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Effects of Heat-Treatments on Transformation Behavior of Matrix Structures in High Alloyed White Cast Iron

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초 록   3%C-10%Cr-5%Mo-5%W, 3%C-10%V-5%Mo-5%W 및 3%C-17%Cr-3%V의 3종류 고합금백주철에 있어서 열처리후의 기지조직의 변태거동을 연구하였다. 15kg 용량의 고주파 유도용해로에 선철, 고철, Fe-Cr, Fe-V, Fe-Mo 및 Fe-W 등을 장입시켜 용해시킨 후 슬래그를 제거시키고 1550℃에서 Y-block의 펩셀주형에 주입시켰다. 적당한 크기로 절단한 시편을 진공분위기하에서 950℃에서 5시간동안 우선 균질화처리를 실시하였다. 그 후 다시 이 시편을 1050℃에서 2시간동안 오스테나이징시킨 후 강제공냉을 행하였다. 강제공냉된 시편을 300℃에서 3시간 유지시킨 후 템퍼링을 실시하였다. 주방상태에서의 기지조직은 3합금 공히 퍼얼라이트이었으며 강제공냉후에는 마르텐사이트 및 오스테나이트로 변태하였다. 또한 기지조직내에 무수히 많은 이차탄화물 입자들이 석출되었다. 템프링후 일부 오스테나이트 및 마르텐사이트는 템퍼드마르텐사이트로 변태하였다.

Abstract   Three different white cast irons alloyed with Cr, V, Mo and W were prepared in order to study their transformation behavior of matrix structures in heat-treated conditions. The specimens were produced using a 15kg-capacity high frequency induction furnace. Melts were super-heated to 1600℃, and poured at 1550℃ into Y-block pepset molds. Three combinations of the alloying elements were selected so as to obtain the different types of carbides and matrix structures : 3%C-10%Cr-5%Mo-5%W(alloy No. 1), 3%C-10%V-5%Mo-5%W(alloy No. 2) and 3%C-17%Cr-3%V(alloy No. 3).

The heat-treatments were conducted as follows: first of all, the as-cast specimens were homogenized at 950℃ for 5h under the vacuum atmosphere. Then, they were austenitized at 1050℃ for 2h and followed by air-hardening in air. The air-hardened specimens were tempered at 300℃ for 3h. The observation of morphology of the matrix structures was carried out in the states of as-cast(AS), air-hardened(AHF) and tempered(AHFT). The matrix structures of each alloy were almost fully pearlitic in the as-cast state but it was transformed to martensite, tempered martensite and retained austenite by the heat-treatments such as air-hardening and tempering.

Key words : white cast iron, transformation, air-hardening, tempering

1. Introduction

Alloyed white cast iron with many kinds of strong carbide-forming elements is a recently developed wear-resistant material for the application to the hot strip and mineral pulverizing mills.[1~11] It contains reasonable amounts of elements, such as Cr, V, Mo, W and Nb, and the carbon content is relatively higher than that of high-speed tool steel with similar alloying elements. MC, M₂C, M₆C, M₇C₃ and NbC carbides can be precipitated as primary and/or eutectic carbides during solidification. In addition, the matrix structure can also be varied by the heat treatments such as air-hardening and tempering, and particularly hard matrix can be obtained due

to the precipitation of numerous minute secondary carbides and the martensite transformation from retained austenite.

Properties such as abrasion wear resistance, surface roughening resistance and seizing or sticking resistance are essentially important to apply these alloyed white cast irons for the rolls and other wear resistant parts of steel rolling and mineral pulverizing mills. Among these properties, the abrasion wear resistance is reported to be dependent upon not only type, morphology, amount and distribution pattern of the precipitated carbides mentioned above, but also the matrix structure. Nevertheless, the matrix transformation due to heat-treatments of these irons was little researched system-

atically.

In this work, alloyed white cast irons with three different chemical compositions were selected for the investigation of their transformation behavior of matrix structures in heat-treated conditions. Heat-treatments such as air-hardening and tempering were employed to induce the transformation of matrix structures from pearlite which was obtained in as-cast state. The identification of the transformed matrix structures was conducted by SEM and X-ray diffraction.

2. Experimental Procedure

The alloys were melted in a 15kg-capacity high frequency induction furnace. Initial charge materials were clean pig irons and steel scraps. Ferro-alloys such as Fe-60%Cr, Fe-80%V, Fe-60%Mo and Fe-75%W were added to a slag-free molten iron so as to minimize the oxidation loss and the slag formation. The melt was subsequently super-heated to 1600°C and transferred into a preheated teapot ladle. After removal of any dross and slag, the melt was poured at 1550°C into pepset molds to produce Y-block ingots. The chemical analysis of the alloys are shown in Table 1.

Table 1. Chemical composition of the three alloys.

Alloy No.	Element(mass%)				
	C	Cr	V	Mo	W
1	2.98	9.95	0.01	5.14	4.87
2	3.04	0.04	10.21	5.21	4.84
3	3.07	17.54	3.14	0.01	0.02

Before air-hardening and tempering, the as-cast specimens were homogenized at 950°C for 5h under the vacuum atmosphere. Then, they were air-hardened after austenitizing at 1050°C for 2h under the vacuum atmosphere and followed by tempering at 300°C for 3h in the air.

The volume fraction of austenite was calculated from the ratio of peak areas of (200) and (220) for ferrite and martensite, and those of (220) and (311) for austenite. The diffraction patterns were obtained by employing a simultaneous rotating and swinging sample stage in order to minimize or cancel the effect of texture structure. The X-ray diffraction was carried out using Mo-Kα line with Zr filter and diffracting angle from 24 to 44 degree.

The specimens were polished, etched and examined metallographically by SEM. Villela's etchant was employed to distinguish the phases clearly.

3. Results and Discussion

The microstructures of each alloy in the as-cast state are shown in Fig. 1. Alloy No. 1 consists of eutectic M$_7$C$_3$ carbide, eutectic M$_6$C carbide and pearlitic matrix. Alloy No. 2 is composed of primary MC carbide, eutectic MC and M$_2$C carbides and pearlitic matrix. On the other hand, alloy No. 3 has a microstructure with coarse primary M$_7$C$_3$ carbide, eutectic M$_7$C$_3$ carbide and pearlitic matrix. The more magnified matrix microstructures are also shown in Fig. 1 in which the typical lamellar structure of pearlite is clearly seen between the carbide structures. Little difference in the morphology of pearlite among the three alloys might be caused by cutting direction of the specimens. The volume fraction of austenite in the matrix (Vr), that of carbides in the alloy (Vc) and the macrohardness (HV30) for as-cast (AS), homogenized (AH), air-hardened (AHF) and tempered (AHFT) specimens are summarized in Table 2.

As listed in Table 2, the Vr value of each alloy in the as-cast state is almost negligible compared with the amounts of pearlite, which reassures the morphology observed in Fig. 1.

Fig. 2 shows the matrix microstructures of each alloy in the air-hardened state. The characteristic feature of the air-hardened state when compared with the as-cast state is the fact that the matrix structures of each alloy have been transformed from pearlite to martensite or austenite. As listed in Table 2, the Vr values of alloys No. 1, No. 2 and No. 3 are 25.3, 10.9 and 6.9%, respectively while the remaining parts of the matrix structures are martensite. As can be judged from the morphology in Fig. 2, the alloy No. 1 reveals that it contained more retained austenite than the alloys No. 2 and No. 3. The evidence of phase transformation from pearlite to austenite or martensite by air-hardening treatment is also manifested by the increase in macrohardness, as listed in Table 2: alloy No. 1 (652 → 905, +138.8%), alloy No. 2 (514 → 695, +135.2%), alloy No. 3 (842 → 912, +108.3%).

Another characteristic feature of the air-hardened state is the dispersion of tiny numerous secondary carbides in the matrix structures. Because of higher cooling rate after solidification encountered in the as-cast specimens, the matrix in the as-cast state is usually supersaturated with C and Cr. Therefore, the homogenizing heat-treatment has to be conducted to reduce C and Cr in the matrix by precipitating secondary carbides, and subsequently Ms temperature is raised. It is
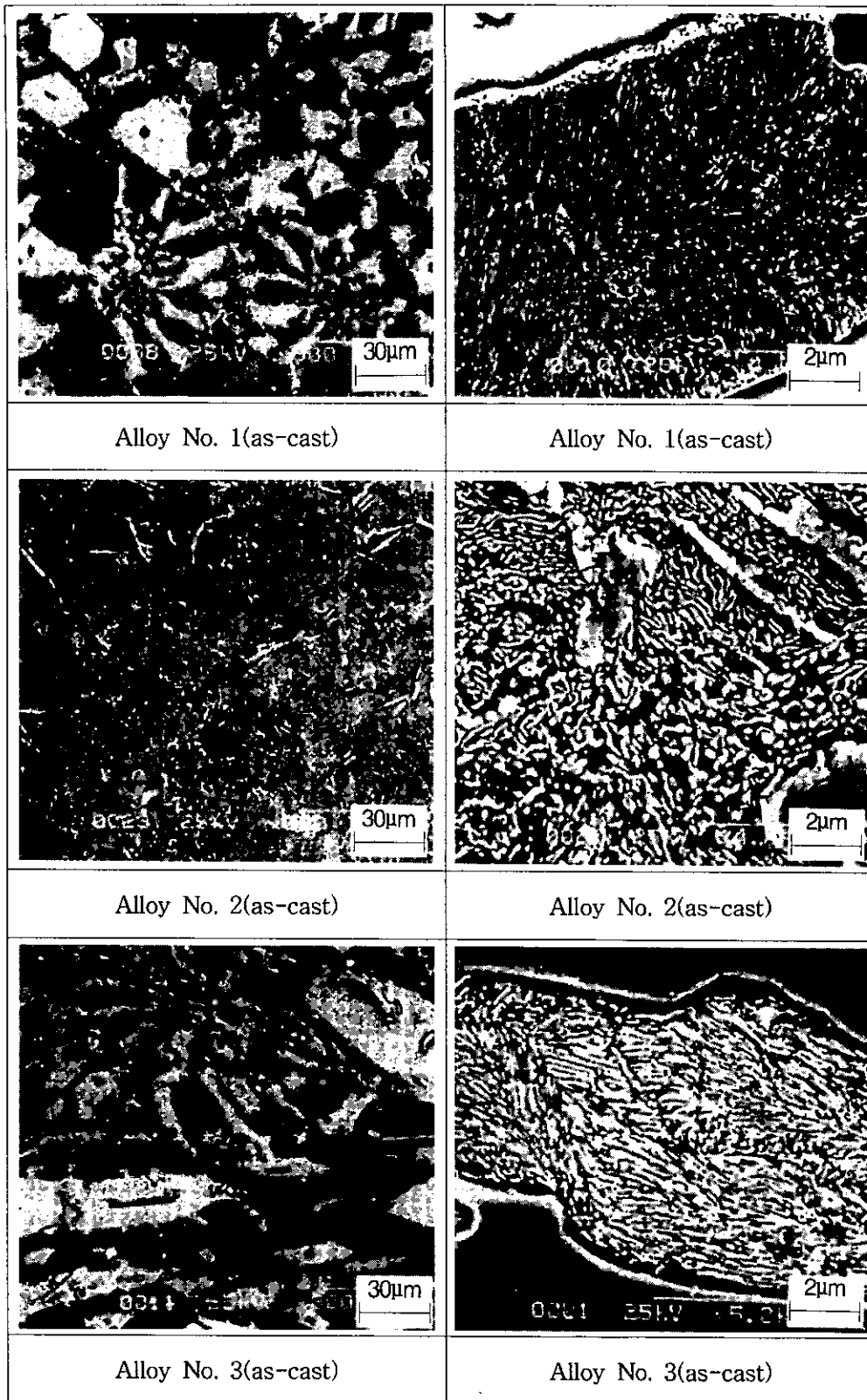
Fig. 1. Matrix microstructures observed in the as-cast state. Lamellar type pearlite is clearly seen between carbide structures(right).

Table 2. Effects of heat-treatments on volume fraction of austenite(Vr) and carbide(Vc), and macrohardness(HV30).

Heat-treatment \ Item \ Specimen	Alloy No. 1			Alloy No. 2			Alloy No. 3		
	V_r (%)	V_c (%)	HV30	V_r (%)	V_c (%)	HV30	V_r (%)	V_c (%)	HV30
AS (As-cast)	0.2	32.9	652	0.2	15.8	514	0.4	29.9	842
AH (Homogenizing)	0.2	32.9	554	0.2	15.8	449	0.3	29.9	593
AHF (Air-hardening)	25.3	32.9	905	10.9	15.8	695	6.9	29.9	912
AHFT (Tempering)	21.5	32.9	905	7.2	15.8	666	5.4	29.9	842

reported that the equilibrium concentration of C and Cr in the matrix is determined by Cr/C ratio and homogenizing temperature.[12] At the constant Cr/C ratio, the equilibrium concentration of C in the matrix decreases with a decrease in the homogenizing temperature whereby more secondary carbides can be precipitated and higher Ms temperature can be obtained. These secondary carbides are not eliminated in the heat-treatments such as air-hardening and tempering which are followed by homogenizing treatment. Because the matrix structures of the three homogenized specimens are being composed of coarse pearlite in comparison to those of the as-cast specimens, the macrohardness value of each alloy is lowered in spite of the precipitation of secondary carbides. The macrohardness of alloyed white cast iron is a function of both the carbide and matrix structure, and therefore, it is natural that the macrohardness decreases when the specimens are homogenized or annealed.

The matrix microstructures of each alloy in the tempered state are also shown in Fig. 2. The morphology of the matrix microstructure in the tempered state is little different when compared with that observed in the air-hardened state. High alloyed cast irons that have undergone a simple air-hardening treatment are usually mixtures of austenite and martensite with the latter constituent predominating as shown in Table 2. Both of these structures are unstable and slowly decompose if left at room temperature: the retained austenite transforms to martensite and the martensite undergoes dimensional changes as a function of time.[13] Therefore, a structure with dimensionally more stable and inherently less brittle can be obtained through a heat-treatment called tempering. The microstructural changes that occur during tempering are also accompanied by the change of physical properties. The change of macrohardness from the air-hardened state to the tempered state is shown in Table 2: alloy No. 1 (905 → 905, 0.0%), alloy No. 2

(695 → 666, -4.2%), alloy No. 3 (912 → 842, -7.7%). As expected from the values of Vr, the decrease of the macrohardness after tempering is rather small. Hardness is known to be a function of both tempering time and tempering temperaure, generally decreasing with increasing the tempering temperature. Therefore, it can be said that more decrease in macrohardness can be expected with tempering temperaure higher than 300 ℃ and tempering time longer than 3h.

4. Conclusion

Transformation behavior of the matrix structures in high alloyed white cast iron has been studied. The results are summarized as follows:

1) In all the alloys, the matrix structures are almost fully pearlitic in the as-cast state. The typical lamellar structure of pearlite is more clearly seen in more magnified microphotographs.

2) In all the alloys, the matrix structures have been transformed from pearlite to martensite or austenite by air-hardening treatment. The Vr value is highest in the alloy No. 1 while it is lowest in the alloy No. 3. Another characteristic feature of the air-hardened state is the dispersion of tiny numerous secondary carbides in the matrix structure.

3) Tempered martensite and austenite are the two phases observed in the tempered state. The decrease of macrohardness from the air-hardened state to the tempered state is not much because of lower tempering temperature and shorter tempering time employed in this experiment.
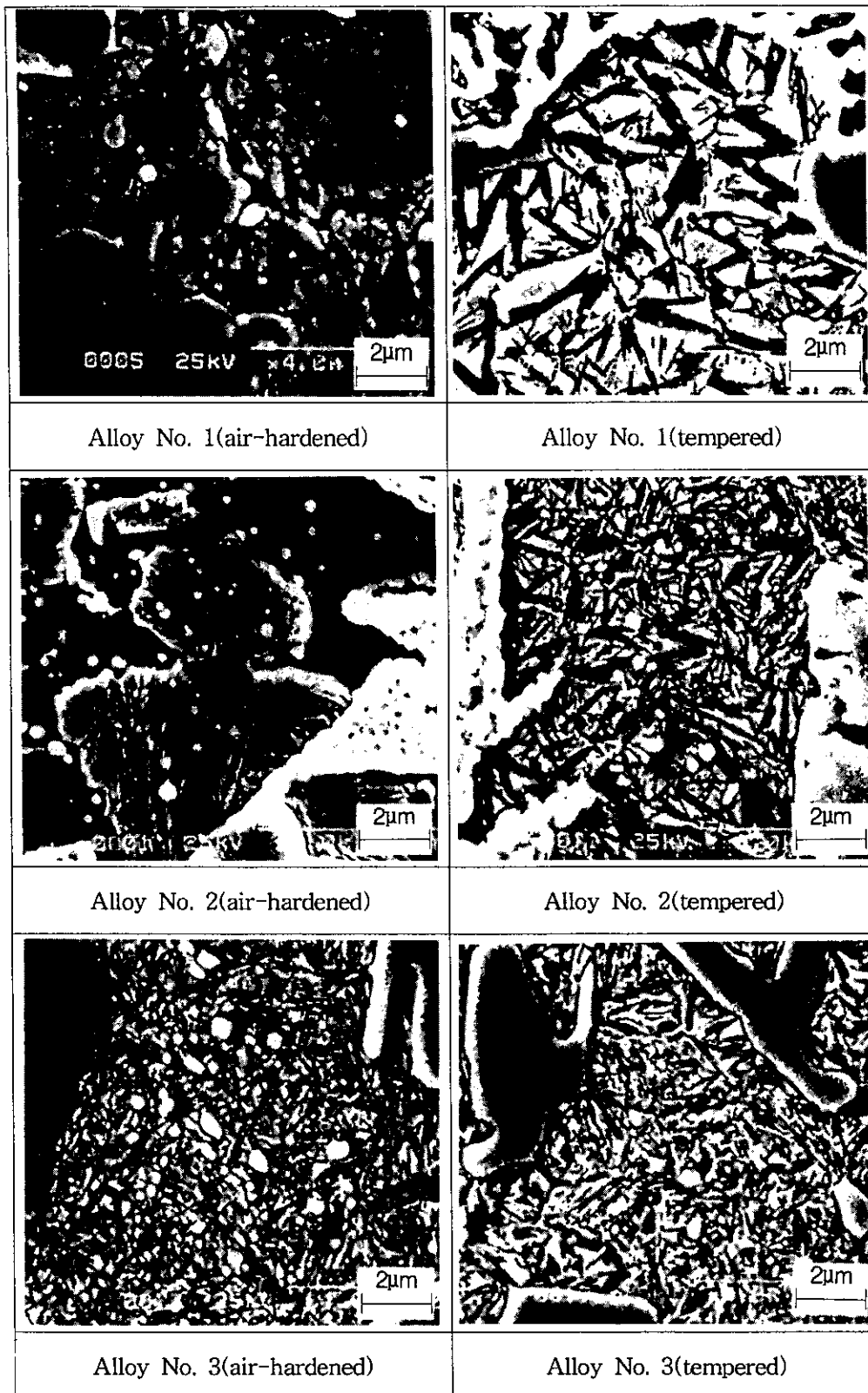
Fig. 2. Matrix microstructures observed in the air-hardened state(left) and in the tempered state(right).

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