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The effect of aluminum addition on the damping capacity of cast iron

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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 the free graphite. These types of alloyed cast irons have useful engineering properties, such as good castability, heat resistance, and machinability [1, 2].

Recently, several studies have focused on the development of ecocirculation materials by recycling the used steel drink cans in foundries, which have both high heat resistance and good wear resistance [3]. Cast irons containing high aluminum element 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 [4]. However, few works have been carried out in detail to study the influence of the addition of aluminum upon the damping capacity of cast iron. Therefore, it is necessary to study the damping capacity of cast iron with the added aluminum.

In the present work, the effects of aluminum addition on damping capacity of cast iron were investigated in detail. Meanwhile, in order to analyze the damping mechanism, the microstructure of cast iron was also investigated.

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 samples. The melting process was carried out in an induction-melting furnace and then the melts were cast into the sand mold. Damping capacity of sample was measured by the free-decaying oscillation method. Fig. 1 presents the centrally excited beam system for damping measurement. EMIC 512-D electromagnetic exciter was used, which had the maximum exciting force of 49N when the frequency was smaller than 30 000 Hz. The Onosokki CF-5200 fast Fourier transforming (FFT) analyzer was used for supply exciting signals to the exciter and analyze the output data from the impedance transducer or the strain signal form the strain gage pasted to the sample surface. Before the damping measurement, the samples were cut into beam shapes, and then were symmetrically bonded to the Titanium supporting chip with an adhesive. The damping capacity was evaluated in a logarithmic decrement (δ) as follows:

$$\delta = \ln(A_n/A_{n+1}) \quad (1)$$

where A_n and A_{n+1} represent the surface strain amplitudes of the nth and $n + 1$th cycles in free decay, respectively.

The unetched microstructures were examined by an optical microscope. In addition, differential thermal analyzer (DTA) was used to determine phase transformation and phase composition.

Usually, the solidification sequence of various phases can easily be deduced by their microstructure morphologies [5]. Fig. 2 presents two types of microstructure morphologies of the cast iron with different compositions. Fig. 2a is the microstructure of cast iron without aluminum. In this picture, it can be clearly seen that the dispersed white parts represent primary phase, while the fine flake phase is graphite. According to the following DTA curves in Fig. 3a, the primary phase is initial austenitic phase. It indicated that the graphite is not directly formed from melts without aluminum and solidified through a eutectic reaction in the residual melts. Fig. 2b shows the microstructure of cast iron with aluminum addition. It is mainly composed of the dispersed coarse flake graphite and the mixing matrix of gray pearlitic around the graphite and ferrite. In this case, the graphite crystallized directly from melts through an eutectic reaction, which can be seen in the DTA curve in Fig. 3b.

The differential temperature analysis (DTA) curves of the samples with different compositions are given in Fig. 3. Fig. 3a shows that the eutectoid reaction and the eutectic reaction in the cast iron without aluminum occur at the temperatures, 1083.1 and 1441.2 K, respectively. In the cast iron with aluminum, these reaction temperatures, which can be seen in Fig. 3b, are 1226.7 and 1493.2 K, respectively. It indicated that because of aluminum addition, the temperatures of both the eutectoid reaction and the eutectic reaction, simultaneously increase. In addition, according to the peak areas of the eutectoid reaction and the eutectic reaction, it can be seen that the peak areas of the cast iron with aluminum are smaller than those of the cast iron without aluminum. According to the knowledge of DTA analysis, the peak area denotes the endothermic degree of the phase transformation. Therefore, it can be deduced that the graphite content of cast iron

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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.

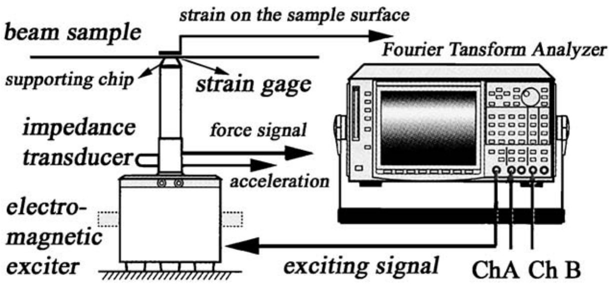

Figure 1 Schematic diagram for the measurement of damping capacity in a centrally excited resonant beam sample.

with aluminum is larger than that of cast iron without aluminum.

Fig. 4 gives the relationship between the damping capacity and the maximum surface strain in the cast irons with different compositions. It can be seen that with increase of the surface strain, the damping capacity correspondingly increases. However, the increase in the degree of damping capacity in the cast iron with aluminum is larger than that of the cast iron without aluminum, and the damping capacity in cast iron with aluminum is larger than that of the cast iron without aluminum when both surface strains are close.

It can be seen that with the addition of aluminum, the microstructure and damping capacity of the cast iron varied. The results of these experiments indicate that the graphite of cast iron without aluminum is not a primary phase. Therefore, the fine flake graphite formed through a eutectic reaction in the residual melts. With addition of aluminum, the morphology of the graphite varied from the fine flake to coarse flake structures, which could be caused by the direct solidification of graphite from melts. Furthermore, the results of the damping measurements showed that the damping capacity of the cast iron with aluminum is larger than that of the cast iron without aluminum.

Generally, the material properties are determined by its microsctructure and the microstructure depends on the solidification behavior of the material. The above-mentioned experiments showed that because of the different solidification microstructures, the damping capacity of the cast iron varied greatly. Therefore, it indicated that aluminum addition changes the solidification process of the cast iron.

Neumann and Schenk [6, 7] and Burylev [8] have studied the influence of the third element additons on the solubility of carbon in the eutectic iron-carbon melts. They found that a linear relationship between the added element in molar fraction and the change in solubility of carbon exists. The influence of the addition X element on solubility of carbon in eutectic iron-carbon melt can be expressed as,

$$\Delta\%C^{(\mathrm{X})} = m'/ \cdot \%X \tag{2}$$

where $\Delta\%C^{(\mathrm{X})}$ is the change in solubility of carbon in the eutectic iron-carbon melt due to addition of the X element, m' constant. For the aluminum and silicon elements, the values of m' constants are -0.22 and -0.29, respectively [7, 8]. It indicated that both aluminum and silicon are the graphite-stabilizing elements and their effects are very close. The previous experiments [9] showed that with the silicon addition, the temperatures of both the eutectoid reaction and the eutectic reaction increase, and the composition of the eutectic reaction shifts left. According to these facts, it can be concluded that the same effect of aluminum addition occurs in the cast iron. The above results of DTA analyzes of the cast irons with and without aluminum further confirmed that the conclusion is true.

Besides, the above experimental results showed that the damping capacities of the cast iron with and without aluminum are different. Though there are large interfaces between the fine flake graphite and the matrix in the cast iron without aluminum, the damping capacity is smaller than that of the cast iron with aluminum. If the damping was caused by the microplastic deformation at the stress concentrations in the matrix around the graphite, the damping capacity of cast iron without aluminum ought to be larger than that of the cast iron with aluminum. Therefore, it indicated that the energy dissipation occurs principally within the graphite rather

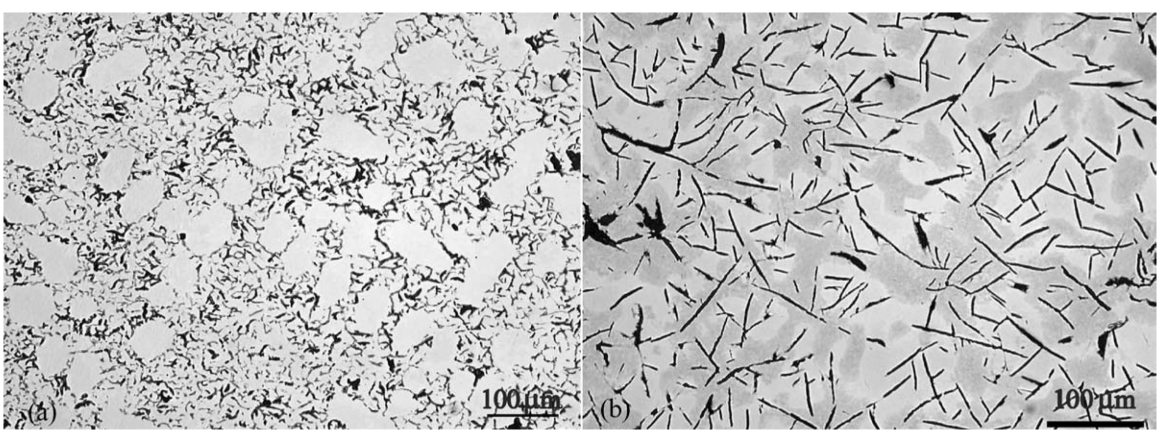

Figure 2 Microstructures of cast iron with aluminum addition: (a) no aluminum and (b) 6% aluminum.

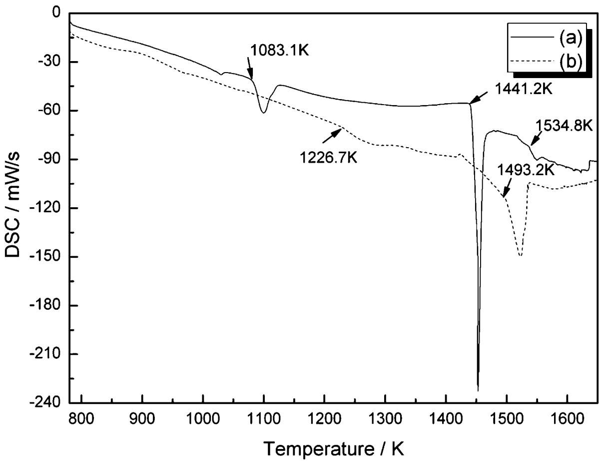

Figure 3 DTA-heating curve obtained from cast iron with aluminum addition: (a) no aluminum and (b) 6% aluminum.

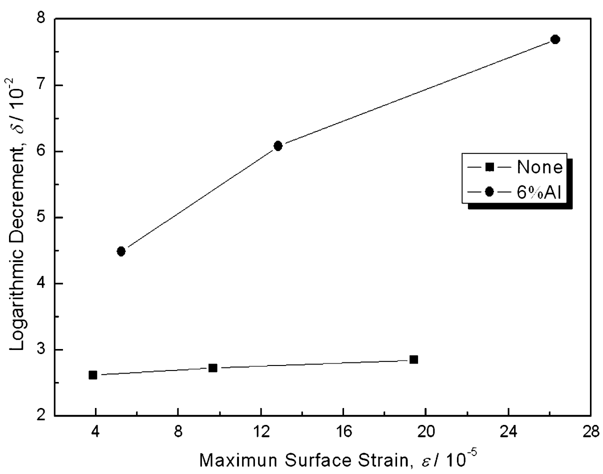

Figure 4 Damping capacity as a function of maximum surface strain in both cast iron samples.

than the matrix. The coarser the flake graphite content, the stronger the damping capacity, consequently. According to Fig. 4, it indicated that the damping capacity of cast iron is dependent not only on the microstructre but also on the strain. The total damping capacity, δ_{total} can be given by:

$$\delta_{\text{total}} = \delta_0 + \Delta\delta_{\text{gr}} + \Delta\delta_{\text{st}} \tag{3}$$

where δ_0 is the background damping of the cast iron, $\Delta\delta_{\text{gr}}$ change of damping capacity due to graphite and $\Delta\delta_{\text{st}}$ change of damping capacity due to strain.

From Equation 3, the total damping capacity of cast iron, δ_{total}, consists of three parts which are δ_0, $\Delta\delta_{\text{gr}}$, and $\Delta\delta_{\text{st}}$. Since the values of δ_0 in all cast irons are close [10] and $\Delta\delta_{\text{st}}$ is only determined by the measuring condition, δ_{total} is strongly related to the value of $\Delta\delta_{\text{gr}}$. The coarser the flake graphite and the higher the graphite content, the larger the change of damping capacity due to graphite, $\Delta\delta_{\text{gr}}$, consequently, which should lead to an increase of the damping capacity of cast iron.

In this study, the influence of aluminum addition on the microstructure and damping capacity of cast iron was investigated. With the aluminum addition, the microstructure varied from the fine flake graphite to the coarse flake graphite and the damping capacity correspondingly increases. According to the microstructure and DTA analysis, the coarse flake graphite formed directly from melts with the added aluminum is caused by the left shift of the composition of the eutectic reaction. Based on the analyzes of the damping mechanism, it indicated that the damping capacity of cast iron is mainly dependent on the graphite shape and content. The coarser the flake graphite and the higher the graphite content, the larger the damping capacity of cast iron.

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References

1. M. REZVANI and R. A. HARDING, *et al.*, *Int. J. Cast Metals Res.* **10** (1997) 1.
2. B. M. MOON and C. P. HONG, *J. Mater. Sci.* **33** (1998) 2875.
3. S. TAKAMORI, Y. OSAWA, *et al.*, *Mater. Trans. JIM.* **43** (2002) 311.
4. K. C. RUSSELL and D. F. SMITH, in Proceedings of an International Conference on Physical Metallurgy of Controlled Expansion Invar-Type Alloys, Las Vegas, TMS, Feb. 27–Mar. 3 (1998)
5. A. P. TSAI, A. FUJIWARA, *et al.*, *Phil. Mag. Lett.* **74** (1996) 233.
6. F. NEUMANN, H. SCHENK, *et al.*, *Giesserei* **47** (1960) 47.
7. F. NEUMANN and H. SCHENK, *ibid.* **14** (1962) 21.
8. BURYLEV, *Chernaya Metallurgiya* **3** (1964) 7.
9. W. OLDFIELD, *B. C. I. R. A. Journal* **10** (1962) 17.
10. R. D. ADAMS and M. A. O. FOX, *J. Iron and Steel Int.* **37** (1973) 4028.

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