Application of seals made of directed reinforced polymeric composite materials to improve wear resistance of friction units of oil well pumps

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Abstract. Here we deal with the perspectives of advanced materials application to improve wear resistance of oil well pumps friction units, in particular, cup packing materials. We present results of wear resistance estimation of some polymeric composite materials with differently directed strengthening (chaotically, perpendicular and parallel to friction forces). Composite materials based on advanced polymers: nylon plastic, polysulphone, polyethylene, polyethylene terephthalate. Dispersed graphite, carbon fiber, dispersed (1 mm) carbon fiber, synthetic high-modulus fibers were used as fillers. The results showed that in friction units of oil well pumps contacting with raw oil it is rational to use seals made of composite materials based on polyamide, strengthened with synthetic high modular fibers perpendicular to the fiction surface.

1. Introduction

An important trend in contemporary mining and oil producing machine-building is enhancing operational properties of essential parts and units. Excessive parts wear in joints in some cases degrades pressure integrity, lubrication mode, results in degradation of mechanism kinematic accuracy [1-3]. Many works are devoted to wear resistance enhancement and friction loss decrease achieved both by application of new materials and wear resistant coatings and surface mechanical treatment [4-6].

Recently there is a tendency of increasing well depths and stratal oil recovery. It necessitates creating new modern equipment for oil recovery and application of new advanced materials, in particular for seals of oil well pumps. These materials should be highly wear resistant in conditions of extreme operation (big depths, raw oil contact and others) [7-9].

Oil well pumps efficiency depends on seals operation. The main parameters of oil well pumps seals efficiency are operational environment hermiticity, life-time and power for friction. Seals imperfections lead to pumps failure before time, process flow disruption, operational environments loss, increased power consumption to overcome friction in seals and violation of sanitary conditions of staff working places.

Our aim was to test several polymer composites with various fillers and differently directed strengthening fibers for friction couples durability acting in raw oil.
Picture 1 shows some kinds of cup packings used in well pumps. The advantages of cup packings are high hermiticity and wear resistance, small dimensions, easy installation and substitution, low cost, minimal production service.

![Kinds of cup packings for well pumps](image)

**Figure 1.** Kinds of cup packings for well pumps

Efficiency and durability of cup packings are determined by seals materials mostly. Mostly these elements are made from different resins. Cup packing hermiticity is provided by friction between the cup seal lip and the shaft surface. Cup packing functioning is possible when there is a sealed fluid thin film on the friction surface (thanks to capillary forces), which minimizes friction harmful effects, heat liberation and wear. But, sometimes dry and abrading friction occurs when the resin operates badly and wears intensively. It is a great disadvantage especially in oil recovering (that is in hostile environment).

All this necessitates application of new materials with high antifriction properties, high resistance to hostile environment and long durability comparing with resin. They should be mouldable by under pressure casting method that is necessary sealing elements should be made of them. Polymers and polymer composites meet these requirements [10, 11].

It should be noted that to receive predetermined-properties engineering materials not polymers but their compositions with other materials, organic or inorganic (metalloplastics, plastics, polymer-concrete, fiber glass and others) are used.

Different fibers are used as fillers in fiber composite materials: threads, taps, and grids of different twinning. Fiber composite materials strengthening can be uniaxial, biaxial and triaxial (picture 2). Strength and rigidity of these materials are determined by the properties of strengthening fibers which receive the main load. The direction of strengthening fibers in composite materials influences their properties greatly (chaotically, parallel and perpendicular) to the friction surface.
Figure 2. Schemes of fiber composite materials strengthening

The friction couple in a stage of a multi-stage centrifugal pump consists of two details, a metal one and a composite material detail, a composite material consists of a matrix and the filler. The matrix is thermoplastic polymer material, and the filler consists of glass filler (15…50%), mineral matters (up to 10%), fluoroplast (up to 7%), molybdenum disulfide or blacklead (1,5…15%), thermofluid connecting matter and others.

In some works [12-15] polyamide, polyurethane and other composite materials are considered promising in different conditions of friction. This work presents results of experimental estimation of wear resistance of some kinds of polymer composite materials with differently directed strengthening fiber under pressure up to 16 MPa and temperature up to 120 °C in oil of northern deposits in order to choose the most promising material for friction units’ seals of oil well pumps.

2. Materials and methods
Chaotically and directly strengthened composite materials based on advanced polymers have been tested: polyamide, polysulfone, polyethylene, polyethyleneeterephthalate. Bronze OF 10-10 was used as base material for comparative analysis. As fillers of composite materials black lead, carbon fibre, dispersed (1 mm) carbon fiber, synthetic high modular fibres were used [16, 19, 20].

Cylindrical samples with diameter 10 mm, made of these materials, were tested together with a roller with diameter 40 mm, polished till $R_a = 0,15$ mkm. Roller material was hardened steel 40X, steel hardness – 42…45 HRC. The test were done in raw oil on the experimental installation, based on the induction motor with the shaft rotation frequency 2730 rot/min, with a loading device. During express tests the load at the contact point of a sample with a roller was equal 20H, and the test pattern corresponded to the classical scheme of two crossed cylinders.

Testing the samples with the variable geometry of the contact area, the wear criterion was the area of wear scar on the sample after the specified trial time (60 min). It is obvious that the best wear resistant material will have the least wear scar at other equal trial conditions. The trial time was chosen so that it was possible to measure the wear scar area precisely by an optical microscope graduated in 0.01 mm.

During specified test pattern there appeared a slot on the composite material fixed sample, its length along sliding direction was $a$, width in perpendicular direction – $b$, height in the slot center – $h$. 
Using works [17,18] to calculate the volume and area of the rectangular planar wear scar during misalignment contact of two cylinders the segment area can be approximately calculated by formula:

$$S = \frac{a^3}{6D} = \frac{2}{3} \cdot a \cdot h,$$

And the volume wear of the cylindrical sample by formula:

$$V = \frac{a^3 + b}{3D},$$

To compare the test results the wear scars were considered to have a rectangular planar form.

3. Discussion of research results
Compositions of composite materials and ways of strengthening (fibre direction to friction surface) were:

1 - bronze OF 10-10;
2 - polyethylene terephthalate without filler;
3 – polyethylene terephthalate with filler - 30% high modular chaotically strengthened synthetic fibre;
4 – polysulphone without filler;
5 – polysulphone with filler - 30% high modular chaotically strengthened synthetic fibre;
6 - polysulphone with filler - 50% high modular perpendicular strengthened synthetic fibre;
7 - polysulphone with filler - 50% high modular parallel strengthened synthetic fibre;
8 – polyamide without filler;
9 – polyamide with filler - chaotically strengthened dispersed graphite;
10 - polyamide with filler - 20% high modular chaotically strengthened synthetic fibre;
11 - polyamide with filler - 35% high modular chaotically strengthened synthetic fibre;
12 - polyamide with filler - 49% high modular chaotically strengthened synthetic fibre;
13 – polyamide with filler - 30% chaotically strengthened dispersed (1 mm) carbon fibre;
14 - polyamide with filler - 50% parallel strengthened carbon fibre;
15 - polyamide with filler - 50% parallel strengthened carbon fibre;
16 - polyamide with filler - 50% high modular perpendicular strengthened synthetic fibre;
17 – polyethylene with filler - 40% chaotically strengthened carbon fibre;
18 - polyethylene with filler - 40% perpendicular strengthened carbon fibre;
19 - polyethylene with filler - 40% parallel strengthened carbon fibre.

Express test results are shown as a bar chart in figure 3.
Sample № 4 made of polysulphone without filler destroyed in 15 min. Synthetic high modular fiber filler 30 % (sample № 5) improves wear resistance, but if the amount of the filler increases (samples № 6, 7) wear resistance decreases again. For samples № 2, 3 of polyethylenterephtalate with synthetic high modular fiber 30 % wear resistance increases.

The most interesting results are of a polyamide, which even without filler (sample № 8) had the best frictional properties among the tested polymers. Chaotic strengthening with synthetic high modular fibers up to 40% (samples № 10, 11) decreases polyamide wear resistance insignificantly as well as similar dispersed carbon strengthening (sample № 13). At the same time, dispersed carbon although it has lubricating properties loosens the structure and worsens composite materials properties (sample № 9).

Analysis of strengthening influence on composite wear resistance shows that composite materials with matrixes of polysulphone and polyamide have higher wear resistance if strengthened perpendicular friction surface (samples № 6, 14, 16). May be, it is because at friction perpendicular to the strengthening fibers, the friction to fiber areas relation, contacting the matrix, is significantly less than one, and at parallel friction (samples № 7, 15) is nearly one. At the same time, for composites with weak fiber adhesion to the matrix and less matrix strength (polyethylene with carbon – samples № 17, 19) this parameter is insignificant.

The experiment results show that wear resistance of the composites with polyamide matrix strengthened with synthetic high modular fibers perpendicular to the friction surface is significantly higher than the wear resistance of similar chaotically strengthened composite materials. Wear resistance of the sample № 16 with the polyamide matrix strengthened 50% with synthetic high modular fibers perpendicular to the friction surface is 3.5 times higher than wear resistance of sample № 8 of polyamide without filler.
4. Conclusion
Basing on the experiments results we can make a conclusion that in friction units of oil well pumps contacting the raw oil it is reasonable to use seals of composite materials based on polyamide, strengthened with synthetic high modular fibers directed perpendicular to the friction surface.

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