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3%C-5%Mo-5%W-10%(Cr or V) 백주철의 응고거동에 관한 연구

류 성 곤
계명대학교 공과대학 재료공학과

Solidification Behavior of 3%C-5%Mo-5%W-10%(Cr or V) White Cast Irons

Sung-Kon Yu
Dept. of Materials Engineering, Keimyung University, Taegu, 704-701

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초 록 10%C-5%Mo-5%W-10%Cr 및 10%C-5%Mo-5%W-10%V 백주철의 응고거동을 열분석을 통하여 연구하였다. 15kg 용량의 고주파 유도용해로에 선철, 고철, Fe-Mo, Fe-W, Fe-Cr, Fe-V 등을 장입시켜 용해시킨 후 슬래그를 제거시키고 1550℃에서 Y블럭의 펩셀주형에 주입하였다. 응고거동을 조사하기 위하여 50g을 Y블럭에서 채취한 뒤 알루미나 도가니에 넣어 재용해시킨 후 10℃/min의 냉각속도로 냉각시키면서 여섯 종류의 다른 온도에서 도중에 급냉시켜 응고조직을 광학현미경으로 관찰하였다. 10%C-5%Mo-5%W-10%Cr 백주철의 경우 초정 오스테나이트, 오스테나이트와 M_7C_3의 공정, 오스테나이트와 M_6C의 공정으로, 10%C-5%Mo-5%W-10%V 백주철의 경우 초정 MC, 오스테나이트와 MC의 공정, 오스테나이트와 M_2C의 공정으로 각각 순차적으로 정출하였다.

Abstract Two different white cast irons alloyed with Mo, W and Cr(or V) were prepared in order to study their solidification behavior during thermal analysis. The specimens were produced using a 15kg-capacity silica lined high frequency induction furnace. Melts were super-heated to 1600℃, and poured at 1550℃ into Y-block pepset molds. Two combinations of the alloying elements were selected so as to obtain different types of carbide structure: 3%C-10%Cr-5%Mo-5%W(alloy No. 1) and 3%C-10%V-5%Mo-5%W(alloy No. 2). To clarify the solidification sequence, each iron(50g) was remelted at 1450℃ in an alumina crucible using a silicon carbide resistance furnace under the argon atmosphere. The molten iron was cooled at the rate of 10℃/min and quenched into water from six different temperatures during thermal analysis. The solidification structures were found to consist of primary austenite, (austenite + M_7C_3)eutectic and (austenite + M_6C)eutectic in the alloy No. 1 and primary MC, (austenite + MC)eutectic and (austenite + M_2C)eutectic in the alloy No. 2.

Key words : white cast iron, solidification, primary austenite, eutectic austenite

1. Introduction

Alloyed white cast iron with many kinds of strong carbide-forming elements is a recently developed wear-resistant material for application to the hot strip and mineral pulverizing mills.1~6) It contains reasonable amounts of elements, such as Cr, V, Mo, W and Nb, and its carbon content is relatively higher than that of high-speed tool steel with similar alloying elements. Various types of carbides, such as MC, M_2C, M_6C, M_7C_3 and NbC, can be precipitated during solidification. In addition, the matrix can also be varied by the heat treatments such as air-hardening and tempering, and hard matrix can be obtained by the precipitation of numerous tiny secondary carbides. Properties such as abrasion wear resistance, surface roughening resistance and heat crack resistance are essentially important to apply these irons for the roll materials. Among these properties, the abrasion wear resistance of the alloyed white cast iron is reported to be dependent upon not only type, morphology, amount and distribution pattern of the carbides mentioned above, but also type of its matrix structure.

In this work, two different chemical compositions were selected for the study of solidification of alloyed white cast iron. The specimens were quenched from six different temperatures during thermal analysis for the evolution of microstructures.

2. Experimental Procedure

2.1 Specimen Preparation

Specimens were produced in a 15kg-capacity silica-lined high frequency induction furnace. Charge materials were clean pig irons and steel scraps. The ferroalloys such as Fe-60%Cr, Fe-80%V, Fe-60%Mo and Fe-75%W, as necessary according to the charge calculation, were added to a slag-free molten iron in the furnace so as to minimize the oxidation loss and the slag formation. The melt was subsequently heated to 1600℃ and transferred into a preheated teapot ladle. After removal of any dross and slag, the melt was poured at 1550℃ into pep-set molds to produce Y-block ingots.

2.2 Thermal Analysis

For studying the solidification sequence of each iron, 50g were taken from the Y-block ingot and melted at 1450℃ in an alumina crucible using a silicon carbide resistance furnace under the argon atmosphere. Then, the molten iron was cooled at the rate of 10℃/min to produce a cooling curve of each iron. Based upon the cooling curve, the molten iron was quenched into water from six different temperatures during thermal analysis.

2.3 Metallographic Examination

The specimens were polished, etched and examined metallographically by optical microscope. Murakamis etchant (10g of potassium ferricyanide, 10g of potassium hydroxide and 100ml of distilled water) was used to clearly distinguish the phases.

3. Results and Discussion

A cooling curve and the microstructures obtained from six different quenching temperatures for the alloy No. 1 (3%C-10%Cr-5%Mo-5%W) are shown in Fig. 1.

On the cooling curve, three reaction or arrest points appeared at 1145, 1140 and 1090℃. First, a specimen was quenched at 1320℃, above the liquidus, to provide a reference sample because the microstructure evolved lags behind the temperature at which the specimen is taken out for quenching due to time interval between the two processes (taken-out and quenching of the specimen). Fig. 1① shows the microstructure of the specimen quenched from 1320℃ which consists of very fine primary austenite dendrites and liquid. A significant undercooling and recalescence were obtained on the cooling curve during the first eutectic reaction. Therefore, two points were taken around the first arrest : just prior to the start of the first arrest (1155℃) and just past the arrest (1140℃). The specimens quenched from 1155℃ and 1140℃ are similar in morphology having coarse primary austenite dendrites, fine (austenite + M_7C_3) eutectic and liquid, as shown in Fig. 1② and 1③. It can be inferred from Fig. 1② that inderdendritic areas, which were liquid at the time of taken-out, have partly transformed to fine (austenite + M_7C_3) eutectic prior to quenching due to time interval between taken-

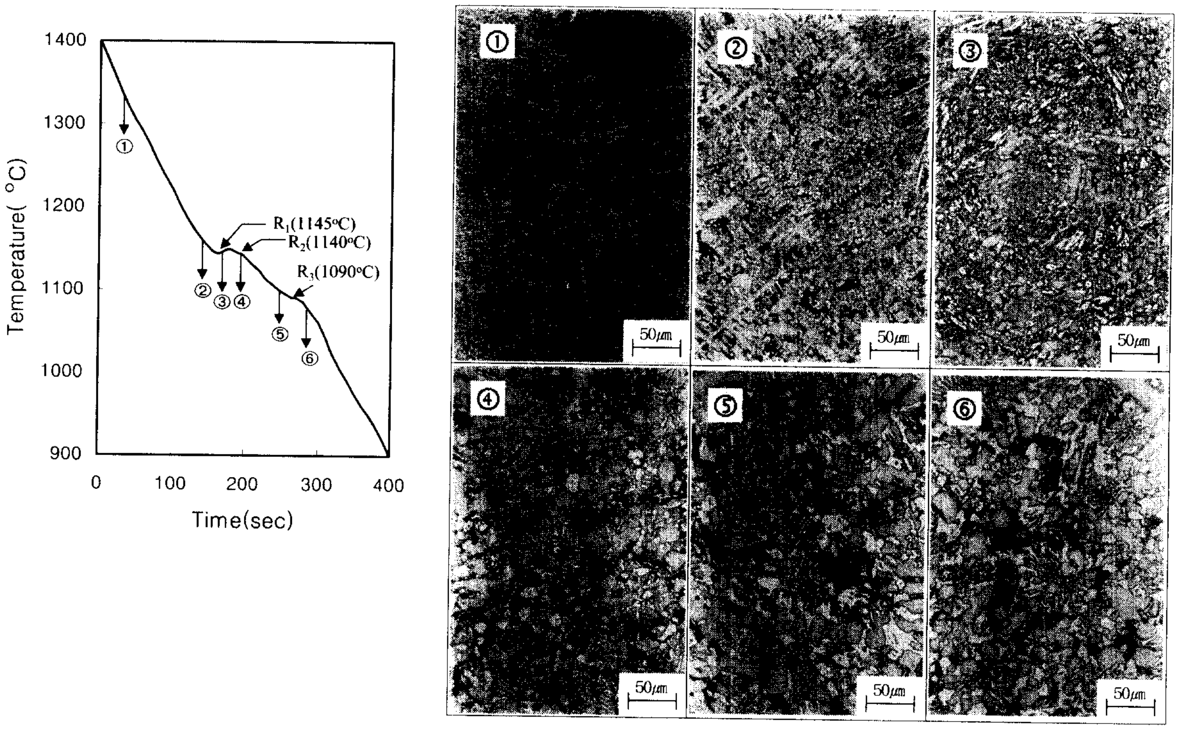

Fig. 1. A cooling curve of alloy No. 1 and microstructures quenched from six different temperatures.

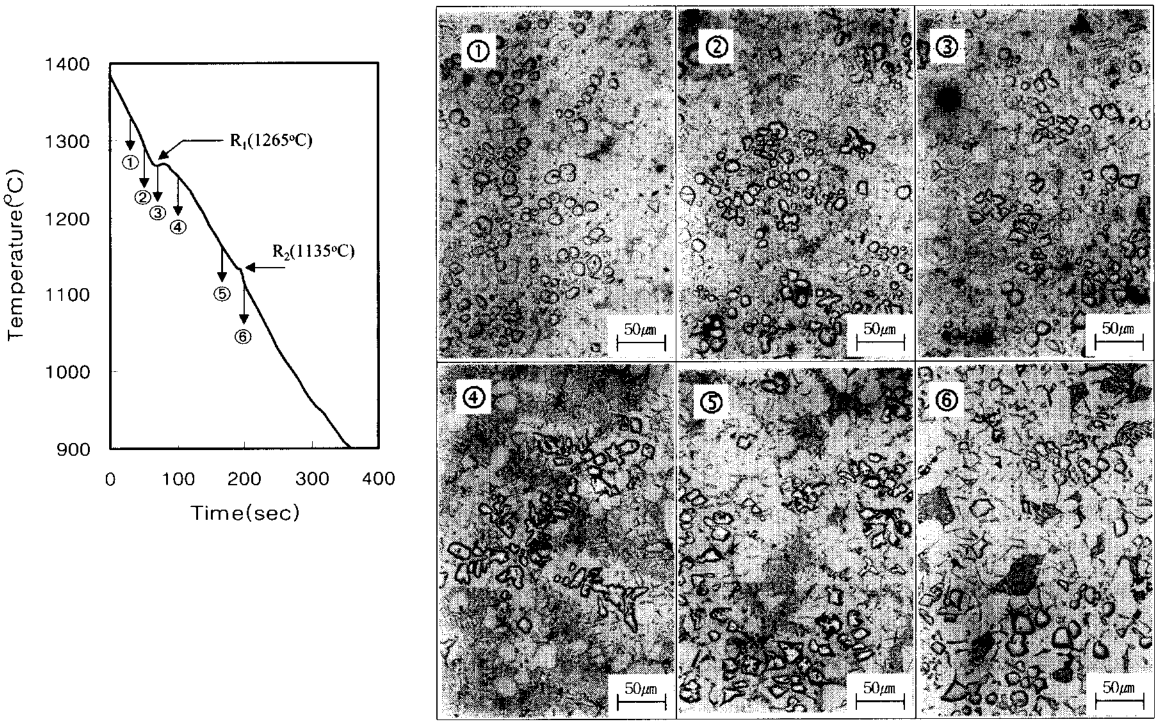

Fig. 2. A cooling curve of alloy No. 2 and microstructures quenched from six different temperatures.

out and quenching. The microstructure of Fig. 1④ quenched from 1140℃, that was just after the second small arrest, consists of developed primary austenite dendrite, (austenite + M_7C_3) eutectic and liquid. As can be seen in Fig. 1④, the (austenite + M_7C_3) eutectic structures solidified as a colony structure with a round shape, as reported in Fe-C-Cr system.7) It can be also observed that M_7C_3 carbide particles became gradually larger from the center to the boundary. The microstructure of the specimen quenched at 1095℃ before the third arrest is shown in Fig. 1⑤ and consists of primary austenite dendrites, (austenite + M_7C_3) eutectic, fish-bone type (austenite + M_6C) eutectic and liquid, which suggests that the arrest was due to precipitation and growth of (austenite and M_6C) eutectic. The lowest quenching temperature was 1075℃ which was after the third eutectic reaction, and the microstructure which is typical morphology in as-cast state, is shown in Fig. 1 ⑥.

Therefore, the solidification sequence for this iron starts with the precipitation of primary austenite dendrites, followed by the precipitation of (austenite + M_7C_3) eutectic and finally (austenite + M_6C) eutectic.

A cooling curve for the alloy No. 2 (3%C-10%V-5%Mo-5%W) with two thermal arrests at 1265 and 1135℃, and microstructures evolved from six different quenching temperatures are shown in Fig. 2.

As shown in Fig. 2①, the microstructure of the specimen quenched from 1350℃ consists of primary nodular MC carbides, fine austenite dendrites, extremely fine (austenite + MC) eutectic and liquid. This fine eutectic structure is thought to have formed prior to quenching due to time elapse in taking out the specimen from the furnace. Three specimens were quenched before, during and after the first eutectic reaction, 1280, 1265 and 1245℃, respectively. All the microstructures consist of primary nodular MC carbides, austenite dendrites, (austenite + MC) eutectic structures and liquid (Fig. 2②, ③, ④). Unlike the primary nodular MC carbide, the eutectic MC carbide solidified in colony shape with coral-like morphology. Fig. 2⑤ and 2⑥ show the microstructures of the specimens quenched from 1155 and 1105℃ corresponding to before and after the second eutection reaction, respectively. The molten material after the first eutectic reaction solidified as (austenite + M_2C) eutectic with lamellar morphology.

Therefore, it can be said that the alloy No. 2 solidified with the precipitation of primary nodular MC carbides and austenite dendrites, followed by the precipitation of (austenite + MC) eutectic and finally (austenite + M_2C) eutectic.

4. Conclusion

The solidification behavior of high alloyed white cast irons has been studied. The results are summarized as follows:

1) The solidification sequence for the alloy No. 1 (3%C-10%Cr-5%Mo-5%W) started with the precipitation of primary austenite dendrites, followed by the precipitation of (austenite + M_7C_3) eutectic and finally (austenite + M_6C) eutectic.

2) The alloy No. 2 (3%C-10%V-5%Mo-5%W) solidified with the precipitation of primary nodular MC carbides and austenite dendrites, followed by the precipitation of (austenite + MC) eutectic and finally (austenite + M_2C) eutectic.

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