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Short communication

Cold formability of friction stir processed aluminum composites containing carbon nanotubes and boron carbide particles

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ABSTRACT

Cold formability of friction stir processed aluminum composites was evaluated by bend-ductility tests. Composites containing carbon nanotubes fractured during bending while those containing boron carbide particles survived; hybrid composites showed cracking but less than those containing solely nanotubes. Weak interfacial nanotube/aluminum bonding and in adequate nanotube distribution were found to be the possible reasons.

1. Introduction

Friction stir processing (FSP), a variant of friction stir welding (FSW) is a novel solid state composite manufacturing technique, which modifies the microstructure of the processed material by mechanically induced sliding motion of a rotating tool [1]. The microstructural modification due to severe plastic deformation and frictional heat improves the mechanical properties of the substrate material such as hardness, strength, ductility, wear and fatigue [2]. In particular, ductility has been reported to enhance in FSP by eliminating microstructural surface defects, i.e. porosity and cracks, and thus making the processed material more tolerant to mechanical loading [3–5].

A range of particles, both at micrometer [6] and nanometer scale [7], have been introduced to prepare surface composites by FSP. Ceramic reinforcements in surface aluminum matrix composites (AMCs) introduced by FSP include cerium oxide [8], aluminum oxide [9], boron carbide [10] and silicon carbide [11]; among carbonaceous nanoreinforcements, carbon nanotubes (CNTs) [7] and graphene nanoplatelets (GNPs) [12] have been incorporated.

Improvements in mechanical properties have been reported both in individually reinforced ceramic particles or CNTs in surface AMCs prepared by FSP [13,14], which are related to grain size refinement and improved distribution quality of reinforcements. However, the combined effect of chemically and morphologically different reinforcements has been less investigated so as to explore their synergic effect together with the influence deriving from FSP. Recently, FSP hybrid Al-5083 composite containing silicon carbide and molybdenum disulphide particles showed better hardness and wear properties [15]. In a different study, CNTs were incorporated along with cerium oxide in Al-5083 for improved hardness, tensile strength and corrosion resistance [8]. Generally, studies focus primarily on the increase in strength and hardness without emphasizing the additional feature of formability of the prepared surface composites and to the best of authors' knowledge no such study is available in literature that focuses on formability together with hardness and strength of surface composites containing dual reinforcements and prepared by FSP.

In this study, surface composites were developed by FSP on aluminum alloy 5083 (Al-5083) plate containing multiwall carbon nanotubes (MWCNTs) and boron carbide (B_4C) particles. For comparison, individually reinforced MWCNTs and B_4C composites were also prepared along with a reference FSP surface without reinforcement. Al-5083 was especially chosen, as it possesses many appealing properties like corrosion resistance, moderate strength and good welding properties [3]. The two reinforcements of different chemical, mechanical and morphological attributes were selected with an expectation that the extremely hard nature of B_4C particles [16] along with exceptionally high strength and stiffness properties of MWCNTs [17] may produce a synergy for improved mechanical properties of the developed composite. Optical and electron microscopy were carried out for microstructural observation and reinforcement distribution while mechanical properties were evaluated by hardness, tensile and bend-ductility tests to characterize the mechanical performance of surface composites

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Table 1
Nominal chemical composition of base metal Al-5083.

Element	Mn	Fe	Cu	Mg	Si	Zn	Cr	Other	Al
Wt%	0.4–1	≥0.4	≥0.1	4–4.9	0–0.4	0–0.1	0.05–0.25	0–0.05	Balance

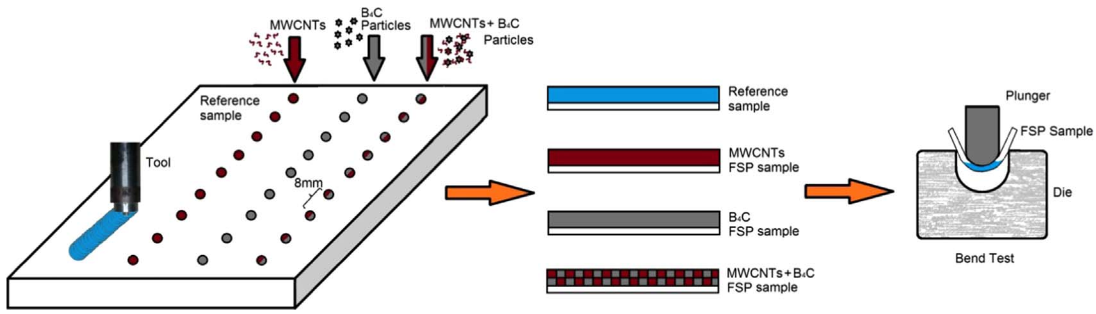

Fig. 1. Schematics of the friction stir processing representing the surfaces composites and bending test.

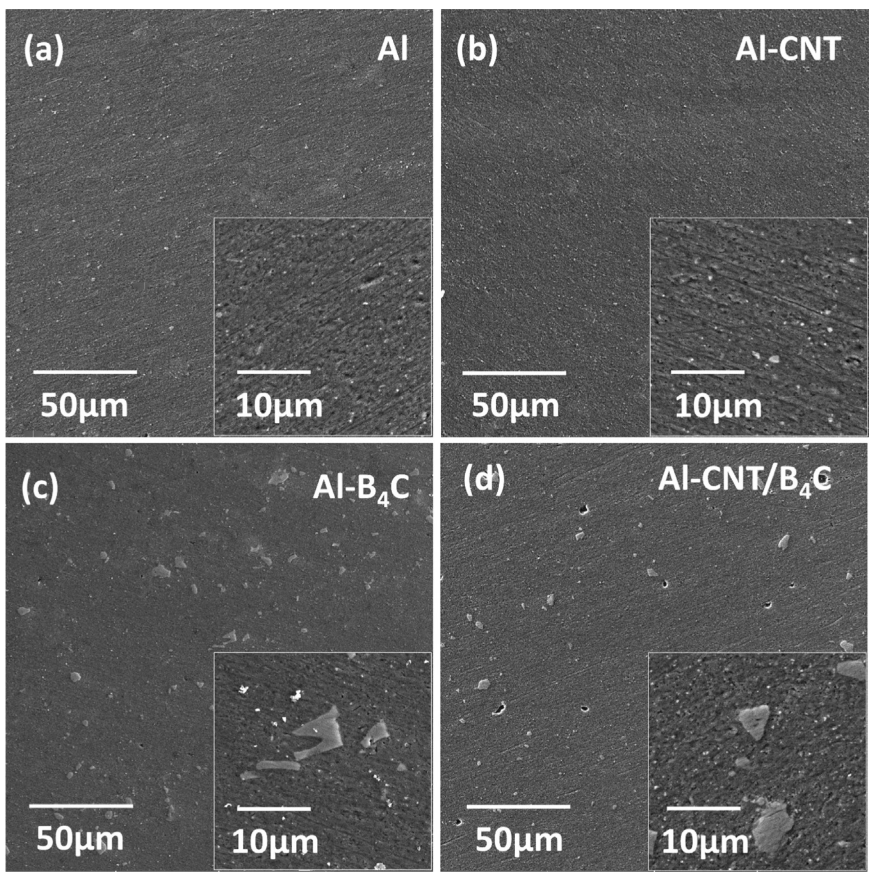

Fig. 2. SEM images of FSP reference sample and surface composites: (a) Al5083, (b) MWCNTs in Al5083, (c) B_4C particles in Al5083 and (d) Hybrid combination of MWCNTs and B_4C particles in Al5083.

containing micrometer size particles and nanometer size tubes, especially the cold formability. Finally, the results were critically discussed in the light of available related data on the research topic.

2. Experimental

2.1. Materials

Commercially available Al-5083 rolled plate of thickness 8 mm was used for surface composite preparation with the composition shown in Table 1. B_4C particles with average size of 10 µm and MWCNTs with average length and diameter of 1 µm and 20–30 nm, respectively, were purchased from Hongwu International Group, China. FSP tool was made of H-13 steel with final dimensions of 16 mm collect diameter, 20 mm shoulder diameter and 4.5–6.0 mm conical threaded pin diameter. The height of the pin was 4.5 mm and an angle of 5° was made from shoulder to pin root to accumulate the possible spreading of reinforcement from cavities; the tool had the hardness value of 550 ± 2.5 HV.