Journal of Alloys and Compounds 434–435 (2007) 689–692

Journal of ALLOYS AND COMPOUNDS

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A new method for production of a copper coating reinforced with nano-diamonds

V.A. Popov [a,*], L.S. Belevsky [b], E.L. Belevskaya [b], Ia.M. Gordon [c], S.A. Tulupov [a]

[a] *Moscow State Institute of Steel and Alloys, 4 Leninsky prospect, Moscow 119049, Russia*
[b] *Magnitogorsk State Technical University, Magnitogorsk, Russia*
[c] *"Hatch", Mississauga, Ontario, Canada*

Available online 22 December 2006

Abstract

A copper coating reinforced with nano-diamonds was produced by the friction cladding (FC) method. The initial bulk material for the coating (a mixture of copper and nano-diamonds) was obtained by mechanical alloying followed by compaction. During the friction cladding, a flexible tool (rotated brush) transfers micro-particles from the bulk material to the surface to be coated. In this work, the coating was applied to cylindrical workpieces. The rotation regimes for a cylindrical workpiece and the flexible tool (brush) were investigated. The friction cladding method allowed obtaining a nano-diamond-reinforced copper coating with excellent adhesion to the base. Electron microscopy revealed no defects in the coating. The nano-diamond particles were evenly distributed in the copper matrix. The method developed yields coatings with improved wear resistance in comparison with non-reinforced coatings.

Keywords: Metals; Nanostructured materials; Mechanical alloying; Scanning electron microscopy (SEM); Transmission electron microscopy (TEM)

Copper is one of the most commercially applicable metals. The improvement of the mechanical and operational properties of copper materials is, therefore, a topical problem. The most promising way of improving the characteristics of copper is developing composite materials, because introduction of alloying elements often results in a decrease of electrical conductivity and not always leads to a considerable increase of strength and hardness.

In this work, we developed a method for producing coatings from a promising composite material, nano-diamond powder-reinforced copper.

1. Techniques and methods

Commercially pure copper was used for the matrix, and nano-diamond powders served as reinforcing particles [1]. The nano-diamonds had a complex multilevel structure. The primary nano-diamond particles were of spherical shape, 3–5 nm in diameter. They were combined into strong aggregates of 20 up to 500 nm in size. In turn, the primary aggregates and agglomerates were joined together into secondary agglomerates of 0.5–5 μm in size. The structure of the nano-diamond powder is shown in Fig. 1, and the main characteristics are presented in Table 1.

The composite material was produced using a technique found to be efficient in production of other composite materials, i.e., mechanical alloying followed by compaction [2,3].

The study included the following technological operations:

- mechanical fusion of copper and the nano-diamond powders to produce granules;
- compaction of the granules;
- heat treatment of the compacted composite material;
- application of the composite material to a pretreated surface by the method of friction cladding using a flexible tool.

Mechanical alloying was performed in planetary mills in an argon atmosphere using either balls or quasi-cylindrical milling bodies. The treatment time was varied from 0.5 up to 4 h. The share of nano-diamond powders varied from 5% up to 15% (w/w). Compaction was performed at room temperature on a press. The specimens were subjected to heat treatment in a vacuum furnace with the alundum muffle. The temperature of annealing was varied from 300 up to 750 °C. The annealing time was from 15 min up to 2 h.

* Corresponding author.
E-mail address: vpopov@misis.ru (V.A. Popov).

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doi:10.1016/j.jallcom.2006.08.337

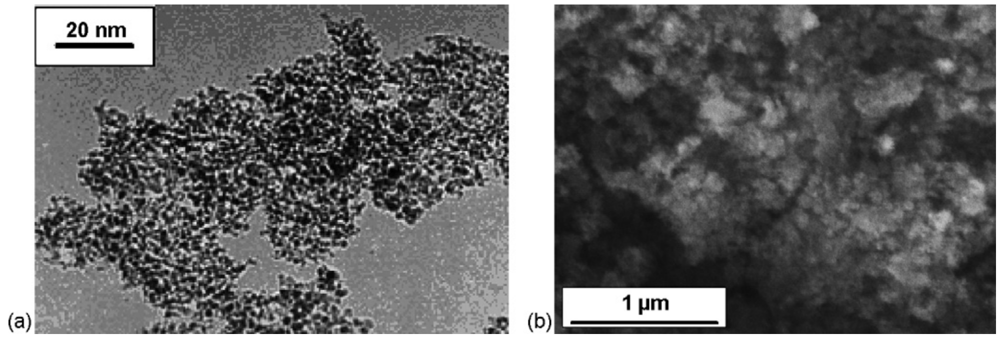

Fig. 1. General appearance of nano-diamond powders: (a) TEM and (b) SEM.

The obtained composite material was applied to a pretreated cylinder surface by friction cladding. Friction cladding (FC) is a new method of surface treatment and application of coatings. It is as follows (see Fig. 2).

The coating material should be a rod or a similar item. The main technological tool is a rotated cylindrical metal brush. The brush rotates with high speed and is pressed on to the treated surface. The rod with the coating material is pressed to the brush so that the ends of its wires scrape metal particles off the rod, fractions of a micron in size, and transfer them to the treated surface. The high speed of rotation of the brush leads to considerable strength of impact of particles on the treated surface, and the particles weld to the surface. The large amount of wires in the brush and the high speed of rotation ensure high performance and uniform transfer of the coating material from the rod onto the treated surface.

The coating material was studied at all stages. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used (JSM6700F electron field emission microscope integrated with JED2300F energy dispersion spectroscopy attachment, JEOL, Japan).

2. Results and discussion

As we have already noted, nano-diamond powders are agglomerates of primary nano-diamond particles. Large-size agglomerates are reduced to smaller size at the first stage of processing during mechanical alloying. As the hardness of the nano-diamonds is higher than that of copper, they incorporate themselves into copper particles. The “mixture” obtained comes off large particles of copper (Fig. 3a), and then the powders are comminuted (Fig. 3b and c). The obtained particles are subsequently joined into new agglomerates (Fig. 3d). Particles of pure copper can occur in the agglomerates but their number is negligibly small.

The granules obtained by mechanical fusion were compacted by pressing. The structure studies of the compacted material showed a sufficiently homogeneous distribution of the nano-diamond powders in the cross-section. No large nano-diamond particles – agglomerates – were found.

The material obtained was applied to a steel surface by friction cladding. The coating was studied on a scanning electron microscope, and its composition was also determined. The micrographs (Fig. 4) confirm the high quality of the coating. The strength of its adhesion to the base was high; the surface

Table 1
Main characteristics of nano-diamond powder

No	Characteristic	Value
1	Appearance	Light-gray powder
2	Mass fraction of the diamond in the basic substance (%), no less than	98.0–99.0
3	Density (pycnometric) (g/cm^3), no less than	3.10–3.20
4	Apparent density (g/cm^3)	0.25–0.35
5	Average size of the primary nano-diamond particles (nm)	3–5
6	Heat resistance in air (°C)	450
7	Heat resistance in vacuum (°C)	800

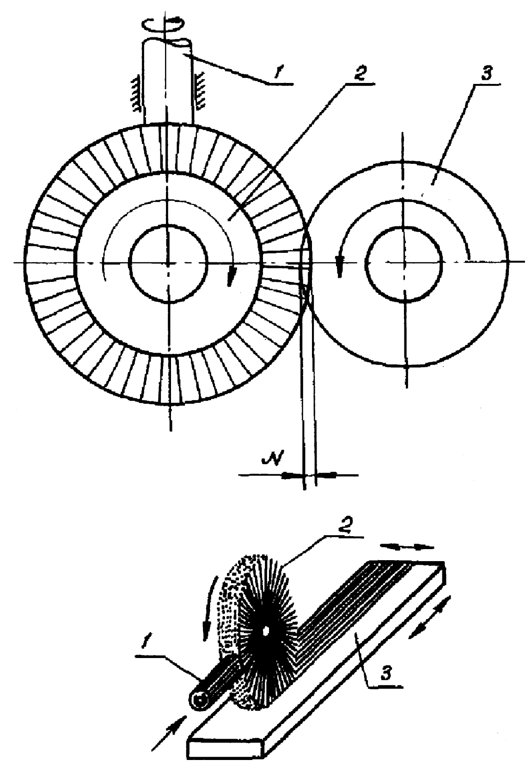

Fig. 2. Scheme of the friction cladding process (top, for cylinder-shaped specimen; bottom, for plane-shaped specimen): (1) Part of the clad material; (2) the tool with flexible elastic elements (RMB); (3) the processed product; (*N*) tightness (displacement of the tool, in mm, onto the processed product).

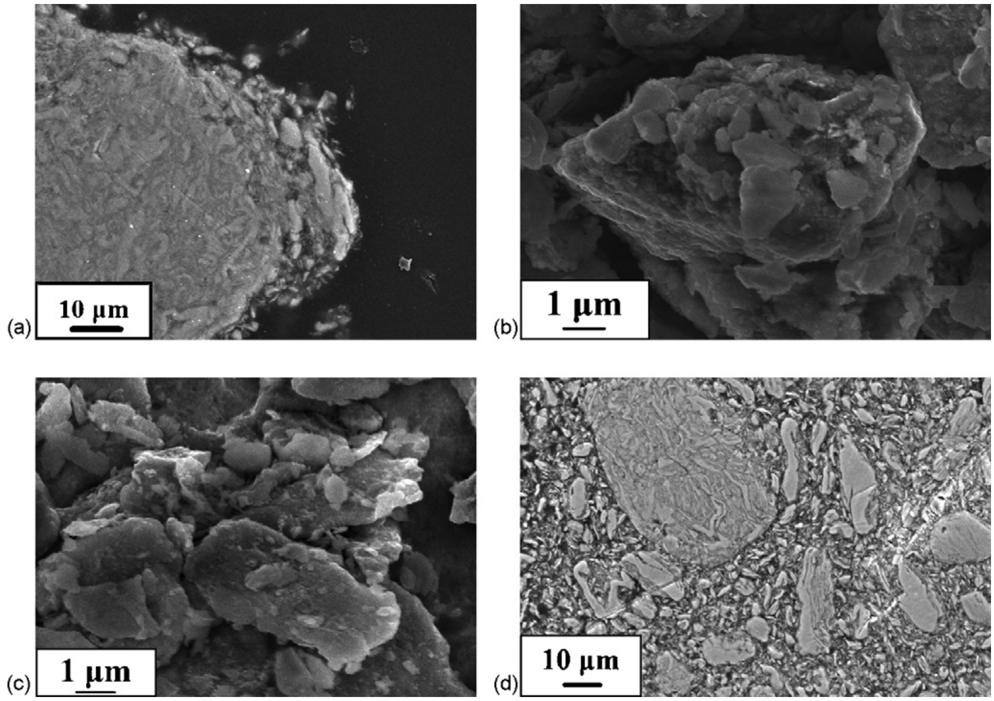

Fig. 3. Granules from a mixture of copper and nano-diamond powders (SEM).

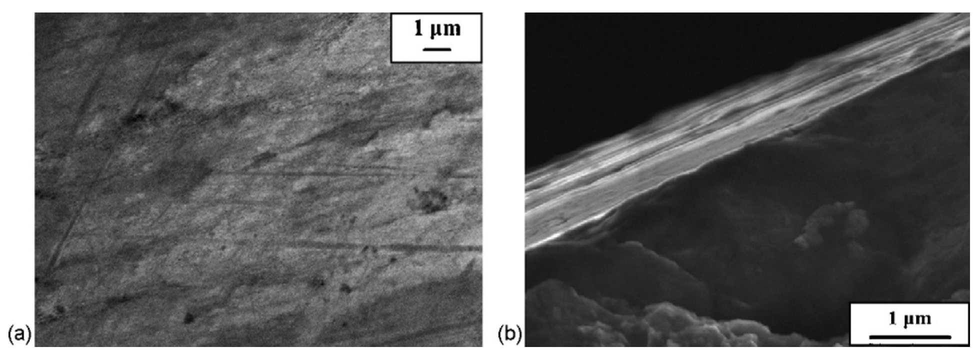

Fig. 4. Surface of a coating from a copper-matrix composite material reinforced with nano-diamond particles. (a) plane specimen and (b) fracture in cross section.

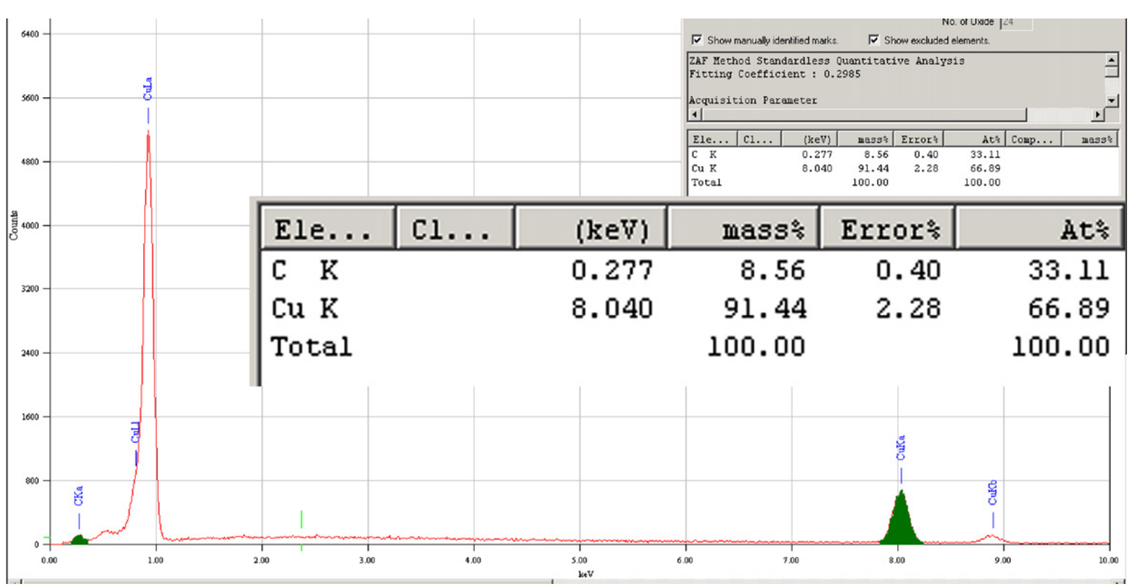

Fig. 5. A characteristic X-ray spectrum obtained by energy dispersive spectrometry (EDS).

was defect-free and absolutely smooth. Analysis of the coating material showed the presence of copper and carbon (Fig. 5). The carbon content for this specimen varied from 8.5% up to 9.2% (w/w), which is a high index of the homogeneity of the distribution of the reinforcing particles in the matrix.

Various deformations (bend, tension, etc.) of diverse configurations of specimens (cylindrical and flat) with the applied coating did not lead to its exfoliation, which suggests its high adhesion to the base.

3. Conclusion

The studies have shown that the developed method yields high-quality coatings of copper reinforced with nano-diamond particles. The reinforcing nano-diamond particles are evenly distributed in the copper matrix. Friction cladding ensures a high adhesion of the coating to the base. Defects are absent both within the thickness of the coating and on the surface.

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