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Nickel–carbon nanocomposites: Synthesis, structural changes and strengthening mechanisms

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Abstract

The present work investigates Ni–nanodiamond and Ni–graphite composites produced by mechanical synthesis and subsequent heat treatments. Processing of nickel–carbon nanocomposites by this powder metallurgy route poses specific challenges, as carbon phases are prone to carbide conversion and amorphization. The processing window for carbide prevention has been established through X-ray diffraction by a systematic variation of the milling parameters. Transmission electron microscopy confirmed the absence of carbide and showed homogeneous particle distributions, as well as intimate bonding between the metallic matrix and the carbon phases. Ring diffraction patterns of chemically extracted carbon phases demonstrated that milled nanodiamond preserved crystallinity, while an essentially amorphous nature could be inferred for milled graphite. Raman spectra confirmed that nanodiamond particles remained largely unaffected by mechanical synthesis, whereas the bands of milled graphite were significantly changed into the typical amorphous carbon fingerprint. The results on the annealed nanocomposites showed that milling with Ni accelerated graphitization of the carbon phases during heat treatments at 973 and 1073 K in both composites. At the finer scales, the nanocomposites exhibited a remarkable microhardness enhancement (~70%) compared with pure nanostructured nickel. The Hall–Petch relation and the Orowan–Ashby equation are used to discuss strengthening mechanisms and the load transfer ability to the reinforcing particles.

Keywords: Nanocomposites; Nanodiamond; Hall–Petch relation; Mechanical synthesis; Carbide formation

1. Introduction

Due to high strength allied to corrosion and wear resistance, nickel alloys and composites are used in a variety of applications, ranging from tools for diverse industrial purposes to advanced turbine jet engines, and novel formulations are continuously sought for innovative functions and extension of existing operation windows [1–4].

A microstructure refined to the nanometer scale provides an improvement in strength [5,6]. In addition, particle dispersions may increase the material hardness [7] through an Orowan-type mechanism or effective load transfer to the particles [8–12]. Dispersoids of diamond or graphite therefore offer reinforcement potential to nanostructured Ni, in combination with thermal conductivity enhancement in the case of diamond [13] and self-lubricating properties for graphite [14].

Mechanical synthesis (MS) has been extensively used to produce nanostructured materials as well as fine dispersions in metallic matrices [10,11,15]. Nevertheless, processing of nickel–carbon nanocomposites by MS poses specific

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