Effect of Electric Current Pulse on Solidification Microstructure of Hypereutectic High Chromium Cast Iron Cooling from the Temperature between Liquidus and Solidus

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In this paper, the solidification course of the hypereutectic High Chromium Cast Iron (HCCI) was treated by the Electric Current Pulse (ECP). Effects of treating time, initial temperature applying ECP and its parameters (voltage, frequency, pulse width) on the microstructure were researched. The results showed that the ECP can promote refining of primary and eutectic carbides significantly. As the result of strengthening role on the solute fluctuation by ECP, the larger effect of nucleation and refinement promoting of carbides was displayed at the initial temperature closer to the liquidus. The more obvious refinement effect was showed under longer treating time. Huge differences in microstructure were shown under different combination of the three ECP parameters. Some combinations promoted primary carbide refinement and eutectic carbide number reduce obviously, and fine granular primary carbides with the size of ~20μm could be obtained. Some other combinations led to a trend of eutectic carbide granulating.

Keywords: hypereutectic high Chromium cast iron, solidification microstructure, electric current pulse, carbides, grain refinement.

Introduction

Hypereutectic HCCI is considered to have higher volume fractions of the hard (hardness about 1600 Hv) and wear resistant M_7C_3 carbides than hypoeutectic HCCI [1], and is thus often the preferred alloy for many hardfacing applications [2, 3]. However, hypereutectic HCCI generally is not favored for casting, due to high scrap and rejection rates which are mainly caused by the coarser and larger primary carbides [2] with the size of 100~300μm.

It is valuable to find a new and more practical technique for refinement of primary carbides. The Electric Current Pulse (ECP) treatment for the solidification course has attracted more attention in the nonferrous metal [4-8]. However, for different processing metal especially ferrous metal in China, and different ECP waveforms, there are considerable differences in the refinement and the understanding of its refinement mechanisms [9-18]. In this work, a constant amplitude sharp ECP treatment for primary M_7C_3 carbide refinement in hypereutectic HCCI solidification microstructure from liquid-solid range is presented.

Experimental Procedure

The chemical composition of hypereutectic HCCI used in the present study is 4.21wt%C, 22.41wt%Cr, 1.61wt%Si, and Fe the balance. The liquidus and solidus temperature are 1357°C and 1289°C obtained by the DSC test, respectively. As cast cylinder hypereutectic HCCI samples (□□18 mm × 150 mm) were firstly prepared in sodium silicate bonded sand.

The ECP treatment was performed under liquid-solid temperature range by sharp ECP generator. The experimental arrangement for ECP treatment is shown in Fig. 1(a). The □□18 mm × 150 mm sample was sealed in an alundum tube by sodium silicate bonded sand and two nickel electrodes. It was soaked at a temperature in liquid-solid range for 3min in the muffle furnace, and then ECP treatment applied on it for certain minutes during the course of furnace cooling to the room-temperature. The temperature history of the furnace chamber and melts was monitored by two thermocouples and a temperature recording instrument. The waveform of ECP was detected in situ by a digital storage oscilloscope and it is a constant amplitude sharp pulse (see Fig. 1(b)).

The cross-section microstructures of the samples were investigated by optical microscope. For optical microscope analysis, the samples were etched in the reagent of 5g $FeCl_3$+100 ml H_2O.

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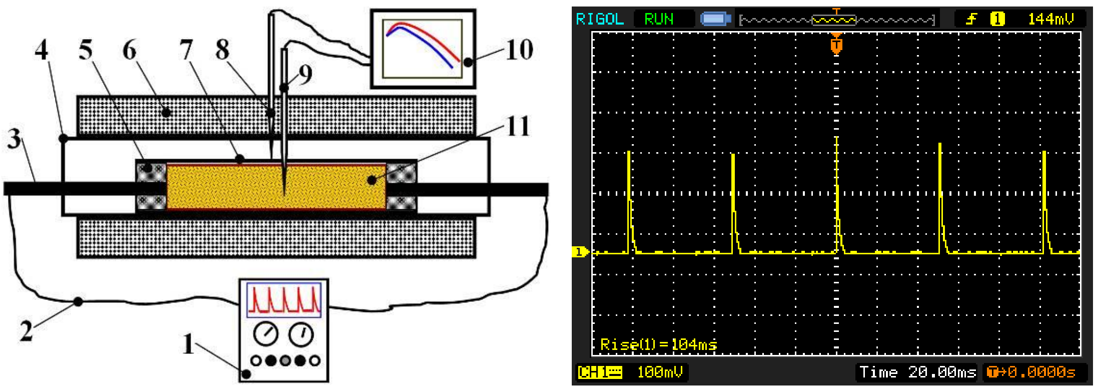

Fig. 1: schematic of ECP experiment: (a) experimental arrangement; (b) typical ECP waveform
1- ECP generator, 2 – copper wire, 3 – nickel electrode, 4 and 7 - alundum tube, 5 - sodium silicate bonded sand, 6 - muffle furnace, 8 and 9 – thermocouple, 10 - temperature recording instrument, 11 – HCCI melt or sample

Results and Discussion

Temperature history of the melts during the course of ECP treatment

The muffle furnace with samples was heated to the furnace chamber temperature of 1350 °C, 1360 °C for two ECP treatments, respectively. Fig. 2 shows temperature history of two samples soaking for 3 min, and then furnace cooling plus ECP treating in the muffle furnace. The ECP voltage, frequency and pulse width were 1400V, 30Hz and 30□s. It shows that the actual melt temperatures of the two samples were 1335 °C, 1343 °C before soaking and 1346 °C, 1353 °C after soaking, respectively. The increases of the melt temperature during the course of soaking were because of the release of latent heat of fusion. After soaking of the samples, they were applied furnace cooling plus ECP along the length direction immediately. The initial temperatures of ECP applying were 1346 °C and 1353 °C for two samples, respectively. After ECP treatment for 5min, the melts temperatures were still higher than the solidus one of 1289 °C. It was indicated obviously that the furnace cooling plus ECP treating of this study were in the liquid-solid temperature rang, and the ECP did not have any direct effects on the eutectic reaction of the melt.

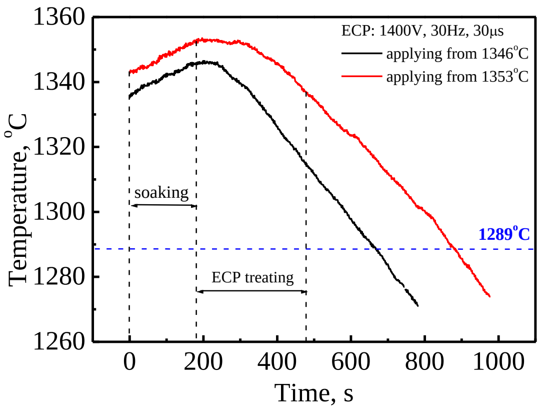

Fig. 2: Temperature history of the samples during soaking for 3 min, and furnace cooling plus ECP treating in the muffle furnace

Effects of initial temperature and time span of ECP treatment on the carbide refinement

The solidification microstructures from 1346°C and 1353°C of the melts ECP treated for different time are shown in Fig. 3 and Fig. 4, respectively. And the melt temperatures after ECP treatment obtained from Fig. 2 are also listed in the figures.

From the microstructures, some treatment effects are shown obviously. Firstly, with increasing ECP processing time, primary carbides and eutectic carbide have been refined significantly. The primary carbides were refined into granular from rod-like, and the eutectic carbide clusters became fine; thickness and length of the flaky eutectic carbide were shortened obviously in 3.5 min (see Fig. 3c and 4c). However, ECP treatment for too long time will make the carbides coarsening trend appeared, the rod-like primary carbides and long flaky eutectic carbides were reemerged again (see Fig. 4e). Secondly, carbide refinement effect is more obvious when the initial temperature of ECP applying is higher. As mentioned above, the samples were still in the liquid-solid temperature range when they were heated to 1346°C and 1353°C. The primary carbides did not melt down completely. The lower the heating temperature is, the larger the size and the number of primary carbides are, which is shown in Fig. 3a and Fig. 4a. The chief effect of ECP is to promote solute atoms fluctuating uniformly in the hypereutectic HCCI melt by its magnetic contraction, and then the primary carbide nuclei number increasing significantly, which is benefit for getting fine primary carbides. Although the temperature T_e of the melt under ECP treatment for 3.5min was higher than that for 2.5min, the size of the primary carbide in the former (Fig. 4c) are finer than that in the later (Fig. 3c). Thirdly, the refinement of the primary carbides is benefit for the refinement of the eutectic carbides. It shows the strong evidence that the more refinement effect of eutectic carbides in the Fig. 4c than that in the Fig. 3c.

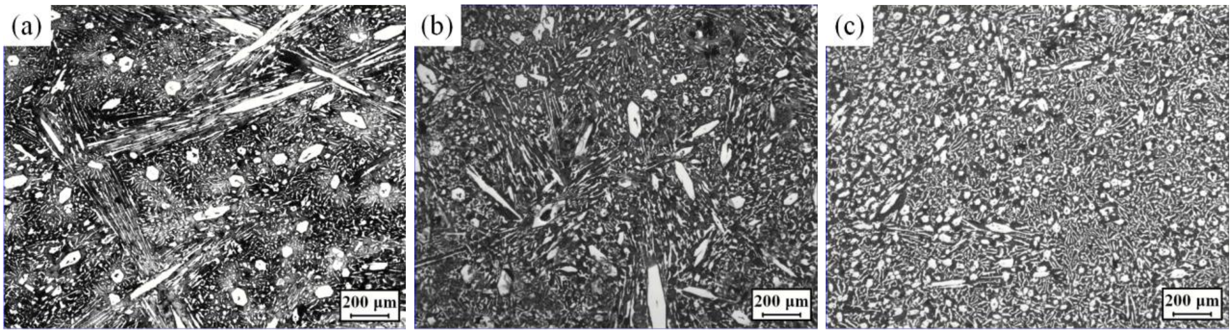

Fig. 3: Solidification microstructures from 1346 °C to T_e of the melts ECP treated for different time: (a) 0 min, T_e =1346 °C, (b) 1 min, T_e =1337 °C and (c) 2.5 min, T_e =1327 °C

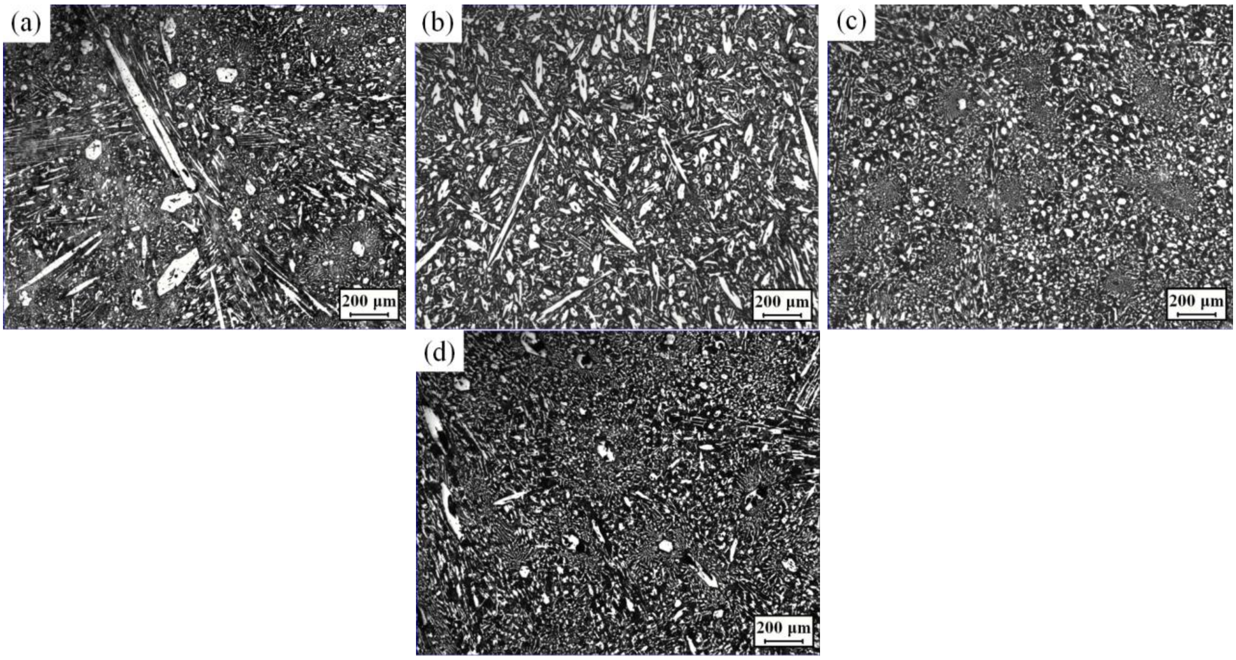

Fig. 4: Solidification microstructures from 1353 °C to T_e of the melts ECP treated for different time: (a) 0 min, T_e=1353 °C, (b) 2.5 min, T_e =1351 °C, (c) 3.5 min, T_e =1346 °C and (d) 5 min, T_e =1336 °C

Effects of ECP parameters on the solidification microstructure

Fig. 5 shows the solidification microstructures from 1353 °C of the melts treated for 3.5 min under different ECP parameter combination of voltage, frequency, pulse width. Huge differences in microstructure were shown under different ECP parameter combination. Two kinds of microstructure characteristic can be summarized. First, certain ECP parameter combination promoted the formation of much more primary carbides, which reduced the number of eutectic carbides. It was shown in Fig. 5c, f and g. Under the ECP parameter combination as 500V, 45Hz and 100μs, the size of the primary carbide was the least, and the number of the eutectic carbide was the smallest (see Fig. 5c). So the number of the eutectic carbide is related to the size of the primary carbide. Second, certain ECP parameter combination promoted eutectic carbide granulating, shown as Fig. 5a, b, d and e. Under these combinations, the size of the primary carbide is a little bit lager than that mentioned as the first one.

Among the three parameters of the ECP, the role of voltage responses in the effect of electro migration [4] on solute atoms, the role of frequency responses in the effect of magnetic contraction [4] on melt, and the role of pulse width responses in the effective treat time. High voltage condition such as 1400V, the ECP frequency should be reduced to offset the effect of electro migration (see Fig. 5g). Low voltage condition such as 500V or 1000V, the ECP frequency should be increased to strengthen magnetic contraction to achieve good melt stirring effect (see Fig. 5c and f).

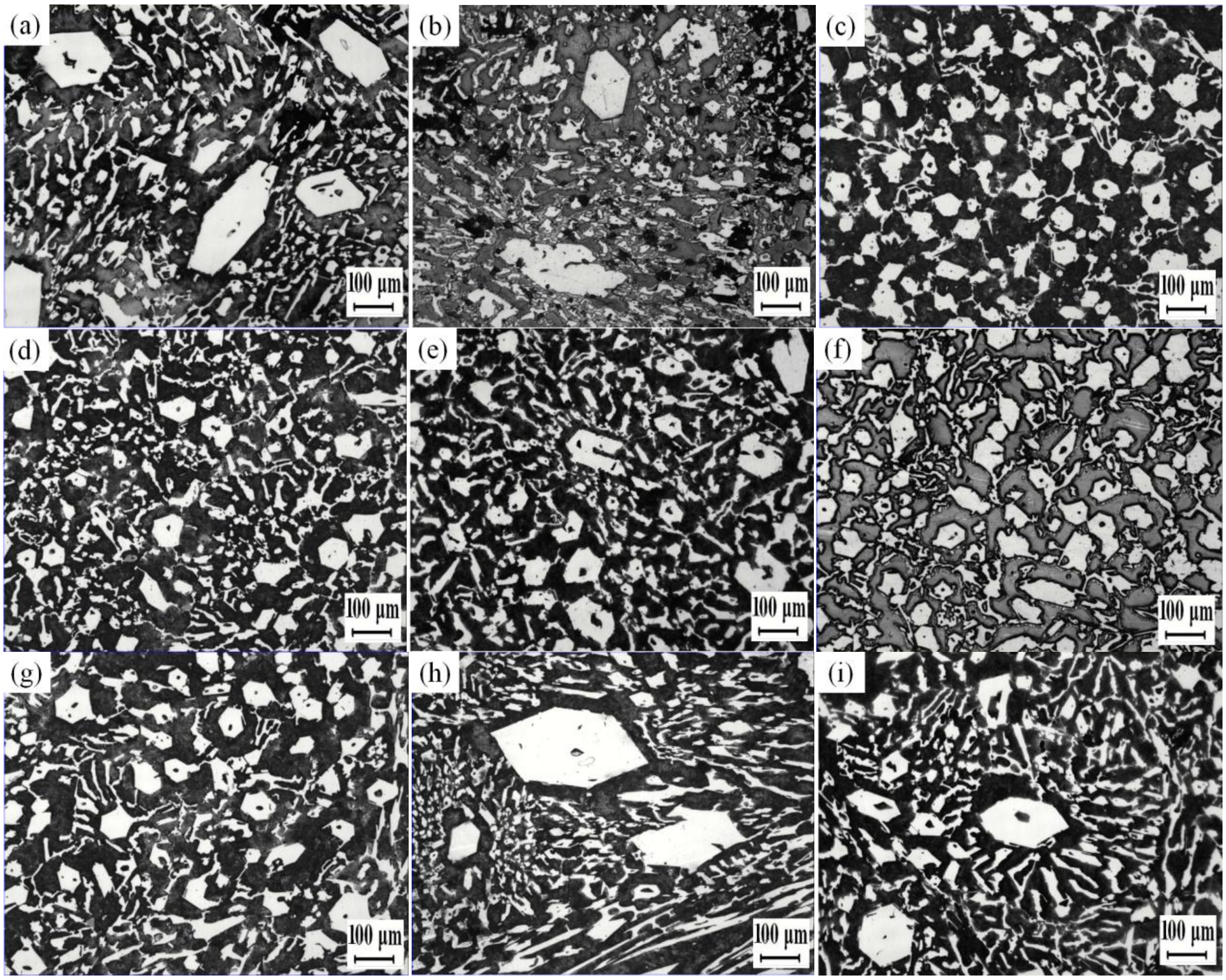

Fig. 5: Solidification microstructures from 1353 °C of the melts after treatment for 3.5 min at different ECP voltage, frequency, pulse width: (a) 500V, 15Hz, 10μs; (b) 500V, 30Hz, 30μs; (c) 500V, 45Hz, 100μs; (d) 1000V, 15Hz, 30μs; (e) 1000V, 30Hz, 100μs; (f) 1000V, 45Hz, 10μs; (g) 1400V, 15Hz, 100μs; (h) 1400V, 30Hz, 10μs and (i) 1400V, 45Hz, 30μs

Conclusions

1. The solidification microstructure evolution of hypereutectic HCCI under ECP treatment has been characterized. The ECP applied temperature near the liqudus and longer ECP treatment time are benefit for the refinement of the carbide. But the carbide will be coarsened under too long treatment time.
2. The ECP parameters such as the voltage, frequency, pulse width have a huge influence on the solidification microstructure. Some combinations of the three ECP parameters promoted primary carbide refinement and eutectic carbide number reduce, and fine granular primary carbides with the size of ~20μm could be obtained. Some other combinations led to a trend of eutectic carbide granulating.

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