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Study of deformations depending on the influence of the reinforcing filler of the metal-based composite material

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Abstract. Metallic materials are reinforced by evenly distributed dispersed particles of various dispersities. We have studied deformations depending on the influence of ultrafine particles of the filler on the physical-mechanical properties and structure of the composite material. The 27.9% increase of modulus of elasticity and the limit of proportionality compared to that for a simple metal bond is explained by the formation of a strong adhesive bond at the interface due to the high specific surface and irregular particle shape which contribute to an increase in adhesion when filling irregularities by the liquid phase.

Keywords: deformation, reinforcing agent, structure, dispersed filler, modulus of elasticity, metal matrix.

Introduction

The properties of composite materials depend not only on the physical-chemical properties of the components, but also on the strength of the connection between them. Maximum strength is achieved if solid solutions or chemical compounds are formed between the matrix and the filling of the reinforcing agent. The metal matrix [1–5] has become the most widespread among the composite materials with zero-dimensional filler.

Metal-based compositions are reinforced by uniformly distributed dispersed particles of various dispersities. Such materials are characterized by the isotropy of their properties [6]. In such materials, when loading, the matrix perceives the entire load, in which with the help of a multitude of particles of the second phase which practically do not dissolve in it, a structure is created that effectively resists the plastic deformation. During deformation dislocations lead to the fact that the shift of atoms to a neighboring position does not occur simultaneously over the entire slip plane, but stretches in time. Such a gradual slip due to small displacements of atoms in the dislocation region does not require significant efforts, which is manifested in the deformation of plastic materials. Reinforcing of such materials consists in creation in them a structure which impedes the movement of dislocations. The strongest inhibition of dislocation movement is created by dispersed particles of the second phase, for example, chemical compounds such as carbides, nitrides, oxides, borides, which are characterized by high strength and high melting point. In dispersity-reinforced materials, the preset strength and reliability are achieved by forming a certain structural state in which efficient braking of dislocations is combined with their uniform distribution in the bulk of material, or with a certain mobility that accumulates around



dislocation barriers to prevent brittle fracture. When designing any composite material the question of the interface between the matrix and the filler is of the highest importance.

The most important characteristic of a composite material is the stability of the interface [1,7-11]. The stability of the interface serves to ensure high operational reliability of the composite during the entire time of its service. To obtain a stable boundary in the composite being created, the question of the thermodynamic compatibility of its constituent phases should be considered.

In this article we develop a composite material with reinforcing fillers made of natural diamond powders of various dispersities with its various contents. **The aim of the work** is to study the deformations depending on the influence of the reinforcing filler on the formation of the structure of materials.

Objects and methods of research.

In this work, we used a standard bundle - tin bronze M2-01 (20 wt.% of Tin, 80 wt.% of Copper) with additions of 0.5–4 wt.% of ultrafine natural diamond (UFND), and powders with dimensions of $3/2\ \mu\text{m}$, $7/5\ \mu\text{m}$, $-40\ \mu\text{m}$.

The tests were carried out in accordance with the Russian State Standard GOST 25.503-97 "Calculations and strength tests. Methods of mechanical compression testing" [12]. The technique is based on Hooke's law, i.e. it is assumed that the strain is proportional to the stress.

The samples diameters and heights were previously measured. The tests were carried out using the IP-1250M test machine with automated control.

The samples were loaded at a speed of 0.2 kN/s before they got a barrel shape, without their destruction. In order to achieve reliable tests, the samples should be arranged in such a way that they have a minimum eccentricity. An automated digital measurement system sends data from the press to a computer and constructs several graphs, namely relationship between deformations and load and time and relationship between load and time (Fig. 1-4).

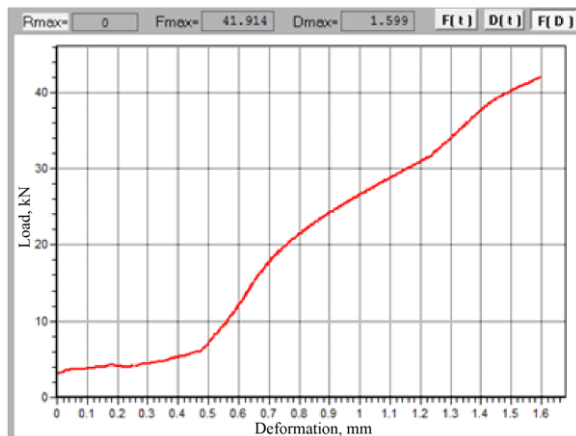


Figure 1. Graph of relationship between deformation and load for samples without UFND

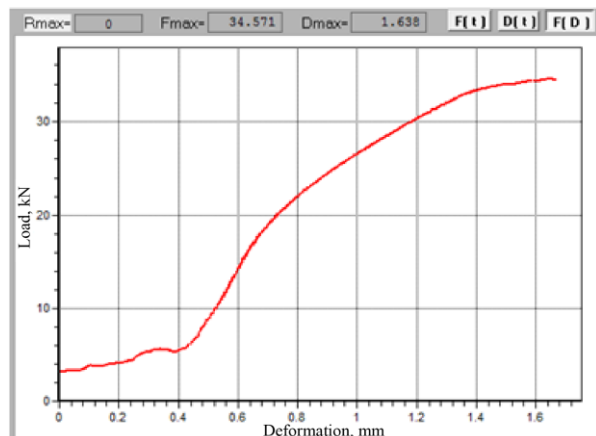


Figure 2. Graph of relationship between deformation and load for samples with 1% of UFND

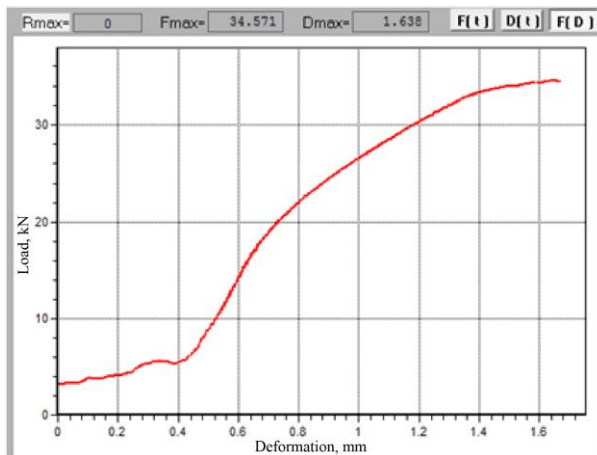


Figure 3. Graph of relationship between deformation and load for samples with 2% of UFND

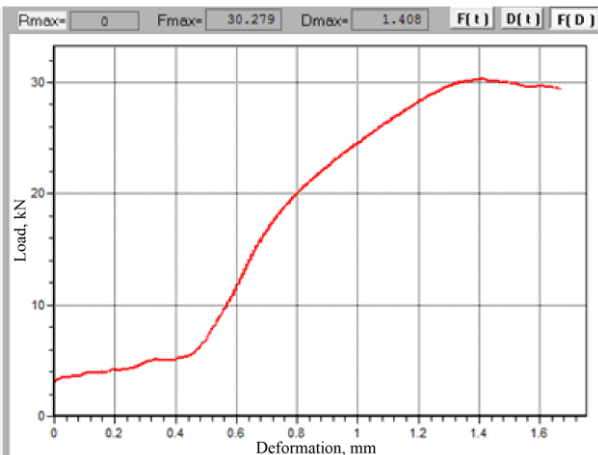


Figure 4. Graph of relationship between deformation and load for samples with 3% of UFND

Three zones are clearly observed in the obtained graphs: two zones of elastic deformation and one zone of plastic deformation. The limit value of the load at which Hooke's law is still fulfilled will correspond to a voltage equal to the limit of the material proportionality.

The presence of two zones of elastic deformation can be explained by the influence of residual porosity. In the first zone of material elastic work, the deformation of the areas around the pores presented in the volume occurs. That is, changes in the shape of pores up to their minimum take place under the action of the load.

In the second zone of elastic deformation, the material, due to a decrease in the volume and number of pores, works as homogeneous and practically non-porous to a certain extent. This may explain the slow growth of strain, depending on the loads in the second zone of elasticity.

To determine the elastic modulus in compression, the dependence of the deformations on the load was used. According to the method described in the GOST 25.503-97, the modulus of elasticity in compression is determined by the following formula:

$$E^c = \frac{\Delta F h_0}{\Delta h_{av} A_0}$$

where ΔF is the load increment, N; h_0 is the initial height, mm; Δh_{av} is the average absolute deformation of the sample under load ΔF , mm; A_0 is the initial cross sectional area of the cylindric sample.

The load increment is determined as

$$\Delta F = 0.1 F_{prop}^{exp}$$

where F_{prop}^{exp} is the load at the expected limit of proportionality.

The loads corresponding to the limit of proportionality were taken for each sample in accordance with the obtained graphs. The load increment was determined by the formula for each composition separately.

To calculate the elastic modulus, we used the values of loads and deformations in two zones of elastic work of the material.

Table 1. The elastic modulus during compression in the first zone of elastic deformation depending on the UFND content.

	F_i , kN	Δh , mm	Δh_i , mm	Δh_{av} , mm	ΔF_i , kN	ΔF_{av} , mm	h_0 , mm	A_0 , mm ²	E^c , MPa
0% UFND	3.13	0	0.09		0.57				
	3.7	0.09	0.1		0.57				
	4.27	0.19	0.18	0.105	0.71	0.5925	9.977	78.92	713.325
	4.98	0.37	0.05		0.52				
	5.5	0.42							
1% UFND	3.05	0	0.08		0.58				
	3.63	0.08	0.14		0.59				
	4.22	0.22	0.12	0.105	0.59	0.585	10.04	79.08	707.331
	4.81	0.34	0.08		0.58				
	5.39	0.42							
2% UFND	3.17	0	0.11		0.56				
	3.73	0.11	0.12		0.61				
	4.34	0.23	0.04	0.0775	0.47	0.5575	10.02	79.02	912.178
	4.81	0.27	0.04		0.59				
	5.4	0.31							
3% UFND	3.08	0	0.08		0.52				
	3.6	0.08	0.14		0.61				
	4.21	0.22	0.07	0.1075	0.52	0.5675	10.03	79.18	668.747
	4.73	0.29	0.14		0.62				
	5.35	0.43							

Table 2. The elastic modulus during compression in the second zone of elastic deformation depending on the UFND content.

	F_i , kN	Δh , mm	Δh_i , mm	Δh_{av} , mm	ΔF_i , kN	ΔF_{av} , mm	h_0 , mm	A_0 , mm ²	E^c , MPa
0% UFND	5.98	0.47	0.04		1.42				
	7.4	0.51	0.03		1.48				
	8.88	0.54	0.04	0.032	1.51	1.452	9.977	78.92	5735.94
	10.39	0.58	0.02		1.39				4
	11.78	0.6	0.03		1.46				
	13.24	0.63							
1% UFND	5.74	0.48	0.03		1.64				
	7.38	0.51	0.02		1.53				
	8.91	0.53	0.04		1.64				
	10.55	0.57	0.03	0.03	1.64	1.6	10.04	79.08	6771.03
	12.19	0.6	0.02		1.52				3
	13.71	0.62	0.03		1.63				
2% UFND	15.34	0.65							
	5.75	0.42	0.05		1.64				
	7.39	0.47	0.04	0.033	1.41	1.565	10.02	79.02	5953.49
	8.8	0.51	0.03		1.65				6

3% UFND	10.45	0.54	0.03		1.52				
	11.97	0.57	0.02		1.53				
	13.5	0.59	0.03		1.64				
	15.14	0.62							
	5.86	0.48	0.03		1.56				
	7.42	0.51	0.04		1.52				
	8.94	0.55	0.03		1.65				
	10.59	0.58	0.04	0.03	1.54	1.558	10.03	79.18	6580.26
	12.13	0.62	0.02		1.54				6
	13.67	0.64	0.02		1.54				
	15.21	0.66							

From the obtained calculated data (Tables 1-2), it can be seen that the highest moduli of elasticity are observed in samples with addition of 1–2% of UFND. Figure 5 presents microstructure images of the deformed samples. The samples were compressed at presses in order to determine the elastic modulus and the limit of proportionality up to a relative deformation of 15-16% at a loading rate of 0.2 kN/s.

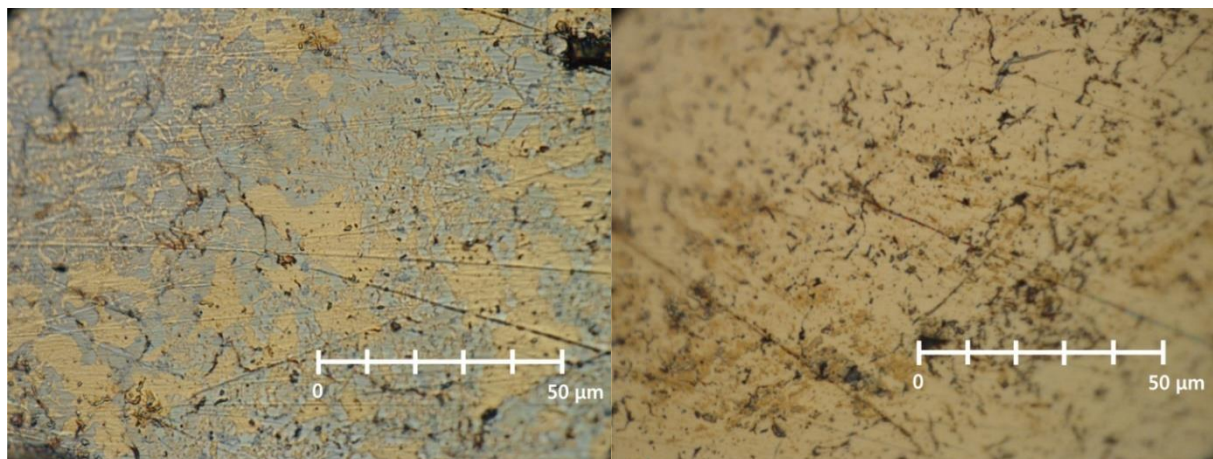


Figure 5. Photographs of the polished surface of the deformed sample with the addition of 2% of diamond powders particles, magnification is x1000.

Conclusion

The increase in the modulus of elasticity of the sample with the addition of 1-2% of UFND compared to that for a simple bundle can be explained by the reinforcing effect of the filler. The bonds between two phases arising in the material with a large specific surface of the filler contribute to the improvement of the physical-mechanical properties of the material. In addition, the UFND particles themselves have a sufficiently high value of the elastic modulus and shear modulus, which respectively will contribute to increasing the strength of the material. Also, it has been found that the addition of UFND particles affects the amount and volume of pores contained in the bulk of the material and increases the density.

The 27.9% increase in values of the modulus of elasticity and the limit of proportionality compared to that for a simple bundle is explained by the formation of a strong adhesive bond at the interface due to the high specific surface and irregular shape of particles which contribute to an increase in adhesion when filling irregularities with the liquid phase.

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