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High damping capacity of Al alloys produced by friction stir processing

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ABSTRACT

Friction stir processing (FSP) was performed on both age-hardened and non-age-hardened Al alloys, with excellent damping properties obtained. The improved room temperature damping capacity of the FSP Al alloys can be mainly attributed to their low amount of solute atoms and the uniform distribution and high density of incoherent phases. The FSP Al alloys also exhibited improved high temperature damping capacity due to their equiaxed grain structure. The grain refinement and grain boundary pinning phase can further optimize the damping property of the FSP Al alloys. This work provides an effective strategy to improve the damping capacity of commercial Al alloys, which are regarded as low damping materials.

1. Introduction

Al alloys are vitally important structural materials due to their low density and excellent mechanical properties [1–3]. However, commercial Al alloys are regarded as low damping materials, which greatly limits their applications in some vibration sensitive equipment [4]. Thus, improving the damping capacity of commercial Al alloys is highly desirable to extend their engineering applications.

Macro-structure design, such as introducing a high density of macroscopic pores into Al matrixes to fabricate foamed Al [5] and friction stir welding (FSW) of high damping NiTi sheets with Al sheets to fabricate layered composites [6], can improve the damping capacity of Al products. However, macro-structure design does not change the physical properties of the matrix and is therefore not a fundamental method for improving the damping capacity of commercial Al alloys.

According to the Granato–Lücke model (dislocation damping mechanism) [7], controlling the presence and movement of movable dislocations can increase the room temperature damping capacity of metals. Crystal lattice defects, such as impurity atoms, vacancies, dislocation cells and walls can effectively pin the movable dislocations during vibration, and therefore deteriorate the room temperature damping capacity of metals [8]. However, the incoherent phases can increase the density of movable dislocations due to the mismatch in thermal expansion coefficients between these phases and the matrix, and therefore improve the room temperature damping capacity [9]. Thus, the room temperature damping capacities of commercial Al alloys are expected to improve by decreasing the dislocation pinning points and increasing the movable dislocations during vibration.

The dislocation damping mechanism is weakened by increased temperature. Luo et al. [10] found that the grain structures with excellent grain boundary (GB) sliding capacity always contributed to excellent high temperature damping capacity of metals. Therefore, the high temperature damping capacities of commercial Al alloys are expected to improve by enhancing the GB sliding capacity.

Commercial Al alloys after friction stir processing (FSP), which was developed based on the basic principles of FSW [11–14], showed excellent superplasticity when the deformation temperature was higher than 200 °C. This was attributed to their equiaxed fine grain structure that can lead to an excellent GB sliding behavior at high temperature [15–20]. Furthermore, other microstructural characteristics, which could improve the room temperature damping capacities of metals, such as the low density of dislocations and vacancies, low amount of solute atoms and uniform distribution of incoherent phases, were also obtained in FSP Al alloys [15–20]. Thus, FSP may be an effectively strategy to improve the damping capacity of commercial Al alloys.

In the present study, the effects of FSP with different rotation rates on the microstructure and damping capacity of the commercial age-hardened and non-age-hardened Al alloys are investigated. The aims are to fabricate Al alloys with excellent damping capacity and understand the key factors influencing the damping behavior of Al alloys.

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Table 1
Parameters of each FSP sample. (LRR-FSP: FSP at low rotation rate; HRR-FSP: FSP at high rotation rate).

BM		Tool rotation rate (rpm)	Traverse speed (mm min^{-1})
6082	LRR-FSP	200	50
	HRR-FSP	1500	50
5086	LRR-FSP	400	100
	HRR-FSP	1200	100
7075	LRR-FSP	400	50
	HRR-FSP	800	50
7055	LRR-FSP	300	100
	HRR-FSP	1500	100
7055-0.25Sc	LRR-FSP	300	100
	HRR-FSP	1500	100

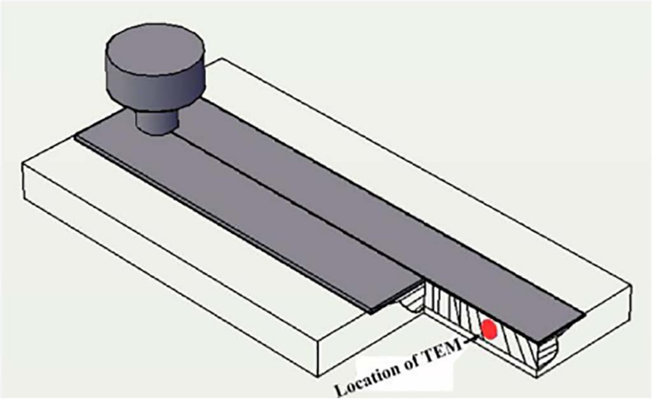

Fig. 1. Schematic illustration of the sampling location of TEM analysis.

2. Experimental

The raw materials were AA 5086-H112 (4.1 Mg, 0.45 Mn, 0.16 Fe and 0.1 Cr), AA 6082-T4 (1.16 Si, 0.77 Mg, 0.68 Mn and 0.27 Fe), AA 7075 (5.5 Zn, 2.4 Mg, 1.5 Cu and 0.13 Fe) after solution treatment (SS), AA 7055-SS (7.82 Zn, 2.24 Cu, 1.95 Mg and 0.16 Zr) and AA 7055-0.25Sc-T6 alloys. FSP was conducted at traverse speeds of 50 to 100 mm min^{-1} and tool rotation rates of 200 to 1500 rpm. The FSW parameters for each FSP sample are shown in Table 1.

The microstructures of the samples were examined by electron backscattered diffraction (EBSD) and transmission electron microscopy (TEM, JEM-2010). EBSD measurements were carried out by scanning electron microscopy (SEM, Hitachi S-3400N-II). A schematic illustration of the sampling location of TEM analysis is shown in Fig. 1. The films for TEM were prepared by grinding to a thickness of 50 μm, followed by thinning using a twinjet electropolishing device.

The damping capacity of the samples was characterized using specimens with dimensions of 1.2 mm × 4 mm × 25 mm. Damping tests were conducted by a dynamic mechanical analyzer (Q800, TA) in single-cantilever mode. Measurements were made at strain amplitudes (ε) of 7×10^{-5} to 2×10^{-1}, temperatures (T) of 40 to 360 °C with a heating rate of 5 °C/min and a constant frequency (f) of 1 Hz.

3. Results and Discussion

Fig. 2 shows the grain size distributions of the base metals (BMs) obtained by EBSD. The 5086 (Fig. 2a) and 7075 (Fig. 2c) BMs showed coarse equiaxed structures, while elongated grain structures were observed in the 6082 (Fig. 2b), 7055 (Fig. 2d) and 7055-0.25Sc (Fig. 2e) BMs.

Fig. 3 shows the grain size distributions of the FSP samples obtained by EBSD. The completely recrystallized grains with an equiaxed shape were observed in all the FSP samples. For the same alloy, the LRR-FSP sample exhibited finer grains than the HRR-FSP sample. Increasing the rotation rate enhanced the heat input during FSP and therefore led to the coarsening of recrystallized grains. The LRR-FSP 6082 alloy exhibited the smallest average grain size (AGS), which was as fine as 0.8 μm (Fig. 3c). The AGS of the HRR-FSP 5086 alloy was ~10.5 μm (Fig. 3b), larger than that of other FSP samples.

Fig. 4 shows the TEM images of the BMs. Some large phases containing Mg, Mn and Fe were observed in the 5086, 6082 and 7075 BMs (Fig. 4a–c). The 7055 and 7055-0.25Sc alloys after SS or T6 treatment

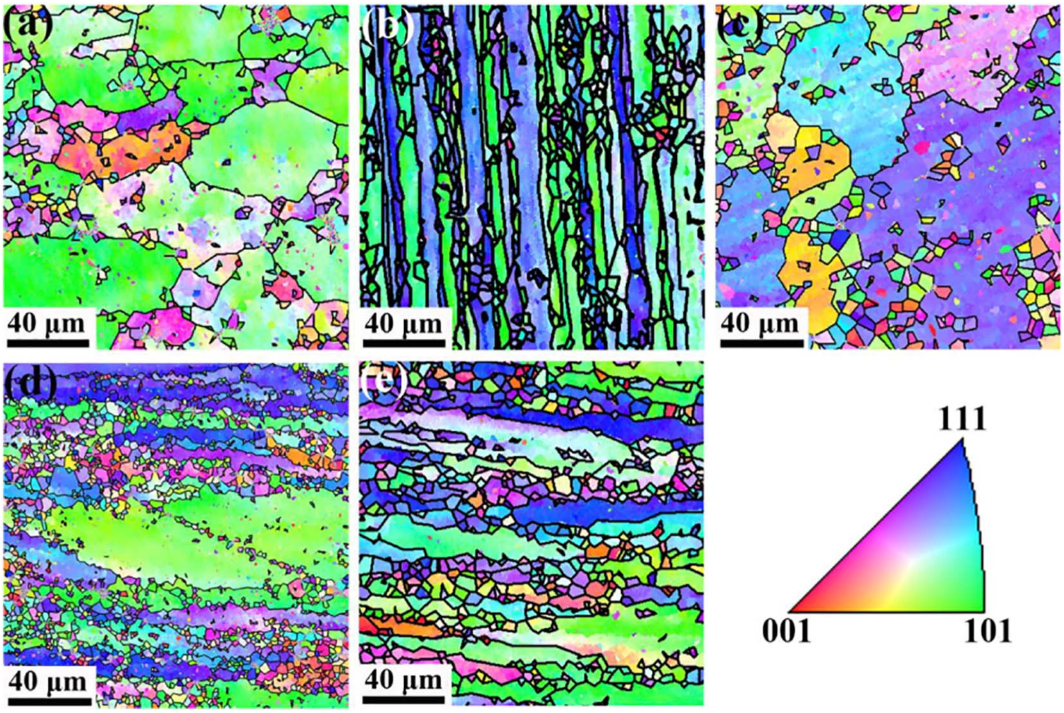

Fig. 2. EBSD maps showing grain structure of (a) 5086, (b) 6082, (c) 7075, (d) 7055, and (e) 7055-0.25Sc BMs.