INFLUENCE OF CERIUM CONTENT ON DAMPING CAPACITIES OF AS-SPRAY DEPOSITED HIGH SILICON ALLOY ZA27①

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ABSTRACT To improve the damping capacity of metals and alloys, the microstructures and damping capacities of as-spray deposited high silicon alloy ZA27 modified by 0.3%, 0.5%, 0.7% cerium were studied. The microstructure of the alloy ZA27 is made up of fine lamellar eutectoid, porosity, light dot-like phase and polygonal silicon-rich phase. The damping capacities of the as-spray deposited alloy ZA27 modified by 0.5% cerium were greatly improved. The high damping capacities attributed primarily to phase interface thermoelastic damping between the lamellar phases with various crystal substructures, except for porosities and fine grain boundaries.

Key words spray deposition damping capacity cerium modification

1 INTRODUCTION

The damping capacity of a material refers to its ability to convert mechanical vibration energy into thermal energy. When utilized effectively in a structural application, this property allows undesirable noise and vibration to be passively attenuated and removed to the surroundings as heat or other forms of energy. Accordingly, material researchers have sought to improve the damping capacity of metals and alloys as serious competitors to traditional engineering alloys through the use of innovative processing techniques and alloying. In recent years high aluminum zinc-based alloys are widely used in industry for their good ambient temperature mechanical properties, damping capacities and wear resistance. At the meantime, spray deposition processing has received considerable attention for its potential to manufacture bulk rapidly-solidified materials. Yang *et al*[1-2] has developed a spray deposited high silicon alloy ZA27 (5% silicon), which possesses good high-temperature property and damping capacity. On the basis of his research achievements, the cerium modification and intrinsic damping mechanism of as-spray deposited high silicon alloy ZA27 were studied.

2 EXPERIMENTAL

2.1 Alloy design

According to the results of Shi[3], 0.3% cerium is the most effective content to refine grains on the condition of conventional casting. We know that under rapid solidification the solid solution limit of alloys is greatly widen in the non-equilibrium solidification. In order to contrast, three spray deposited materials with ceri-

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um contents of 0.3%, 0.5% and 0.7% were made to investigate the most effective cerium modification content under the condition of rapid solidification.

2.2 Materials synthesis

The alloy ZA27 utilized in present study was one of commercial grade, nominally composed of 27.0% Al, 2.0% Cu, 0.2% Mg and 70.8% Zn. The melting process were carried out as follows: firstly the prepared alloy was melted in a resistance furnace, at temperature of 530 ℃ 5% silicon was added into it; then heated the melt to 700 ℃, some Al-18% Ce master alloy were molten into it. For the purpose of composition homogenization the melt was superheated to 780 ℃, 15~20 min; finally lowered the melt temperature to 740 ℃ and transferred it into the middle package of the spray deposition equipment to get the deposits. In order to contrast, the ZA27 alloy with 5% silicon cooled in a permanent mould was also made.

2.3 Damping capacity measurements

The damping capacity of structural materials has been quantified by researchers using a broad assortment of instruments and scales of measure[4–5]. Commonly used units of measure such as inverse quality factor, Q^{-1}, logarithmic decrement, δ, are interchangeable with a proper conversion for cases of relatively low damping capacity. In this study, the measure of damping utilized is inverse quality factor. The temperature and frequency range of interest is 35~200 ℃ and 1~4 Hz, respectively.

The damping capacities and elastic modulus were determined using Multifunction Internal Friction Apparatus built by the Laboratory of Internal Friction and Defects in Solids of Chinese Academy of Science. The working principle of the equipment is shown in Fig. 1. Its maximum surface strain amplitude produced in the specimen may varies from 10^{-6} to 10^{-4}. Sample length between clamps was 70 mm.

In present study, the furnace temperature was increased at a rate of 2 ℃/min from 30 to 200 ℃ and the maximum surface strain amplitude of it produced in the specimen

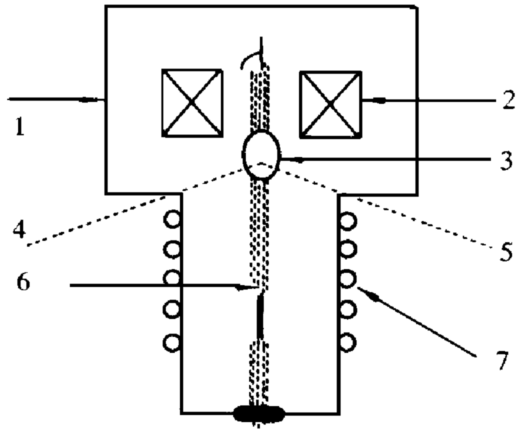

Fig. 1 Schematic diagram of multifunction internal friction apparatus (an inverse torsion pendulum)
1—vacuum chamber; 2—electromagnet; 3—mirror; 4—light source; 5—photocell; 6—specimen; 7—heaters

maintains 5×10^{-5}. During the temperature cycle, the sample was oscillated at two discrete frequencies of 1, 4 Hz. All of experiments were carried out in a vacuum chamber amounted to 0.11 Pa.

2.4 Microstructural characterization

Microstructural characterizations of the as-spray deposited high silicon alloys ZA27 containing 0.3%, 0.5% and 0.7% cerium were conducted on polished and etched samples utilizing standard metallographic techniques. Microstructure obversation and micro-zone composition analysis were carried out on a Hitachi S-2700 Scanning Electron Microscope.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Damping capacity

Typical sets of data corresponding to the as-cast high silicon ZA27, as-spray deposited high silicon ZA27 modified by 0.3%, 0.5%, 0.7% cerium are shown in Fig. 2. In each of the figures, the darkened symbols denoting elastic modulus and the light symbols denoting damping capacity for each of the two frequencies used.

Several interesting trends may be noted from Fig. 2, which are found to be characteristics of all the as-spray deposited high

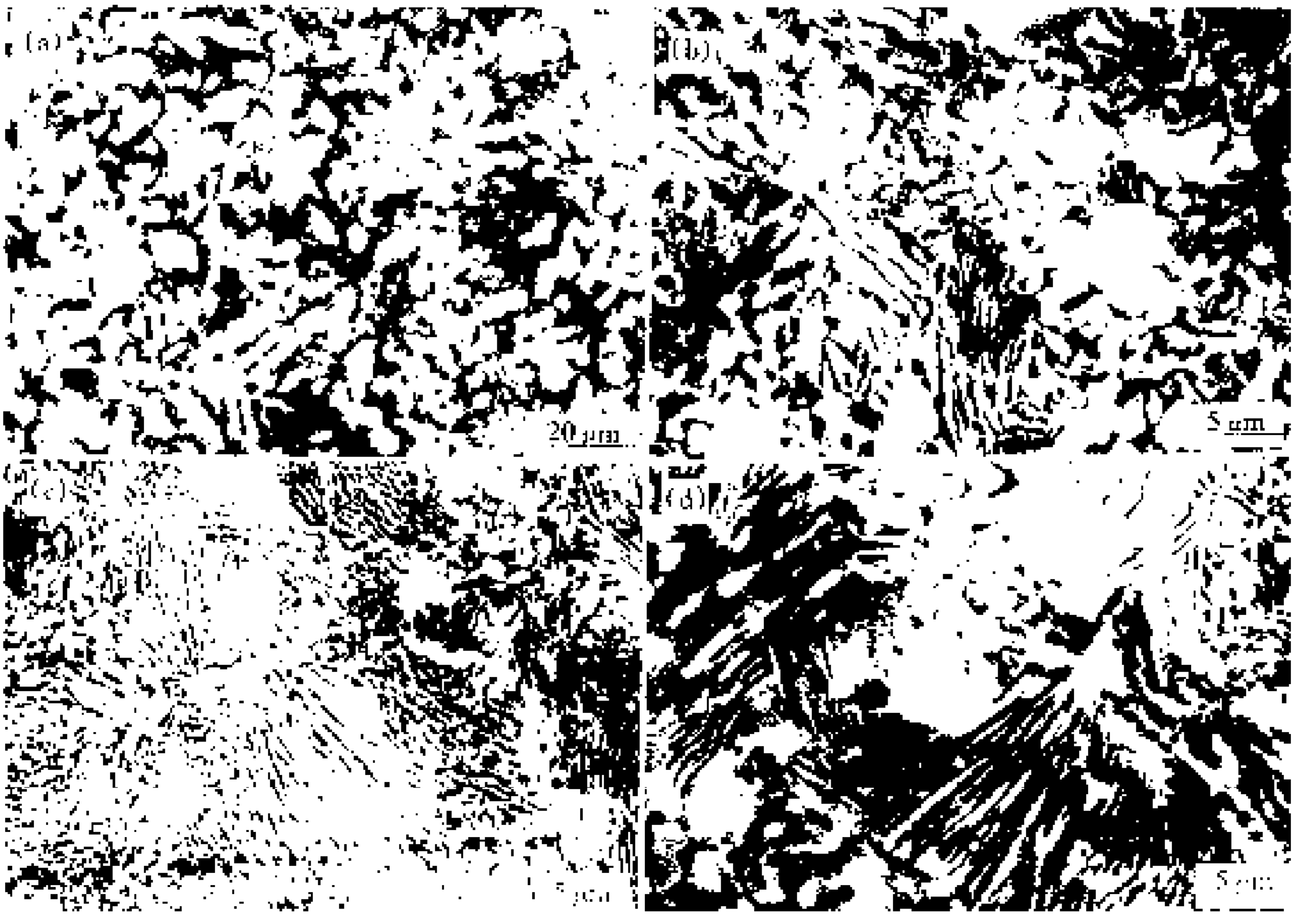

Fig. 2 Relationships among damping capacities, elastic modulus silicon alloy and temperature of material investigated

(a) —as-cast; (b) —modified by 0.3% Ce; (c) —modified by 0.5% Ce; (d) —modified by 0.7% Ce

○—1 Hz; △ —4 Hz

ZA27. First, the elastic modulus is seen to decrease in a linear fashion with temperature increasing. Next, the damping capacities have no frequency dependence below 80 ℃, while it is also found to rapidly increase with temperature increasing and frequency decreasing above 80 ℃. At last the as-sprayed high silicon ZA27 alloy modified by 0.5% cerium has the largest damping capacity value among them.

3.2 Microstructures

The variance of damping capacity is related to the difference of microstructures (Fig. 3). All of microstructures of spray deposited high silicon ZA27 alloy are made up of porosity, fine lamellar eutectoid, light dot-like phase and polygonal silicon-rich phase. The as-spray deposited high silicon ZA27 alloys modified by 0.3%, 0.7% cerium are coarser than that modified by 0.5% cerium, so the addition of 0.5% cerium is the most effective content to the as-spray deposited high silicon ZA27 alloy. Comparing with the conventional cast high silicon ZA27 alloy, a large amount of lamellar eutectoid phase appeared and their number increased and size decreased. There are two main factors influencing the form of lamellar eutectoid, one is the atomizing and rapid solidification process that increased the actual nucleating and undercooling; the other is the effect of cerium modification. The existence states of cerium in the alloy have two forms, solutionizing and forming high melting point $Al_{11}Ce_3$[6] phases. (Table 1). These $Al_{11}Ce_3$ phases have similar crystal structure with primary α (Al) phases whose surfaces (011), $(\bar{0}11)$ parallelto the surfaces (110), $(\bar{1}10)$, respectively.

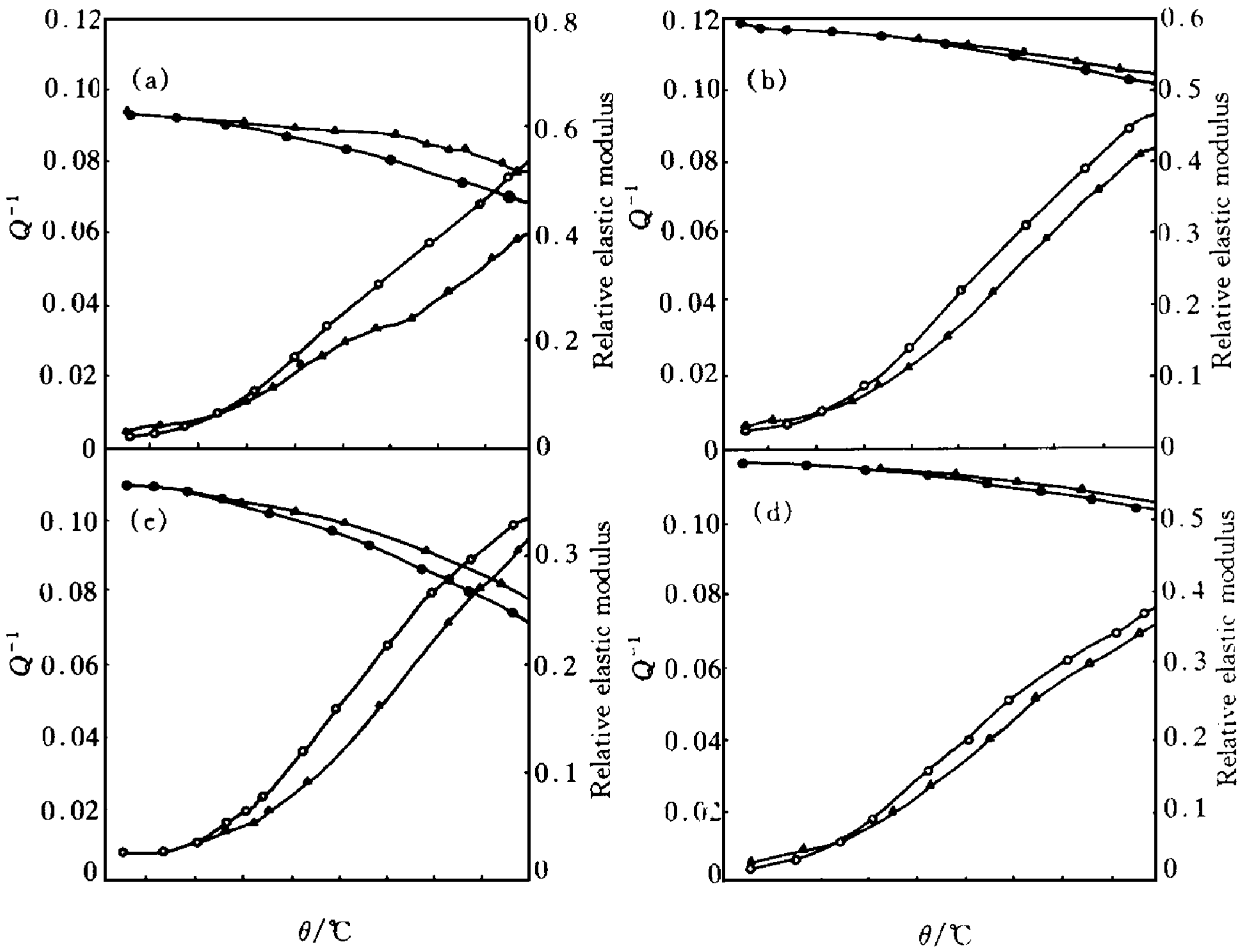

Fig. 3 Microstructure of as-spray deposited high silicon alloys ZA27 investigated
(a) —no modified, as-cast; (b) —modified by 0.3% Ce;
(c) —modified by o.5% Ce; (d) —modified by 0.7% Ce

Table 1 Micro-zone composition of as-spray deposited high silicon ZA27 alloy (modified by 0.5% Ce) (%)

Element	Average	Light dot-like phase	Lamellar eutectoid	Polygonal Si-rich phase
Al	33.068	55.550	54.865	17.102
Si	6.242	7.755	4.462	17.777
Ce	1.458	2.607	0.508	27.915
Fe	0.750	1.376	0.423	0.395
Cu	1.929	5.379	3.391	6.225
Zn	56.535	31.433	36.350	30.586

This particular crystal structure promotes the first α(Al) phases to nucleate on the cerium-rich phase. At the flying stage of droplets, a large cooling rate was achieved by the strong heat exchange between the droplets and ultrasonic gas, while deposition on substrate the heat conductivity was limited by the heat dissipation of the substrate. The change of cooling rate from rapid to slow is beneficial to the formation of fine lamellar eutectoid phases.

3.3 Damping mechanisms

A variety of mechanisms may contribute to the overall damping behavior of metals and alloys. These may include effects due to thermoelasticity, crystallographic defects, eddy current, Snoeck effects, stress-induced odering, etc[6, 9]. There is no peak phenomena observed in the as-spray deposited materials in the temperature range 30~ 200 ℃. The following discussion will address the factors which are thought to have been active in the as-spray deposited materials.

3.3.1 Porosity

Defects which may be present in crystalline materials include point defects (vacancies), line defects (dislocation), surface defects (grain boundary and phase interface) and bulk defects (micrometer-sized pore and microcrack). The microstructural results of the present study revealed a distribution of micrometer-sized pores (less than 5% (in volume)) in the as-spray deposited materials. The larger the amount of the micro-sized pores, the higher the damping capacities of the as-spray deposited materials. In the present study all process parameters are the same, so the amount of micrometer-sized pores maintains a fixed value.

3.3.2 Grain boundaries

Discussion on grain boundary viscosity, relaxation, and anelasticity in polycrystalline metals by Ke, Lazan, Nowick *et al* have indicated that viscous flow at grain boundaries will serve as a source of internal friction. The energy dissipated in the boundaries is dependend on temperature, the shear stress, and the anelastic shear strain. In view of this, the fine grain microstructure of the as-spray deposited material may play an important role in the dissipation of elastic strain energy in the upper range of the investigated temperature. The variance of damping capacities between the as-cast and as-spray deposited high silicon alloy ZA27 could prove it.

3.3.3 Phase interfaces

Except for the porosity and fine grain boundaries, the very fine lamellar interfaces also play a primary role to the improvement of the damping property. The lamellar eutectoids are composed of zinc-rich and aluminum-rich phase whose crystal substructure are *hcp* and *fcc* respectively. The substructure of *hcp* possesses more sliding directions than that of *fcc* with temperature increasing, the thermal expansion coefficient gap between various substructure broadened, the high damping capacity attributed primarily to interface mismatch-induced dislocations between the lamellar phases with various crystal substructure. The variance of damping capacity between the as-spray deposited high silicon ZA27 alloy with different modification effects could proved it.

4 CONCLUSION

The addition of 0.3%, 0.5%, 0.7% cerium to as-spray deposited high silicon ZA27 alloy are beneficial to refine the grain and lamellar eutectoid. The microstructure of the as-spray deposited high silicon ZA27 alloy was made up of porosity, finer lamellar eutectoid, light dot-like phase and polygonal silicon-rich phase, the finer the lamellar eutectoid, the higher the damping capacity of materials. The addition of 0.5% of cerium to the alloy is the most effective content to the as-spray deposited high silicon ZA27 alloy. Two reasons of fine lamellar phases forming are given, one is the influence of cerium modification to the solidification processing, the other is the cooling rate change of the atomized droplets from rapid to slow during atomizing and deposition.

Except for the porosity and fine grain boundaries, the very fine lamellar eutectoids and phase interface play a primary role to the improvement of the damping property. The lamellar eutectoids are composed of zinc-rich and aluminum-rich phase whose crystal substructure are *hcp* and *fcc* respectively. The probable sliding directions of substructure *hcp* is more than that of *fcc*. Therefore the high damping capacity attributed primarily to interface mismatch-induced dislocations between the lamellar phases with various crystal substructure.

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