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Nanodiamond dispersions in metallic matrices with different carbon affinity

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Dispersing nanodiamond (nD) particles in metallic matrices can be achieved by ball milling resulting in metal-diamond composite powders [1-7]. The matrices have been selected considering the whole range of carbon affinity: copper that shows extremely reduced affinity towards carbon phases, potentially compromising the composite interfaces, and nickel and tungsten that are mild and strong carbide formers, respectively, displaying thus intermediate and strong carbon affinities. For the latter matrices, dispersing carbon phases represent a challenge due to carbide conversion.

The materials produced are designated as Cu-10nD, Ni-10nD and W-20nD (where 10 and 20 indicate the atomic fraction of nD). Close monitoring of the milling conditions enabled to homogeneously disperse the carbon phases and obtain nanostructured matrices (Figures 1 (a-c)), as well as to minimize milling media contamination and carbide formation, especially in the case of the W-based composite. Apparent interfacial bonding could be inferred the from transmission electron microscopy (TEM) images.

The metallic matrices have been subsequently dissolved to allow for a detailed analysis of nanodiamond. Electron diffraction demonstrated that its crystalline structure was preserved during milling (Figure 2). Microhardness measurements revealed remarkable strength enhancements of the nanostructured composites over that of pure metals of comparable grain sizes [9] (Table 1). The strengthening mechanisms that justify the hardness increments in Cu-10nD and Ni-10nD include second-phase reinforcement (due to the potential load bearing ability of diamond), as well as Orowan and solid solution strengthening. The hardening effect observed in the W-20nD composite over that of pure milled tungsten is probably related to the nanodiamond reinforcement, nevertheless the influence of a fine dispersion of carbides cannot be ruled out [3].

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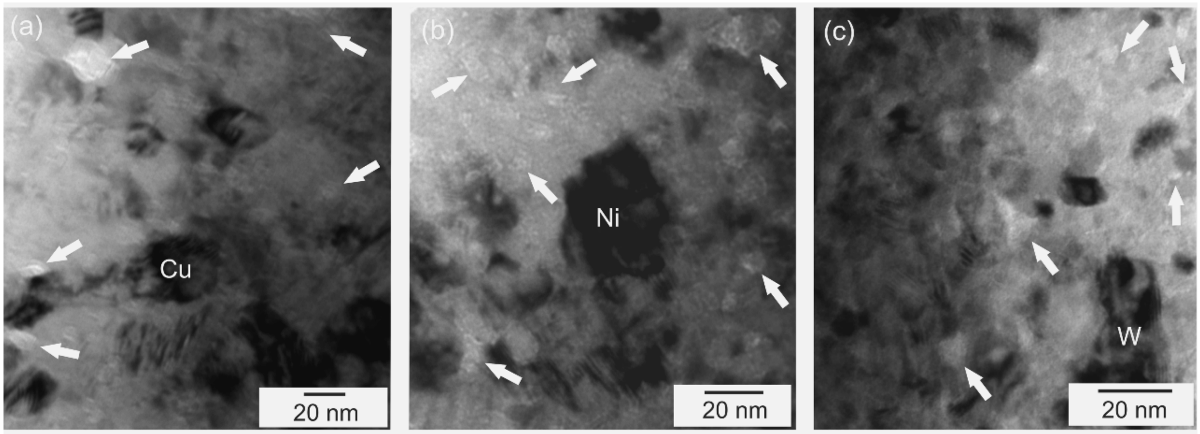

Figure 1. (a) Bright-field TEM images of the milled composites. (a) Cu-10nD milled for 4 h at 400 rpm, (b) Ni-10nD milled for 4 h at 200 rpm and (c) W-20nD milled for 4 h at 200 rpm.

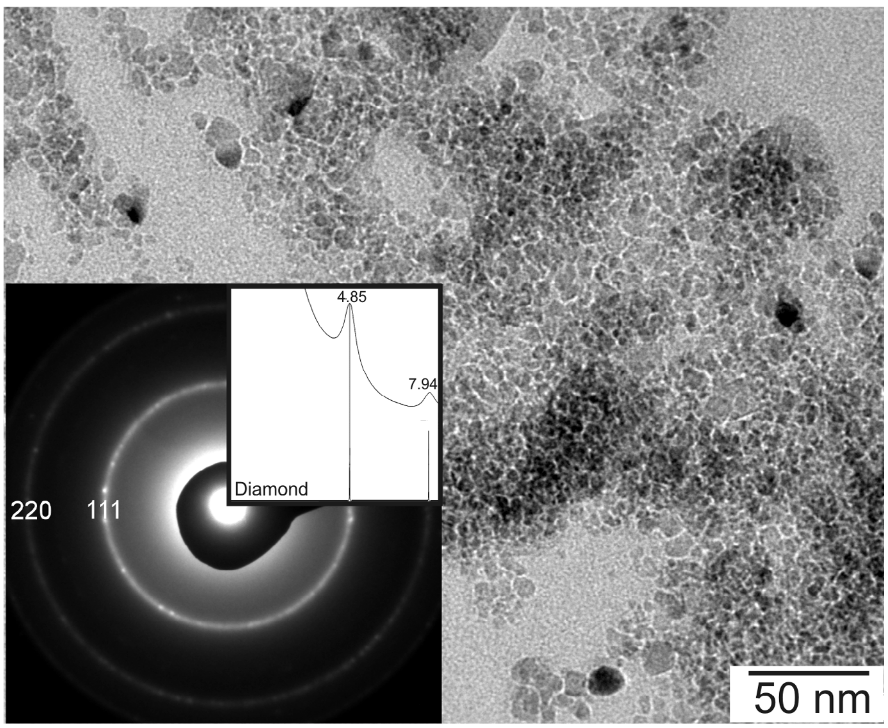

Figure 2. Typical bright-field TEM image of nanodiamond powder extracted from the milled composites. The characteristic ring diffraction pattern with an integrated radial profile demonstrates that the nanodiamond particles preserved the structure during milling (diamond simulation included with legend in nm).

Table 1. Microhardness values of pure copper, nickel and tungsten, and milled Cu-10nD, Ni-10nD and W–20nD composites.

Conditions	Vickers Microhardness (GPa)
Nanostructured pure copper (10-30 nm) [8]	2.5
As-milled Cu-10nD (4 h) [1]	3.62 ± 0.04
Nanostructured pure nickel (10-20 nm) [8]	6.0
As-milled Ni-10nD (4 h) [2]	8.83±0.14
As-milled pure tungsten (4 h) [3]	16.1 ± 0.8
As-milled W–20nD (4 h) [3]	21.4 ± 1.1

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