技術資料

Effects of Alloying Elements and Heat-Treatments on Abrasion Wear Behavior of High Alloyed White Cast Iron

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Abstract

Three different white cast irons alloyed with Cr, V, Mo and W were prepared in order to study their abrasion wear behavior in as-cast and heat-treated conditions. The specimens were produced using a 15kg-capacity high frequency induction furnace. Melts were super-heated to 1600°C, and poured at 1550°C into Y-block pepset molds. Three combinations of the alloying elements were selected so as to obtain the different types of carbides : 3%C-10%Cr-5%Mo-5%W(alloy No. 1: M_7C_3 and M_6C), 3%C -10%V-5%Mo-5%W(alloy No. 2: MC and M_2C) and 3%C-17%Cr-3%V(alloy No. 3: M_7C_3 only).
A scratching type abrasion test was carried out in the states of as-cast(AS), homogenizing(AH), air-hardening(AHF) and tempering(AHFT). First of all, the as-cast specimens were homogenized at 950°C for 5h under the vacuum atmosphere. Then, they were austenitized at 1050°C for 2h and followed by air-hardening in air. The air-hardened specimens were tempered at 300°C for 3h. 1 kg load was applied in order to contact the specimen with abrading wheel which was wound by 120 mesh SiC paper. The wear loss of the test piece(dimension: 50 × 50 × 5 mm) was measured after one cycle of wear test and this procedure was repeated up to 8 cycles. In all the specimens, the abrasion wear loss was found to decrease in the order of AH, AS, AHFT and AHF states. Abrasion wear loss was lowest in the alloy No. 2 and highest in the alloy No. 1 except for the as-cast and homogenized condition in which the alloy No. 3 showed the highest abrasion wear loss. The lowest abrasion wear loss of the alloy No. 2 could be attributed to the fact that it contained primary and eutectic MC carbides, and eutectic M_2C carbide with extremely high hardness. The matrix of each specimen was fully pearlitic in the as-cast state but it was transformed to martensite, tempered martensite and austenite depending upon the type of heat-treatment. From these results, it becomes clear that MC carbide is a significant phase to improve the abrasion wear resistance. (Received March 4, 2000)

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, M_2C, M_6C, M_7C_3 and NbC carbides can be precipitated as primary and/or eutectic carbides during solidification. In addition, the matrix 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 abrasion wear resistance of these irons was little researched systematically.

In this work, alloyed white cast irons with three different chemical compositions were selected for the investigation of abrasion wear resistance. Heat-treatments such as air-hardening and tempering were employed to obtain the different matrix structures. Then, the effect of type of carbide and matrix on the abrasion wear resistance was investigated using a scratching type abrasion wear testing machine. The worn parts of the specimens were also examined by SEM to derive the mechanism of abrasion

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Table 1. Chemical composition of the three alloys and co-existent carbides of the alloys.

Alloy No.	Element(mass%)					Carbide Type
	C	Cr	V	Mo	W	
1	2.98	9.95	0.01	5.14	4.87	M_7C_3, M_6C
2	3.04	0.04	10.21	5.21	4.84	MC, M_2C
3	3.07	17.54	3.14	0.01	0.02	M_7C_3

wear.

2. Experimental Procedure

2.1 Specimen Preparation

To obtain the alloys with several combinations of the different carbides, the four alloying elements such as Cr, Mo, W and V were designed so as to make their sum approximately 20%. Specimens were produced in a 15 kg -capacity high frequency induction furnace. Initial charge materials were clean pig iron and steel scrap. Ferro-alloys 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 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 and co-existent carbides of the alloys are shown in Table 1.

2.2 Heat Treatment of Specimens

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 holding at 1050°C for 2h under the vacuum atmosphere and followed by tempering at 300°C for 3h in the air.

2.3 Measurement for Austenite

The volume fraction of austenite was calculated from the ratio of peak areas of (200) and (220) for ferrite and martensite, and that 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-K α line with Zr filter and diffracting angle of 24 to 44 deg.

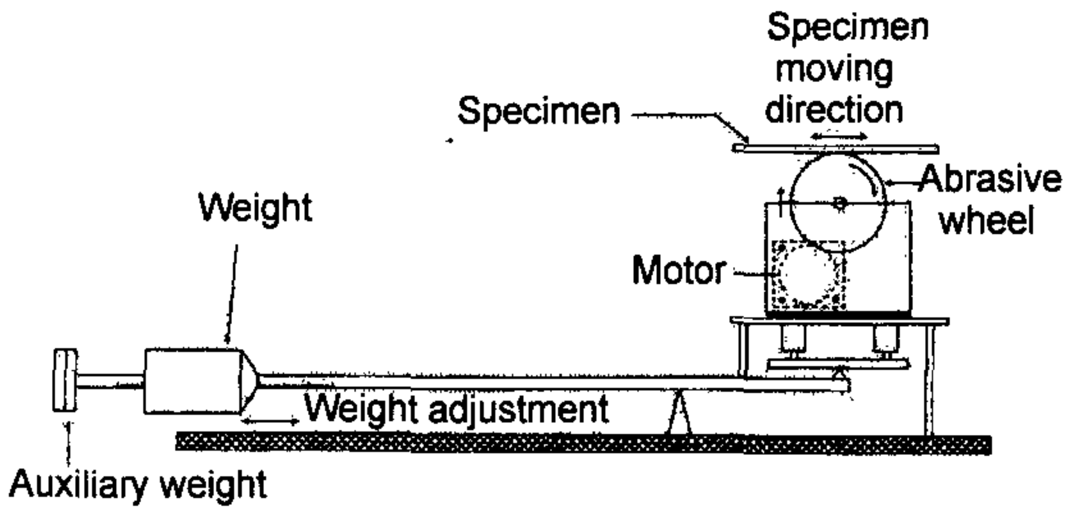

Fig. 1. A schematic drawing of abrasion wear testing machine.

2.4 Wear Test

A schematic drawing of a main portion of the abrasion wear testing machine is illustrated in Fig. 1. 1 kg load was applied in order to contact the specimen with abrading wheel which was wound by 120 mesh SiC paper. The wear loss of the test piece(50 × 50 × 5 mm) was measured after one cycle of the test which was taken for 400s, and this procedure was repeated up to 8 cycles.

2.5 Metallographic Examination

The specimens were polished, etched and examined metallographically by SEM. Two etchants such as Villela's and Murakami's were employed to distinguish the phases clearly.

3. Results and Discussion

3.1 Abrasion Wear Behavior in As-Cast State

For later discussions, 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.

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

Specimen	Alloy No. 1			Alloy No. 2			Alloy No. 3		
Types of heat-treatment	Vγ(%)	Vc(%)	HV30	Vγ(%)	Vc(%)	HV30	Vγ(%)	Vc(%)	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

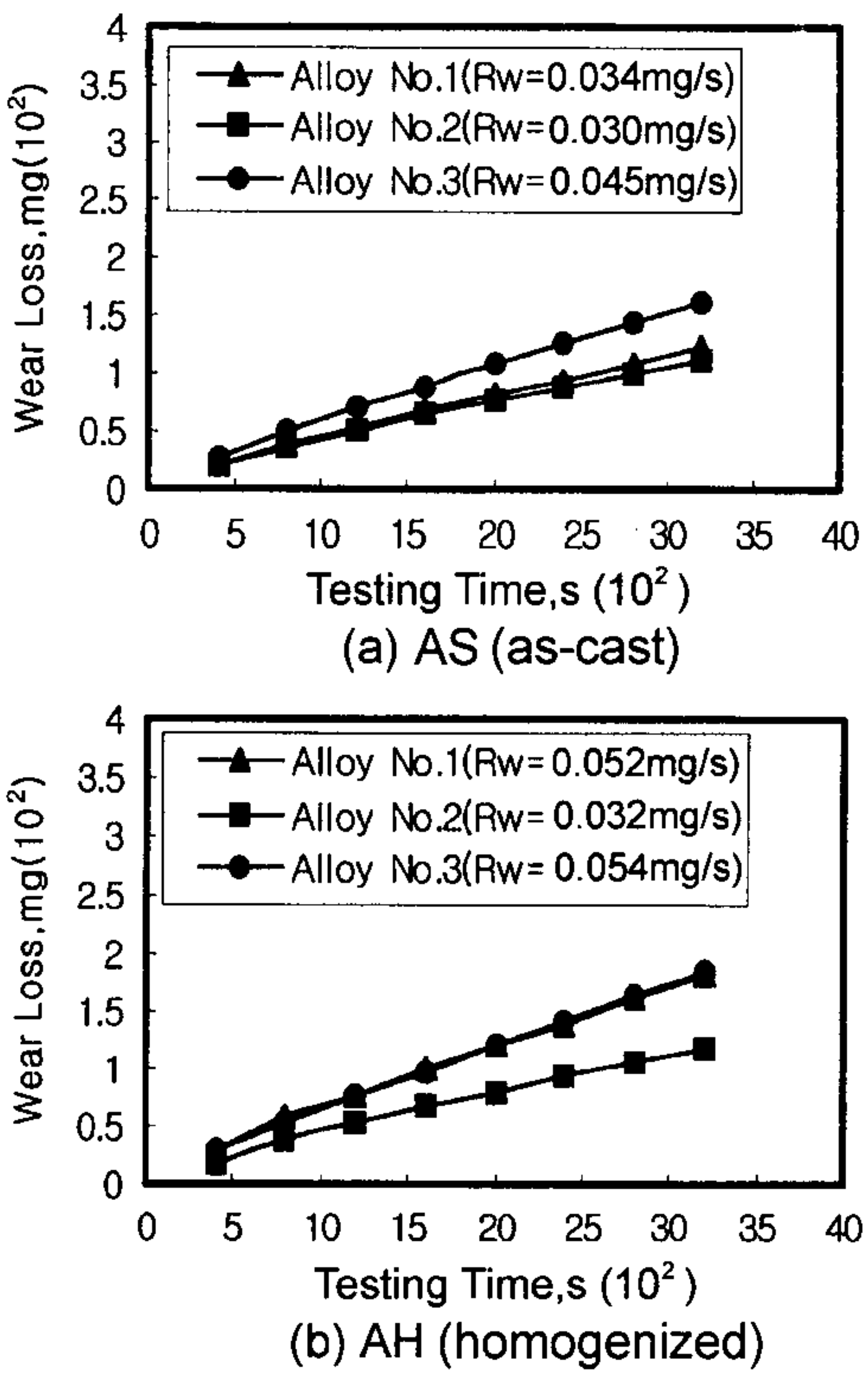

Fig. 2. Relationship between wear loss and testing time in as-cast and homogenized states.

The abrasion wear test results of each alloy in the as-cast state are shown in Fig. 2(a).

Since nearly linear relations are obtained between wear loss and testing time in all the specimens, it is convenient to adopt the term "wear rate(Rw: mg/s)" which is expressed by the slope of each straight line. The range of Rw values in the as-cast specimens was from 0.030 to 0.045 mg/s depending upon the alloy type. The lowest Rw value, which means the highest abrasion wear resistance, was obtained in the alloy No. 2 which contains high V and consists of primary MC carbide, eutectic MC carbide and M_2C carbides and pearlitic matrix. The alloy No. 3, which showed the worst abrasion wear resistance, has a microstructure with primary M_7C_3 carbide, eutectic M_7C_3 carbide and pearlitic matrix. On the other hand, the Rw value of the alloy No. 1 ranked between the alloys No. 2 and No. 3, consisting of eutectic M_7C_3 carbide, eutectic M6C carbide and pearlitic matrix. Because the as-cast matrix structures in the three alloys are all pearlitic, it can be said that the abrasion wear resistance in the as -cast state depends mainly upon the type, morphology and amount of carbides. As shown in Table 2, the volume fraction of carbides of the alloy No. 1 is the highest and that of the alloy No. 2 is the lowest, and the macro-hardness of the alloy No. 2 is also the lowest among the three alloys. In spite of the lowest volume fraction of carbides and macrohardness, the highest wear resistance was obtained in the alloy No. 2. This could be attributed to the fact that the main carbide of this alloy is MC type which is hardest and toughest among the carbides in alloyed white cast iron, and M_2C carbide which is also hardest next to the MC carbide could resist such a scratching type abrasion. On the other hand, the alloy No. 3 shows the highest Rw value in spite of its highest macrohardness of HV 842. The reasons are possibly due to the fact that the large massive and hexagonal primary M_7C_3 carbides not only make the alloy brittle but also are broken away by spalling.

3.2 Abrasion Wear Behavior in Heat-Treated State

The results of the abrasion wear test of the homogenized specimens are shown in Fig. 2(b). The Rw values ranged from 0.032 to 0.054 mg/s. It is clear that the abrasion wear loss of each alloy is increased by homogenizing when compared with that of the as-cast alloy. The Rw values rise from 0.034 to 0.052 mg/s in the alloy No. 1, from 0.030 to 0.032 mg/s in the alloy No. 2, from 0.045 to 0.054 mg/s in the alloy No. 3. The increasing ratios are 52.9, 6.3 and 16.7%, respectively. The abrasion wear resistance increases in the order of alloy No. 3, No. 1 and No. 2. Therefore, a similar postulation which was suggested in the as-cast state can be applied to this case. As the matrix structures of all the homogenized specimens in this work are composed of coarse pearlite in comparison to those of the as-cast specimens, the macrohardness of matrix is lowered in spite of the precipitation of secondary carbides. The abrasion wear resistance of alloyed white cast iron has been generally considered to be a function of both the carbide and matrix structure, and therefore, it is natural that the wear resistance decreases when the specimens are homogenized or annealed.

In case of air-hardened specimens shown in Fig. 3(a), the Rw values ranged from 0.009 to 0.033 mg/s indicating that the abrasion wear loss is reduced by the air-hardening from 0.034 to 0.033 mg/s in the alloy No. 1, from 0.030 to 0.009 mg/s in the alloy No. 2, from 0.045 to 0.024 mg/s in the alloy No. 3, and the reduction ratios of Rw are 2.9, 70 and 46.7%, respectively. The lowest Rw value is also obtained in the alloy No. 2, as was the case in the as-cast and homogenized states. However, the highest Rw value is obtained in the alloy No. 1 which was ranked secondly in the as-cast and homogenized conditions. As shown in Table 2, the Vr value of the alloy No. 1 is 25.3% while those of other two alloys are low, i.e., 10.9% for No. 2 and 6.9% for No. 3, which could account for the highest Rw value of the alloy No. 1. It has been reported that the iron with more retained austenite shows better abrasion wear resistance under the adequately high load like 3 kg at the same wear test and it is explained that the retained austenite transforms into induced martensite by the abrasion energy or load[12]. Therefore, it is considered that the 1 kg load might be not enough for inducing the martensite transformation from the retained austenite.

The results of abrasion wear test of the tempered specimens are also shown in Fig. 3(b). The Rw values ranged from 0.010 to 0.035 mg/s, indicating the abrasion wear loss is reduced remarkably in the alloys No. 2 and No. 3 by tempering when compared with that of the as-cast specimen : alloy No. 1(0.034 → 0.035 mg/s, +2.9%), alloy No. 2(0.030 → 0.010 mg/s, -66.7%), specimen No. 3 (0.045 → 0.026 mg/s, -42.2%). When it is compared with the air-hardened state, however, the abrasion wear loss of the tempered specimen increases a little in the alloys No. 2 and No. 3 and their increasing ratios are 11.1 and 8.3%, respectively.

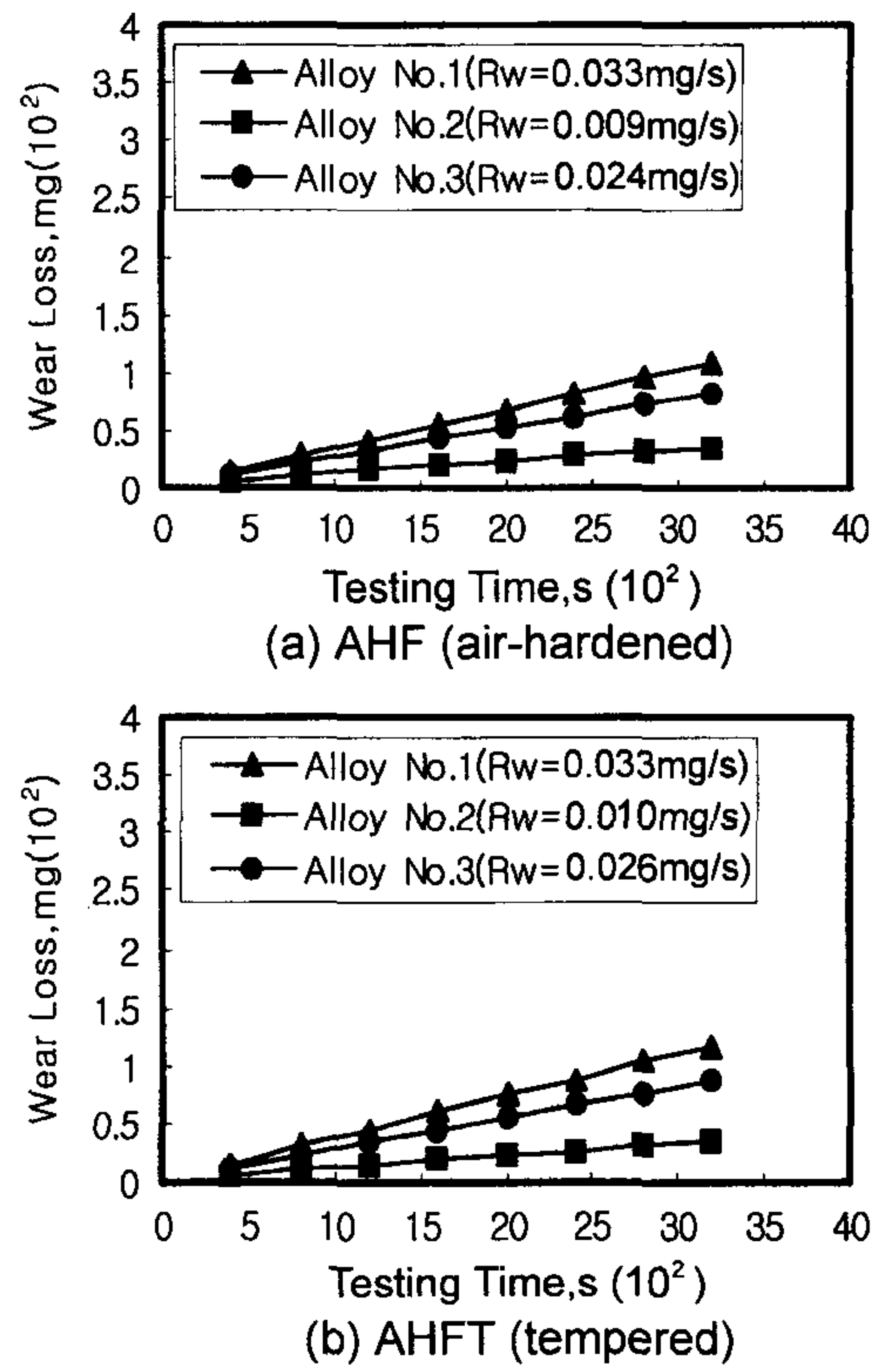

Fig. 3. Relationship between wear loss and testing time in air-hardened and tempered states.

3.3 Observation of Worn Surface

For more discussions about the abrasion wear behavior, the worn surface of tempered specimens were investigated using SEM. The SEM microphotographs of the worn surface and those of the cross-section near the surface are shown in Fig. 4. Many scratched lines are observed on the worn surface. In the alloy No. 1 which showed the worst

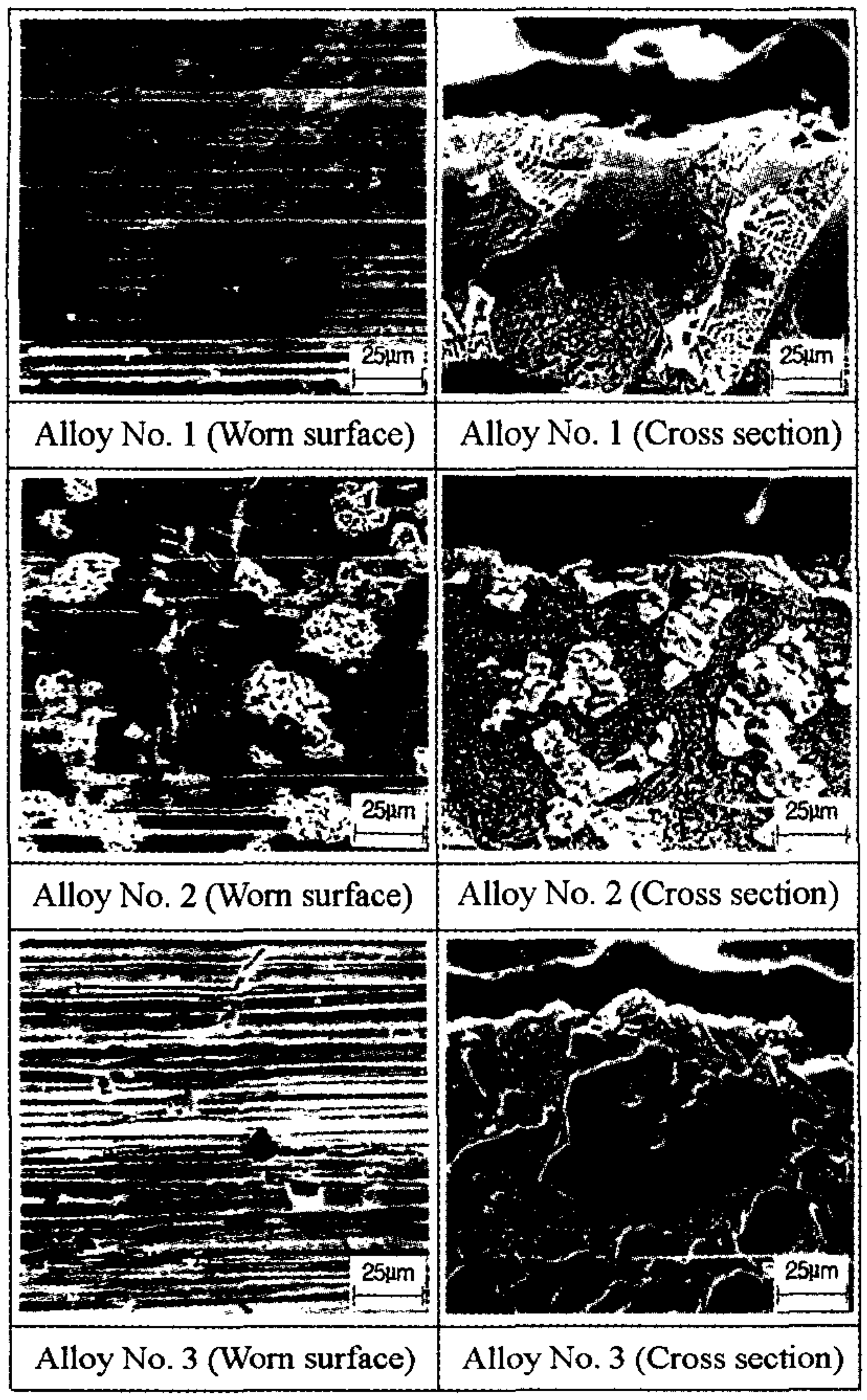

Fig. 4. SEM microphotographs of worn surface and cross section to worn surface in tempered specimens.

wear resistance, many cracks caused in the carbides, and deep and coarse stripes in the matrix structures can be seen. However, the worn surface of the alloy No. 2 is smoother with thin scratching lines and free of cracks. As shown clearly in the cross-sectional microstructure of this figure, the matrix of the alloy No. 2 is even while those of the alloys No. 1 and No. 3 are uneven because the M_7C_3 carbides were worn away. This proves that the matrix with precipitation of hard secondary MC carbides raises the wear resistance. As for the alloy No. 1 which showed the worst wear resistance, a spalling or a tearing-away can be recognized on the M_7C_3 carbides. Similar behavior is found to occur in the alloy No. 3. Therefore it can be said from above investigation that the abrasion wear resistance of the alloys No. 1 and No. 3 depends mainly on massive M_7C_3 carbides while that of the alloy No. 2 is enhanced by the support of hardened and strengthened matrix.

4. Conclusion

Abrasion wear behavior of high alloyed white cast iron has been studied. The results are summarized as follows:

1. In all the alloys, the abrasion wear loss was found to decrease in the order of AH, AS, AHFT and AHF states.
2. In the as-cast and homogenized conditions, the abrasion wear loss was lowest in the alloy No. 2 and highest in the alloy No. 3, while it was lowest in the specimen No. 2 and highest in the alloy No. 1 in air-hardened and tempered condition.
5. The lowest abrasion wear loss of the alloy No. 2 could be attributed to the fact that it contained primary and eutectic MC carbides and eutectic M2C carbide with extremely high hardness. Therefore, it becomes clear that MC carbide is a significant phase to improve the abrasion wear resistance.

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