Investigation of loading speed influence on fatigue wear of - polymer materials

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Abstract. Antifriction and friction materials used in many construction structures, devices and road construction machines simultaneously undergo dynamic and impact loads. The article considers the influence of dynamic and impact loads on the friction and wear of polymer composite materials. The materials of the maslyanit group are established to have high resistance to frictional and bulk fatigue and are capable of long-term operation without failure under cyclic dynamic and impact nature of loading. Test results show that pure kapron, despite its homogeneous structure and greater elasticity than maslyanits, is more prone to bulk fatigue failure under the cyclic impact. This fact is fundamental for confirming the mechanism of fatigue crack blocking by solid particles of the filler. Researches confirm that introduction of the solid particles capable of additional relaxation of stresses in a crack tip zone reduces the speed of distribution of the fatigue crack defined by the speed of polymer loading. The conducted research also confirms high tribotechnical properties of the composite material Maslyanit KSC which has increased hardness of surface layers and high impact viscosity of deep layers as a result of surface “cementation”.

1. Introduction
The discreteness of contact of rubbing parts causes high-frequency impact pulses in the areas of microroughness and adjacent areas. However, due to the insignificance of microroughness protrusions and elastic properties of polymers, their impact wave has a small amplitude, and it is impossible to evaluate its role in fatigue wear separately from the influence of the nominal load in the contact. In addition to the indicated pulses of transverse deformations, the surface layers in the friction contact of parts of construction and road-building, transport machines and technological equipment undergo dynamic loads changing in time, which may manifest as an impact. Correct forecasting of operational fatigue resistance and strength properties of antifriction materials is impossible without studying the influence of their loading dynamics.

2. Problem statement
If the failure in metals results from the formation of "pure" cracks with their clearly defined analytical field stress at the crack tip [1], the failure of polymer composite material is a more complex process. Instead of pure cracking, we encounter a "damage zone", which may include fiber breakage,
microblocking of the fiber, fiber pulling, matrix cracking, dislocation, exfoliation, structural irregularities, delamination, or any combination [2, 3].

According to the physical chemistry of polymers [4, 5], in pure polymers put into a force field, there is a process of orienting the parts of chain macromolecules rolled up into globules, or collected in packs, connected with the complex of relaxation phenomena and structural changes of material.

The orientation of the deformed polymer structure leads to the strengthening of the crack tip zone. Therefore, if the orientation speed exceeds the crack growth rate, the strengthening will stop the crack growth for some time. If the speed of the force field is high, the orientation may fail to surpass the crack growth, which will lead to the failure of the surface (wear) or the polymer volume [6]. It follows that critical values of magnitude and speed of load application for homogeneous polymers depend on their relaxation capabilities.

We have found above [7] that the friction of materials causes the orientation of their working surfaces, which gives them high wear resistance. This correlates with the regularity established by G.A. Gorokhovsky and his colleagues for orientation of molecular structure elements of the polymer working layer: PE, PTFE, PCA and FFS and increase of their wear resistance at low loading speeds [6].

3. Materials and methods

Since polymers react differently from metals and low molecular weight solid materials under mechanical loading, it is not enough to use methods of testing these materials for complete description of their behavior under mechanical loading test. Besides, the existing methods of polymer impact failure investigation do not allow to consider the simultaneous effect of impact and friction [8]. For this reason, we have developed a methodology reflecting the special properties of polymers. To compare the effect of dynamic loading and impact loads, we made two types of samples: with eccentricity and with a protrusion (shoulder) on the working surface. We studied the influence of loading speeds (dynamics) on the friction pair operation on the materials previously tested and recommended in our study [9] for the most loaded units of road construction and agricultural machinery (ball and cardan joints, etc.): maslyanits KSC and KS-2 with fiberglass and the most characteristic representative of maslyanits without fibrous filler is maslyanit D(S-1). The comparison included the testing of pure kapron without filler.

We tested on a standard MI-1M friction machine at a linear speed of \( V = 0.42 \) m/s using the scheme shown in Figure 1. The height of the shoulder for an impact loaded roller A is 6 mm, the maximum distance of point B from the opposite point (stroke of the loaded roller) is 6 mm.

Figure 1. Friction unit to the MI-1M friction machine for impact wear

The load in the impact study was equal to 647 N, in the case of impact-free dynamic loading - 647 N and 1254 N, and the rate of increase of these forces due to eccentricity by 8 ÷ 12 N was 53 ÷ 80 N/s.
We neglected the reduction of speed and load as a result of sample wear, since this factor had the same effect on samples in all experiments.

4. Results and Discussion

Tables 1 and 2 show the results of materials testing.

**Table 1. Dynamic loading test results for maslyanits**

| Materials          | Wear speed (mm/h) under loads: | Coefficient of friction under loads: |
|--------------------|--------------------------------|-------------------------------------|
|                    | 647 H                          | 1254 H                              |
| Maslyanit KSC      | 0.85                           | 1.76                                |
| Maslyanit KS-2     | 2.04                           | 3.11                                |
| Maslyanit D (S-1)  | 3.73                           | 7.90                                |

Table 1 shows that the maslyanit KSC has minimal wear. Material wear tests on other machines showed the same ratios. We have obtained a slightly different pattern of friction coefficients: when they are in the area of lower values, they increase for all materials with an increase in the load on the roller, although the pressure due to an increase in the actual contact area does not increase in proportion to the load, but by a smaller value. The fact of a general reduction of friction coefficient is possible to explain by rational squeezing out due to "cemented" barrier and consumption of plasticizer material in the friction zone (we used lubricant No. 158), as well as reduction of adhesive component and a smaller value of overlap coefficient, which favourably affects the temperature regime of friction process. The increase in the coefficient of friction with increased load may result from the increased height of the wave of deformed material running in front of the roller.

**Figure 2.** Samples of maslyanits: D(C-1) (1), KS-2 (2) and KSC (3) tested under dynamic loading (p=1254 N)

Wear on all samples started at maximum load areas. The surfaces of wearing samples (Figure 2) and the flaky shape of the wear particles indicate the fatigue nature of the wear.

It is established [10], that the sizes of the wear products decrease at introduction of fibrous fillers into the material or at reduction of loading. If no filler is available, the wear particle may be
proportional to the size of the sample friction path. So, for the case of rolling friction of PA610 under a similar scheme without dynamic loading E. A. Fedorchuk [11] has received that the wear particle with triangular section covers all track of friction and has the thickness to 3 mm depending on pressure.

For dynamic loading, the sample was struck twice in one revolution: when the roller came into contact with the protrusion and jumped off it with a stronger impact. Thus, there are two phases in the impact process: the deformation phase, during which the normal component of the contact point velocity decreases to zero, remaining negative, and the recovery phase, during which the normal component of the contact point velocity increases from zero to the previous value. A crack appeared in this place on the kapron sample, resulting in the failure of the sample after 5 minutes of operation (Figure 3).

Table 2. Impact test results for maslyanits under impact loading of 647 N

| Materials          | Wear speed (mm/h) |
|--------------------|-------------------|
| Maslyanit KSC      | 0,73              |
| Maslyanit KS-2     | 1,50              |
| Maslyanit D(S-1)   | 2,62              |
| Capron (control sample) | Sample was destroyed |

Figure 3. Samples from maslyanit KSC (1), maslyanit D (S-1) (2) and kapron (3) tested under impact loads.

Thus, the test results show that pure kapron, despite its homogeneity and greater elasticity than maslyanit KSC, is more prone to bulk fatigue failure under the cyclic impact. This fact is fundamental for confirming the mechanism of fatigue crack blocking by solid particles of the filler. As we noted above, in homogeneous polymers, stress peaks arising at low loading speeds are smoothed by relaxation processes seeking to balance the system. The resulting orientations of the molecular chains can stop the growth of fatigue cracks. Research results on the influence of friction impact effects show the low ability of oriented kapron sections to block crack growth.

Studies have shown high wear resistance and contact strength of high-filled maslyanits. The introduction of the solid particles capable of additional relaxation of stresses in a crack tip zone reduces the speed of distribution of the fatigue crack defined by the speed of polymer loading. At the same time, such a mechanism for blocking cracks does not exclude but favours the orientation of molecular chains and packs due to the delay of the crack along the front of its growth. High tribotechnical and strength properties of maslyanite KSC under friction-dynamic loading are also due
to the mixture of resins as a binding component: kapron resin with glass fiber KS-30a and phenol-formaldehyde novolac resin SF-010, which gives it a high impact strength.

5. Conclusion

We conclude that the materials of the maslyanit group have high resistance to frictional and bulk fatigue and are capable of long-term operation without failure under cyclic dynamic and impact nature of loading. The conducted research also confirmed high tribotechnical properties of the composite material Maslyanit KSC, which has increased hardness of surface layers and high impact viscosity of deep layers as a result of surface "cementation".

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