Proceedings of the 72nd World Foundry Congress
21-25th May 2016, Nagoya, Japan

Primary M_7C_3 Carbide Refinement of Hypereutectic High-Chromium White Cast Iron

Yuuki Kudo, Setsuo Aso, and Ikuzo Goto
Graduate School of Engineering Science, Akita University, 010-8502 Akita, JAPAN

Refining primary M_7C_3 hexagonal rod-like carbides is an effective method for improving the mechanical properties of hypereutectic high-chromium cast iron (HCCI). In this work, three hypereutectic HCCIs—4.0C–25Cr, 4.5C–28Cr, and 5.0C–31Cr—were poured into molds at 15°C, 100°C, and 200°C above the liquidus temperature of each alloy. The primary M_7C_3 carbides of each alloy poured at 15°C above the liquidus temperature were distributed randomly, without solidifying, along the heat flow. Therefore, the hexagonal cross section of the primary M_7C_3 carbides was primarily observed in the solidification structure. The average carbide size of the alloy poured at 15°C above the liquidus temperature was 25 μm, which was one-fourth the carbide size of the alloys poured at higher temperatures. Because the size of the primary carbides was refined when the alloys were poured at 15°C above their respective liquidus temperatures, the three aforementioned alloys were poured at this temperature to prepare four-step wedges. The carbide size decreased with step thickness. In particular, the primary carbide size of the 4.0C–25Cr alloy was most refined to approximately 20 μm. The primary M_7C_3 carbides were simultaneously solidified nondirectionally. These structures should improve the mechanical properties of the alloys.

Keywords: *abrasion, cooling rate, four-step wedge, hardfacing, M_7C_3 hexagonal rod-like carbide.*

1. Introduction

High-chromium cast irons (HCCIs) are generally hypoeutectic compositions because coarse primary M_7C_3 rod-like carbides formed at the hypereutectic composition often cause low brittleness [1]. By contrast, the hypereutectic hardfacing alloys are used in applications such as coal pulverizer liners and gravel pumps, which involve severe abrasion and little impact [2]. Generally, grain refining is an effective method for improving the mechanical properties of alloys; consequently, the hardfacing process, which features a faster solidification rate, is recommended for this application. Also, hypereutectic HCCIs improve the mechanical properties by inducing grain refining. Numerous researchers have reported that Ti is an effective element to reduce the size of primary M_7C_3 carbides because TiC serves as the heterogeneous nuclei for M_7C_3 carbides [3]. However, because the carbon content of a melt is decreased by the crystallization of TiC, the size and volume ratio of primary M_7C_3 carbides will inevitably be reduced [4]. The purpose of this research is to investigate the refining of the primary M_7C_3 carbides of hypereutectic HCCI by controlling the solidification conditions and clarify the limit of refinement by the relationship between the carbide size and the solidification conditions.

2. Experimental

2.1 Materials and processing

The alloy compositions are shown Table 1. The electrolytic iron, electrolytic chromium, electrolytic nickel, metallic silicon, and graphite were used as the raw materials. These materials were melted in an induction furnace and poured into two types of CO_2 process sand molds. The shape of the specimens obtained by these molds was a four-step wedge block with dimensions of 40 mm × 160 mm with a 10-mm step and a rectangular block with dimensions of 30 mm × 30 mm × 100 mm. The rectangular blocks of each alloy were poured at 15°C, 100°C, and 200°C above the liquidus temperature. The four-step wedge block of each alloy was poured at 15°C above the liquidus temperature.

Table 1 Chemical composition of the alloys used in this work (mass%).

C	Mn	Si	Ni	Cr	Mo	Cr/C
4.0	1.5	0.8	0.5	25	1.0	6.2
4.5	1.5	0.8	0.5	28	1.0	6.2
5.0	1.5	0.8	0.5	31	1.0	6.2

2.2 Observation of microstructure and carbides

Each block was cut in the longitudinal direction, and the resulting cross sections were polished and etched with a hydrochloric acid–picric acid mixture. The solidification microstructures near the center of the block or step were observed in the cross section of each block using an optical microscope. The carbide size and area fraction were determined using image processing software. The size of rod-like primary carbides was determined as their length in the short-axis direction.

3. Results and discussion

3.1 Effect of pouring temperature

Figures 1 and 2 show the macrostructures and microstructures, respectively, of the 4.0C–25Cr alloy specimens poured at 1355°C, 1440°C, and 1540°C. The macrostructure of the specimen poured at 1355°C is nondirectional, whereas the macrostructure of the 4.0C–25Cr alloy specimens poured at 1440°C and 1540°C is columnar. The primary M_7C_3 carbides with a large hexagonal rod-like structure are evident in Fig. 2 for the specimens poured at 1440°C and 1540°C. By contrast, the primary M_7C_3 carbides in the specimen poured at 1355°C solidified in a nondirectional fashion because of the lower thermal gradient in the molten metal. Therefore, the short-axis direction of the carbides was primarily observed. Figure 3 shows the effect of pouring temperature on the primary M_7C_3 carbide size; the primary M_7C_3 carbide size increases with pouring temperature.

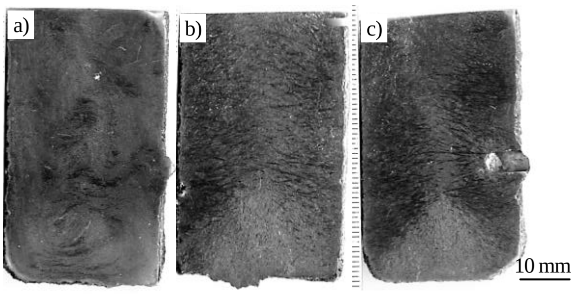

Fig. 1 Macrostructure of 4.0C–25Cr alloy specimens poured at a) 1355°C, b) 1440°C, and c) 1540°C.

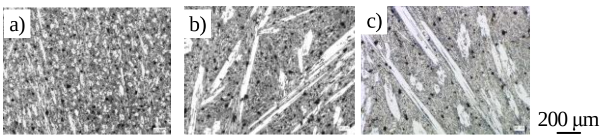

Fig. 2 Microstructure of 4.0C–25Cr alloy specimens poured at a) 1355°C, b) 1440°C, and c) 1540°C.

3.2 Effect of cooling rate

Figure 4 shows the effect of step thickness on the primary M_7C_3 carbide size of four-step wedge blocks of the three investigated alloy compositions poured at 15°C above the liquidus temperature of each alloy. The carbide size increases with step thickness and decreases with carbon content. The minimum carbide size is approximately 20 μm on the 10-mm-thickness step of the 4.0C–25Cr alloy. We measured the cooling rate of each alloy by constructing cooling curves for the temperature range between the pouring and eutectic temperatures. The size of primary carbides decreases inversely with the square root of the cooling rate. For the size of carbide to be 10 μm or less, a cooling rate of not less than 6°C/s is required.

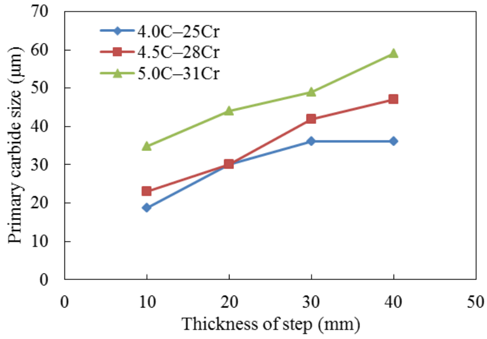

Fig. 3 Effect of pouring temperature on the primary M_7C_3 carbide size.

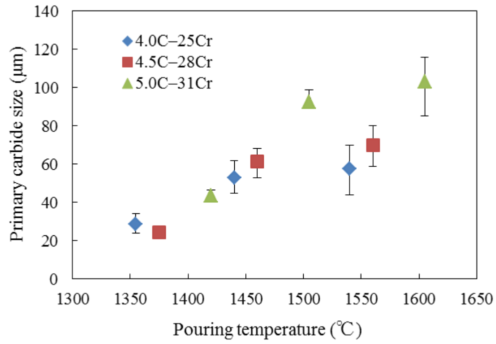

Fig. 4 Relationship between the step thickness of the four-step wedges and the primary M_7C_3 carbide size.

4. Conclusions

The size of primary carbides decreases with the pouring temperature and step thickness of the four-step wedge. Consequently, the size of the primary carbides decreases inversely with the square root of the cooling rate. The primary M_7C_3 hexagonal rod-like carbides solidified nondirectionally when each alloy was poured at 15°C above the liquidus temperature of the alloy.

References

[1] R.B. Gundlach: Friction, Casting, *ASM Handbook*, ASM International, 15 (2008) 896.

[2] P. Crook and H.N. Farmaer: Friction, Lubrication and Wear Technology, *ASM Handbook*, ASM International, 18 (1992) 758.

[3] H. Fu, X. Wu, J. Xing, Y. Lei and X. Zhi: J. Materials Engineering and Performance. 18 (2009) 1109-1115.

[4] Q. Liu, H. Zhang, Q. Wang, X. Zhou, P.G. Jönsson and K. Nakajima: ISIJ International. 52 (2012) 2210-2219.