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Effects of ZnO coating on the damping and tensile properties of $LiNbO_3$ particle-reinforced aluminum composite

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ABSTRACT

An aluminum matrix composite reinforced by ZnO-coated $LiNbO_3$ particles was fabricated using a pressure infiltration technique. The effect of the ZnO coating on the damping and tensile properties of the composite were investigated. The result shows that the damping capacity of the coated $LiNbO_3$/ZL102 composite is 150% up compared with uncoated $LiNbO_3$/ZL102 composite at room temperature. The reason is the ZnO coating causes more electrical energy converted into Joule's heat resulting in the stronger piezo-damping and thus a better damping capacity. The ultimate tensile strength of the coated $LiNbO_3$/ZL102 composite is 17% up on that of uncoated $LiNbO_3$/ZL102 composite, which is ascribed to the increased load transfer from the matrix to the reinforcement due to the improved interfacial bonding with the help of the ZnO coating.

1. Introduction

In engineering design, particular attention has to be paid to mechanical vibrations, because they produce undesirable noise, affect the precision of machine tools or lead to rupture by fatigue. And since application fields such as aerospace and transport require lightweight and simple structures nowadays, it is of great interest to develop materials that exhibit good mechanical properties and high damping capacity simultaneously.

Particle-reinforced metal matrix composites (PMMCs) have proved to be the best choice for such materials [1]. Al and Al-based alloys, because of their low melting point, low density, reasonably high thermal conductivity, heat treatment capability, processing flexibility and low cost, have been widely selected as the metal matrix. However, the commonly introduced ceramic particles such as SiC, Al_2O_3 and TiB_2 enhance the mechanical properties rather than the damping capacity [2–5].

From the 1990s, piezoelectric particles have been applied in polymer matrix composites to improve the damping capacity and the results showed to be very effective [6–9]. The caused damping mechanism by the piezoelectric particles is referred to as piezo-damping. Mechanical vibrating energy is first transmitted to the piezoelectric particles and converted into alternating electrical potential energy by the piezoelectric effect. Then the electrical potential energy is further converted into Joule's heat through a resistive network. Recently these smart particles started to be used in metal matrix composites [10,11]. However, there is just a little knowledge on the properties of such composites. And it is well known that the interface between the matrix and the reinforcement plays a crucial role in determining the properties of metal matrix composites. Therefore in this paper, $LiNbO_3$ piezoelectric particles were used and $LiNbO_3$/ZL102 Al matrix composite was prepared. The interface was modified by coating ZnO on $LiNbO_3$ particles. And its effects on the piezo-damping, overall damping capacity and tensile properties of the composite were investigated.

2. Experimental

$LiNbO_3$ particles with a Curie point of 1150 °C were kindly supplied by Shanghai Jianyuan Crystals Co., Ltd. and electrically polarized before use. Particles have an average diameter of 40 μm. The commercial ZL102 Al alloy was used as the metal matrix.

The $LiNbO_3$ particles were coated with ZnO through a sol–gel method. The sol was prepared using zinc acetate dehydrate (ZnAc), diethanolamine (DEA) and isopropanol. First, DEA was dissolved in isopropanol, followed by the addition of ZnAc under stirring. The mixture was heated under reflux for 1 h at 70 °C. Then, additional isopropanol was added to adjust the solution concentration to 0.1 M of ZnAc. The molar ratio of DEA to ZnAc was maintained at 1.0. The solution was then stirred at 40 °C for 2 h to yield a clear and homogeneous solution, which served as the coating solution after being cooled to the room temperature. The $LiNbO_3$ particles were dipped in the sol and stirred for 30 min while the coated particles

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were filtered, cleaned with ethanol, and dried for 1 h at 120 °C in air. Finally, the particles were thermally treated for 1 h at 700 °C.

Composites were fabricated using a pressure infiltration technique. The preform was calcined at 700 °C to obtain sufficient preform strength. The molten ZL102 Al alloy (730 °C) was poured onto the pre-heated preform (450 °C) in a steel die and a pressure of 30 t was added. Finally, the bulk composites were annealed at 450 °C for 1 h. The volume fraction of $LiNbO_3$ was 60% for all composites. A specimen of ZL102 Al alloy was fabricated using the same way as a reference one.

The microstructure of the coated and uncoated $LiNbO_3$ particles as well as the as-cast composites was examined using a JSM-6460 scanning electron microscope (SEM). The ZnO coating was observed by a FEI Sirion 200 type field emission scanning electron microscope (FESEM). The phase composition of the coated particle was identified by a Philips X'Pert X-ray diffractometer with Cu Kα radiation. The interface between $LiNbO_3$ particle and ZL102 Al alloy was observed through a JEM-2010 transmission electron microscope (TEM). The damping capacity measurements were performed on a TA 2980 type dynamic mechanical thermal analyzer (DMTA) using a single cantilever testing mode. Rectangular bar samples for the damping capacity measurements with dimensions of 35 mm × 5 mm × 1 mm were obtained by spark machining. The damping capacity, in terms of loss tangent ($\tan\phi$), is calculated from

$$\tan\phi = \frac{E''}{E'} \quad (1)$$

where E'' is loss modulus and E' is storage modulus or dynamic modulus. The tensile test was carried out on a Zwick/Roell Z020 tension machine.

3. Results and discussion

3.1. Characterization of the coated $LiNbO_3$ particle

SEM micrographs of the as-received $LiNbO_3$ particle and ZnO-coated $LiNbO_3$ particle calcined at 700 °C are shown in Fig. 1. The surface of the as-received particle is rough, which then becomes smooth and clear after coated by ZnO. From Fig. 1b, a layer of ZnO film uniformly distributes on the particle surface. In addition, the ZnO film is formed by the stacking of ZnO nanometer particles whose average diameter is about 15 nm shown in Fig. 2. Fig. 3 shows the X-ray diffraction (XRD) pattern of ZnO-coated $LiNbO_3$ particle calcined at 700 °C. Peaks for ZnO and $LiNbO_3$ were identified. No other diffraction peaks can be found besides those of ZnO and $LiNbO_3$, which indicate that no reactions take place between ZnO and $LiNbO_3$.

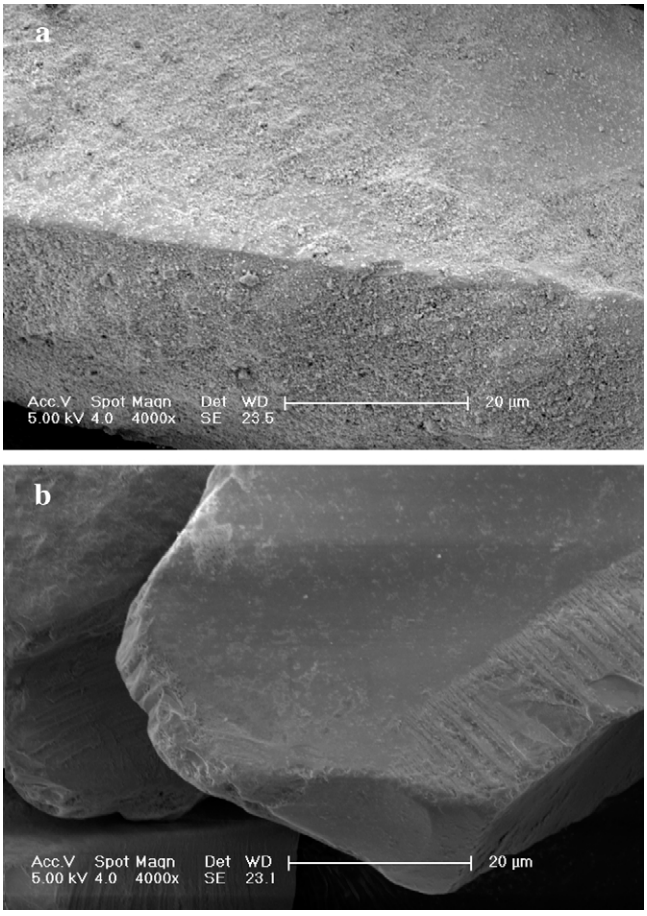

Fig. 1. Surface morphologies of uncoated $LiNbO_3$ particle (a) and ZnO-coated $LiNbO_3$ particle (b).

3.2. Microstructure of the composite

Fig. 4 shows the microstructure of the composite with ZnO-coated $LiNbO_3$ particles, whose average diameter is 40 μm. It can be seen that the $LiNbO_3$ particles distribute uniformly. To be mentioned, the microstructure of the composite with uncoated $LiNbO_3$ particles is very similar with Fig. 4.

TEM photographs of the ZnO-coated $LiNbO_3$/ZL102 composite are given in Fig. 5. In Fig. 5a, the interface shows to be made up of a continuous layer with a thickness of about 50 nm. The possibility of the reaction of ZnO and molten aluminum has been reported [12–14] and the reaction equation can be written as follows:

$$3ZnO + 2Al \rightarrow Al_2O_3 + 3Zn + Q \quad (2)$$

where +Q represents the exothermal reaction. The standard free energy change (ΔG_T^0) can be calculated in the following equation [13]:

$$\Delta G_T^0(\text{in calories}) = -59500 + 27.3T\log T - 305.04T \quad (3)$$

Apparently, reaction between ZnO and Al can occur from the perspective of thermodynamics due to a negative free energy change in the present situation. However, Fig. 5b shows the selected area electron diffraction pattern (SADP) of the interfacial region, in

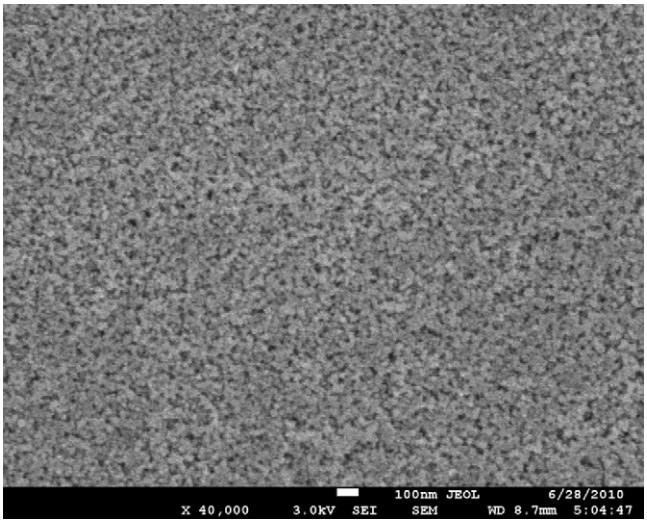

Fig. 2. FESEM micrograph of the ZnO coating on $LiNbO_3$ particle.