STUDY OF THE INFLUENCE OF QUICK-HARDENED ALLOY ON THE PROPERTIES OF METAL POLYMERS

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The article explores the effect of quick-hardened alloy PR-N65X25S3R3 based on nickel, (chemical composition – Ni64,6Cr25C1,2Si2,7B2,5Mn0,2Fe3,8) on the physical and mechanical properties of metal-containing polymers. Carried out tests and results have shown that the use of quick-hardened alloys, which are characterized by a set of unique properties, is appropriate. The developed metal-containing polymers that contain aromatic polyamide phenylone and 5 - 20 wt.% of self-fluxing amorphous alloys PR-N65X25S3R3 are characterized by 2 times greater abrasive wear resistance and better adhesive strength between the components. Due to the use of quick-hardened alloy it was possible to increase the effective filler content from 15 wt.% to 20 wt.% that will increase the electromagnetic properties of metal-containing polymers.

Keywords: metal-containing polymers, self-fluxing alloys PR-65X25S3R3, tribological properties.

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1. Introduction

Composite polymeric materials, which have higher performance characteristics than initial polymers have, are widely used in mechanical engineering. The properties of such composite materials directly depend on the polymer matrix and filler, so they can be varied within wide limits, selecting components to obtain materials with specified properties. An example of such polymeric composite materials can be polymers filled with fine particles of metals that have recently attracted increasing attention and are widely used as functional materials with a valuable set of physical and mechanical, tribological and thermophysical properties. As it is shown in the work [1], the use of metals and alloys as fillers, together with the use of the original method of processing, allowed to get structural metal-containing polymers for friction units; they can operate in a wide range of temperatures and at high loads. However, due to insufficient adhesion between the matrix and the filler, the effective amount of filler in metal-containing polymers is only 15 wt.%. That allows their use in industries where only both physical-mechanical and electromagnetic properties are important.

Probably, in order to increase electromagnetic properties of metal-containing polymers, it is rational to use quick-hardened alloys that are characterized by a set of unique properties. It is known that the mechanical properties of amorphous metals are largely determined by the absence of dislocations. The absence of dislocations leads to the fact that metal glasses have a very high hardness, and due to the high hardness they are durable. Another important advantage of amorphous metal alloys is their extremely high corrosion resistance that is also achieved because of the absence of defects in the structure. Such alloys have much smaller oxide film, different from the film that is formed on crystalline metals [2, 3]. Thus, the interaction between the polymer and the filler will be different from that studied in [1], and therefore we can expect an increase in the physical and mechanical characteristics of metal-containing polymers containing quick-hardened alloys as filler. In view of the above, the goal of the work was to study the effect of quick-hardened alloy on the physical and mechanical properties of metal-containing polymers.

2. Objects and research methods

Today, the significant development of technology favored the expansion of the use of thermo- and heat-resistant polymers, characterized by long-term availability in a wide range of temperatures, high strength properties, resistance to deformations and exposure to corrosive media. Such polymers include the aromatic polyamide phenylone, a polymer analogous to

Nomex by DuPont, which was chosen as a binder for the manufacture of metal-containing polymers. Aromatic polyamide phenylone is a promising thermally stable polymer for structural purposes, which can be used for a long time to a temperature of 533 K, which is not inferior in strength to the best brands of reinforced plastics [4]. However, the phenylone recycling in products causes certain difficulties, for example, low deformability and fluidity of phenylone in the softening temperature range narrow the temperature range of its processing and require the application of high pressures, resulting in product size limitations. Modification of phenylone with various kinds of fillers is also accompanied by difficulties associated with insufficient adhesive strength between the polymer matrix and the filler. As a consequence, strength parameters and heat resistance of composites are reduced, and, the more, the higher their content. Therefore, the development of metal-containing polymers based on heat-resistant APP with an increased adhesion strength between phenylone and filler is an urgent task in the development of composites with increased physical and mechanical properties. Fine powders (particle size 40 - 100 microns) of self-fluxing alloys PR-N65X25S3R3 based on nickel, (chemical composition – $Ni_{64,6}Cr_{25}C_{1,2}Si_{2,7}B_{2,5}Mn_{0,2}Fe_{3,8}$) were used as filling material. The following compacted powder compositions were used: aromatic polyamide phenylone + 5–20 wt. % of a fine metallic filler were prepared by the original technique in a vortex mixer. The resulting mixtures were pelleted on a hydraulic press at room temperature; then, the pelleted samples were dried in an oven at a temperature of 473–523 K since the processing of undried phenylone impairs its strength properties and results in surface flaws [5]. The dried and pelleted workpieces were subjected to compression molding to manufacture products. Tribological characteristics of the samples were determined on a disk friction machine (steel 45 was used as a counterbody that was heat treated to a hardness of 48-50 HRC). Friction conditions: PV = 0.6 MPa·m/s, friction path S = 1000 m. The same treatment and pre-running of the samples were performed before the tests. The wear of the samples was determined on VLR-200analytical scales with an accuracy of 0.0002 g, the modulus of elasticity in compression was determined on the FP-100 rupture machine (GOST 4651-2014), microhardness was determined using PMT-3M device (GOST 9450-76), abrasive abrasion index was determined on the Hekkert machine (GOST 11012-69).

3. Discussion of the results

Tribological properties of polymer compositions that contain aromatic polyamide phenylone and 5 - 20 wt.% of self-fluxing amorphous alloys PR-N65X25S3R3 are given in table. 1. As can be seen from the data (Table 1), the characteristics of metal-containing polymers are determined by the degree of filling: with increasing in filler content wear intensity (Ih•10-8) and friction coefficient (f) decrease and reach a minimum at a content of 20 wt.% of the filler, obeying Ratner's law that connects physical-mechanical and tribological properties of materials (see Table 2). The appearance of a dispersed metal powder in the polyamide matrix strengthens the composite material and inhibits the development of deformation processes in the matrix during abrasion that increases the wear resistance of metal-containing polymers. On the other hand, increasing the content of metal filler reduces the temperature at the “metal-containing polymers – counterbody” interface (see Table 1) that inhibits the development of destructive processes and, consequently, leads to increased wear resistance of filled systems. No microcracks are observed on the friction surfaces of the MP (see Fig. 1) that indicates the plastic destruction of the material under the influence of sliding friction, but there are traces of adhesion to the counterbody in the form of areas of material shifted in the direction of friction. In this case, the higher wear resistance of the composition is, the less common they are.

Table 1

Dependence of tribological properties on the filler content

Properties	Friction on the transfer film			Friction on the restorative surface			Hardness
	$I_h \cdot 10^{-8}$	*f*	T, K	$I_h \cdot 10^{-8}$	*f*	T, K	HRE, MPa
Phenylone	3,43	0,49	393	3,91	0,52	403	88
Phenylone +10 wt.% PR-N	0,49	0,57	374	0,79	0,54	389	97,9
Phenylone +20 wt.% PR-N	0,34	0,61	366	0,78	0,56	381	99,9
Phenylone +30 wt.% PR-N	0,66	0,66	332	0,87	0,61	339	89,5
Phenylone +40 wt.% PR-N	1,11	0,67	320	0,93	0,63	322	88,4

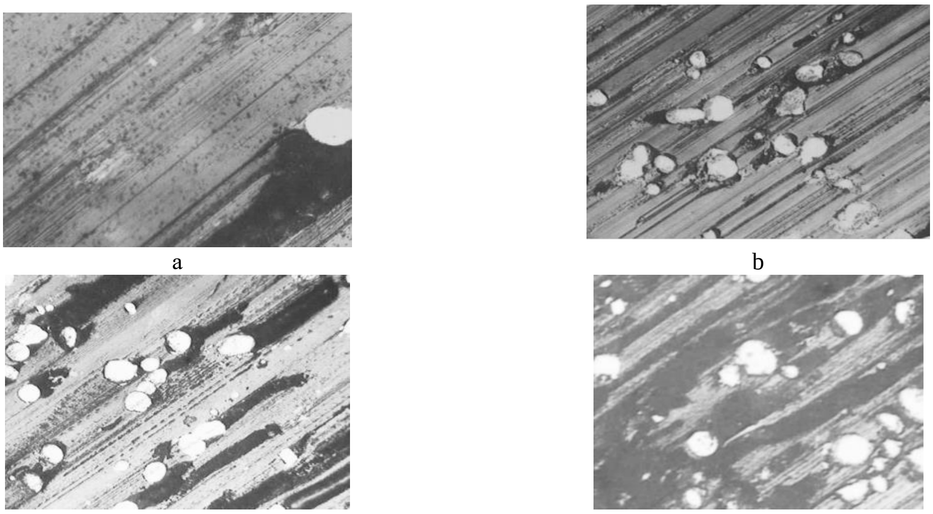

Fig. 1. Friction surfaces of metal-containing polymers containing: a – 10, b – 20, c – 30, g – 40 wt.% of the filler. Magnification x100

As can be seen from Fig. 2, the indicator of abrasive abrasion of metal-containing polymers is determined by the degree of filling and reaches a minimum at a filler content of 20 wt.%, that is due to the increased strength of the compositions, as in the case of wear while friction without lubrication. This dependence indicates good adhesion between the filler and the polymer matrix. When the filler content increases to 40% by weight, the plasticity of the materials decreases to a critical value, pores and agglomerates of particles occur in the volume of the material, and all this leads to a certain increase in the abrasion index. As noted by the authors of the work [6], when the polymers are worn with fixed abrasive particles, some irregularities plow the material, others – cut it. With decreasing plasticity of the polymer, due to its filling of 30 - 40 wt.% of metal particles, abrasive wear occurs because of microcracking; the material is removed due to brittle fracture near the filler, when side cracks adjacent to the grooves intersect with cracks from other grooves. As a result, the filler part is removed together with the wear products (Fig. 2 b). This nature of wear is evidenced by the increase in surface roughness: Ra = 0,588 (10 wt.%) – 0,811 (40 wt.%). Comparing the developed composite materials based on aromatic polyamide phenylone and 5 - 20 wt.% of self-fluxing amorphous alloys PR-N65X25S3R3 (see table. 2 example 1 – 4) with metal-containing polymers containing carbonyl nickel as a filler (table. 2 example 5), we can see that with the same content of fillers developed metal-containing polymers containing quick-hardened alloy exceed in abrasion 2 times by increasing the microhardness at the "polymer matrix – filler" interface 5 times, while maintaining high modulus of elasticity at compression and wear resistance in the mode of friction without lubrication. Thus, the use of quick-hardened alloys, which are characterized by a set of unique properties, is appropriate. Due to the high indicators of physical-mechanical and tribological properties, the developed metal-containing polymers polymers will be used in various industries, such as: metallurgical, machine-building, chemical etc.

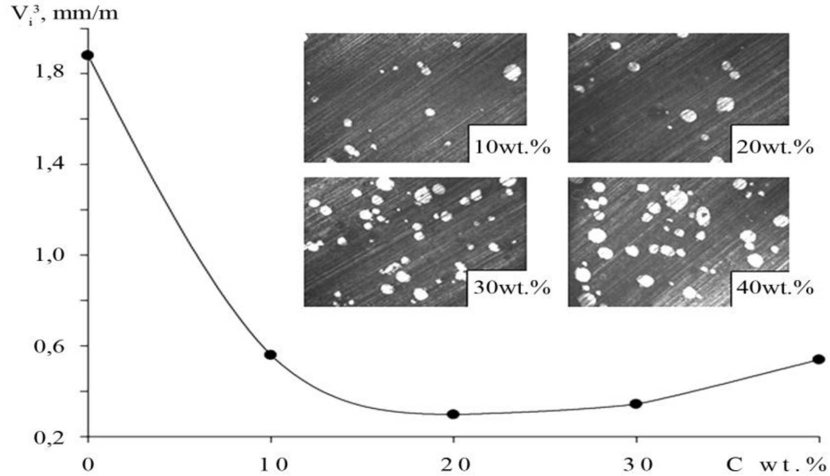

Fig. 2. Dependence of the indicator of abrasion of metal-containing polymers on the degree of filling and friction surface of metal-containing polymers after abrasive wear

Table 2

№ of the example	Content of the composition, wt.%		The modulus of elasticity under compression, GPa	Abrasion index, mm^3/m	Intensity of linear wear, $x10^{-8}$	Microhardness at the phase boundary, HF
	Phenylone	alloys PR-N				
1	90	10	3,07	0,57	0,49	163,0
2	80	20	3,09	0,50	0,34	164,9
3	70	30	3,24	0,29	0,66	154,1
4	60	40	3,26	0,30	1,11	105,0
5*	80	–	2,94	1,01	0,45	32,8

*The composition contains 20 wt.% of dispersed carbonyl Nickel powder.

4. Conclusions

Carried out tests and results have shown that the use of quick-hardened alloys, which are characterized by a set of unique properties, is appropriate. The developed metal-containing polymers are characterized by 2 times greater abrasive wear resistance and better adhesive strength between the components. Due to the use of quick-hardened alloy it was possible to increase the effective filler content from 15 wt.% to 20 wt.% that will increase the electromagnetic properties of metal-containing polymers.

References

1. **Burya, O.I.** Metalopolimery na osnovi fenilonu: rozrobka, vlastyvosti, zastosuvannya / O.I. Burya, K.A. Yeriomina, I.I. Polovnikov // International research conference “Tekhnolohiyi zabezpechennya zhyttyediyal′nosti lyudyny”. Abstact book. Kyiv, November 16–17, 2017 – P. 238 – 247.

2. Attraktive Anwendungsgebietes für Glas-metalliolien mit eingelagerten Hartpartikeen // Mittex. – 1990. 97, №10. – P. 434.

3. **Starodubtsev, Yu.** Amorfnyye metallicheskiye materialy / Yu. Starodubtsev, V. Belozerov // Silovaya Elektronika. – 2009. – No. 2: Tekhnologii. – P. 86 – 89.

4. **Sokolov, L.B.** Termostoykiye aromaticheskiye poliamidy (Heat-resistant aromatic polyamides) / L.B. Sokolov, V.D. Gerasimov, V.M. Savinov, V.K. Belyakov. – Moscow: Khimiya, 1975. – 256 p.

5. **Yanovskii, Yu.G.** Thermal expansion of polymer composites filled with carbon nanotubes / Yu.G. Yanovskii, G.V. Kozlov, A.I. Burya and Yu.S. Lipatov // Fiz. Mezomekh. – 2007. – No. 6. – P. 63 – 67.

6. **Myshkin, N.K.** Tribologiya. Printsipy i predlozheniya / N.K. Myshkin, M.I. Petrokovets. – Gomel': IMMS NANB, 2002. – 310 p.