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Investigation of Microstructure and Impact Toughness of Semisolid Hypereutectic High Chromium Cast Iron Prepared by Slope Cooling Body Method

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Abstract: In this study, Semisolid hypereutectic high Cr cast iron specimen was obtained by slope cooling body method under the condition of different technics parameters (different pouring temperatures and slope angles). By microstructures analysis and impact toughness test of semisolid specimens, the results indicate that, firstly, the primary carbides in the semisolid microstructure are finer than those in the hypereutectic high Cr cast iron prepared by conventional method; secondly, with a decrease in the semisolid forming temperature, the primary carbides become fine; thirdly, the optimal impact toughness value of the semisolid specimen increases above one times more than that of hypereutectic one prepared by conventional method. The results also indicate that, there are lots of shrinkage porosities in the semisolid microstructure, furthermore, with a decrease in the semisolid forming temperature, the tendency of shrinkage porosities become obvious. Thus, in the next work, it would be significant for improving the impact toughness of semisolid hypereutectic high Cr one to eliminate shrinkage porosities by extrusion forming or other methods.

Key words: Semisolid hypereutectic high cast iron, Slope cooling body method, Impact toughness, Shrinkage porosity

INTRODUCTION

Since the semisolid slurry of Sn-Pb 15% alloy had been prepared in 1971, by Spencer and Flemings, at the Massachusetts Institute of Technology (MIT) of America, using mechanical stirring method, semisolid forming technologies were developed rapidly (Su *et al.*, 1998). Besides such stirring method, there are electromagnetic stirring, osprey processing, Strain Induced Melt Activation (SIMA), slope cooling body method etc. (Ying *et al.*, 2000; Yang *et al.*, 2002; Mao *et al.*, 1998). Compared with the other methods mentioned above, the slope cooling body method possesses several advantages, such as a simple process for slurry preparation, low cost and high production efficiency etc. The principle of the slope cooling body method is that (Xing, 1990), as a high temperature melt flowing along the surface of the cooling body, a lot of crystal nucleus formed on the surface are dissociated from the surface wall, to obtain a fine structure after solidification. Aiming at the preparation for semisolid slurry of Al-Si alloy and gray cast iron etc., some documents (Kitamura *et al.*, 1990; Hayatt *et al.*, 2002; Motegi *et al.*, 1998; Guan *et al.*, 2004) about the application of the slope cooling body method have been reported in recent years and the results indicated that the semisolid slurry was solidified into specimens in the pressure condition, whose strength and toughness were improved obviously.

High Chromium Cast Iron (HCCI) is used as a kind of good anti-abrasive material. The morphology and volume percentage of the hard and brittle phase carbides in it have a pronounced effect on improving wear resistance. Compared with hypoeutectic HCCI, although hypereutectic HCCI possesses superior wear resistance, the latter is applied much less than the former in engineering. The reason is that the toughness of hypereutectic HCCI decreases remarkably, as a result of the emergence of bulky primary carbides (Zhou, 1986). Llwellyn *et al.* (2004) investigated the scouring erosion resistance of the hypereutectic HCCI, in which fine primary carbides occurred and the result indicated that, compared with that of hypoeutectic HCCI, its wear resistance was markedly improved. In conclusion, for the exploitation and application of hypereutectic HCCI, it would be significant to obtain fine primary carbides in the microstructure.

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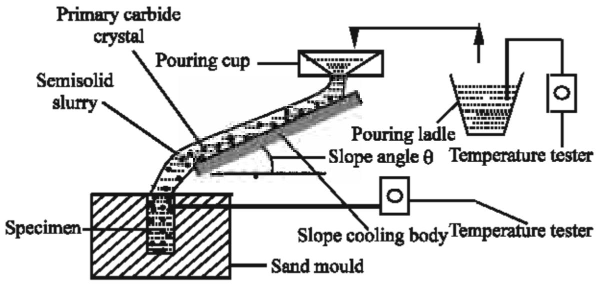


Fig. 1: The sketch map of semisolid hypereutectic HCCI specimens prepared by the slope cooling body method

In this study, in order to improve the toughness of hypereutectic HCCI, according to the principle of the slope cooling body method, the semisolid hypereutectic HCCI slurry containing lots of dissociative primary carbide crystals was prepared and then was solidified in sand mold, leading to fine primary carbides in the semisolid specimen. The plan for preparing semisolid specimen is shown schematically in Fig. 1. Subsequently, the microstructures and impact toughness of the specimens are studied according to the test procedure as follows:

TEST PROCEDURE

The chemical compositions of the hypereutectic HCCI utilized in this study are given in Table 1 (Huang *et al*., 2004). The liquidus temperature and the solidus temperature were measured using Differential Thermal Analysis (DTA) and their values are 1293 and 1193°C, respectively. The pouring temperature of metal liquid is measured in the ladle, using a digital display type temperature tester. The slurry temperature measured in the sand mould, named the semisolid forming temperature, which is measured using a temperature tester, type 128 M Smart Reader Plus. The cooling body is made of gray cast iron slot. Before pouring, a graphite coating is applied on the surface of the cooling body to allow more precipitating primary carbide crystals to dissociate easily from the cooling body wall. The pouring temperatures of 1310, 1330 and 1350°C and the slope angles of 15°, 30° and 45° are decided, respectively in this experiment. The flow length of semisolid slurry on the surface of the cooling body is 450 mm. After cutting, polishing and etching, microstructure observation of the specimen is operated by Optical Microscope (OM). The etchant is an 8% solution of nitric acid in ethanol. In addition, shrinkage porosities observation of the specimen (without etching treatment) is operated by Scanning Electron Microscopy (SEM).

Table 1: The chemical composition of hypereutectic HCCI (wt.%)

C	Cr	Mn	Si	S	Fe
4.08	17.10	0.63	0.755	0.025	Balance

Before impact test, the impact toughness specimens are heat-treated (980°C for 2 h; air-cooling; tempering at 280°C for 2 h) to obtain martensite matrix (Zhou, 1986). The impact toughness test is conducted in an impact test rig, type 294/147J. The shape of specimen (without notch) is 20×20×110 mm and the impact span of specimen is 70 mm. Moreover, the impact toughness values of the semisolid hypereutectic HCCI specimens prepared under different forming technics parameters are compared with that of hypereutectic HCCI specimen prepared by the conventional method.

TEST RESULTS

Microstructures: Under the conditions of the invariable flow length of the slurry on the surface of the cooling body, the three pouring temperatures of the metal liquid and the three inclination angles of the cooling body, the nine semisolid forming temperatures measured are shown in Table 2. It can be seen that each group temperature is almost same among three groups of temperatures (1235 and 1237°C, 1256 and 1254°C, 1228 and 1227°C). The microstructures corresponding to the two near semisolid forming temperatures, are hardly any different (Huang *et al*., 2004), thus, the one selected randomly from each group microstructure is observed in this study. The micrographs of the semisolid microstructures corresponding to the six semisolid slurry temperatures are shown in Fig. 2. In Fig. 2a and b, when the semisolid forming temperature is lower, besides a few thin-rod shaped primary carbides, many fine ones will occur, as the temperature increasing, the size of primary carbides increases as shown in Fig. 2c and d, with a farther increase in the temperature, the primary carbides become bulky evidently, as shown in Fig. 2e and f. Moreover, compared with the primary carbides in the conventional specimen (as shown in Fig. 3), it can be seen that the primary carbides in the semisolid microstructures become finer obviously.

Impact toughness: According to the method mentioned above, the different impact toughness specimens, corresponding to six different semisolid forming temperatures, are tested respectively. It can be seen from Fig. 4, when the semisolid forming temperature is lower than 1256°C, as the temperature decreasing, the impact toughness value will decreases gradually; while the temperature is higher than 1256°C, it will not almost change and at 1256°C, the value reaches the maximum

Table 2: The semisolid slurry temperatures corresponding to the conditions of different processes

Pouring temperature (°C)	1350			1330			1310		
Slope angle of cooling body (°C)	15	30	45	15	30	45	15	30	45
Semisolid forming temperature (°C)	1235	1256	1285	1228	1237	1254	1220	1227	1243

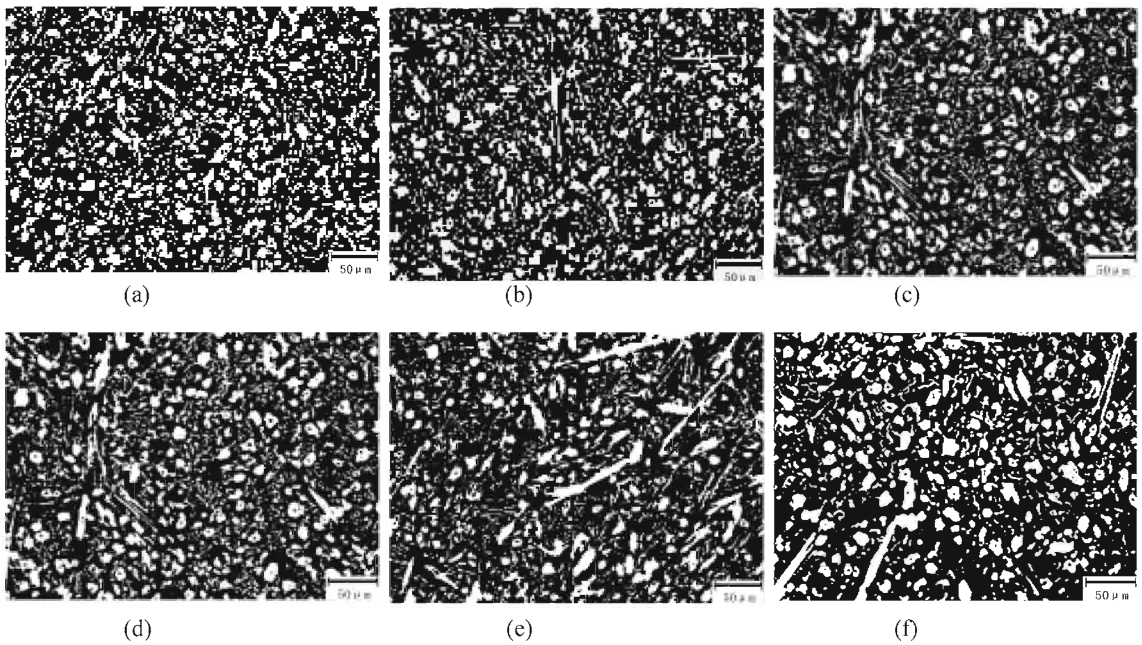


Fig. 2: The micrographs of the microstructures of hypereutectic HCCI corresponding to the different semisolid slurry temperatures: (a) 1220°C; (b) 1227°C; (c) 1235°C; (d) 1243°C; (e) 1256°C; (f) 1285°C

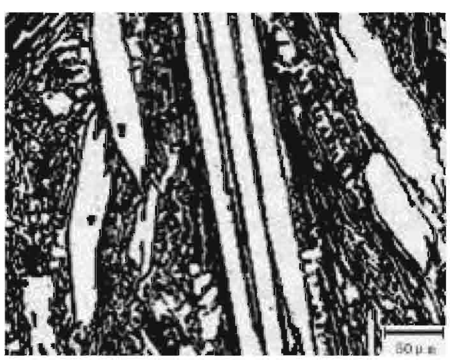


Fig. 3: The micrograph of the microstructure of hypereutectic HCCI specimen prepared by the conventional method

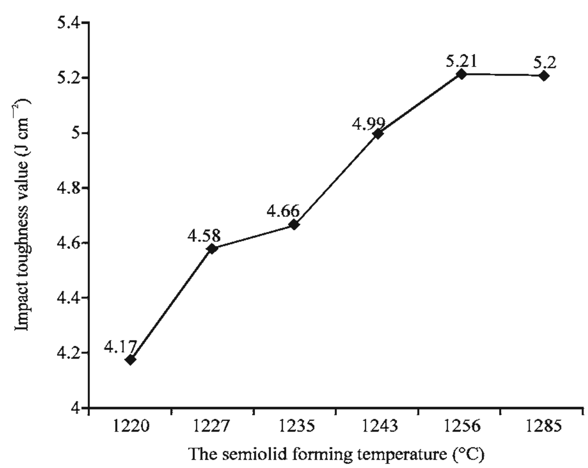
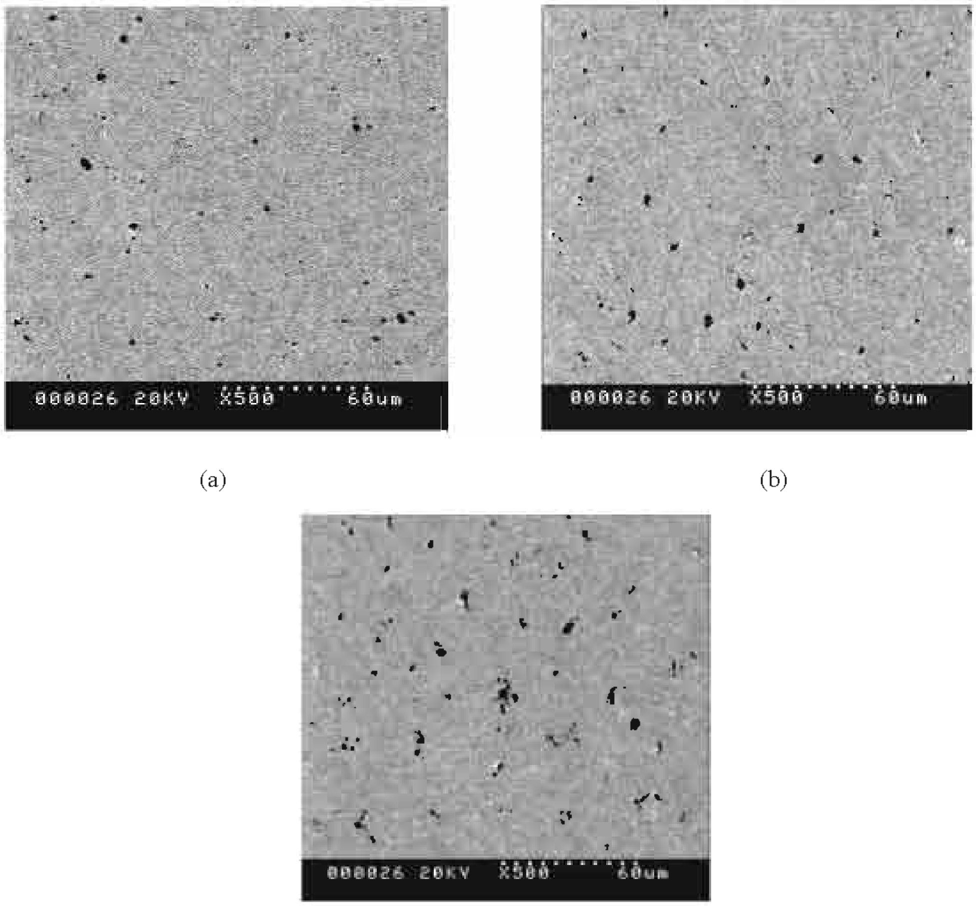


Fig. 4: The impact toughness values of the semisolid hypereutectic HCCI specimens corresponding to different semisolid forming temperatures

5.21 J cm^{-2}. Compared with the impact toughness value 2.5 J cm^{-2} of the conventional specimen, the optimal impact toughness value of semisolid specimens is improved above one times.

Shrinkage porosities: Figure 5a-c are the SEM photographs of the shrinkage porosities in the specimens corresponding to the semisolid forming temperatures 1256, 1235 and 1220°C, respectively. From Fig. 5, it can be seen that, with a decrease in the semisolid forming temperature, the tendency of the shrinkage porosities becomes obvious. In Fig. 5a-c, the tendency of the shrinkage porosities becomes evident gradually.



(a) (b) (c)

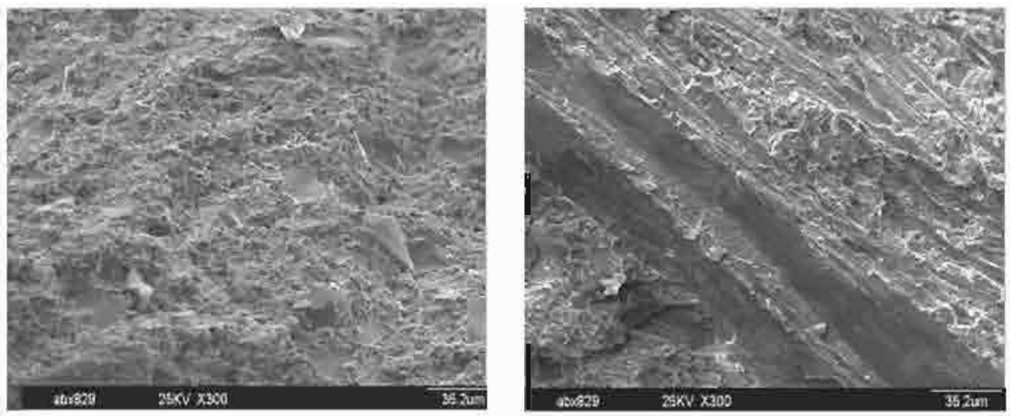
Fig. 5: The SEM photographs of shrinkage porosities of the hypereutectic HCCI corresponding to the semisolid forming temperature: (a) 1256°C; (b) 1235°C; (c) 1220°C

RESULTS AND DISCUSSION

As the mentioned above, with a decrease in the semisolid forming temperature, the primary carbides in the hypereutectic HCCI specimen becomes fine gradually. The reason is that a decrease in the semisolid forming temperature not only leads to an increase in the number of the precipitating primary carbides on the surface of the cooling body, but also hinders the growth of primary carbides in solidification.

It can be seen from Fig. 4, when the semisolid forming temperature is lower than 1256°C, although the primary carbides become fine ulteriorly with a decrease in the semisolid slurry temperature, the impact toughness value of the semisolid specimen decreases gradually. The reason is that the lower the semisolid forming temperature is, the poorer the compensation ability of the metal liquid in solidification is, resulting in an evident tendency of shrinkage porosities in the microstructure, namely, resulting in the uncompacted microstructure, which leads to the lower impact toughness value. When semisolid forming temperature is high than 1256°C, the impact toughness will be invariable, such fact is collectively affected by the relatively bulky primary carbides and the relatively compacted microstructure, moreover, due to a little change in the latter, the former plays a predominant role on the impact toughness value.

It can be known from the impact test result, compared with the impact toughness value of conventional specimen, the impact toughness values of the semisolid specimens are improved obviously. To explain such fact, Fig. 6 shows the SEM photographs of fracture morphologies of hypereutectic HCCI specimens (prepared by slope cooling body method and the conventional



(a) (b)

Fig. 6: The SEM photographs of the fracture morphologies of hypereutectic HCCI prepared by: (a) the slope cooling body method; (b) the conventional method

method, respectively) after the impact tests. From Fig. 6a, it can be known that cracks extend mainly along the matrix in the microstructure of the semisolid specimen. From Fig. 6b, it can be known that cracks extend mainly across the bulky primary carbides in the microstructure of the conventional specimen. Moreover, because the crack extension resistance in a matrix is greater than that in the carbide, the impact toughness values of all the semisolid specimens are markedly improved more than that of the conventional specimen.

In a word, compared with that of conventional specimen, although the impact toughness of semisolid specimen is improved obviously, there are lots of shrinkage porosities in the semisolid specimen, resulting in the impact toughness values, which are not improved enough. Therefore, to eliminate the shrinkage porosities in the microstructure by extrusion forming or other methods, it would be significant for improving the impact toughness.

CONCLUSIONS

The primary carbides in the semisolid hypereutectic HCCI prepared by slope cooling body method becomes finer obviously more than that in hypereutectic HCCI prepared by conventional method; with a decrease in the semisolid forming temperature, the primary carbides become finer gradually.

For the impact toughness value of the semisolid hypereutectic HCCI specimen, when the semisolid forming temperature is lower than 1256°C, with a decrease in the temperature, it decreases gradually. While the semisolid forming temperature is higher than 1256°C, it almost does not change; the optimal impact toughness value of the semisolid specimens is improved above one times more than that of the conventional specimen.

The shrinkage porosities, in the semisolid hypereutectic HCCI specimens, hinder an improvement of the impact toughness, thus, it would be significant for improving the impact toughness to eliminate the shrinkage porosities in the microstructure.

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