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X%C-5%Cr-5%V-5%Mo-5%W-5%Co 다합금계백주철의 응고조직에 관한 연구

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The Solidification Microstructure of X%C-5%Cr-5%V-5%Mo-5%W-5%Co Multi-Component White Cast Iron

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초 록 광학 및 주사전자현미경을 사용하여 X%C-5%Cr-5%V-5%Mo-5%W-5%Co 조성을 가진 다합금계백주철에서 정출되는 탄화물의 종류 및 형태를 3차원적으로 관찰하였는 바 MC, M_2C 및 M_7C_3의 3종류의 탄화물이 정출되었다. MC탄화물은 꽃잎, 구상 그리고 산호초형태의 3종류, M_2C탄화물은 층상 및 판상의 2종류, M_7C_3탄화물은 고크롬백주철에서 관찰되는 막대형태의 한 종류만 관찰되었다. 첨가한 합금원소중 Co는 기지조직에만 고용되었기 때문에 탄화물의 형상에는 영향을 미치지 않았다.

Abstract Type and three-dimensional morphology of carbides precipitated in the X(X=1.70, 1.92, 2.21, 2.50, 2.86)%C-5%Cr-5%V-5%Mo-5%W-5%Co multi-component white cast iron were investigated using an optical microscope and SEM. The types of carbides precipitated were MC, M_2C and M_7C_3. Morphology of the MC carbide took three forms, that is, petal-like, nodular and coral-like. MC carbide seemed to change its morphology from petal-like through nodular, and finally to coral-like with an increase in carbon content. M_2C carbide was classified into lamellar and plate-like type. The lamellar M_2C carbide precipitated in the iron with low molybdenum and tungsten contents, and higher contents of both elements in the iron were needed to form the plate-like M_2C carbide. The morphology of M_7C_3 was rod-like similar to that observed in high chromium white cast iron. However, cobalt does not affect the type and morphology of precipitated carbides.

Key words: multi-component white cast iron, MC, M_2C and M_7C_3 carbide, morphology

1. Introduction

As for the materials of hot strip mill rolls, chilled cast iron, Ni-hard cast iron with some graphite and low carbon white cast iron had been used in the past while hypo-eutectic high chromium cast iron is now mainly adopted. Roll materials for pulverizing mills of minerals, slag and cement clinker, which should have high abrasive wear resistance, have been changed from Ni-hard cast irons to eutectic and hyper-eutectic high chromium white cast irons containing large amounts of eutectic carbides which are able to improve the working performance and productivity.

Multi-component 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.[1~11] It contains reasonable amounts of elements such as Cr, V, Mo, W and Co, 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 and M_7C_3 can be precipitated during solidification, while the hard matrix can be obtained by the precipitation of numerous tiny secondary carbides and heat-treatments such as normalizing and tempering. From the view point of toughness, wear resistance and sticking or seizing resistance, the carbon level of the roll materials for hot strip mills is maintained low, say, in the range of 1.7-2.3%, and that for pulverizing mills is kept to be more than 2.5% so that more carbides can be formed.

In this work, the solidification structures of X%C-5%Cr-5%V-5%Mo-5%W-5%Co multi-component white cast iron and the type and three dimensional morphology of precipitated carbides were clarified.

Table 1. Analyzed chemical composition of the five specimens(mass%).

Specimens \ Elements	C	Cr	Mo	W	V	Co
No. 1	1.70	5.13	5.75	5.16	5.06	4.88
No. 2	1.92	5.80	5.66	5.10	4.96	4.92
No. 3	2.21	5.03	5.56	5.17	4.95	4.81
No. 4	2.50	5.12	5.74	5.12	5.07	5.01
No. 5	2.86	5.04	5.67	5.10	4.84	4.91

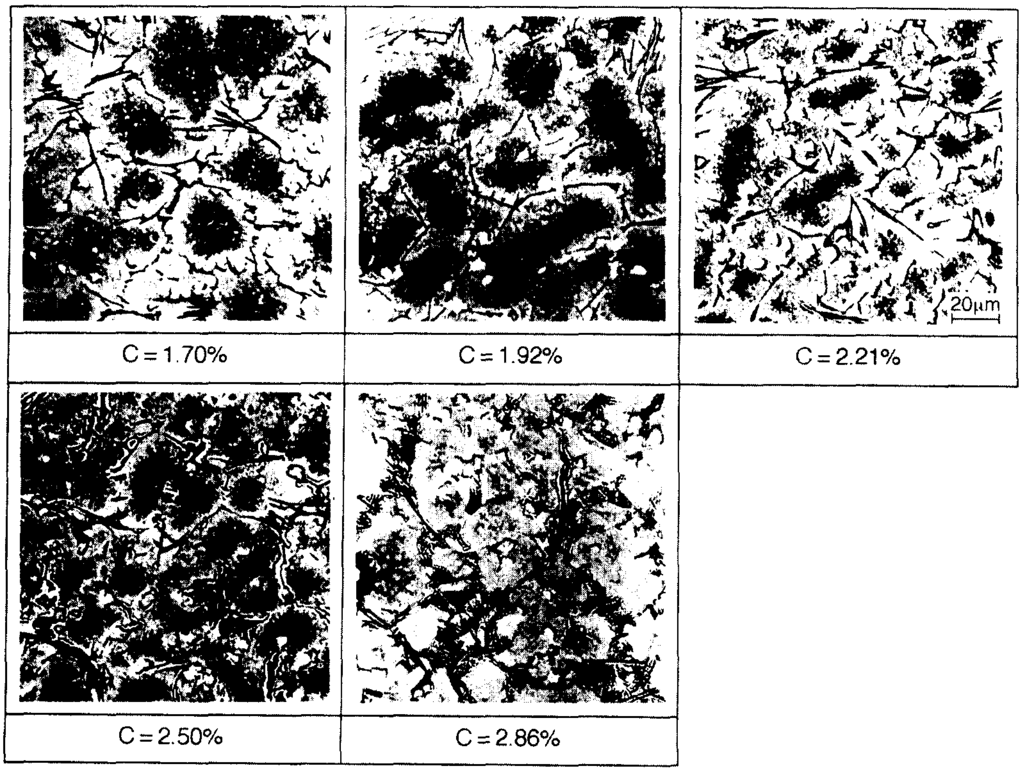

Fig. 1. Influence of C content on as-cast microstructures of multi-component white cast iron.

2. Experimental Procedure

The basic alloy composition of specimens used in this study was kept to be approximately 5% for each element of Cr, V, Mo, W and Co. Carbon content was varied from 1.70 to 1.92, 2.21, 2.50 and 2.86%, respectively. Each charge(450g) was melted using an alumina crucible in a graphite resistance electric furnace. Charge materials were clean pig irons, steel scraps, Fe-60%Cr, Fe-80%V, Fe-60%Mo, Fe-75%W and Co, which were added according to the charge calculation. After removal of any dross and slag, the melt was poured from 1530℃ into an exothermic mold with 22mm in diameter. The optical microscope and SEM were utilized to observe the microstructure of each specimen in detail.

3. Results and Discussions

The chemical compositions of the five specimens are shown in Table 1. The effect of carbon content on as-cast microstructures are shown in Fig. 1.

In the specimens with carbon content less than 2.50 %, chunky, petal-like, nodular, coral-like, lamellar and plate-like carbides are co-existing in the matrix. On the other hand, the specimen with 2.86%C contains ledeburitic carbides in addition to the carbides mentioned above. The alloy concentrations of every structural constituent in the specimen were quantitatively analyzed using EDS. SEM microphotograph and alloy concentrations in the phases of the specimen 5 are shown in Fig. 2 and Table 2, respectively. Nodular carbide(A) contains mainly vanadium and some of other alloying elements, while plate-like carbide(B) is of high molybdenum and tungsten contents. Carbide similar to

Table 2. Alloy concentrations of the phases in Fig. 2(mass%).

Phases \ Elements	Cr	Mo	W	V	Co	Fe
A	3.5-4.5	6.5-11	8-11	50-55	0.5-1.0	17-25
B	10-14	28-32	18-19	9-11	0.7-1.2	21-34
C	6-8	24-27	15-17	2.0-2.5	2-3	42-50
D	21-22	9.5-12	5-6	3.0-3.5	2-3	52-58
E	3.5-4.5	1-2	2.5-4.5	1.0-2.2	6-7	79-84

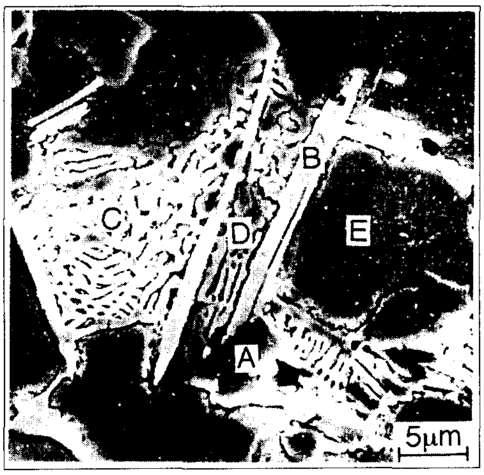

Fig. 2. SEM microstructure of the iron with 2.86%C(specimen No. 5).

ledeburite(C) is rich in molybdenum, tungsten and iron.

Carbide D contains mainly iron and chromium in which other elements such as molybdenum and tungsten are also dissolved. Matrix of the specimen(E) is iron-base solid solution containing most of cobalt added.

Deep etched specimens were prepared for the observation of carbide morphology by SEM. MC and M_2C carbides were precipitated in the lower carbon specimens(up to 2.50%C) while M_7C_3 carbide appeared in addition to MC and M_2C carbides in the specimen No. 5. The morphology of MC carbide precipitated can be classified into three kinds: 1) petal-like, 2) nodular and 3) coral-like as shown in Fig. 3. The flaky carbide(a) observed under an optical microscope has three dimensionally petal-like morphology, which resembles the graphite eutectic cell in gray cast iron. Under an optical microscope, nodular carbide(b) takes roughly round shape and is three-dimensionally disconnected one by one. The optical microstructure in (c) consists of the mixture of chunky, nodular and flaky carbides, which has coral-like morphology under SEM. It seems that the MC carbide tends to change its morphology from petal-like to nodular, and finally to coral-like with an increase in carbon content.

M_2C carbide takes two kinds of morphology as shown in Fig. 4; lamellar(a) and plate-like(b). Both molybdenum and tungsten are significant elements to form M_2C or M_6C carbide. Fine lamellar M_2C carbide precipitates in the iron with low molybdenum and tungsten contents, and higher content of both elements in the iron are needed to form coarse plate-like M_2C carbide; the more both elements, the more plate-like M_2C carbide.

Fig. 5 shows the optical microstructure and the three-dimensional morphology of M_7C_3 carbide which is co-existing with MC and M_2C carbide. The M_7C_3 carbide takes a rod-like morphology which is similar to that observed in high chromium white cast iron. From these results, it can be found that the morphology of carbides in multi-component white cast iron, which is determined by type, shape, volume and distribution of the carbides, can be widely controlled by the combinations of carbon and each alloying element.

4. Conclusion

The solidification microstructure of X%C-5%Cr-5%V-5%Mo-5%W-5%Co multi-component white cast iron has been studied. The results are summarized as follows :

1) Three types of carbides, that is, MC, M_2C and M_7C_3 were found to precipitate in the multi-component white cast irons investigated.

2) The type and morphology of precipitated carbides were changed markedly by variation of carbon content.

3) The morphology of MC carbide could be classified into three kinds of groups: petal-like, nodular and coral-like. M_2C carbide exhibited two kinds of morphology; plate-like and lamellar. M_7C_3 carbide took a rod-like form which is similar to that observed in high and low chromium white cast iron.

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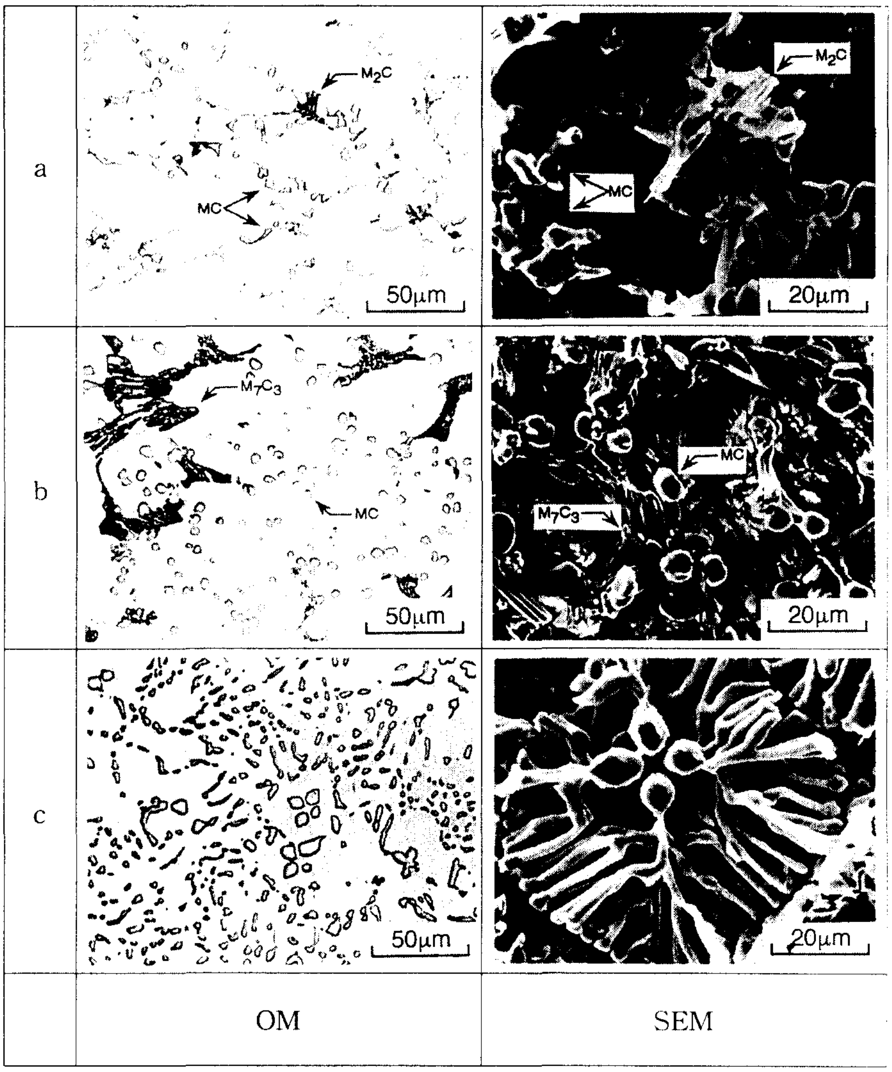

Fig. 3. Correspondence of optical microstructure and its three-dimensional morphology of three types of MC carbide(a: petal-like, b: nodular, c: coral-like).

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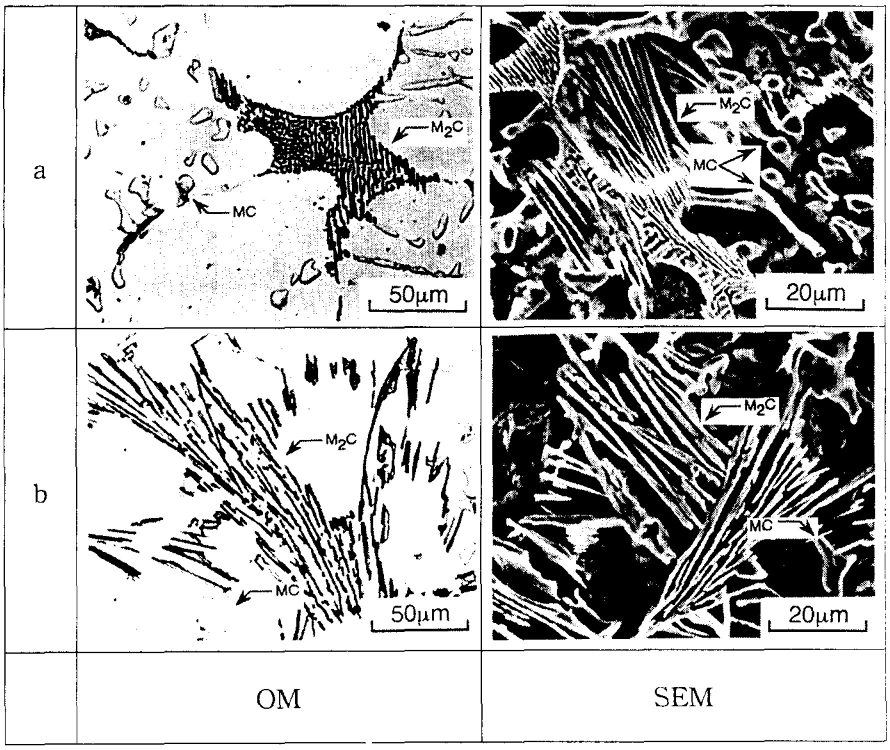

Fig. 4. Correspondence of optical microstructure and three-dimensional morphology of M_2C carbide(a: lamellar, b: plate-like).

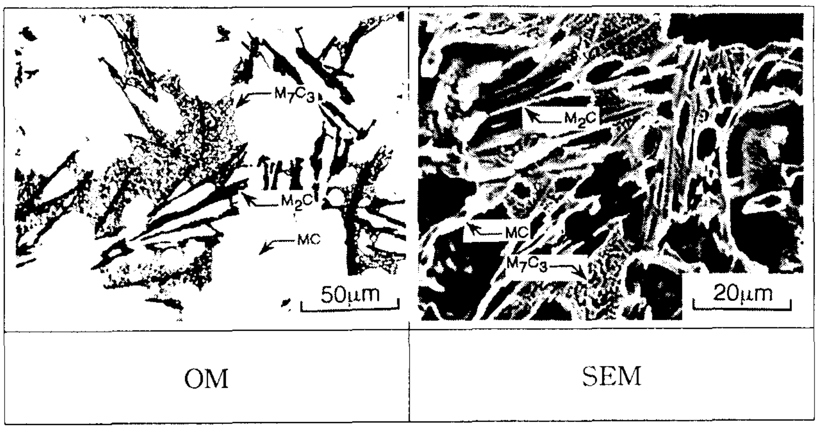

Fig. 5. Correspondence of optical microstructure(a) to three dimensional structure(b) of rod-like M_7C_3 carbide.

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