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CARBON PLASTIC FOR STRUCTURAL PURPOSES BASED ON ALIPHATIC POLYAMIDE

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In the context of contemporary trends in saving energy raw material resources, it stands to mention the ever-growing role of polymer composite materials. It is promising to develop certain types of polymer structural materials with consideration of the special requirements of specific customers, namely heat-resistant polyamide binders. Heat-resistant polymers prevail over traditional materials in terms of strength by 2 times, and by weight – by 3-5 times. Moreover, they feature excellent chemical stability, insignificant minor temperature changes in size, high impact and tribological resistance. Replacing conventional metal materials in mechanical engineering with composite polymer materials based on polyamide binders ensures the reduction of materials consumption of machine parts by more than 2 times with a significant increase in their operating resource and reliability, and reduces the labor-consuming nature of manufacturing products from them, as well.

The high status from among plastics of structural purpose is given to polymer composites based on thermoplastic binders, which include aliphatic polyamides (PA). The specified polymers feature a fairly low coefficient of friction when paired with any metals, they feature good well and quick wearing-in; the wear of friction pairs when using parts with PA is reduced by 1.5-2 times, the cost of products made from them is 50% less compared to products made of metals; they are resistant to the effect of oils, alcohols, esters, alkalis and weak acids. Due to its improved properties, polyamides are used as structural, electrical insulation and antifriction materials in the automotive, aviation, oil-production, electrical engineering, radio-engineering, instrument-making and medical industries. The disadvantages of aliphatic PAs include a significant decrease in physical and mechanical characteristics in a humid environment, low stability of strength and electrical insulation properties, as well as insufficiently high dimensional accuracy of products made from them [1, 2].

The aliphatic PA of the PA-6.6 brand (polyhexamethylenadipamide) is distinguished by its durability and wear resistance, thermal stability (up to +140°C) and tensile strength. It is resistant to corrosion and aggressive environments, which makes it an indispensable material for manufacturing products that work under hard conditions, where high mechanical strength, rigidity, thermal and chemical resistance are required. For the purpose of creating a new composite material of structural purpose the PA-6.6 was reinforced with Ural carbon fiber. The samples of polymer composite were manufactured at temperatures of 513, 518, and 523 K.

At the initial stage of research, the study covered the effect of pressing tempe-rature on the heat resistance of carbon plastic (CP). Data of thermogravimetric analysis (Table 1) showed that reinforcement of PA-6.6 with carbon fiber allowed to significantly increasing its heat resistance: the temperature corresponding to 30 and 50% weight loss of samples for CP, respectively, was 23 and 44 degrees higher than for the original polymer.

Table 1.

Heat resistance of PA-6.6 and carbon plastic based thereon

Temperature, K	Material	
	PA-6.6	Carbon plastic
T_{30}	678	723
T_{40}	701	767

Note: T_{30}, T_{40} – temperatures of 30 and 40% weight loss of samples, K

The results of studying the effect of processing temperature on the thermophysical properties of CP showed that the best possible complex of thermophysical indicators were featured by plastic obtained by compression pressing at a temperature of 518 K (Fig. 1). Samples of this CP featured a low specific heat capacity (1.1-18 kJ/kg · K) and high values of the coefficient of thermal conductivity (0.74-0.94 Vt/m · K).

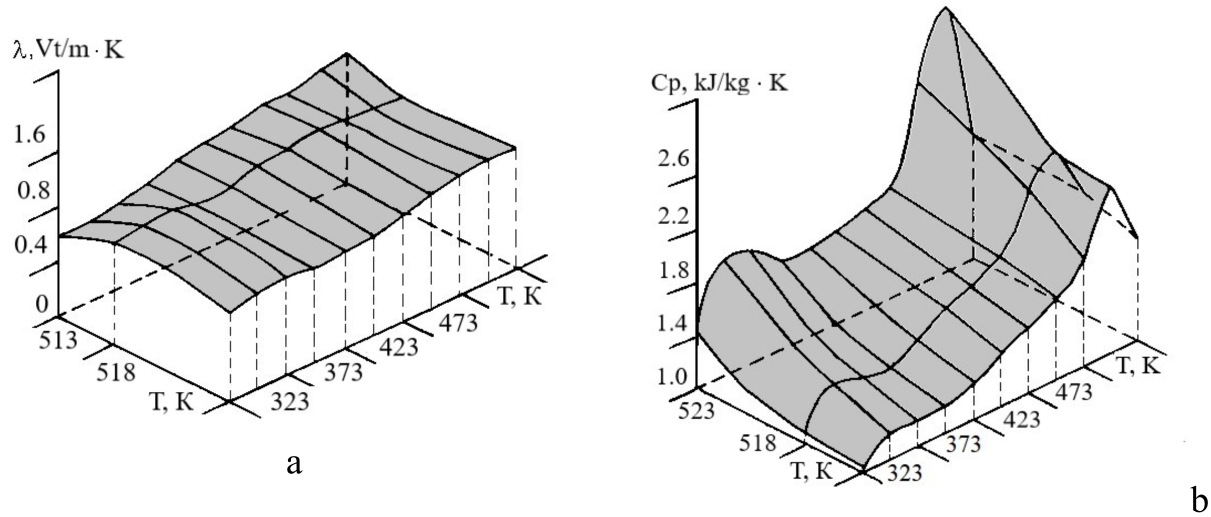

Figure. 1. Effect of the pressing temperature on the coefficient of thermal conductivity (a) and specific heat capacity (b) of carbon plastic based on PA-6.6

The surge in heat capacity ΔCp which was clearly manifested in all temperature curves at a temperature of 548 K, corresponded to softening temperature of CP pressed at temperatures of 513, 518 and 523 K.

Analysis of the study results showed that in the temperature range of 323-573 K, the specific heat capacity of CP increased with increase in pressing temperature, whereby this process was more significantly manifested in the range of high temperatures (Fig. 1b).

Alongside with the heat capacity and thermal conductivity, the thermal expansion of polymers reflects the forces acting between the particles and the features of thermal fluctuations of bound particles [3]. Based on changes in the temperature coefficient of linear expansion (TCLE) and its temperature dependence, it is possible to make a conclusion that the processes of rearrangement of the molecular structure of polymers, crystallization, polymerization, and structural glass-transition thereof occur. Moreover, TCLE characterizes the degree of anisotropy of the material, the amount of thermal stress and strain in structural elements when the temperature changes [4].

Calculating TCLE is important for several reasons. First, a decrease in TCLE leads to minimal shrinkage of plastics when the temperature changes during their manufacture. Second, unequal expansion or compression of the components of the composition can lead to occurrence of residual stresses that have a significant effect on the mechanical properties of the material [5].

In our case, the calculation of the carbon plastic TCLE, carried out using the curves of the sample relative elongation as a function of temperature (Fig. 2), showed that reinforcement of PA-6.6 with Ural carbon fiber can reduce this indicator by almost 6 times. The temperature coefficient of linear expansion of the CP in the temperature range of 298-323 K was in the range of 15.1-33.7 and increased with increasing temperature, and the glass-transition temperature was 516 K [6].

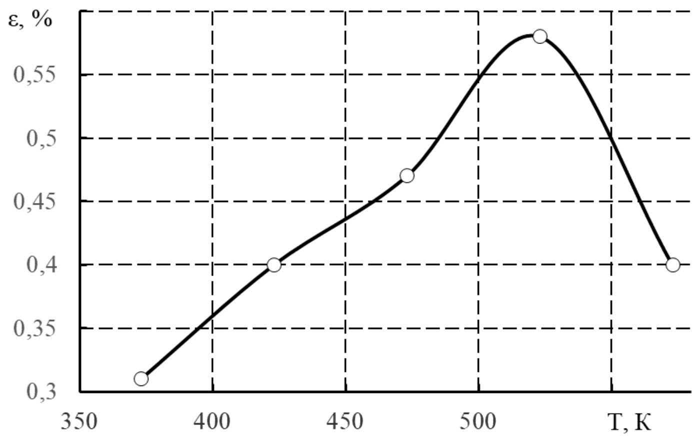

Fig. 2. Dependence curve of carbon plastic relative elongation
based on PA-6.6 from temperature

Apart from improved thermophysical properties, the CP converted at 518 K featured high physical-mechanical and tribological characteristics. In particular, the developed material featured 20% higher strength indicators compared to PA-6.6: compressive strength is 110 MPa, fracture energy is 718 kJ, elasticity modulus at contact – 2750 MPa.

Attention was drawn to the fact that a good correlation was observed between the dependence of relative wear resistance and hardness according to Rockwell of CP on the processing temperature: these indicators featured a maximum value for the temperature of 518 K and amounted to 87.6 and 0.105, respectively.

Data on the effect of processing temperature on CP friction and wear are presented in Table 2.

Table 2.

Effect of processing temperature on tribotechnical characteristics of carbon plastic based on PA-6.6

Tribological properties	Processing temperature, K	
	503	518
Coefficient of friction f	0.20	0.18
Linear wear intensity $I_h \times 10^{-8}$	0.18	0.16

Note: friction and wear of carbon plastic were carried out on a counterbody made of steel 45 (hardness 45-48 HRC, roughness Rα = 0.16-0.32 μm) at a specific pressure of 0.4 MPa and a sliding speed of 1 m/s, the friction path was 1000 m

The obtained results showed that the best tribological characteristics were featured by CP pressed at a temperature of 518 K, therefore the study of the effect of operating modes on the coefficient of friction and the linear wear intensity were carried out using samples pressed at the said temperature (Table. 3).

As a result of study, it was found that the change in operating modes made significant effect on the processes of CP friction and wear. The best tribological properties were featured by the sample of the material operated at a sliding speed of 1.5 m/s. Over the entire range of loading, it featured a low coefficient of friction (0.13-0.28) and minor wear, and at a sliding speed of 2.0 m/s and a loading of more than 1 MPa featured a catastrophic wear and the CP featured the loss of its performance (Table 3).

Table 3.

Effect of operating modes on the coefficient of friction and the linear wear intensity of carbon plastic based on PA-6.6

Speed of sliding, m/s	Specific load, MPa				
	0.4	0.6	0.8	1	1.2
Coefficient of friction					
1.5	0.39	0.25	0.22	0.21	0.19
2.0	0.28	0.18	0.15	0.15	0.13
Linear wear intensity $I_h \times 10^{-8}$					
1.5	0.13	0.19	0.24	0.35	0.51
2.0	0.16	0.25	0.26	0.37	–

According to the data obtained, the maximum allowable value of the performance criterion *PV* for carbon plastic, it was 2.0 MPa · m/s.

Therefore, the data of the conducted thermal, thermophysical, physical-mechanical and tribological studies indicate that the best possible set of properties were featured by CP pressed at a temperature of 518 K.

In general, CP based on PA-6.6 featured high thermal conductivity, low values of specific heat capacity, TCLE and coefficient of friction, and a good wear resistance, as well, which allowed to recommend it for use as a material for structural purposes.

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