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MWCNTs/AZ31 surface composites fabricated by friction stir processing

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Abstract

Multi-walled carbon nanotubes (MWCNTs) were successfully dispersed into a magnesium alloy (AZ31) using friction stir processing (FSP). Distribution of the MWCNTs was changed on the basis of the travel speed of the FSP tool. The grain size of the MWCNTs/AZ31 surface composites was smaller than that of the FSPed AZ31 without the MWCNTs. The addition of the MWCNTs appears effective for fabricating the composites consisting of fine matrix grains. The maximum microhardness of these composites was ∼78 Hv, which is almost double that of the AZ31 substrate (41 Hv). It is considered that both the grain refinement of the AZ31 matrix and the reinforcement by the MWCNTs increased the microhardness of the surface composites.

Keywords: MWCNTs; AZ31; Surface composites; Friction stir processing; Grain refinement; Microhardness

1. Introduction

Multi-walled carbon nanotubes (MWCNTs) have been tested for reinforcing various matrices [1–3] because they have many unique mechanical [4–9] and physical properties [10–14]. For example, such reinforcements can improve the strength of matrices due to the extremely high tensile strength of the MWCNTs. However, there are few reports about MWCNTs reinforced metal matrix composites because the uniform dispersion of MWCNTs in metal is exceedingly difficult. Additionally, MWCNTs easily react with the molten metal during the usual fabrication process, such as the vortex method [15]. These shortcomings limit the applications of the MWCNTs.

Recently, much attention has been paid to a new surface modification technique named friction stir processing (FSP) [16–19]. FSP is a solid state processing technique to obtain a fine-grained microstructure. This is carried out using the same approach as friction stir welding (FSW), in which a rotating tool is inserted into a substrate and produces a highly plastically deformed zone. It is well known that the frictioned zone consists of fine and equiaxed grains produced due to dynamic recrystallization [20]. Though FSP has been basically advanced as a grain refinement technique, it is a very attractive process for also fabricating composites. Mishra et al. [21] fabricated the SiC/Al surface composites by FSP, and indicated that SiC particles were well-distributed in the Al matrix, and good bonding with the Al matrix was generated.

In this study, the MWCNTs were dispersed in a magnesium alloy (AZ31) which is one of the best structural materials to decrease the weight of various vehicles. The MWCNTs/AZ31 surface composites were produced by FSP, and their metallographic examinations and hardness tests were carried out.

2. Experimental procedure

Commercially available MWCNTs (outer diameter: 20–50 nm, length: ∼250 nm) synthesized from hydrocarbons, and an AZ31 rolled plate (thickness: 6 mm) were used in this study. The MWCNTs are typically entangled with each other and contain a few graphite granule inclusions (Fig. 1). The strong aggregation makes a uniform dispersion of MWCNTs in the matrix difficult.

The MWCNTs were filled into a groove (1 mm × 2 mm) on the AZ31 plate before the FSP was used, as shown in Fig. 2. The FSP tool made of SKD61 has a columnar shape (Ø 12 mm) with a probe (Ø 4 mm, length: 1.8 mm). The probe was inserted

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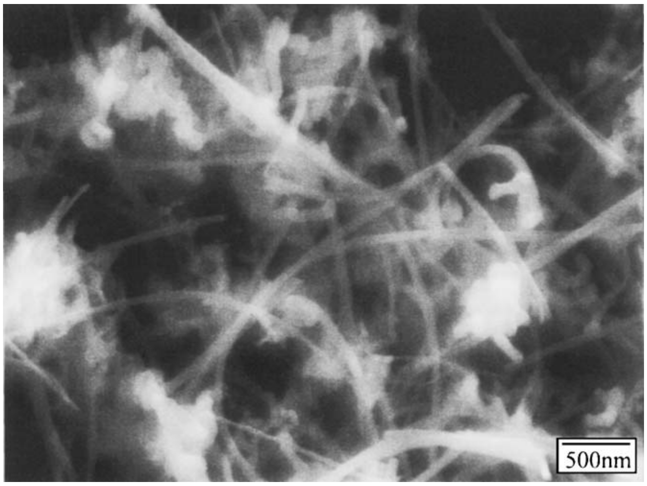

Fig. 1. SEM image of the as-received MWCNTs.

into the groove filled with the MWCNTs. A constant tool rotating rate of 1500 rpm was adopted and the travel speed was varied from 25 to 100 mm/min. The tool tilt angle of 3° was used.

Transverse sections of the as-received AZ31 and as-produced FSPed samples were mounted and then mechanically polished. The distribution of the MWCNTs was observed by SEM (JEOL JSM-6460LA), and the grain size of the etched sample was evaluated by optical microscopy. The grain size was estimated using the mean lineal intercept method. The microhardness was measured using a micro-vickers hardness tester (Akashi HM-124) with a load of 200 g.

3. Results and discussion

Figs. 3 and 4 show OM and SEM images obtained from the surface composites fabricated by the FSP, respectively. The dispersion of the MWCNTs in the AZ31 matrix was related to the travel speed of the rotating tool. Entangled MWCNTs, which were similar to the as-received MWCNTs, could be observed in the sample FSPed at 100 mm/min. Though the sample FSPed at 50 mm/min showed a better dispersion of the MWCNTs, there were some regions which included the aggregated MWCNTs. On the other hand, a good dispersion of the MWCNTs, which were separated from each other, could be observed for

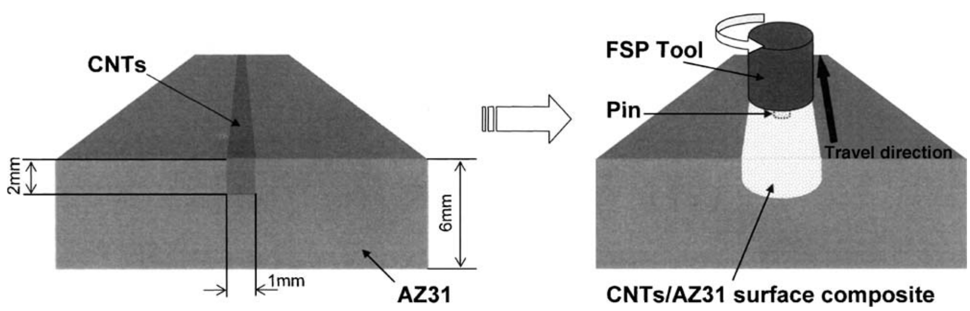

Fig. 2. Schematic of the friction stir processing.

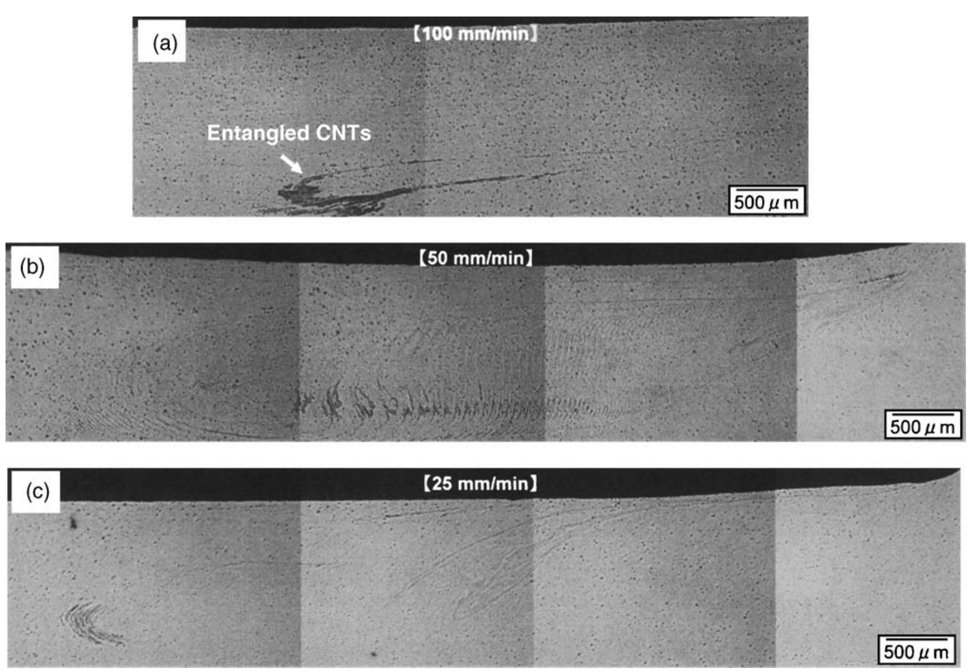

Fig. 3. OM images of the MWCNTs/AZ31 surface composites. The constant tool rotating rate was 1500 rpm. The travel speeds of (a), (b) and (c) were 100, 50 and 25 mm/min, respectively.