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Optimizing Wear Resistance and Impact Toughness in High Chromium Iron Mo-Ni Alloy

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An alloy with carbon and chromium in the range of 2.0 to 2.5% and 20 to 25%, respectively, with the addition of Mo and Ni in the range of 1.0 to 1.5% each when heat-treated at a quenching temperature of 1010 °C and tempering temperature of 550 °C produces a hardness in the range of 54 to 56 HRC and a microstructure that consists of discontinuous bands of high volume (35-40%) of wear resistant primary (eutectic) carbides in a tempered martensitic matrix with uniformly dispersed secondary precipitates. This alloy has been found to possess adequate impact toughness (5-6 J/cm^2) with a wear resistance of the order of 3-4 times superior to Mn steel and 1.25 times superior to martensitic stainless steel with a reduction in cost-to-life ratio by a factor of 1.25 in both the cases.

Keywords abrasion, heat treatment, high Cr iron

1. Introduction

High Cr iron alloys are one of the most suitable choices for resisting wear in the handling of raw materials and intermediate products, such as iron ore, coke, sinter, in the primary functions of an iron and steel industry. The alloy encompasses a wide range of variation in the main alloying elements, i.e., carbon and chromium, with optional addition of Ni, Mo, and some other elements like Nb, V, or W depending upon the application-specific requirements (Ref 1). However, the real issues that need to be addressed in the applications for handling raw materials and intermediate products in the iron and steel industry are not only the wear (abrasion, erosion, and corrosion) resistance of the alloy because of relatively high abrasivity of iron ore, coke, sinter, etc. but also the requirements of sustaining impact also because of relatively larger particle size and large volume of the bulk materials. The present study is an attempt to select an optimum composition of high Cr iron alloy and evolve the optimum heat treatment cycle attain the microstructure and bulk mechanical properties so as to strike a balance between the wear resistance and resistance to impact for any such applications.

2. Experimental

The high Cr iron alloys are primarily used for resisting abrasion, erosion, and corrosion wear under dry and slurry conditions in the handling of aggressive raw materials in metals and mining, cement, and mineral processing industries. An optimum combination of carbon and chromium can produce a reasonably high volume of primary and/or eutectic carbides that enhances wear resistance, and the matrix supporting the carbides in these alloys can be adjusted by alloy contents and heat treatment to develop a proper balance of wear resistance and toughness (Ref 2). The nominal chemical composition of the test bars cast in a commercial foundry along with the experimental quantities of liners plates for handling of coke, sinter and iron ore in hoppers and chutes in blast furnace and raw material handling plants of the integrated iron and steel plants is given in Table 1.

The specimens prepared from the test bars of sizes 40 mm, in diameter and 300 mm in length were hardened at a temperature of 1010 °C and tempered at temperatures in the range of 300 to 600 °C at an interval of 100 °C. The specimens were evaluated for bulk hardness (Rockwell C scale) with 150 kg load, microstructure using Neophot 30 optical microscope, microhardness (Vickers scale) of different phases using Leitz MM6 microhardness tester with 50 g load, volume fraction of primary carbides and retained austenite using Leica Q600S image analyzer, dry sand rubber wheel abrasion test according to ASTM standard G65 by allowing the continuous flow of silica sand (AFS 60) @ 400 g/min between the rotating rubber wheel (200 rpm) and the rectangular test specimens of 25 mm × 75 mm sizes having 10 mm thickness under 130 N load for 6000 revolutions (30 min) and impact testing according to ASTM standard E23 using 10 mm × 10 mm × 75 mm Charpy specimens with 2.0 mm v-notches under dynamic loading at ambient temperature.

3. Results and Discussions

The mechanical and metallurgical characteristics of the high Cr iron alloy are presented in Table 2. The typical as-cast, hardened and hardened, and tempered photomicrographs are presented in Fig. 1.

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Table 1 Nominal chemical composition of high Cr iron alloy

Chemical composition of high Cr iron alloy, wt.%							
C	Si	Mn	S	P	Cr	Ni	Mo
2.0-2.5	0.8 Max	0.4 Max	0.04 Max	0.04 Max	20-25	1.0-1.5	0.10-1.5

Table 2 Summary of mechanical and metallurgical characteristics of high Cr iron alloy

High Cr iron alloy	Hardness, HRC	Primary carbide, vol.%	Retained austenite, vol.%	Impact, J/cm^2	Weight loss, mg	Microhardness, HV	
As-cast	44	35-40	···	···	···	Primary carbide Matrix	985-1120 500-520
Air-hardened (1010 °C)	56	35-40	25-30	···	···	Primary carbide Matrix	985-1120 500-520
Tempered (300 °C)	54	35-40	20-25	5.5-6.5	50-55	Primary carbide Matrix	985-1120 580-600
Tempered (400 °C)	55	35-40	15-20	4.5-5.5	40-45	Primary carbide Matrix	985-1120 580-600
Tempered (500 °C)	59	35-40	10-15	5.0-5.5	35-40	Primary carbide Matrix	985-1120 500-520
Tempered (600 °C)	53	35-40	5-10	5.5-6.5	50-55	Primary carbide Matrix	985-1120 600-620

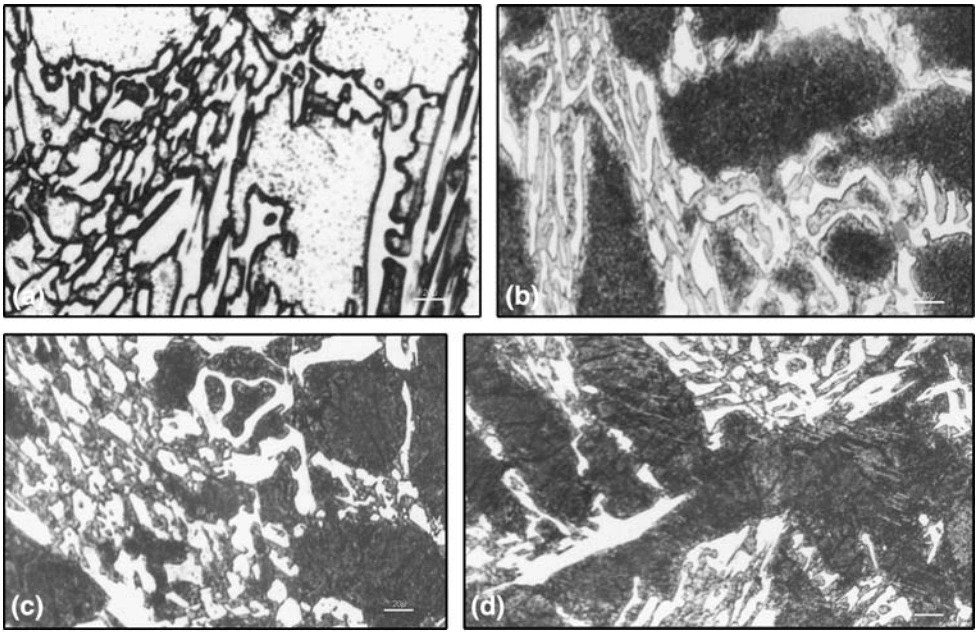

Fig. 1 Typical photomicrographs of high Cr iron alloy castings

It can be noted that the hardness of the cast alloy increases upon hardening at 1010 °C. This increase in hardness can be explained in terms of conversion of austenite into martensite. However, it can also be noted that the microhardnesses of the matrix phases remain almost equal in as-cast and hardened conditions. As can be observed from the as-cast microstructure (Fig. 1a), the formation of carbides and austenite in high Cr iron alloys takes place in the form of austenite-carbide eutectic. The hardening of high Cr iron alloy results not only in the transformation of already present austenitic phase in as-cast specimens but also in the reorientation of the primary carbides and formation of austenite within the eutectic regions (Fig. 1b). The similar microhardnesses of the matrix phases might have been observed due to the formation of austenite within the eutectic regions whereas the increase in bulk hardness might be due to the partial transformation of austenite into martensite. The continuous decomposition of retained austenite and its conversion to martensite upon tempering at temperatures starting from 300 to 500 °C can be observed from the increasing hardness (Ref 3). The increase in microhardness of the matrix phase starting from the tempering temperature of 300 °C and decrease at the tempering temperature of 500 °C confirms complete decomposition of austenite and its conversion to martensite (Ref 4).

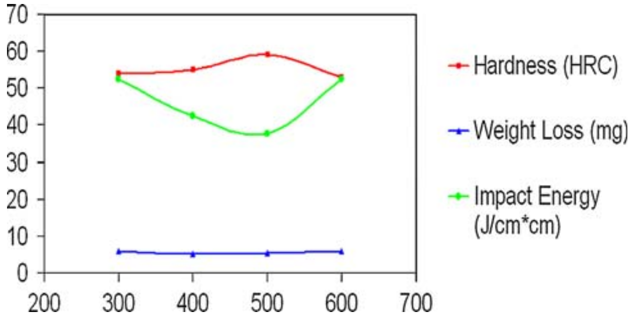

Fig. 2 Effect of tempering temperatures on hardness, wear resistance and toughness of high Cr iron alloy castings

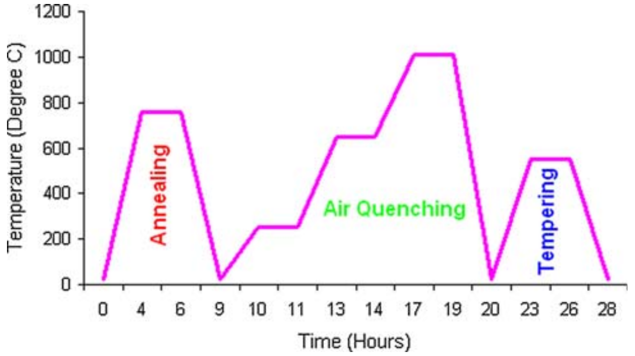

Fig. 3 Heat treatment cycle employed for the high Cr iron alloy lining materials

The difference in the microstructures of specimens tempered at 300 and 500 °C can be observed in the photomicrographs presented in Fig. 1(c) and (d), respectively. The decrease in hardness with the increase in tempering temperature beyond 500 °C is suggestive of tempering of the martensitic phase (Ref 5). However, the increase in microhardness upon tempering at 600 °C is suggestive of enriching the matrix with precipitates of secondary carbides (Ref 6). The microhardness of the primary carbides that remains in the range of 985 to 1120 HV across the specimens is suggestive of the presence of wear resistant M_7C_3 carbide since as-cast condition remains unchanged even upon tempering at 600 °C (Ref 7). The impact toughness and wear resistance upon tempering at different temperatures are consistent with the hardness, microhardness, and microstructural constituents in different specimens. The present study therefore confirms that the microstructure consisting of tempered martensite with secondary precipitates uniformly dispersed through the matrix and discontinuous bands of primary carbide is responsible for a combination of wear resistance and impact toughness of high Cr iron alloy, which is produced with a combination of suitable chemical composition and heat treatment (Ref 8). It can be noted from Fig. 2 that an optimum combination of hardness, wear resistance, and impact toughness can be obtained at a tempering temperature of 500 °C. However, the phenomenon of secondary hardening is also observed to be starting at a temperature of 400 °C and completing at 500 °C. It can be noted that the tempering temperatures above 500 °C results in increase in impact toughness and decrease in hardness and wear resistance. It was therefore decided to employ a tempering temperature of 550 °C for the actual lining materials to prevent in-service failures. The complete heat treatment cycle employed for the actual lining materials is depicted in Fig. 3.

The field (industrial) trial with liner plates with high Cr iron alloy produced according to the chemical composition and heat treatment as specified has indicated a 3-4 times increase in service life compared to 1.0%C-6.0%Mn steel liners fabricated using rolled/cast plates and heat-treated (water-quenched) to a hardness of 40-42 HRC and 1.25 times increase compared to 0.75%C-12%Cr martensitic stainless steel liners fabricated using forged blanks and heat-treated (oil-quenched and tempered) to a hardness of 50-52 HRC, with a reduction in cost-to-life ratio by a factor of 1.25.

4. Conclusions

The chemical composition and heat treatment parameters of high Cr iron alloy can be altered to produce a combination of metallurgical and mechanical properties that helps striking a balance between wear resistance and impact toughness for use in handling of aggressive raw materials and intermediate products in metals and mining, cement, and mineral processing industries. The alloy with C in the range of 2.0 to 2.5 wt.% and Cr in the range of 20 to 25 wt.% with the addition of Ni and Mo in the range of 1.0 to 1.5 wt.% each when air-hardened at a temperature of 1010 °C and tempered at a temperature of 550 °C produces the most suited combinations of hardness, wear resistance, and toughness for its application as lining materials for bulk solid handling equipments.

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