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Laminating; the best way to improve Charpy impact energy of nanocomposites

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Abstract

An Al–TiC nanocomposite powder with different percentages of TiC nanoparticles, was synthesized via high energy ball milling. With increasing the TiC nanoparticles content, the crystallite size began to decrease, which led to an increase in the hardness of the produced nanocomposite. An Al–TiC laminated nanocomposite was then fabricated and the effect of process parameters on its Charpy impact energy (CIE) in both crack divider and crack arrester configurations was investigated. Comparison between the experimental results shows that for each of the crack divider and crack arrester configurations, the CIE of the laminated nanocomposite is much higher than that of monolithic one. We also reported an accurate estimate of the process parameters in order to maximize the Charpy impact energy in Al–TiC laminated nanocomposite. Accordingly, 99 datasets were collected from the experiments and then by a modeling algorithm called gene expression programing (GEP), a mathematical relation between the CIE and process parameters was developed. Afterwards by an optimization algorithm called Biogeography Based Optimization (BBO), the process parameters were optimized in order to achieve maximum CIE. Experiments were performed at the optimized parameters to prove the validity of the analysis which shows the potential application of these calculations and analysis in materials engineering.

Keywords: A. Milling; B. Nanocomposites; Charpy impact energy; Optimization

1. Introduction

Aluminum alloys reinforced with ceramic particles such as SiC [1],TiC [2–5],B_4C[6],TiB_2 [7,8], Al_2O_3 [9,10], and graphite [11] have shown a significant potential for various high performance applications. The most common applications of these composites are in commercial aerospace, space technology, automobile, general industrial and engineering structures [12–16].

So far, several methods have been used to produce Al–TiC composite and some of its mechanical properties have been studied. According to Roy et al. [6], a lower wear rates and coefficient of friction were seen in the Al matrix composites reinforced with SiC, TiC, TiB_2 and B_4C particles in comparison with pure aluminum. Naresh Rai et al. [17] reported that the microstructures of forged and rolled specimens of mentioned composite, reveal uniform distribution of the TiC particles, which are responsible for the enhancement of the tensile strength of the composite. Kishore et al. [18] conducted an investigation on the hardness of composite by addition of the TiC particles to the Al-6061 using micro hardness testing. An increase of hardness was reported due to adding TiC reinforment to Al6061 matrix. Malek Ali et al. [19] fabricated an Al–TiC composite and observed that Al–TiC has better strength than other Al based composites having same volume fraction of reinforced particles.

The concept of gene expression programming (GEP) algorithm was introduced by Ferreria [20] in 2001. The most important feature of GEP is formulation process variables (function finding)

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based on simple coding which leads to a strong problem solving ability [21–23]. This application is capable in finding an expression that performs well for all fitness cases within a certain error of the correct value.

Biogeography based optimization (BBO), in the form of a computational algorithm, developed by Dan Simon in 2008 [24]. BBO algorithm shares information among solutions with the migration operator [25]. According to Simon [24] the performance of BBO algorithm is better than or similar to that of the other algorithms although it uses less control parameters so that a potential for solving multi-modal and multidimensional optimization is obtained.

Application of GEP in different materials engineering problems has been reported. Minimizing the synthesis time in high energy ball milling [23], calculating the hardness of metal matrix nanocomposites [22] and predicting the bond strength of fiber reinforced polymers (FRP)-to-concrete composite joints [21] are some of these applications. However, BBO application in materials science has been reported only by Abdellahi [26], by which the synthesis time of nanostructured powders was minimized during high energy ball milling.

Due to the high strength, a low impact resistance is obtained for Al/TiC nanocomposite and therefore it is of interest to find a way to overcome this disadvantage. Lamination of the bulk composites into several layers could be a potential solution to enhance the impact resistance. Basically, changing the plane–strain condition to plane–stress in lamination process results in an increase of the impact resistance. Layers in a laminated composite are alternately separated by discrete interfaces which arrest, a propagating crack under impact loading conditions. The resistance against crack propagation is related to the delaminated interfaces under dynamic conditions and is responsible of the high fracture resistance of the composites, which is much better than that of the individual components of the composite [27]. To the best of our knowledge there is no published work on investigating CIE of the Al-nano TiC-laminated composite.

In the present work, for the first time, an Al-nano TiC-laminated composite with enhanced CIE, four times higher than its monolithic counterpart was produced. Also for the first time in Materials Engineering, an accurate modeling was carried out on the CIE of Al-nano TiC-laminated composite. At the end, an optimization was performed on the process parameters for maximizing CIE and the results were compared with those of the experimental conditions. In this study, Gene expression programming (GEP) and Biogeography Based Optimization (BBO) algorithms as powerful tools, have respectively been utilized for modeling and optimizing of CIE of laminated Al/TiC nanocomposite.

2. Materials and methods

Aluminum fine powder (Merck, stabilized about 2%fat) and titanium carbide (TiC-Sigma Aldrich) with the average particles size of less than 200 nm and with a more than 95% purity, were used as raw materials. SEM images of Al and TiC powders are shown in Fig. 1.

A planetary ball mill with stainless steel vials and balls was used to process the powder mixture. The milling vial was purged 4 times and back-filled with high purity argon (99.99%) to prevent the oxidation of the powders during milling. The milling speed and ball to powder weight ratio (BPR) were 300 rpm and 10:1, respectively.

TiC powder with various weight percentages (0.5, 1, 1.5 and 2 wt%) as reinforcement and Al powder as metal matrix, were milled at different processing times up to 15 h to produce Al-x wt%TiC (x=0.5, 1, 1.5 and 2) nanocomposite. A Philips X-ray diffraction (XRD) with CuKα radiation at 30 kV and 25 mA was utilized to determine the products of the synthesis reactions at various milling. The morphology of the milled powders was monitored using a Hitachi S4160 scanning electron microscopy (SEM) operated at 15 kV.

Cold pressing at 280 MPa was used to consolidate the ball milled product. Processed mixture was poured into aluminum cans in several layers with a two-part epoxy polymer as the adhesive material between alternate layers. The adhesive polymer, composed of resin and curing agent, was modified using core–shell rubber particles and titanium carbide particles [27]. Core–shell rubber particles were composed of a methacrylate butadiene-styrene (MBS) copolymer with a nominal diameter of

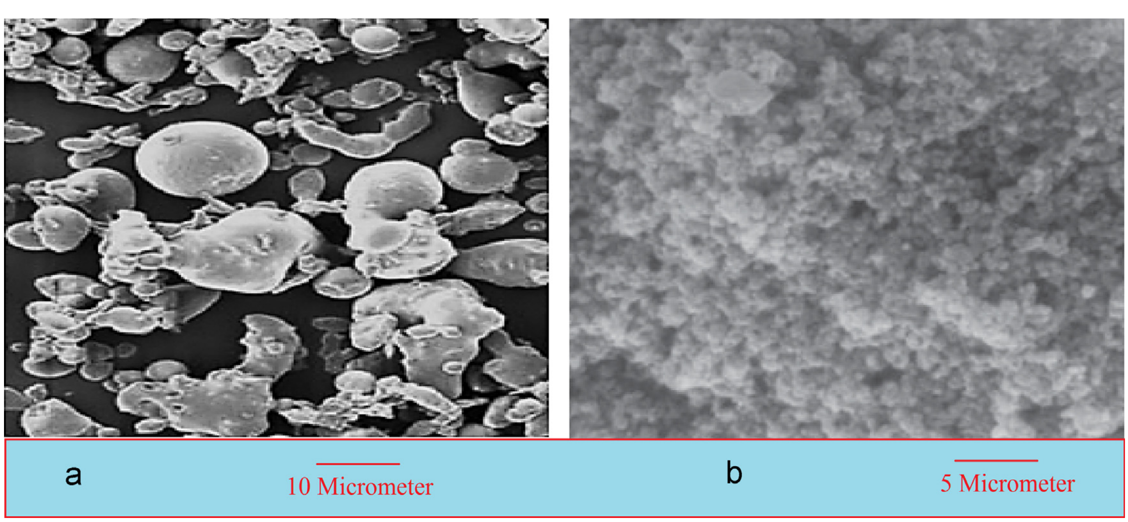

Fig. 1. SEM images of as received (a) Al and (b) TiC powders.