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Solidification sequence of ductile cast iron - In-situ observation and modeling -

Hideyuki Yasuda[1], Akira Sugiyama[2], Tomoya Nagira[3], Kohei Morishita[1], Masato Yoshiya[3], Tomohiro Nishimura[1] and Koshiro Yamane[4]
[1] Department of Materials Science and Engineering, Kyoto University, Japan
[2] Osaka Sangyo University, Japan
[3] Department of Adaptive Machine Systems, Osaka University, Japan
[4] IHI Master Metals, Japan

Radiography was performed to examine solidification and melting behaviors in hypereutectic cast iron specimens with / without Mg addition. The specimens without Mg addition showed that graphite particles exhibited spherical shape at the beginning and then transformed to the flake-like shape. Growth of γ-Fe dendrites was followed by nucleation of graphite particles ahead of the eutectic front. In contrast, growth of graphite particles and γ-Fe dendrites occurred nearly at the same time in the specimens with Mg addition and the spherical graphite particles were engulfed by γ-Fe or eutectic. The addition of 0.05mass%Mg significantly reduced the temperature range in which the graphite particles grew as the primary phase. Image-based analysis of melting behavior clearly proved that even 0.05mass% addition modified the phase equilibrium of the liquid, γ-Fe and graphite phases.

Keywords: *Radiography, X-ray imaging, spheroidal graphite, cast iron*

1. Introduction

Small addition of Ce or Mg to hypereutectic cast iron changes morphology of graphite particles from a flake shape to a more compacted / spheroidal shape [1-2]. The solidification sequence in the cast iron is rather complicated [3]. The shape of graphite particles transforms from lamellar graphite in a coupled eutectic structure to compacted graphite, and from compacted graphite to spheroidal graphite in the divorced eutectic structure with increasing Mg or Ce content in the melt [3-5]. The results show that the divorced eutectic growth is normally selected in the melt containing Mg or Ce. However, it is still unclear how the solidification proceeds in the melt with / without Mg and the spheroidal graphite particles form.

In recent years, radiography using synchrotron radiation X-rays has enabled to the observation of solidification in metallic alloys. The technique has been developed for observing solidification of Fe-based alloys [6]. The solidification of the cast iron with hypoeutectic composition [7] and the hypereutectic compositions were observed [8-10].

This paper demonstrates the solidification sequence in the hypereutectic cast iron with and without Mg [8-9]. Second, the influence of Mg on the phase equilibrium (liquid phase, γ-Fe and graphite) is presented [10].

Table 1 Compositions of specimens (mass%).

Sample	C	Si	Mn	Mg	S	CE
0.05Mg	3.73	2.57	0.45	0.05	0.004	4.59
0.002Mg	3.69	2.71	0.45	0.002	0.004	4.59

2. Nucleation and growth of graphite

Table 1 lists initial compositions of the specimens used for the radiography. The carbon equivalent values, which is calculated by [mass%C] + [mass%Si] / 3, are 4.59 for both specimens. Figures 4 (a) and (b) show the solidification structure in 0.002Mg and 0.05Mg at 0.17K/s [9], respectively.

In 0.002Mg (Fig. 1(a)), graphite particles were spheroidal just after the nucleation events. The transition to the flake-like shape was observed at t>-99s. γ-Fe dendrites were immediately followed by the eutectic solidification (γ-Fe and graphite. referred to as the eutectic). In addition, a number of graphite particles nucleated ahead of the eutectic front even though the primary graphite particles were pre-existing.

Different solidification structures were observed in 0.05Mg (Fig.1(b)). Nucleation of graphite particles and dendrites of γ-Fe occurred nearly at the same time and they grew independently. Nucleation events of the primary graphite particles continuously occurred until the eutectic solidification commenced. The graphite particles with spherical shape grew for 20s and then were engulfed by the eutectic front. In 0.05Mg, the temperature range in which the graphite particles grew

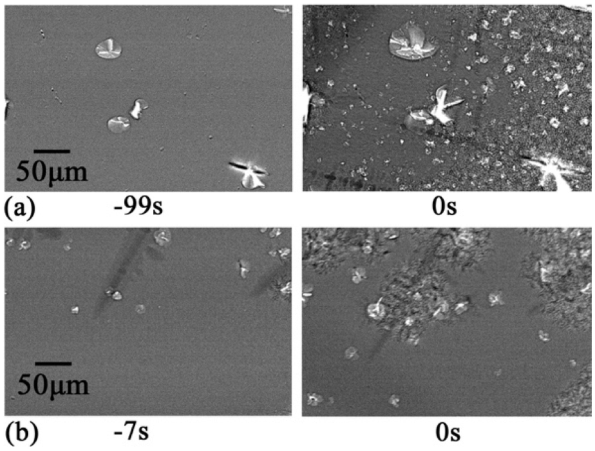

Fig. 1 Solidification (a) in 0.002Mg at 10K/s and (b) in 0.05Mg at 10K/s [9]. Time is designated 'zero' when the eutectic solidification front reached the center of observation area.

independently was only 3-4K. In addition, the nucleation frequency of graphite particles in 0.05Mg was approximately three times larger than that in 0.002Mg.

3. Influence of Mg on phase equilibrium

There are two possible explanations for the decrease in the temperature range of the primary graphite particles; one is modification of phase equilibrium (thermodynamic influence) and the other inhabitation of graphite nucleation (kinetic influence). However, the inhibiting conflicts with the promotion of graphite nucleation (Fig.1(b)).

A thermal image analysis [10] was performed to examine the Mg influence. During the heating procedure (0.194K/s), a part of the specimen was locally melted but the melting region was not extended only in the 0.05Mg specimen. Melting of matrix was immediately followed by melting of graphite particles in 0.05Mg. On the other hand, melting of the matrix started and melting of graphite was hardly observed in 0.002Mg. The addition of 0.05mass%Mg slightly decreased the eutectic temperature (6K) and largely decreased the liquidus temperature (45K). The difference between the liquidus and the eutectic temperatures was estimated to be 56 K for 0.002Mg and 17 K for 0.05Mg, respectively. The differential image analysis proved the thermodynamic influence of Mg largely reduced the difference between the liquidus and the eutectic temperatures.

4. Summary

The addition of 0.05mass%Mg significantly caused a significant increase of the graphite nucleation events and decreased the temperature range in which the primary graphite particles grew independently. The solidification sequence in 0.002Mg is 1) "L » Gr", 2) "L » Gr " + "L » γ" (divorced eutectic), 3) "L » Gr" + " L » γ" + "L » Gr" (divorced eutectic) and 4) "L » γ + Gr " (coupled eutectic). For 0.05Mg, 1) "L » Gr" or "L » γ", 2) "L » Gr" + "L » γ" (divorced eutectic), 3) "L » Gr" + "L » γ" + "L » Gr" (divorced eutectic) and 4) "L » γ + Gr" (coupled eutectic). The differential image analysis demonstrated the influence of Mg on the phase equilibrium. The addition of 0.05mass% Mg decreased the eutectic temperature slightly and the liquidus temperature remarkably.

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