matrix is filled with a magnetically soft alloy with a concentration of up to 10.0%, while when filled with carbonyl iron to 10.0% it increases by 60%.

References

[1] Okhlopkova A A, Petrova P N, Gogoleva O V 2011 Wear-resistant composite materials based on ultrahigh molecular weight polyethylene for use in extreme conditions Materialovedenie (Materials Science) 9 pp 10-13

[2] Serolyutin E G, Gavrilo Yu Yu, Voskresenskaya E N and others. 2010 Composite materials based on ultrahigh-molecular polyethylene: properties, prospects of use Chemistry for Sustainable Development 18 pp 375-388

[3] Kobzev D E, Baronin G S, Dmitriev V M, Kombarova P V, Zavrazhin D O 2012 Intensification of solid-phase plunger extrusion of nano-modified high-density polyethylene by ultrasonic action Materialovedenie (Materials Science) 4 pp 37-40

[4] Petukhova, E S, Petrova P N, Sokolova M D, Fedorov A L, Argunova A G, Grunenko D A, Chikalev E V 2018 The study of polyethylene composite conductive materials Diagnostics, resource and mechanics of materials and structures 4 pp 14-22

[5] Kurbanov N I, Guseynova Z N, Kuliev A M, Alieva R V, Bagirova Sh R 2015 Study of the properties of nanocomposite polymeric materials based on high-density polyethylene with copper-containing filler Perspective materials 1 pp 58-62

[6] Long H Nguyen, Torsten R Lässig, Shannon Ryan, Werner Riedel, Adrian P Mouritz, Adrian C Orifici 2016 Composites: Part A 84 pp 224–235.

[7] Okhlopkova T A, Borisova R V, Nikiforov L A, Spiridonov A M, Sharin P P, Okhlopkova A A 2016 Technology of liquid-phase compounding of ultra-high-molecular-weight polymers with ultrasonic vibrations Russian Journal of Applied Chemistry Vol 89 No 9 pp 1469-1476

[8] Dintcheva N Tz, Arrigo R, Morici E, Gambarotti C, Carroccio S, Cicogna F, Filippone G 2015 Multi-functional hindered ford ultra-high molecular weight Polyethylene -based nanocomposites Composites Part B 82 pp 196–204

[9] Gogoleva O V, Popov S N, Petrova P N, Okhlopkova A A 2014 Study of the structures and properties of composite materials created on the basis of ultrahigh molecular weight polyethylene and thermally expanded graphite Herald of Mechanical Engineering 9 pp 42-45.
[10]  Okhlopkova A A, Andrianova O A, Popov S N 2003 Modification of polymers with ultrafine compounds (Yakutsk: YF Publishing House of the Siberian Branch of the Russian Academy of Sciences) P 224

[11]  Semenov A B, Muranov A N, Kutsbakh A A, Semenov B I 2017 Injection molding of structured multiphase materials RUDN Journal of Engineering Researches 18 (4) pp 407–425

[12]  Maksimkin A V, Kaloshkin S D, Cherdyyntsev V V, Senatov F S, Danilov V D 2011 Structure and properties of ultrahigh molecular weight polyethylene filled with dispersed hydroxyapatite Materialovedenie (Materials Science) 11 pp 13-21

[13]  Glazyrin A B, Basyrov A A, Nikolaev A V, Zaripov T F, Sultanov A I. 2016 Metal - filled polymer compounds for 3D printing Modern Science 12 pp 35-38

[14]  Zhuravlev V A, Ssulvaev V I, Korovin E Yu, Dorohhkin K V 2014 Electromagnetic Waves Absorbing Characteristics of Composite Material Containing Carbonyl Iron Particles Materials Sciences and Applications 5 pp 803–811

[15]  Kraev I D, Govorov V A, Shirokov V V, Shashkeev K A, 2017 Investigation of the effect of carbonyl iron dispersity on the radio absorbing characteristics of a composite based on them Aviation materials and technologies 1 (46) pp 51–60.

[16]  GOST 11629-2017 Plastics. Method for determining the coefficient of friction Introduction date 2018-07-01.