Damping characteristics of cast irons with aluminum addition

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Cast iron can exist in a great number of different forms depending on the chemical composition, the degree of nucleation of the melt, and casting conditions. If the carbon equivalent is suitable or if there are appreciable quantities of graphite stabilizing elements, then the carbon solidifies mainly as free graphite. These types of alloyed cast irons have useful engineering properties, such as good castability, heat resistance, and machinability [1].

Recently, several studies have focused on the development of eco-circulation materials by recycling the used steel drink cans, which have both high heat resistance and good wear resistance [2]. Cast irons with high aluminum contents are under consideration for practical applications as machine tool parts because of their excellent properties, such as high damping capacity, in spite of their poor mechanical properties caused by high graphite content [3]. However, there have been few works on the comprehensive damping characteristics of cast irons with aluminum additions.

In the present work, the comprehensive damping capacities of cast irons with aluminum additions were investigated by three methods. The first method of free-decaying oscillation is used to measure the damping capacity at room temperature [4]. Secondly, the spectrum of damping capacity with temperature is acquired using a model 2980 dynamic mechanical analysis (DMA) [5]. Thirdly, the ultrasonic attenuation at high frequencies is measured by using ultrasonic echo waves [6]. In the three methods, the damping capacities of cast irons are evaluated by the logarithmic decrement (δ), the tangent of phase lag (ϕ), and the attenuation coefficient (α), respectively.

The compositions of the cast iron specimens used in the experiments are listed in Table I. High purity iron, carbon, silicon, and aluminum (purity better than 99.9%) were used to prepare the samples. The melting process was carried out in an induction-melting furnace and then the melts were cast into sand molds. For the measurement of free-decaying oscillation, the samples were cut into bars of 150 mm × 10 mm × 1 mm. Samples for DMA measurements were 60 mm × 10 mm × 1 mm. For the measurement of ultrasonic attenuation, the surface grinding of samples was carried out to obtain specimens of 5.5 ± 0.1 mm thickness and 30 ± 0.1 mm diameter with plane parallelism to an accuracy of better than ±0.5 μm. In addition, the etched microstructures were examined using an optical microscope.

TABLE I Chemical composition of the cast iron samples (wt.%)

Sample	C	Si	Al	Fe
1	3.2	2.4	0	Bal
2	3.2	2.4	6	Bal

Fig. 1 presents the microstructures of the two cast irons. Fig. 1(a) is the microstructure of cast iron without aluminum, in which the dispersed white parts are the primary phase (austenitic-phase). Due to the large constitutional supercooling in front of the liquid–solid interface in the residual melt, fine flake graphite solidified through the eutectic reaction. Fig. 1(b) shows the microstructure of the cast iron with the aluminum addition. Initially, dendritic $Fe_3AlC_{0.5}$ carbide formed; this is a very hard structure [7]. Because the residual melt was very close to the eutectic composition when aluminum was added [8], the constitutional supercooling in front of the liquid–solid interface was small. Consequently, coarse flake graphites formed and, within a eutectic cell, these coarse flake graphites connected with each other.

Fig. 2 shows the relationship between the damping capacity and the maximum surface strain in cast irons without and with aluminum addition. It is obvious that with increase in strain amplitude, both of the damping capacities increase. However, the change in damping capacity is different for the two compositions. For cast iron with aluminum, the damping capacity increased markedly to a maximum of 0.077. On the contrary, the damping capacity of cast iron without aluminum is nearly independent of strain amplitude.

Fig. 3 gives the spectra of damping capacity with temperature for both cast irons. With aluminum addition, the background damping capacity of the cast iron increases significantly. The two damping peaks, P_1 and P_2, near the temperatures of 170 K and 240 K in both cast irons are associated with dislocations [9].

The ultrasonic attenuation as a function of frequency is presented in Fig. 4. It can be seen that the ultrasonic attenuation in both cast irons increases with frequency. For the same frequency, the ultrasonic attenuation in

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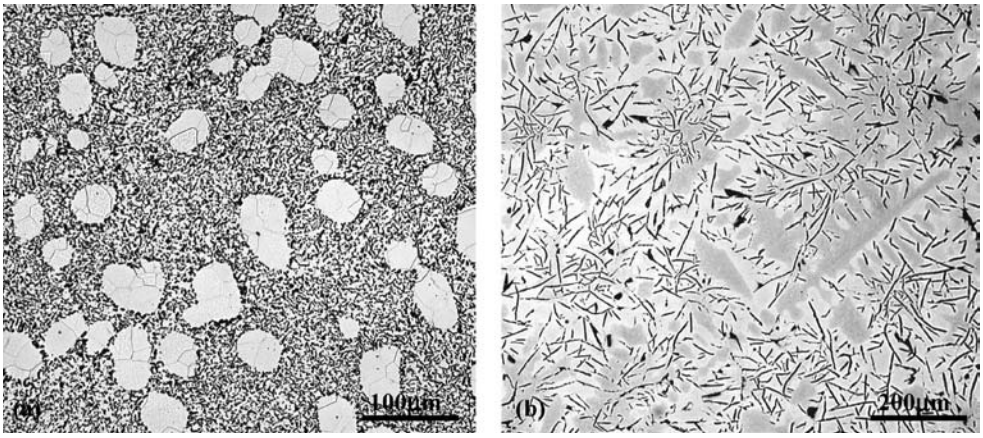

Figure 1 Microstructures of cast irons with (a) no aluminum addition and (b) 6 wt.% aluminum.

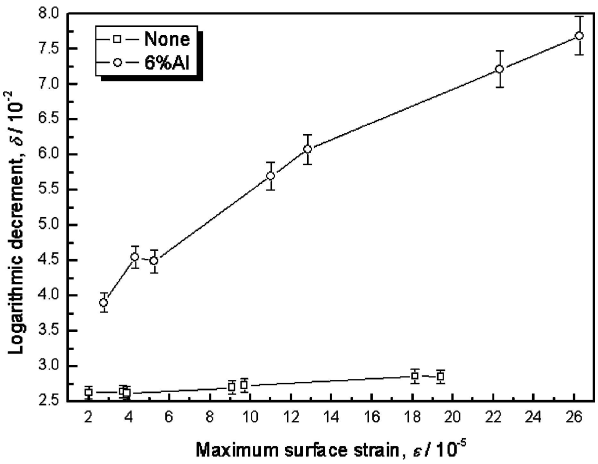

Figure 2 Logarithmic decrement as a function of maximum surface strain in cast irons without and with aluminum.

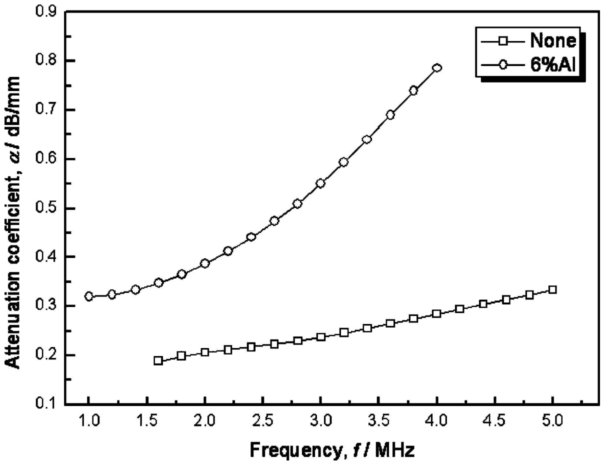

Figure 4 Ultrasonic attenuation as a function of frequency in cast irons without and with aluminum.

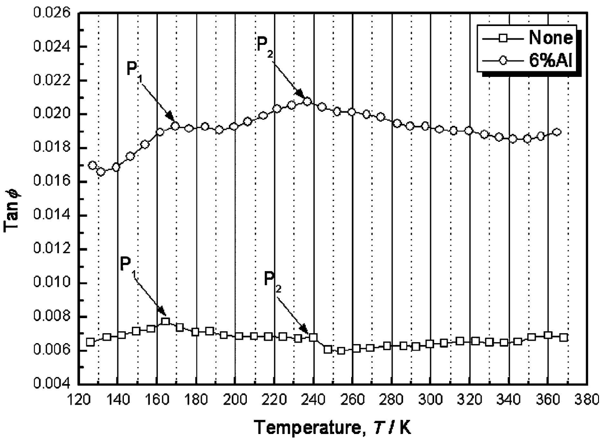

Figure 3 Damping capacity as a function of temperature in cast irons without and with aluminum at 0.1 Hz.

the cast iron with aluminum is larger than that in the cast iron without aluminum. Also, at high frequencies, the rate of increase of the ultrasonic attenuation in the cast iron with aluminum is more rapid than in the cast iron without aluminum.

Generally, material properties are determined by microsctructure. The measurements of the free-decaying oscillation and DMA indicated that with aluminum addition, the damping capacity of the cast iron increased markedly. According to recent investigations [10], the energy dissipation in cast irons is dominated by the graphite rather than the matrix. It can be deduced that with aluminum addition, the large damping capacity was mainly due to the network of coarse flake graphite within a eutectic cell. Moreover, the formation of the hard $Fe_3AlC_{0.5}$ carbide, meant that there were always many defects on the boundaries between that phase and the matrix, which further promoted the damping capacity.

Attenuation during the propagation of an ultrasonic wave in a solid material results from the absorption loss plus the scattering loss. The absorption process which includes the internal friction caused by the zero- to three-dimensional lattice defects and the thermoelasticity is linearly dependent on frequency [11]. However, the scattering loss is particularly influenced by phase boundaries. If the dimension of the phase or grain is much smaller than the ultrasonic wavelength, the scattering loss shows a cubic dependence on the size and a four-fold dependence on frequency [12]. Therefore, the large absorption loss (with aluminum addition) was due to the defects on the boundaries between the hard $Fe_3AlC_{0.5}$ carbide and the matrix. Meanwhile, the scattering loss increased markedly on account of the network of coarse flake graphites. As a result, the ultrasonic attenuation of the cast iron with aluminum addition is much larger than that of cast iron without aluminum and has a significant rate of increase at high frequencies.

In this study, the damping capacities of cast irons without and with aluminum addition were investigated by the three methods of free-decaying oscillation, DMA, and ultrasonic echo waves. The experiments show that with aluminum addition, the damping capacity of cast iron increases significantly, primarily as a result of the graphite morphology, and in particular the network of coarse flake graphites.

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References

1. M. REZVANI, R. A. HARDING, *et al.*, *Int. J. Cast Metals Res.* **10** (1997) 1.
2. S. TAKAMORI, Y. OSAWA, *et al.*, *Mater. Trans. JIM* **43** (2002) 311.
3. K. C. RUSSELL and D. F. SMITH, "Proceedings of an International Conference on Physical Metallurgy of Controlled Expansion Invar-Type Alloys", Las Vegas, TMS, February 27–March 3 (1998).
4. F. X. YIN, Y. OHSAWA, *et al.*, *Mater. Trans. JIM* **42** (2001) 385.
5. F. X. YIN, S. TAKAMORI, *et al.*, *ibid.* **43** (2002) 466.
6. E. P. PAPADAKIS, *J. Appl. Phys.* **42** (1971) 2990.
7. A. RADHAKRISHNA, R. G. BALIGIDAD and D. S. SARMA, *Script. Mater.* **45** (2001) 1077.
8. S. TAKAMORI, T. KIMURA and Y. OSAWA, *J. Jpn. Foundry Eng. Soc.* **74** (2002) 3.
9. P. MILLET, R. SCHALLER and W. BENOIT, *J. Phys.* **46** (1985) C10 405.
10. J. R. DRYDEN and G. R. PURDY, *Acta Metall.* **37** (1989) 1999.
11. W. P. MASON and H. J. MCSKIMIN, *J. Acoust. Soc. Am.* **19** (1947) 464.
12. A. B. BHATIA and R. A. MOORE, *ibid.* **31** (1959) 1140.

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