Development of Wear-Resistant Metal Polymer for Agricultural Machinery

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Abstract. The article considers the influence of the content of HB-4 amorphous alloy on the tribological properties of aromatic polyamide phenylone C-2. It was found that the introduction of a dispersed filler in the amount of 10-20 mass.% leads to a positive effect: reduction of abrasion index and roughness during friction on rigid abrasive particles of the original polymer 4,7 and 1,4 times, respectively, reaching minimum values at 20 mass.% of the filler. The improvement in properties occurs due to the fact that the particles of the hard alloy (607–809 HV) strengthen the polymer matrix; as a result, the surface of metal polymers undergoes less deformation. It was found that the effective content of filler for aromatic polyamide is 20 mass.%.

Introduction

During the harvest (corn, barley and wheat) agricultural machinery is subjected to excessive abrasive wear due to interaction with cereals. As a result, there is a tightness loss in the friction units, loss of accuracy of the relative position of parts and movements etc. [1]. These factors are often the main cause of equipment failure: jams, shocks, vibrations which lead to failure of the latter. Thus, farms incur large losses due to the loss of quality crops due to downtime and equipment repairs. In particular, grain losses increase due to undermilling of grain during harvesting because of abrasive wear (more than 4 mm) of threshing drums made of 65G steel. So, in order not to lose the harvest, enterprises face the issue of timely purchase of new beaters that requires additional financial costs.

There are several ways to increase the abrasion resistance of individual parts of the equipment. The simplest of them is to apply a special coating on parts that are subject to excessive wear. However, this method is not suitable for use in agricultural machinery, because cereals, acting as solid abrasive particles, erase a thin layer of coating. Because of this, parts of agricultural machinery must be made of solid materials that are able to resist the action of abrasive particles. Such materials include polymer composite materials (PCMs) which have proven to be an excellent substitute for traditional metals and alloys in many branches of modern industry. The use of them has significantly increased the service life of friction units, while reducing repair and maintenance costs [2, 3].

Aromatic polyamide phenylone (APPh) can be distinguished among the other polymer matrices used for the manufacture of PCMs. It is characterized by stability under the influence of high temperatures and aggressive environments. APPh -based PCMs containing dispersed (graphite, talc, asbestos etc.) and discrete (organic and carbon fibers) fillers (FLs) are characterized by a low coefficient of thermal linear expansion, high wear resistance under friction without lubrication and thermal conductivity. One of the main disadvantages of these PCMs is a low abrasion index [4].

Amorphous alloys (AAs) are one of the promising FLs for the creation of PCMs with a high rate of abrasion resistance. It is known from the literature [5, 6] that the indicators of corrosion resistance, strength, hardness (up to 1000 HV) and plasticity of the AAs are superior to known serial materials. The most widespread are AAs based on metals of the transition group such as iron (Fe), nickel (Ni), cobalt (Co) in combination with such metalloids as boron (B), silicon (Si) and carbon (C) [7] are the most common due to good mixing of interacting components.

Given the above, the aim of the work was to study the influence of HB-4 amorphous alloy on abrasion index during friction with rigidly fixed abrasive particles of composites based on heat-resistant APPh C-2.

Objects and methods of the research

APPh C-2 was chosen as a polymer matrix for the manufacture of metal polymers (MP). It is dispersed (20-40 μm) white powder [8] characterized by a wide temperature range of operation (153-553 K), stability under the influence of many aggressive environments.

Dispersed (17–133 μm) HB-4 AA ($Fe_{60}Cr_4Co_7V_2W_1Mo_1Nb_1B_{20}C_2Si_2$) was chosen as a filler for APPh C-2. It was obtained by grinding fast-hardened amorphous tape (LLC "Melta" manufacturer, Kyiv) in a ball mill. Preparation of metal polymers was carried out by compression molding [9] with the exception of ferromagnetic particles (because the AA contains as much as 60% iron).

Abrasion index when rubbed during friction with rigidly fixed abrasive particles (skin dispersion was 40–60 μm) was determined on a Heckert experimental machine [10]. Studies of the morphology of the friction surfaces of the developed metal polymers were carried out using a "BIOLAM-M" microscope. The roughness of APPh and MP on its basis was determined on a 170621 profilometer using a sharp solid needle (probe) which moved along the test surface copying its irregularities. The microhardness at the interface between the "polymer filler" and the particles of HB-4 AA was studied on a PMT-3M microhardness tester. Rockwell hardness (HRE) was measured using a 2074 TPR instrument [11].

Results of the research

Analysis of the results of friction of composites (see Table 1) with rigidly fixed abrasive particles showed that the introduction of HB-4 alloy leads to a decrease in the abrasion of the polymer 3,1-4,7 times. The obtained results are subjected to Ratner's laws – the increase in the hardness of the initial material, as the amount of the FL increases, leads to an overall increase in the wear resistance of MP [8].

As can be seen from the data presented in Figure 1, abrasion index decreases sympathetically with increasing path of the experiment. This is due to the fact that the particles of the amorphous alloy have a high microhardness (607–809 HV), and, as a result, reduce the roughness of the abrasive skin by 20%.

This occurs because the abrasive particles become brittle and weaken in contact with superhard FL; as a result, the friction surface of the composite undergoes less deformation (Figure 2) resulting in a decrease in the roughness of the latter (see Figure 3).

It is interesting to note that with increasing friction path, the roughness of the MP is stabilized at the FL content of up to 20 mass.%. At the same time, when the content of the FL is 25 mass.% there is another dependence. With the increase of the path over 120 m there is an increase in roughness that is associated with the loss of particles of HB-4 alloy from the sample due to excessive amount of the FL that causes pores and cracks at the "polymer-filler" interface as evidenced by microhardness data (Table 1).

Table 1. Performance properties of the initial polymer and composites based on it.

Filler content, C, mass.% \ Indicator	Abrasion index V_i, mm^3/m	Rockwell hardness (HRE)	Microhardness at the "polymer filler" interface, HV
0	1,80	88,0	-
10	0,58	100,5	113,32
15	0,45	101,5	117,30
20	0,42	102,5	127,64
25	0,38	104,0	100,07

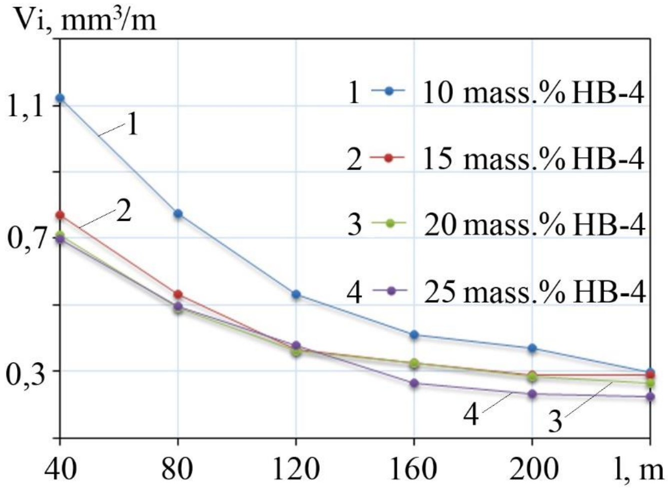
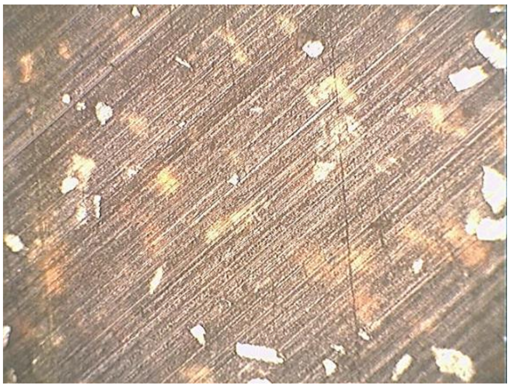


Figure 1. Dependence of abrasion index (V_i, mm/m^3) on the friction path (l, m).

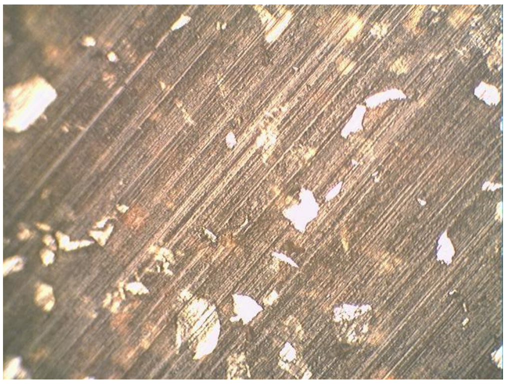
The growth of the number of defects in the volume of the composite is due to the excessive number of AA. Before the formation of the final products in the mixing process, the initial components of the PCMs were exposed to a magnetic field (B = 0,12 T). Under the action of the latter, the ferromagnetic particles of the filler were activated that caused their magnetization. Because of the strong magnetic interaction during the mixing, the particles colliding formed agglomerates behaving like elementary magnets. In this case, the more FL is in the mixture, the greater the probability of intersection of the trajectories of the particles, and thus the greater the probability of formation of agglomerates. APPh melt does not penetrate into such agglomerates, as a result of which voids are found inside them [9, 10].

a



b

c



d

Figure 2. Friction surfaces (× 200) of metal polymers containing: a - 10, b - 15, c - 20, d - 25 mass.% of the filler after friction with rigidly fixed abrasive particles.

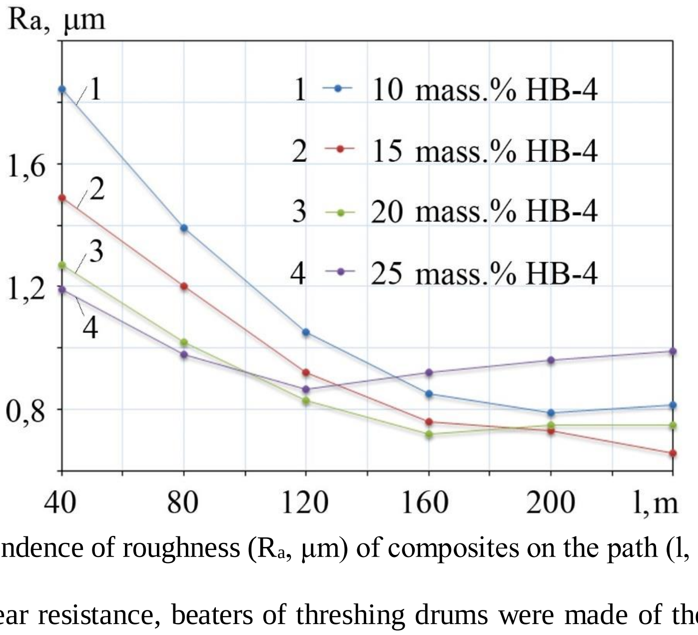


Figure 3. Dependence of roughness (R_a, μm) of composites on the path (l, m) of friction.

Due to the high wear resistance, beaters of threshing drums were made of the MPs (filler content 20 mass.%) (see Figure 4) instead of serial ones (65 G steel).

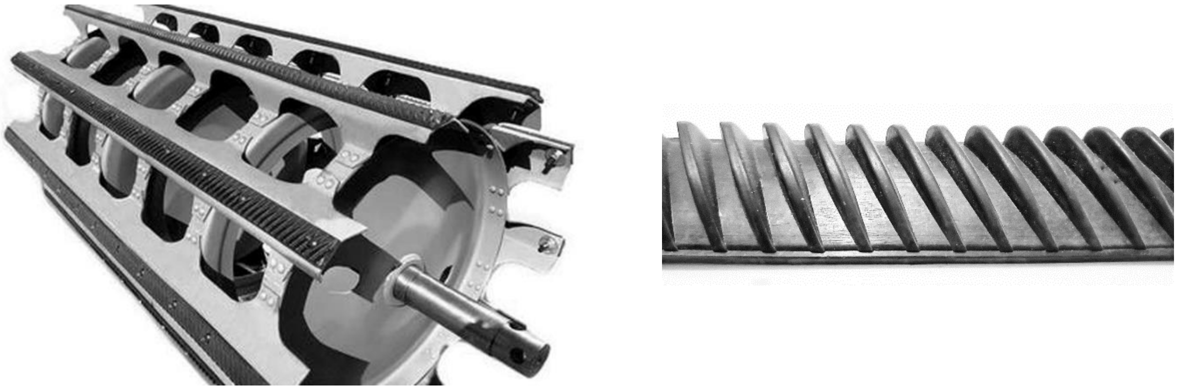


Figure 4. General view of the threshing drum and beater made of metal polymer

When harvesting seed plots of cereals, the use of this MP allowed not only to significantly increase the wear resistance of the beaters, but also to reduce crop damage while maintaining its purity (environmental friendliness). All this allowed to increase the nutritional properties and ability of seeds to germinate and growth energy. According to production tests, the use of these beaters for agricultural enterprises also has an economic effect because it reduces the number of injured grain, downtime and repair of equipment.

Conclusion

Given the above, we can conclude that the introduction of HB-4amorphous alloy is a promising way to improve the tribotechnical characteristics of aromatic polyamide; its use leads to a decrease in abrasion index 3,1-4,7 times, respectively, and to some increase in hardness (by ~ 18%). The effective degree of filling is 20 mass.% of HB-4, because as the amount of alloy increases to 25 mass.% it is more difficult to distribute the alloy evenly and avoid the appearance of agglomerates of particles that lead to increased numbers of defects in the MP and, consequently, deterioration.

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