INFLUENCE OF Al-5Ti-1B MASTER ALLOY ON MICROSTRUCTURE AND DAMPING CAPACITY OF ZA27 ALLOY[①]

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ABSTRACT The modification mechanism and damping capacity of conventional as-cast ZA27 alloy modified by Al-5Ti-1B master alloy were investigated. The cantilever beam technique was used for the measurement of damping capacity. As the experimental results showed, the commercial Al-5Ti-1B master alloy is a powerful modifier, it can decrease the grain size of Al-rich primary α phase greatly and transform its dendritic structure to a fine petal-like one. Meanwhile, it can improve the damping capacity greatly, and the best modification effect and highest damping capacity can be obtained at 0.088% Ti content. It is believed that $Ti(Al,Zn)_3$, $TiAl_3$, TiB_2 are effective nucleators to ZA27 alloy, the damping mechanism of ZA27 alloy is associated with the viscous sliding or slipping of the grain boundaries and phase interfaces. The more the grain boundaries and interfaces, the higher the damping capacity of ZA27 alloy can be obtained.

Key words ZA27 alloy Al-5Ti-1B master alloy modification damping capacity damping mechanism

1 INTRODUCTION

The damping capacity of a material is a measure of the energy that is dissipated in the material during mechanical vibration under cyclic loading. The materials that have high damping capacity are termed as high-damping materials. High-damping materials allow undesirable mechanical vibration and wave propagation to be passively suppressed, which proves valuable in the control of noise and the enhancement of vehicle and instrument stability. It is well known that many viscoelastic materials such as rubbers, polymers, and plastics have the ability to damp out noise and vibration. However, in applications where elevated damping levels must be accompanied by good mechanical properties at temperatures much above ambient temperature, only high-damping metals (HIDAMETS) and certain high-damping ceramics are available for passive damping. Such passive damping, on its own or combined with active damping, is finding more and more applications in structures where noise and vibration cannot be tolerated. However, the frequently used metals and alloys usually exhibit low damping capacity. Accordingly, investigators have sought to improve the damping capacities of metals and alloys by various techniques and approaches. High aluminum zinc-based alloy (ZA27) has high as-cast strength, hardness, wear resistance as well as other favorable physical properties. These properties make it be an attractive alternative to aluminum, brass, bronze, or iron for the designer of structures and machine parts that can be cast, therefore it has obtained more and more applications in industry. A series of studies have been carried out to improve its performance and widen its application area[1-4]. Among these researches, Liu *et al*[4] used titanium salt as the refining agent to modify the ZA27 alloy. The experimental results indicated that the plasticity and toughness of as-cast ZA27 alloy

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may be obviously improved by Ti addition. On the basis of the research described above, the effect of the addition of Al-5Ti-1B master alloy to ZA27 alloy on the microstructure and damping capacity was studied, the appropriate content of Al-5Ti-1B alloy was determined, the modification mechanism and damping mechanisms were also discussed.

2 EXPERIMENTAL

2.1 Material and sample preparation

The ZA27 alloy was prepared from electrolytically refined Zn(99.99%), Al-50Cu master alloy, commercially pure Mg and commercially pure Al (99.6%) at 750 ℃. The nominal ingredient (mass fraction) is 27.0% Al, 2.0% Cu, 0.02% Mg and 70.98% Zn. The alloy was modified by commercial Al-5Ti-1B ingot-type master alloys added from 0.01% to 0.12% Ti (nominal composition). The chemical analyses of the materials are reported in Table 1.

Table 1 Chemical composition of materials (mass fraction, %)

Material	Ti	B	Si	Fe	Al
Al-5Ti-1B	4.81	0.95	0.07	0.02	Balance
ZA27+0.02Ti	0.018	0.004			
ZA27+0.05Ti	0.053	0.011			
ZA27+0.09Ti	0.088	0.018			
ZA27+0.12Ti	0.124	0.025			

The modifying experiment was started by melting the predetermined amounts of the ZA27 alloy in a graphite crucible resistance furnace. When the melt was heated up to 740 ℃, this temperature was kept for 20 min before the modifier was added. Just after the addition of the modifier, the melt was stirred for 2 min with a graphite rod and kept this temperature for 10 min, then the graphite crucible was taken out of the furnace. The melt was allowed to stand for some time in order to allow the temperature of the melt to be lower and any dross emerge to the melt surface. The melt was poured into the preheated permanent mold at 600 ℃ after the dross was skimmed off. The rectangular damping sample was sectioned by electric spark linear cutting from the ingot. The nominal dimension of all specimens is of 85 mm × 6 mm × 3 mm.

2.2 Experimental approach

2.2.1 Measurement of damping capacity

Material damping is characterized not only by the phase lag of deformation behind the applied load in forced vibration and the suppression of respond amplitude but also by the decay of vibration amplitude in free vibration[5, 6]. There are several parameters that can be used to characterize damping capacity, and the characteristic parameters being simply related to each other. Among them, the logarithmic decrement, δ, and the inverse quality factor, Q^{-1}, are two widely used material damping parameters. In this research, the cantilever beam technique[6] was used for the measurement of damping capacity. The logarithmic decrement, δ, derived from the amplitude decay of a specimen under free vibration, is given by[5]

$$\delta = \frac{1}{n}\ln\left(\frac{A_i}{A_{i+n}}\right) \tag{1}$$

where A_i and A_{i+n} are the amplitudes of the ith cycle and the $(i+n)$th cycle at times t_1 and t_2, respectively, by n periods of oscillation.

At recent international conferences on internal friction and ultrasonic attenuation in solids, Q^{-1} was the most frequently adopted measure of damping. Consequently, we will use Q^{-1} as the measure of damping in the following.

For the case of relatively small damping capacity, the relationship between δ and Q^{-1} is simple and is given by[5, 7]

$$Q^{-1} = \frac{\delta}{\pi} \tag{2}$$

For HIDAMETS ($Q^{-1} \geqslant 10^{-2}$), Eqn. (2) must be modified[7] when δ is used to measure the damping, more precisely,

$$Q^{-1} = \frac{\delta}{\pi}\left(1 - \frac{\delta}{2\pi} + \cdots\right) \tag{3}$$

2.2.2 Metallurgraphic examination

For the metallurgraphic work, samples were cut from the ingots, polished utilizing standard metallurgraphic techniques, then etched in Palmerston's chromic acid reagent. Amary-1 optical and JSM-840 scanning electron microscope were used to assess the modification degree of the primary α phase in the microstructure.

3 RESULTS AND DISCUSSION

3.1 Damping capacity

Table 2 shows the damping capacities of ZA27 alloys modified by various amounts of Al-5Ti-1B master alloy. According to Table 2, damping capacity vs Ti content curves were made (Fig. 1). Fig. 1 shows that the damping capacity of unmodified alloy ZA27 is 1.00×10^{-3}, the damping capacity increased with the increasing of Ti content and reached its highest level ($Q^{-1} = 1.80 \times 10^{-3}$) when the amount of Ti is 0.088%. Compared with the damping capacity of the unmodified ZA27 alloy, 80 percent increment was obtained. The damping capacity remains nearly constant when the Ti content is higher than 0.088%, so the 0.088% Ti is the most effective content to improve the damping capacity of ZA27 alloy.

3.2 Microstructures

The variance of damping capacity is related to the difference of microstructures. Fig. 2(a) shows the microstructure of as-cast ZA27 alloy with large dendrites of Al-rich primary α-phase (black), eutectic (α+ η) (gray) around the primary α-phase, non-equilibrium eutectic and β phase (light) in the regions. According to the Zn-Al phase diagram[8], solid solution β formed by a peritectic reaction at 443 ℃ is unstable and decomposes below 275 ℃ into α and η solid solution by a eutectoid reaction(Fig. 2(d)). Fig. 1 and Fig. 2 show that Al-5Ti-1B master alloy is an appropriate modifying agent, the addition of Al-5Ti-1B master alloy to ZA27 alloy is beneficial to refining the microstructure, it greatly decreases the grain size of the Al-rich primary α phase and transforms its dendritic structure to a fine petal-like one. Fig. 1 also shows the degree of modification increases with the increasing of Ti content to a certain level (0.088% Ti, 0.018% B), increasing Ti addition beyond this level does not produce any further grain refining. The changes in microstructure are associated with the addition of Al-5Ti-1B master alloy. After the Al-5Ti-1B master alloy modifying agent was added into Zn-Al melt and stirred, the Al-5Ti-1B master alloy dissoluted, $Ti(Al, Zn)_3$ crystals were formed during holding and/or cooling the melt before solidification, meanwhile, there were a lot of unmelted $TiAl_3$ and TiB_2 crystals in the melt. The lattice parameters of $Ti(Al, Zn)_3$, $TiAl_3$, TiB_2 are very near to that of the α phase[9, 10]. Thus, $Ti(Al, Zn)_3$, $TiAl_3$, TiB_2 are effective nucleators to ZA27 alloy, the Al-rich α phase can nucleate on the small crystals of these intermetallic compounds, and so the microstructure is refined.

Table 2 Effect of Ti content on damping capacity of ZA27

w(Ti)/%	0	0.025	0.053	0.088	0.131
$Q^{-1}/10^{-3}$	1.00	1.20	1.50	1.80	1.75

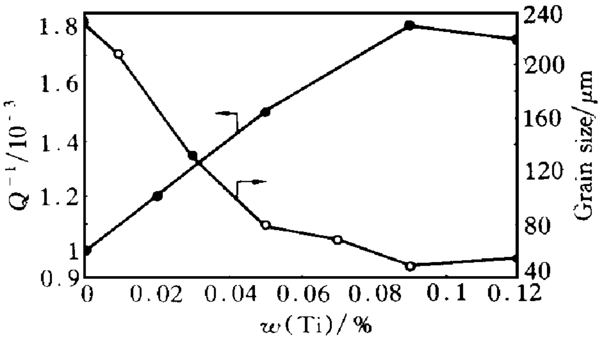

Fig. 1 Effect of Ti content on damping capacity and average grain size of primary α phase

3.3 Damping mechanism

In the metals and alloys, the damping may arise from thermoelastic damping, magnetic damping, viscous damping and defect damping. The first three types of damping generally result from the bulk response of a material; the fourth mechanism, defect damping, is an intrinsic source, stems from the internal friction exerted on atomic movement in the regions of defects in crystalline metals and alloys, and represents a large part of the overall damping of crystalline materials under conventional conditions[7, 11].

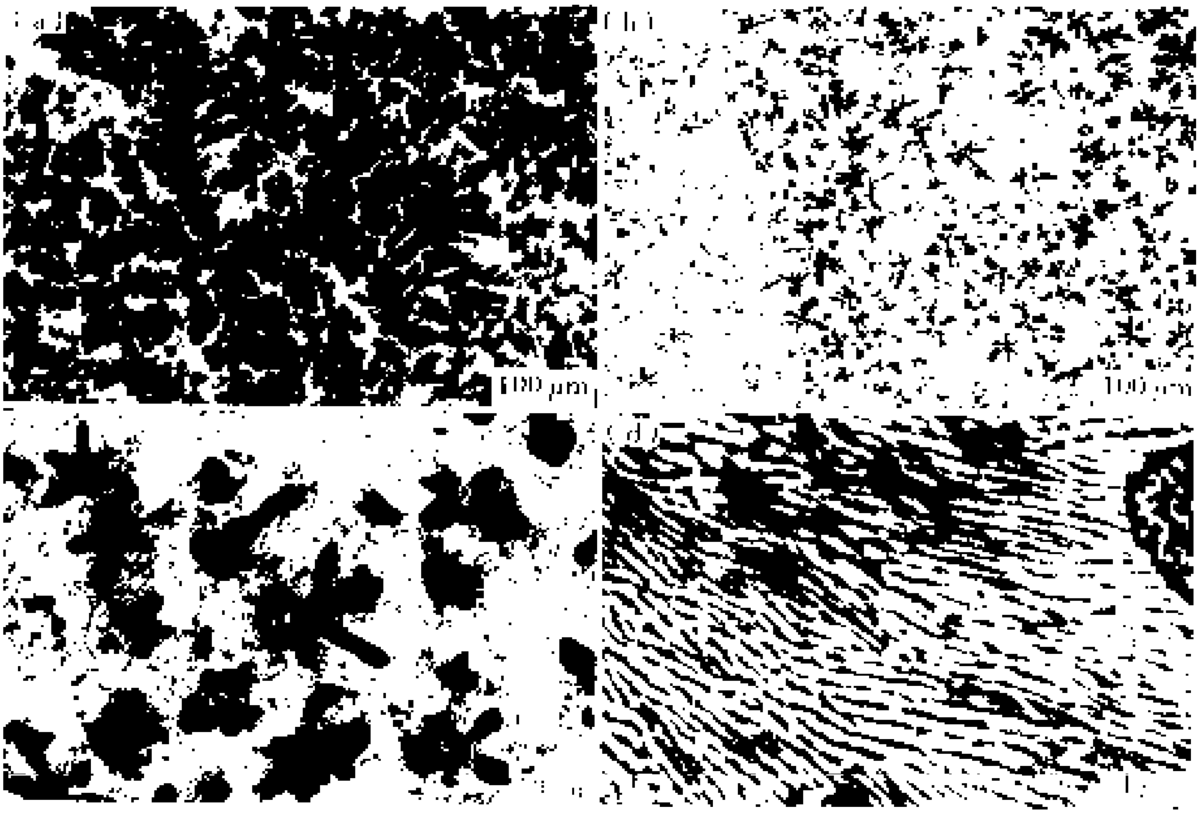

Fig. 2 SEM microstructures of as-cast ZA27 alloy
(a) —Unmodified; (b) —Modified with 0.053% Ti; (c) —Modified with 0.088% Ti;
(d) —Unmodified, showing the lamellar structure of eutectoid ($\alpha + \eta$)

Material damping is extremely sensitive to the presence of defects. According to the defectology, any type of defect will be a source to dissipate energy because of internal friction by the intrinsic movement of the defect under cyclic applied stress. The defects in polycrystalline metals and alloys include point defects (vacancies and disorders), line defects (dislocations), surface defects (grain boundaries and phase interfaces) and bulk defects (micropores and microcracks). Point defects give rise to damping in the range of low to intermediate levels, line defects give rise to damping levels in the intermediate to high range, and surface defects give rise to damping levels in the high range[12]. According to the previous studies[3, 13, 14], at the phenomenological level, the damping mechanism of ZA27 can be classified as the dynamic hysteresis mechanism. The dynamic hysteresis is produced by the stress-induced ordering of defects overcoming local barriers by thermal activation. The damping capacity of ZA27 alloy is associated mainly with the viscous sliding or slipping of grain boundaries and phase interfaces. The grain boundaries and phase interfaces bear the shear stress when the material is under cyclic loading, the phase interfacial slipping or the grain boundaries interfacial sliding may occur when the magnitude of the shear stress at the interface is sufficient enough to overcome frictional loads, and thus cause the frictional energy loss. The addition of Al-5Ti-1B master alloy to ZA27 alloy can refine the primary α-phase and grain size greatly, thus the area of grain boundary and phase interface are increased greatly, and so refined microstructure can lead to an increment in damping capacity greatly.

4 CONCLUSIONS

(1) Al-5Ti-1B commercially master alloy is a powerful modifier, it can greatly decrease the grain size of Al-rich primary α-phase and transform the dendritic structure to a fine petal-like one. The best modification effect can be obtained

at 0.088% Ti (0.018% B).

(2) The damping capacity increases with increasing the amount of Ti content. The highest damping capacity can be obtained at 0.088% Ti, and it is consistent with the most effective modification effect. The damping capacity of the alloy remains unchanged when the Ti content is higher than 0.088%.

(3) The damping mechanism of as-cast ZA27 alloy is dynamic hysteresis mechanism. It is associated with the viscous sliding or slipping of the grain boundaries and phase interfaces. The more the area of the grain boundaries and phase interfaces, the higher the damping capacity of ZA27 alloys can be obtained.

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