Metal Science and Heat Treatment, Vol. 55, Nos. 5 – 6, September, 2013 (Russian Original Nos. 5 – 6, May – June, 2013)

COMPOSITE MATERIALS

UDC 621.891

EFFECT OF NANODISPERSED DIAMOND ADDITIONS ON PROPERTIES OF COMPOSITE MATERIALS BASED ON BRONZE

M. N. Safonova,[1] P. P. Tarasov,[1] A. S. Syromyatnikova,[2] and A. A. Fedotov[1]

Translated from *Metallovedenie i Termicheskaya Obrabotka Metallov*, No. 5, pp. 3 – 6, May, 2013.

The effect of adding diamond micropowder on the physicomechanical properties of alloy based on tin bronze is studied. A favorable effect is demonstrated for use of diamond particles as a nanofiller in a metal matrix on composite material structure.

Key words: hardness, density, micropowder, tin bronze, diamond tool.

INTRODUCTION

Currently there is considerable interest in studying nanostructured materials, among which a special place is occupied by carbon clusters. The variety of fundamentally new properties of these materials makes it possible to use them for qualitatively new applications in various branches of industry, including diamond tool development. In spite of the significant number of tool materials it is promising to look for new compositions, providing high abrasive tool wear resistance and increased productivity

In the V. M. Bakul' Institute of Ultrahard Materials of the Ukrainian National Academy of Sciences a series of production processes has been developed for preparing synthetic diamonds by detonation synthesis [1] for various functional purposes. A promising area for resolving this problem is use of detonation synthesis in order to obtain a metal matrix composition for drill bits, containing nanodispersed diamond as small size dispersion strengthening particles [2].

Introduction of a small amount of these additions makes it possible to improve material mechanical operating properties. At the same time, the mechanism of the effect of ultrafine additions on structure and properties of composite materials requires further study.

The aim of this work is to study the effect of adding nanodispersed diamond powder to a metal binder (tin bronze M1) on physical and mechanical properties of composite materials, intended for manufacturing a diamond abrasive tool.

[1] M. K. Amosov North-East Federal University, Yakutsk, Russia (e-mail: marisafon_2006@mail.ru).

[2] V. P. Larionov Institute of Physicotechnical Problems of the North, Yakutsk, Russia.

METHODS OF STUDY

The standard binder used in the work was tin bronze M1 (20% tin, 80% copper) with addition of 1, 2, and 3 wt.% of natural diamond powder (NDP) with sizes of 3.2 μm, 7.5 μm, –40 μm, and submicron powder (ultrafine diamond, i.e., UFD). Powders were obtained from wastes of cutter manufacture in the enterprise Sakhadiamond JSC by crushing in mills.

Microscopic analysis of the grain size composition of powders was performed in a Biolam microscope at a magnification of × 1350 (Fig. 1).

Specific magnetic susceptibility (χ), specific electrical resistance (ρ), content of unburnt impurities (unburnt residues), were determined. The abrasive capacity of powders was measured according to GOST 9206–80 (Table 1).

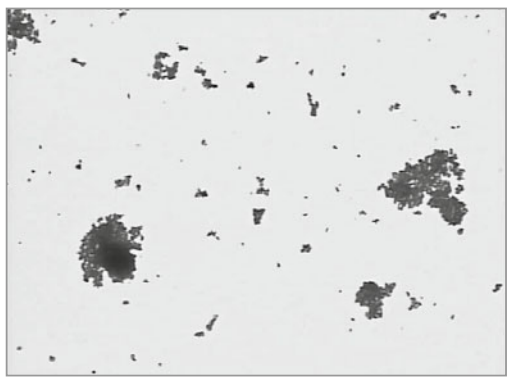

Fig. 1. Ultrafine diamond submicropowder (UDS) from natural diamonds.

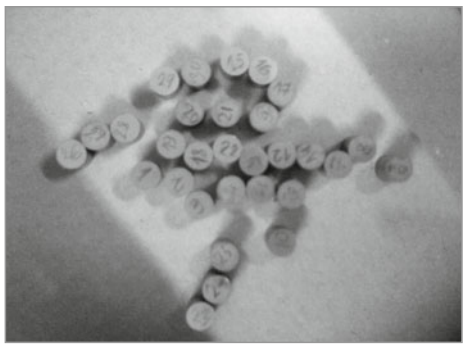

Fig. 2. Test composite external appearance.

Physical and mechanical properties of pressed and sintered materials (Fig. 2) were evaluated by a standard method.

Material density was determined from results of measuring the dimensions of specimens with a micrometer MK 0–25 mm according to GOST 9507–78, and their weight was measured on fourth class VLTÉ-500 laboratory electronic scales. Residual porosity was calculated by an equation:

$$P = (1 - \rho_a/\rho_t) \times 100\%,$$

where ρ_t is theoretical (calculated) pore-free material density, ρ_a is actual test specimen density. A hydrostatic method was used in the case of loss or distortion of specimen geometric shape.

Specimen sintering was carried out in a vacuum of 0.1×10^{-3} Pa in an SNVÉ furnace. Combined sintering provided constant process conditions for a given batch of specimens. The sintering temperature was varied from 550 to 600°C. Below 550°C specimens did not sinter, but at 600°C and above there is shape distortion. The optimum temperature determined by testing is 575°C. Sintering duration lasted from 15 to 60 min. With the aim of determining sintered specimen porosity they were weighed on an electronic balance and linear dimensions were measured. Calculation of porosity was carried out by the same equation as that for green specimens. Hydrostatic weighing was used with distortion of specimen regular shape.

Material hardness was measured in a FR-3e instrument from Leco according to the standard procedure. The indentor was ball 3.174 mm in diameter and the load was 588.4 N (60 kg) according to the *HRH* scale.

One of the most important parameters governing operating capacity of any abrasive tool is its wear resistance. Tribological tests were carried out in a SMTs-2 friction machine with rotary movement by finger-disk scheme with a load of 300 N. Cylindrical specimens 10 mm in diameter and 10 mm thick were fastened to an upper holder of the machine. On the lower shaft a counterbody (heat treated material) was installed in the form of a disk 52 × 16 × 10 mm. the treated material used was steel 40Kh, heat treated to a hardness of 50 *HRC*. Test duration was 10 – 20 min, and the shaft rotation rate was 300 rpm (50 m/sec). Before and after testing tool specimens and counterbody were carefully treated with ethanol and weighed with an accuracy to 0.0001 g on an electronic balance.

The relative weight of composite material wear was calculated by an equation:

$$\Delta m = \frac{m_1 - m_2}{m_1},$$

where m_1 and m_2 are specimen weight before and after testing respectively, g.

TABLE 1. Diamond Powder Physicochemical Properties

Powder	GC, μm	$\chi \times 10^{-8}$, m^3/kg	ρ, Ω · m	UR, %	AC
NDP (–40 μm)	40 – 0	62.1	3.1×10^9	5.7	2.86
NDP (7/5 μm)	7 – 0	4.0	7.5×10^{10}	Not determ.	1.90
NDP (3/2 μm)	3 – 0	737.0	5.2×10^9	2.9	0.57
UFD	3 – 0*	538.0	8.3×10^{10}	3.1	Not determ.

* With prevalence 1/0 and 0.5/0.

Notations: NDP is natural diamond powder; UFD is ultrafine diamond (submicron powder); GC is powder grain size composition from results of microscope studies; χ is magnetic susceptibility; ρ is specific electrical resistance; UR is unburnt residue; AC is abrasive capacity(according to GOST 9206–80).

RESULTS AND DISCUSSION

Morphometric studies in a DiaInspect. OSM instrument showed that within the diamond powder composition there are grains of fragmentary shape. This shape of grains is typical for natural diamond powder. The results obtained indicate that test powders 7/5, 3/2, and UFD with respect to grain size composition and impurity content do not correspond to the GOST specifications for diamond production (Table 1). In view of the fact that the powder contains many extraneous, predominantly metal impurities, it is necessary to purify them previously and then to carry out a study of physicochemical properties with the aim of selecting the optimum fields of application. Presence of metal impurities in diamond powder does not prevent use in the form of a strengthening phase in composite materials based on a metal.

The maximum hardness is achieved with introduction into the alloy composition of micropowder with a size of about –40 μm. This is possible to explain by strengthening the structure due to presence of coarse (about 40 μm) diamond particles and the compacting effect of finer particles by absorption of gases liberated during sintering.

It should be noted that specimens with addition of diamond particles have significantly lower porosity than spe-

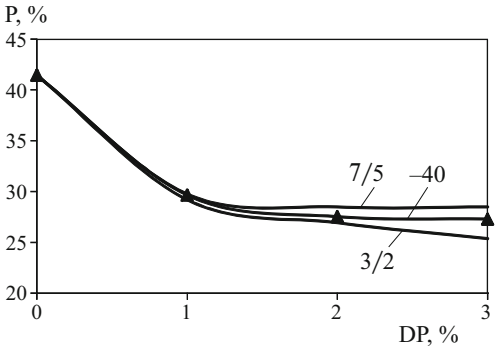

Fig. 3. Dependence of final porosity P of composites based on bronze M1 on their diamond powder DP content with sizes 3/2, 7/5, and –40 μm (numbers on the curves).

cimens not containing diamond (42 and 30% respectively (Fig. 3).

The minimum final porosity is observed for specimens with addition of micropowder with a size of 3/2 μm, and this is due to the high absorption properties diamond micropowder (Fig. 3).

Comparison of the surface structure of composite diamond-containing materials based on bronze M1 showed that specimen with addition of nanodispersed natural diamond have a more complete structure than specimens without this addition. The structure of a metal composite matrix after addition of natural diamond became denser (Fig. 4).

A powder briquette consists of an enormous number of particles, coated with an oxide film, absorbed gases, vapors, traces of organic substances (lubricant, etc.), entering at different stages of the production chain starting from powder preparation and ending molding and sintering. This property of micropowders depends on the magnitude of their specific surface, i.e., on micropowder fineness. The higher value of material porosity with a micropowder addition size of 7.5

TABLE 2. Wear of Composites Based on Bronze M1 with Addition of Diamond Powder

Composite		m_1, g	m_2, g	Δm, g
M1 (base)	(*1*)	5.335	4.320	19.020
M1 + 3% DP 3/2	(*2*)	5.124	4.607	10.100
M1 + 2% DP 3/2	(*3*)	5.214	5.184	0.571
M1 + 1% DP-40	(*4*)	5.263	5.036	4.308
M1 + 2% DP-40	(*5*)	5.224	4.908	6.042
M1 + 3% DP-40	(*6*)	5.147	4.855	5.661
M1 + 2% DP 7/5	(*7*)	5.190	5.082	2.084
M1 + 1% DP 3/2	(*8*)	5.278	5.165	2.144
M1 + 1% DP 7/5	(*9*)	5.304	5.052	4.755
M1 + 3% DP 7/5	(*10*)	5.155	5.067	1.705

Note. Conditional composite number given in brackets.

Notations: m_1 and m_2 are specimen weight before and after wear testing respectively; Δm is relative wear.

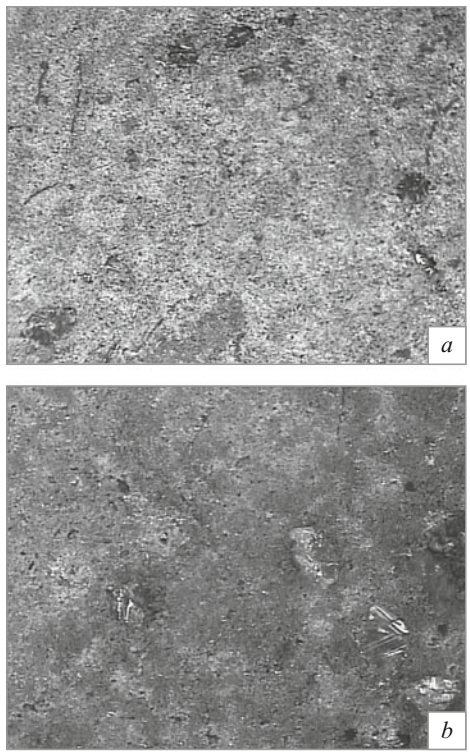

Fig. 4. Structure of composite based on bronze M1 with additions: *a*) 50% NDP; *b*) 50% NDP + 2% UFD.

than with a powder size of –40 may possibly be explained by presence in the latter of finer diamond particles.

The least relative wear was demonstrated by specimens of compositions M1 + 2% DP 3/2 (Table 2).

As a result of these tests it has been established that addition of 1, 2, 3 wt.% of nanodispersed natural diamond powder with a size correspondingly of 3.2 μm, 7.5 μm, and –40 μm, and submicron UFD, compared with standard binder M1, promotes a reduction in composite material wear intensity (Table 2).

CONCLUSIONS

Addition of finely dispersed diamond particles in a small amount into a metal matrix, i.e., tin bronze M1, has a favorable effect on the quality of composite materials obtained. Density, hardness, and wear resistance increase, and there is a reduction in material porosity, and this makes it possible to predict an improvement in operating indices for a diamond tool manufactured from them.

REFERENCES

1. N. V. Novikov and G. P. Bogatyreva, "Nanodiamods of static and detonation synthesis, and prospects for their application," *Sverkhtverd. Mater.*, No. 2, 3 – 12 (2008).
2. E. Yu. Dolmatov, *Ultrafine Diamonds of Detonation Synthesis. Preparation, Properties, and Application* [in Russian], Izd. SpBGTU, St. Petersburg (2003).