

# A High Cr-Mo Alloy Iron

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The structure, hardness, abrasion, and erosion wear of Cr-Mo white iron (containing approximately 28% Cr and 1% Mo) heat treated at certain temperatures were studied. Results show that the heat treatment of white iron changes the structures and properties; that is morphology, amount, size, and distribution of secondary phases are affected. When white iron was heated at 800 to 850 °C the secondary phase precipitated at the phase boundary, making the abrasion and erosion wear worse. When the iron was heated at 900 to 950 °C, the secondary phase precipitated dispersively at the matrix, and the corrosion wear was optimum. If the iron is heated at 1000 to 1050 °C, the resistance of abrasion is inhibited, as the secondary phases precipitate in large amounts, and the hardness is increased. When the white iron is tempered at 500 to 600 °C, the resistance of abrasion is better.

**Keywords** chromium, molybdenum, wear, white iron

## 1. Introduction

White iron with high chromium content is commonly used as a resistant material (Ref 1-4) because the carbide  $M_7C_3$  formed in the solidification possesses greater hardness than the silica sand, which is one of the hardest abrasives. The wear resistance of white iron comes not only from carbide, but also from the matrix. It needs many carbides marked with high hardness and toughness matrix, so that the white iron must be heat treated to obtain a good matrix.

## 2. Experiment

The specimen composition (wt%) is 2.83% C, 0.68% Si, 0.65% Mn, 28.03% Cr, 0.032% S, and 0.057% P. The alloy iron was made by melting in an induction furnace, casting into bulk specimens, and cutting into 30 × 60 × 100 mm samples. These samples were then heated at various temperatures (Table 1) and

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air cooled. The purpose of tempering is to research the effect on the properties of alloy iron, to confirm the necessity of temper, and to select the process of temper. The microstructure was examined by transmission electron microscope (TEM). The microcompositions of phases were examined by energy dispersive spectrometer (EDS). The thin foil preparation was performed at -15 °C with the voltage of 40 V and the current of 30 mA in a solution of 10% perchloric acid and 90% ethanol.

The volume of the austenite was determined by an x-ray diffractometer. The sample size was 15 × 20 × 5 mm. The conventional abrasion test was conducted on the rubber wheel machine. The abrasive selected for testing was a clean washed 70 silica sand. The testing load was approximately 98 N. The erosion wear test was conducted on a refitted pin in sand machine full of acid solution. Sample size is  $\phi 10 \times 40$  mm; linear speed is 3.8 m/s. Five same samples were tested in all the wear tests mentioned, and weight loss was used as the measurement.

## 3. Results

The structures of the high Cr-Mo alloy iron are shown in Table 1, while the morphology is shown in Fig. 1. The structure of as-cast iron is eutectic austenite and eutectic carbide of (Cr,

**Table 1 Heat treatment process, structure, hardness, and the amount of retained austenite**

	As-cast	800 °C	850 °C	900 °C	950 °C	1000 °C	1050 °C	1100 °C
Structure	A + $M_7C_3$	A + $M_7C_3$	A + $\chi$ $M_7C_3$	A + $\chi$ $M_7C_3$	M + Ar + $\chi$ $M_7C_3$ $M_7C_3$ II	M + Ar + $\chi$ $M_7C_3$ $M_7C_3$ II	M + Ar + $\chi$ $M_7C_3$ $M_7C_3$ II	M + Ar + $\chi$ $M_7C_3$ $M_7C_3$ II
Ar, %	68.5	68	66	57	39	15	9.5	10.5
Hardness	53.5	53.5	55	58	61.5	63.5	64	63.5

A, austenite and M, martensite. See text for description of  $M_7C_3$  II and  $\chi$ .

**Table 2 Content of Cr, Mo in the matrix**

Heating at	As-cast	800 °C	850 °C	900 °C	950 °C	1000 °C	1050 °C	1100 °C
Cr, %	19.96	19.08	18.83	15.06	13.21	10.23	9.99	10.26
Mo, %	0.83	0.79	0.76	0.24	0.02			

$\text{Fe}_7\text{C}_3$ . When it is heated at 800 °C, there are a few  $\chi$  phases precipitated along the grain boundaries. Many  $\chi$  phases and  $\text{M}_7\text{C}_3$  II precipitate after being heated at 950 °C, and the austenite is transformed into martensite by air cooling. The matrix structure is illustrated in Fig. 2.

The alloy elements distribution of high Cr-Mo alloy iron is changed with the heat treatment condition (Table 2). The matrix of as-cast iron contains many more elements Cr and Mo, whose contents lower after heat treatment by precipitating the secondary phase. The changes in the austenite amount with heat treatment are shown in Table 1. The austenite amount decreases insignificantly when the iron is heated at a relatively low temperature, but decreases significantly if the heating temperature is > 900 °C. The retained austenite is approximately 15% when the iron is heated at 1000 °C.

The effect of heat treatment on the hardness and wear volume is indicated in Fig. 3. The higher the heat treatment temperature, the harder is the iron. The curve of corrosion wear related to the heat treatment temperature is shown as a peak at 850 °C and valley point from 900 to 950 °C. The curve of abrasion wear is shown as a peak at 850 °C and valley point at 1000 to 1050 °C. The wear morphology is shown in Fig. 4.

The effect of temper on hardness and wear volume is illustrated in Fig. 5. The white iron is very stable if the air hardening temperature is < 900 °C. However, abrasion wear volume will decrease to a minimum when the air hardening temperature is > 1000 °C.

#### 4. Analysis and Discussion

Judging from microanalysis, the austenite matrix of as-cast iron is very stable, as there are more alloy elements in it. It will not transform during iron cooling, so that the structure of as-cast iron is eutectic austenite and eutectic carbide  $\text{M}_7\text{C}_3$ . This is maintained until it is heated at approximately 800 °C. When the temperature of heat treatment is > 800 °C, the destabilization of eutectic austenite occurs by the secondary phases precipitating and the austenite transforming into martensite following air cooling. The higher the temperature of heat treatment, the higher the volume of precipitated secondary phases and transformed martensite. If the temperature is > 1050 °C, some small secondary phases will remelt into the matrix. Hence, the retained austenite does not reduce again.

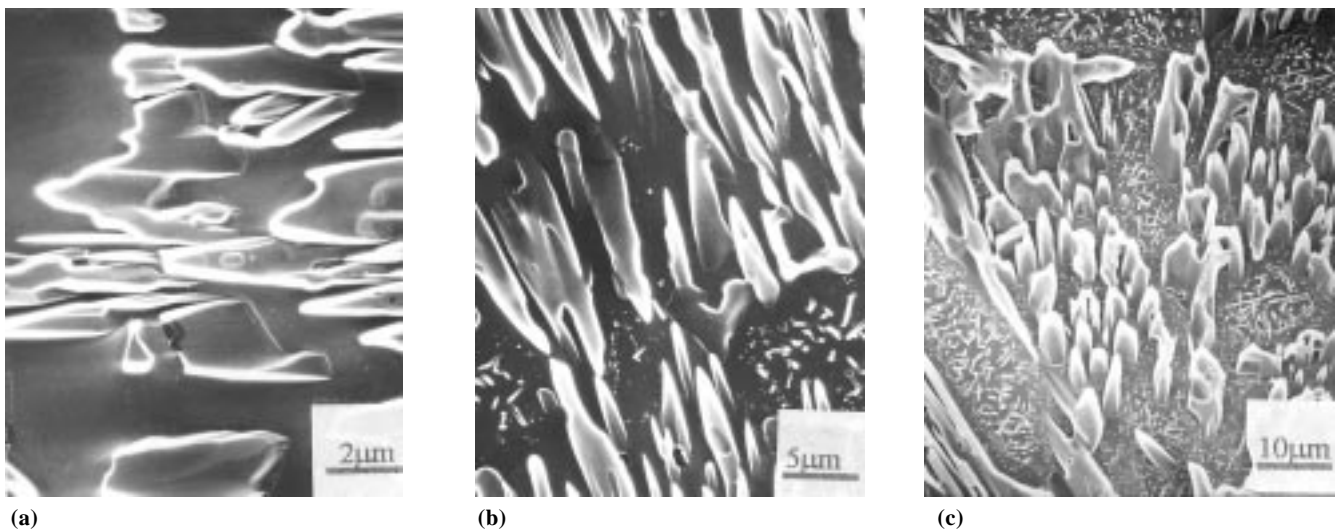


Fig. 1 The microstructure of Cr-Mo white iron (a) as-cast, (b) 900 °C air hardening, and (c) 1000 °C air hardening

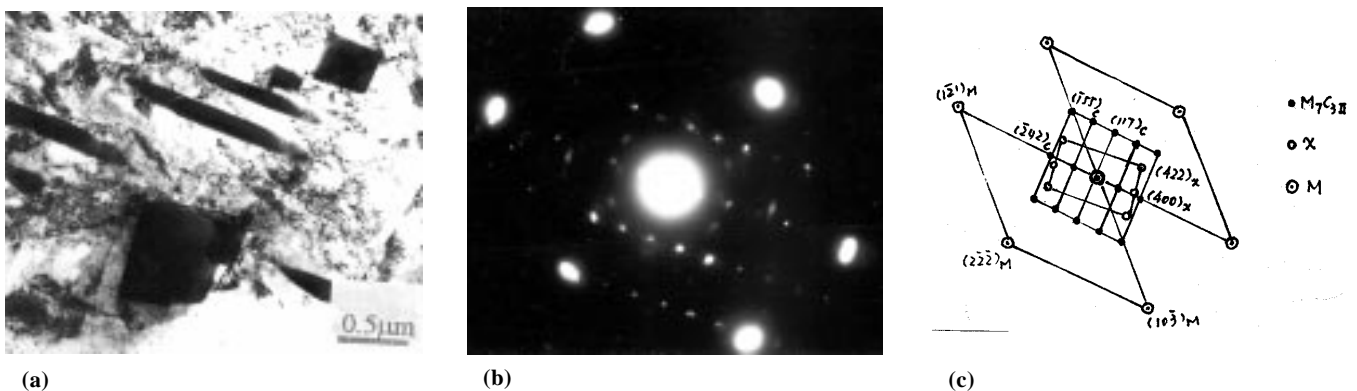


Fig. 2 The matrix structure of Cr-Mo white iron heated at 1000 °C (a) matrix structure, (b) diffraction pattern, and (c) indexed diffraction pattern

According to Pearce (Ref 2), the secondary phase is carbide  $M_{23}C_6$  II in the destabilization of high Cr iron, but in this test, there are two secondary phases of the  $\chi$  phase and carbide  $M_7C_3$  II in the high Cr-Mo iron. The difference in the secondary phase is due to the Mo. Mo forms the  $\chi$  phase easily in high Cr iron. The  $\chi$  phase precipitates prior to  $M_7C_3$  II from destabilized austenite, so many more elements have been removed. As the alloy element Cr lowers around the  $\chi$  phase, the following precipitation is carbide  $M_7C_3$  II. In Fig. 3 the hardness of alloy iron continuously increases with the precipitation of the  $\chi$  phase and  $M_7C_3$  II; then the martensite transforms from austenite. The hardness rapidly increases from 850 to 1050 °C due to the increased precipitation in the secondary phases.

The relationship between wear and heat treatment is more complex than that between hardness and heat treatment. When the iron is heated at 850 °C, the wear of abrasion and erosion is very great due to the secondary phase precipitation along the boundaries. This leads to the chromium being lower around the eutectic  $M_7C_3$  (Fig. 6). The areas adjacent to the grain boundaries are chromium depleted and can be quickly corroded. The strength of eutectic  $M_7C_3$  combined with the austenite matrix lowers. Also the brittleness of the iron increases. All of this results in bad wear resistance.

Good wear resistance of abrasion and erosion occurs at different temperatures of heat treatment. For abrasion, the wear resistance is very good when the iron has been heat treated at 1000 to 1050 °C, since the hardening is greater in this range. Good resistance of erosion will be obtained depending on not only the good abrasive resistant material, but also the corrosion-resistant matrix. If the corrosion resistance of the matrix is poorer, the carbide  $M_7C_3$  will lose the support of the matrix, and it is easily peeled, bringing about severe wear.

The high Cr-Mo iron possesses high corrosion resistance due to the chromium raising the electrode potential of the matrix and making the matrix passivation. The structure shows good corrosion resistance only if the chromium content of a phase is > 11.7%. When the iron has been heat treated at 900 to 950 °C, the matrix containing approximately 15% Cr displays good corrosion resistance. At the same time, there are many small secondary phase precipitates from the matrix, and the hardness of the iron increases remarkably. Now the iron dis-

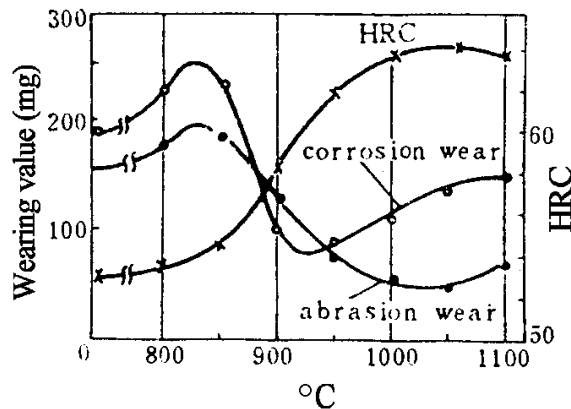


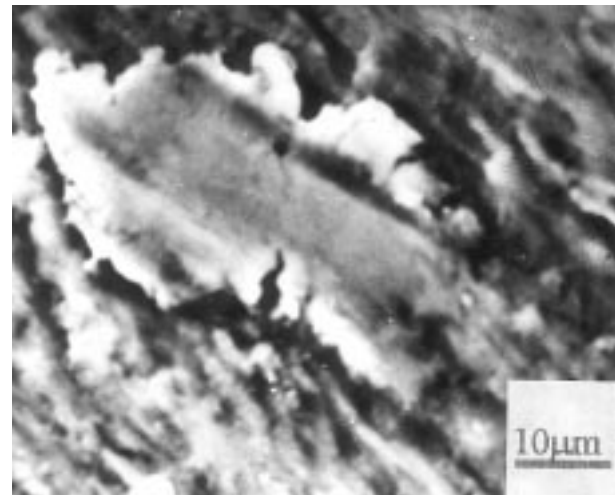
Fig. 3 The effect of heat treatment temperature on wear and hardness of white iron as tested at room temperature

plays the best corrosion resistance by being heat treated at 900 to 950 °C.

## 5. Influence of Temper on the Properties of High Cr-Mo Alloy Iron

The influence of tempering on the properties of high Cr-Mo alloy iron is different from the prior heating temperature. The matrix of iron heated at 900 °C is stabilized austenite, and it does not change when the tempering temperature is < 600 °C. By increasing the tempering temperature, the austenitic matrix decomposes, the hardness of iron increases, and the corrosion resistance lowers. These opposite changes of properties determine that there is little variation of erosion resistance, so the iron heated at 900 °C does not need tempering.

The matrix of iron heated at 1000 °C is alloy martensite having a high stabilization for tempering. The hardness of martensite does not fall until the tempering temperature is >600 °C.



(a)



(b)

Fig. 4 Morphology of (a) corrosion wear at 850 °C air hardening and (b) abrasion wear at 1000 °C air hardening

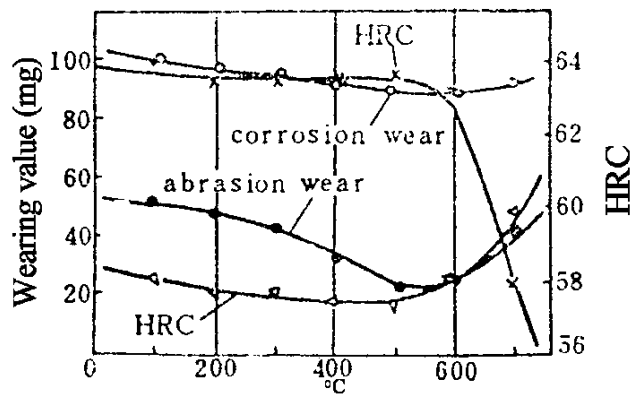


Fig. 5 The effect of tempering temperature on the properties of white iron. Open circle, solid triangle, 900 °C air hardening; solid circle, x, 1000 °C air hardening

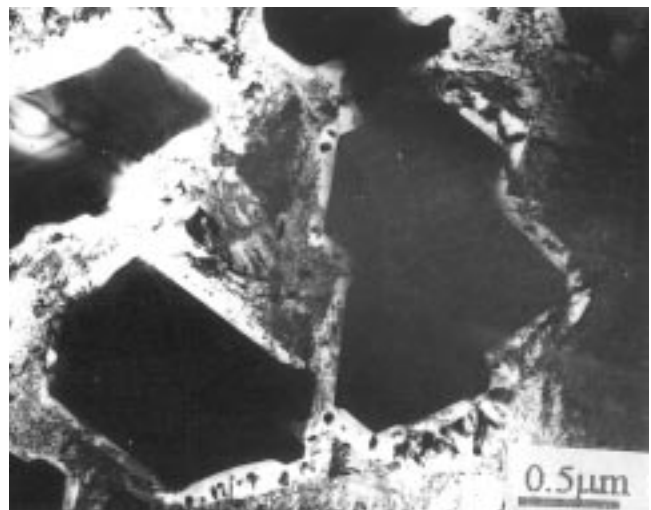
The tempering for martensite matrix of iron is always required to relax the hardening stresses and increase the toughness. To obtain a good abrasion resistance, it is necessary that the iron be heated at > 1000 °C and air cooling be performed.

## 6. Conclusions

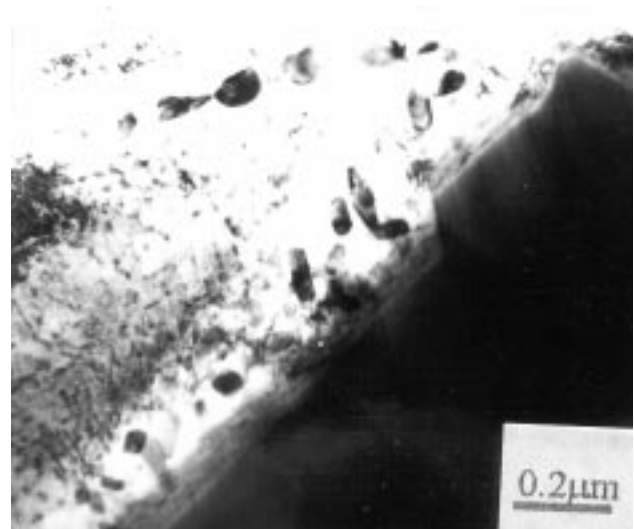
- The structure of high Cr-Mo alloy iron is eutectic austenite and  $M_7C_3$ . The austenite matrix destabilizes when the iron is heated at a high temperature, because there are two secondary phases,  $\chi$  and  $M_7C_3$  II, precipitated from matrix, and the austenite transforms into martensite during air cooling.
- The boundary precipitation occurs when the iron is heated at 850 °C, which results in the wear resistance getting worse.
- If the iron is applied to resist erosion, it should be heated at 900 °C. However, if the iron is applied to resist abrasion, it should be heated at 1000 °C and tempered at approximately 500 to 600 °C.

## References

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(a)



(b)

Fig. 6 The precipitation at phase-boundary of white iron heat treated at (a) 800 °C and (b) 850 °C

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