Journal of Nuclear Materials 426 (2012) 115–119

Contents lists available at SciVerse ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

Tungsten–nanodiamond composite powders produced by ball milling

D. Nunes [a,b,c,*], V. Livramento [a,b], U.V. Mardolcar [d,e], J.B. Correia [b], P.A. Carvalho [c,f]

[a] *Associação Euratom/IST, Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade Técnica de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal*
[b] *LNEG, Estrada do Paço do Lumiar, 1649-038 Lisboa, Portugal*
[c] *ICEMS, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal*
[d] *Departamento de Física, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal*
[e] *Centro de Ciências Moleculares e Materiais, Faculdade de Ciências da Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal*
[f] *Departamento de Bioengenharia, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal*

ARTICLE INFO

Article history:
Received 9 January 2012
Accepted 15 March 2012
Available online 24 March 2012

ABSTRACT

The major challenge in producing tungsten–nanodiamond composites by ball milling lies in successfully dispersing carbon nanoparticles in the metallic matrix while keeping carbide formation at a minimum. Processing windows for carbide minimization have been established through systematic variation of the nanodiamond fraction, milling energy and milling time. Materials characterization has been carried out by X-ray diffraction, scanning and transmission electron microscopy and microhardness testing. Nanostructured matrices with homogeneously dispersed particles that preserved the diamond structure have been produced. Differential thermal analysis has been used to evaluate the composites thermal stability.

1. Introduction

Due to the high melting point, high resistance to plasma erosion and moderate tritium retention [1], refractory metals such as tungsten are currently under intense investigation for plasma-facing applications in nuclear fusion reactors [2]. Nevertheless, the demand for operation temperatures above the range proposed for ITER first wall (below 573 K) is still challenging, especially on what thermal conductivity and microstructural stability are concerned [2].

Nanostructured tungsten–diamond composites are envisaged for plasma-facing parts, where thermal management and radiation resistance are major issues, since: (i) a microstructure refined to the nanometer scale improves strength [3,4] and lessens radiation embrittlement due to an increased number of defect recombination sites [5]; (ii) the extremely high thermal conductivity of diamond [6] turns its dispersions into excellent candidates for thermal management applications; and (iii) hard particle dispersions provide supplementary hardness through load transfer to the reinforcement phase [7–12] and can enhance microstructural thermal stability through grain boundary pinning [13]. Diamond dispersoids offer therefore potential reinforcement to nanostructured W, in combination with thermal conductivity enhancement and microstructural thermal stability.

However, nanostructured materials are generally associated with a lower thermal conductivity due to scattering at defects such as grain boundaries and interfaces, thus a compromise between strength/stability and thermal conductivity has to be reached regarding the grain size of both diamond and tungsten. The use of multiscale diamond dispersions has been suggested for that purpose [14]. Additional issues concerning the use of tungsten–diamond composites in fusion reactors include: (i) *in situ* transmutation and phase transformations induced by high-energy neutrons [15] and the fact that (ii) at elevated temperatures tungsten reacts with the carbon allotropes to form carbides [16], limiting the operation temperature. Nonetheless, thermal conduction requires energy transfer at the interfaces and, since electrons dominate heat conduction in tungsten while phonons control it in diamond, carbide interlayers may in fact assist the necessary electron–phonon coupling [17].

Whilst the above heat conduction and stability aspects demand further research, the primary challenge lies in homogeneously dispersing the carbon phase in the strong carbide former matrix while keeping the carbide reaction at a minimum, which is the object of the present study.

Ball milling has been extensively used to produce nanostructured materials as well as fine dispersions in metallic matrices [7–12,14,18], and can be employed to process tungsten–nanodiamond (W–nD) composites. However, continued milling of graphite (G) is known to induce amorphization [19–21] and to some extent the same can be expected for the other carbon allotropes. Furthermore, tungsten reacts with carbon during high-energy milling at room temperature [22], and milled materials tend to become

* Corresponding author at: ICEMS, Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisboa, Portugal. Tel./fax: +351 218418120.
E-mail address: daniela.nunes@ist.utl.pt (D. Nunes).

0022-3115/$ - see front matter
http://dx.doi.org/10.1016/j.jnucmat.2012.03.028