“In-situ” synthesis of TiC reinforcing nanoparticles inside aluminium matrix from nanodiamond and titanium precursors during mechanical alloying

V.A.Popov

National University of Science and Technology “MISIS”, Leninsky prospect, 4, Moscow Russia
Popov58@inbox.ru

Abstract

The development of new, advanced materials, including metal matrix composites with reinforcing nanoparticles, has been a focus of ongoing research to increasing the quality and the service life of various products. However, one of the problems impeding the wide application of these materials is the presence of foreign inclusions and contaminants on the nanoparticle surface because the surface corresponds to the interface between the reinforcing particles and the metal matrix. Despite their low levels, these contaminants can significantly decrease the adhesive strength between the composite components. Casting technologies lead to the absence of wettability, preventing the regularly spaced distribution of the reinforcing particles during melting, ultimately leading to their removal from the alloy. The goal of this study is to develop an “in-situ” method for the synthesis of reinforcing particles directly in the metal matrix, thus avoiding atmospheric contamination at the matrix-reinforcements interface.

In this study, the possibility of developing an “in-situ” synthesis of titanium carbide (TiC) nanoparticles inside an aluminium matrix by mechanical alloying was examined. Commercially available nanodiamonds [1-3] produced by detonation synthesis and titanium powder served as the starting materials for the nano-carbides synthesis. Commercially available aluminium powder was used to generate the matrix. Mechanical alloying was carried out in Retsch PM400 planetary mills in an argon atmosphere, without using surfactants, in sealed steel grinding jars of 500-ml nominal volume. The initial materials were treated using chromium steel milling balls 12 mm in diameter. The ratio of the weight of the balls to that of the treated mixture (charge ratio) was 7:1. The rotational speed of the carrier was 300 rpm. The grinding jars were air-cooled during the operation. To prevent strong overheating, the mill was stopped for 5 min for each 10 min of operation. The real time, without accounting for stops, was considered to be the treatment time. The duration of treatment was 8 h. The mechanically alloyed granules were investigated by X-ray diffractometry (XRD), scanning electron microscopy (SEM) and differential scanning calorimetry (DSC). The DSC was carried out at a Netzsch 404 C instrument in platinum crucibles; a dynamic inert atmosphere (argon; blowdown rate, 70 ml/min) was maintained. The XRD was performed on a Bruker D8 ADVANCE diffractometer in monochromatized CuKα radiation (with the diffracted-beam monochromator). Morphology of composite granules surface was investigated with Zeiss Supra 25 scanning electron microscope.

The investigations indicated that the synthesis of the nanoparticles proceeded to completion. The XRD patterns showed only aluminium and titanium carbide peaks. No peaks from residual titanium were observed; in addition, no products from an aluminium-titanium reaction and no other compounds were observed. Therefore, the obtained composite granules consist of the aluminium matrix and reinforcing titanium carbide particles. The results of the granule structure investigation using SEM reveal that the titanium carbide particles have a regularly spaced distribution in the aluminium matrix, and their sizes range from 10 to 30 nm. Thus, they can be classified as nanoparticles. The DSC curve shows that chemical reactions between the titanium carbide nanoparticles and the aluminium alloy begin at temperatures higher than 750 °C

In conclusion, mechanical alloying allows executing “in-situ” synthesis of titanium carbide nanoparticles inside aluminium matrix and developing “Al+nano-TiC” composite material without the occurrence of unwanted chemical reactions as minimum up to 750 °C.

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