

Effects of Heat Treatment on Erosion Behavior and Microstructure of High Chromium White Cast Irons

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Abstract: Influence of destabilization heat treatment on hardness, microstructure and erosion resistance of 27 wt.% Cr irons have been investigated. The specimens were heat treated by destabilization at 950 and 1100°C for 3 h and then air cooled followed by tempering in 400°C for 1 h then air cooling. The microstructure was analyzed by X-ray diffraction, scanning electron microscopy and light microscopy. The results show that the microstructure in 27 wt.% Cr after destabilization and tempering, consists of secondary carbides in a tempered martensitic matrix. It was found that erosion resistance of the irons was improved after destabilization and tempering heat treatment at 1100°C more than at 950°C destabilizing temperature.

Key words: Erosion resistance, heat treatment, microstructure, high chromium white cast irons, treatment, microstructure

INTRODUCTION

High chromium white cast irons are used widely in the minerals, cement and mining industries because of their relative low production cost and excellent wear resistance (Durman, 1988; Pearce, 2002; Imurai *et al.*, 2015). Their high resistance to wear in these demanding situations stems from the presence of hard eutectic M_7C_3 carbides in their microstructures.

The 25-30 wt.% Cr alloys have been developed to provide resistance to the combined effects of corrosion and abrasion in slurry transport and in wet grinding. The mechanical properties and wear resistance of these irons depend on the morphology, type and distribution of carbides and on the nature of the matrix structure which in turn depend on the section size, chemical composition of the wear part and on any subsequent heat treatments (Tabrett *et al.*, 1996; Laird *et al.*, 2000; Pearce, 2002; Wiengmoon *et al.*, 2015). By destabilization and tempering heat treatments the abrasion and corrosion resistance for high chromium white irons can be improved. The microstructure of 25-30 wt.% Cr irons after air hardening from destabilization treatment generally consist of a martensitic matrix with precipitated secondary carbides and a small amount of retained austenite (Inthidech *et al.*, 2006; Karantzalis *et al.*, 2009; Wiengmoon *et al.*, 2011).

Increased the amount of carbides (by either increasing the carbon content or by micro alloying), heat treatments or a suitable cooling rate lead to improving in wear resistance (Yan and Zhou, 1987; Hann and Gates, 1997).

The present research studied the influence of heat treatments on hardness, microstructures and erosion resistance of high chromium cast irons 27% wt. Cr. The erosive wear was determined by solid particle liquid impinging erosion test and the microstructure were studied by optical microscope, scanning electron microscopies and X-ray diffraction.

MATERIALS AND METHODS

Experimental procedures

Material and heat treatment: Chemical compositions of the high chromium white cast iron used in this work is shown in Table 1. The as-received specimens were cut off and annealed to retrieve the original properties at 950°C for 2 h followed by slow cooling in furnace. The specimens then hardened by destabilization heat treatment at 950°C and 1100°C for 3 h air cooled and tempered at 400°C for 1 h, then air cooled to room temperature.

Microstructural investigation: Silicon carbide papers were used for grinding step followed by polishing step with diamond pastes 1 μ m finish. The specimens were chemically etched in a solution containing 0.5 g copper (II) chloride, 11 mL concentrated HCl, 11 mL distilled water and 11 mL absolute ethanol (Kalling's reagent). The microstructures were studied using high quality laboratory reflected Metallurgical Microscope (FL-MV6000-NMM-8000RF-200000).

X-Ray Diffraction (XRD) analysis: X-ray crystallography was carried out using a (SHIMADZU Lab XRD-6000,

Table 1: Chemical composition of cast irons used in this research

Chemical composition (%)	Values
Iron	27 Cr
C	2.5
Si	0.867
Mn	0.678
P	0.035
S	0.04
Cr	27.5
Mo	0.1
Ni	0.194
Cu	0.159
Co	0.18
Al	0.031
Fe	Bal.

Japan) set-up with a copper X-ray source set for a 2θ range of 20-120° and recording data at 0.02° steps with a speed of 8° min⁻¹.

Hardness test: Rockwellmacro hardness testing was carried out with a (TH300, TIME High Technology, Ltd.), load 150 kgf. The mean values are based on three different areas.

Erosive wear testing: Erosion testing was performed by using high velocity slurry comes out from a nozzle and impacting on the test specimen. This test is conformed to ASTM Standard (Anonymous, 2000, 2010). The abrasive used in this test are in the range 600-800 and 400-600 μm silica sand (20 wt.%). The test duration time of each specimen was 10 h with the mass loss of specimens measured at every 2 h with an accuracy of ±0.0001 g.

RESULTS AND DISCUSSION

Microstructure: The annealed microstructure of the 27 wt.% Cr iron, shown in Fig. 1. After hardening via destabilization treatment at 950 and 1100°C air quenching and tempering at 400°C, this gives a distribution of secondary carbides in a tempered martensite matrix with an amounts of residual austenite as shown in Fig. 2 and 3. In addition, the newly formed matrix was reinforced with secondary carbides of the type M₇C₃. In studies on high chromium white cast irons with similar chromium contents and destabilization temperatures, other researchers also reported this kind of secondary carbides (Wiengmoon *et al.*, 2015; Zeytin *et al.*, 2011; Xiaofeng *et al.*, 2012).

Moreover, the microstructure has been characterized by XRD. Two X-ray patterns for the annealed and the heat treated irons at 1100°C are shown in Fig. 4. In the annealed condition, the alloy contained ferrite and Cr₇C₃. For the destabilized conditions, XRD analysis confirmed the martensitic matrix in alloy. This has proved the microstructural change observed from micrographs in Fig. 3.

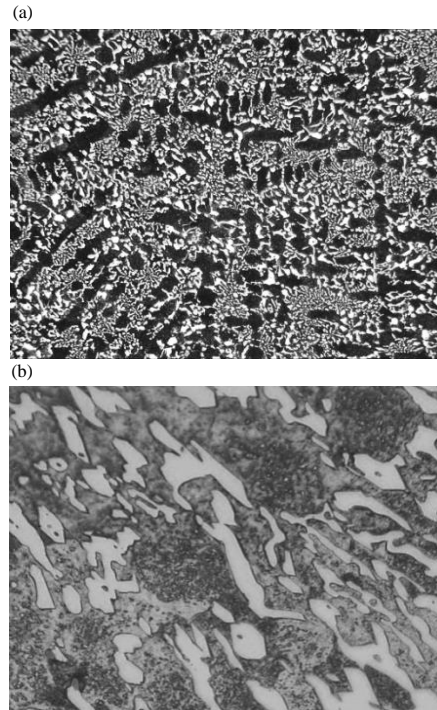


Fig. 1: Light Micrographs (LM) show microstructure in the annealed condition: a) Low magnification 160X and b) High magnification 800X

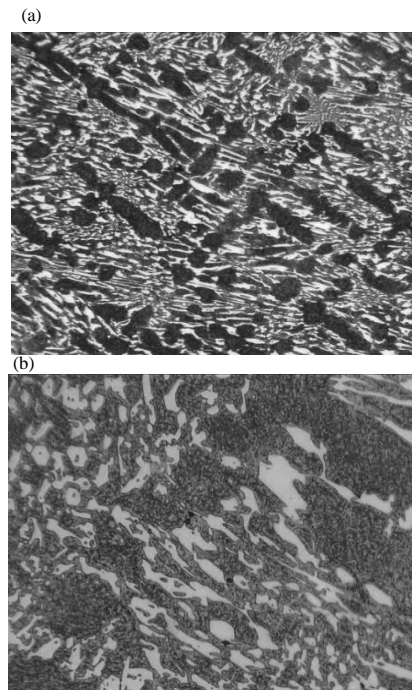


Fig. 2: Light Micrographs (LM) show microstructure after heat treatment at 950°C: a) Low magnification 160X and b) High magnification 800X

Overall macro hardness: Figure 5 shows the hardness of the annealed condition, after-destabilization at 950°C and 1100°C followed by tempering conditions. In the annealed condition, the macro hardness values 27 Cr alloys

were about 53 HRC. After destabilization at 950°C, the hardness is increased to 58 HRC while it is increased to 61 HRC after destabilization at 1100°C, resulting from secondary carbide precipitation which destabilized the austenite leading to the martensitic matrix formation. After destabilization heat treatment at 950 and 1100°C followed by tempering treatment, the overall 58 HRC and 57 HRC, respectively. The small reduction of hardness after tempering in relatively high temperature is due to an increase in the volume fraction of secondary carbides within the tempered martensite and a possible reduction in the retained austenite.

Erosive wear resistance: Jet slurry erosion tests using high chromium white irons destabilized and tempered at different temperature were conducted in the presence of silica sand particles with sizes ranging from 600-800 and 400-600 μm. The mass loss of the wear specimens is shown in Fig. 6 as a function of erosion time. After 4 h as can be seen in Fig. 6 there is a linear relationship between the mass loss and erosion time for all the specimens tested. In jet slurry erosion test, when a larger particle is used an increasing in mass loss with time is observed (Stachowiak and Stachowiak, 2004). Figure 6 shows that the destabilization at 950°C followed by tempering at 400°C specimens exhibits the higher wear.

High chromium cast iron commonly form carbide type M_7C_3 which has a higher hardness than silica sand as can be seen in Table 2 and therefore they expected to shows an excellent wear resistance against the silica abrasives. In this test, the matrix worn first and leaves the carbide to provide the supports (Poolthong *et al.*, 2004).

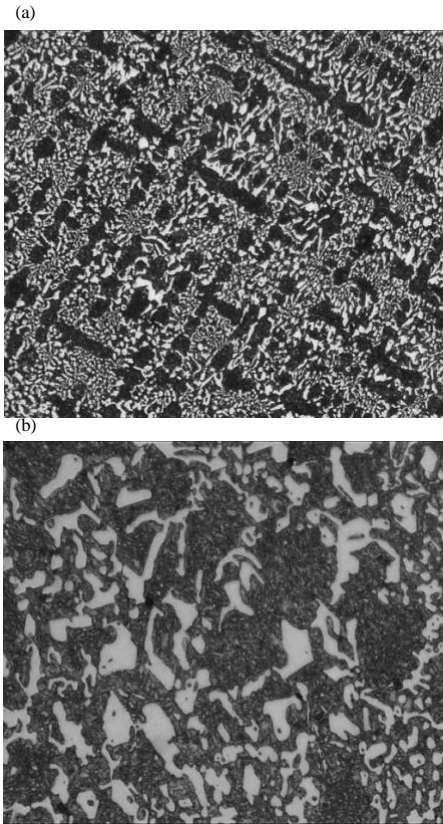


Fig. 3: Light Micrographs (LM) show microstructure after heat treatment at 1100°C: a) Low magnification 160X and b) High magnification 800X

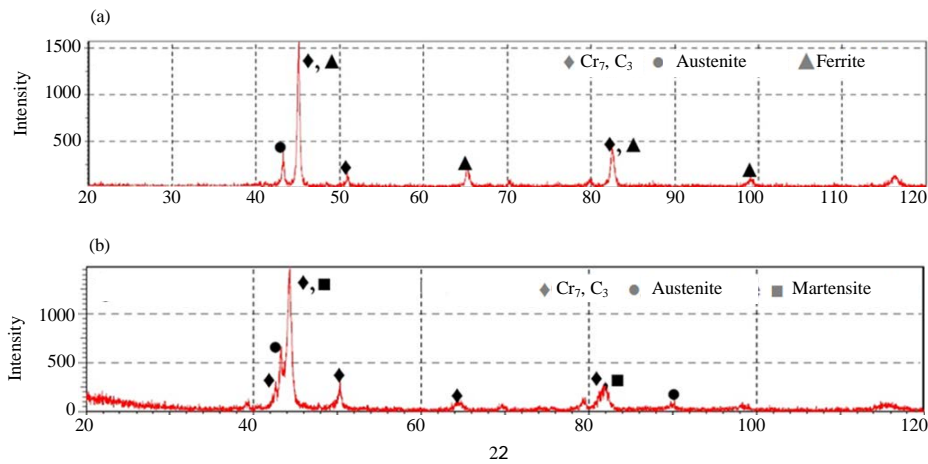


Fig. 4: XRD indicating phases present in 27 wt.% Cr irons microstructure: a) Annealed condition and b) After destabilization at 1100°C and tempered at 400°C

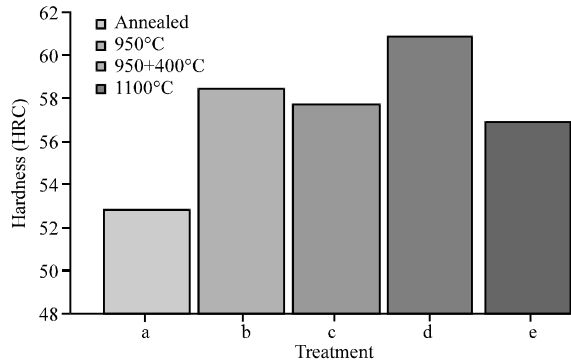


Fig. 5: Effects of heat treatment on the macro hardness of 27 wt.% Cr irons: a) Annealed at 950°C; b) After destabilization at 950°C; c) After destabilization at 950°C followed by tempering at 400°C; d) After destabilization at 1100°C and e) After destabilization at 1100°C followed by tempering at 400°C

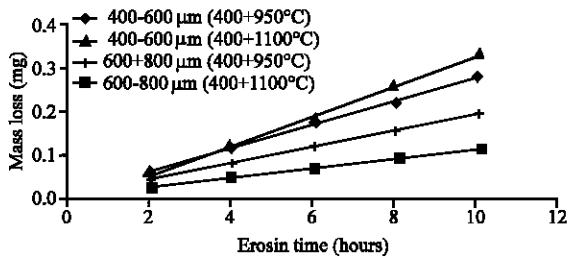


Fig. 6: Mass loss versus erosion time for 27 Cr (950+400°C) and (1100+400°C) specimens in the presence of 600-800 and 400-600 µm silica sand slurry (20 wt.%) at 45°

Table 2: Hardness of microstructural constituents of the alloy and abrasive materials (Poolthong *et al.*, 2004)

Materials	Vickers hardness
Silica	900-1280
M7C3-type carbide	1200-1800
High carbon martensite	770-800
Austenite	350-400

The erosive wear of the high chromium white iron specimens studied using two silica sand with a particles size of 600-800 µm and 400-600 µm. The mass loss shown in Fig. 7 and 8 as a function of erosion time. From Fig. 7 and 8 it can be seen that the mass loss of high chromium white irons increases with increasing the size of silica sand particles for both heat treatments. As it supposed for the same concentrations as the size of the particles increases less particles are probable to contact and the load on particle would be increased.

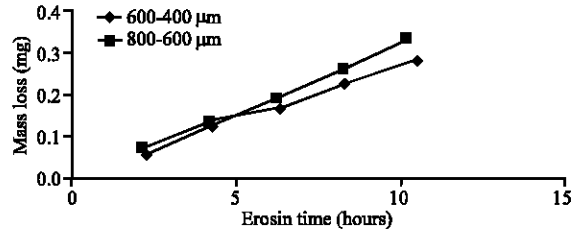


Fig. 7: Mass loss versus erosion time of the 27 Cr treated at (950+400°C) specimen tested in the presence of 600-800 and 400-600 µm silica sand slurry (20 wt.%) at 45°

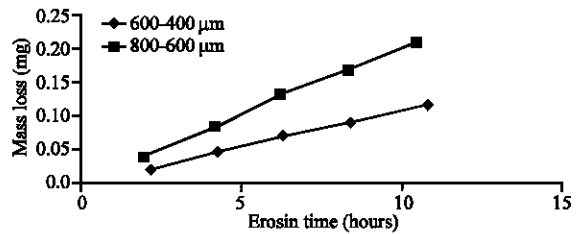


Fig. 8: Mass loss versus erosion time of the 27 Cr treated at (1100+400°C) specimen tested in the presence of 600-800 and 400-600 µm silica sand slurry (20 wt.%) at 45°

Figure 9 a-d shows the local worn surface morphologies of different high chromium white iron specimens after the wear test at 45° in the present of 600-800 and 400-600 µm silica sand slurry (20 wt.%). It can be seen from the figure that the surface featured evident cutting produced by angular particles and some ploughing. Material displaced by ploughing is evident along with a large number of pits and shear lips a combination of these types of damage causing deeper grooves and more material pile-up. For destabilized high chromium white iron at 950°C and subsequent tempering treatment in such a case, the wear rate is relatively high, as seen in Fig. 9a, c. For the specimen subject to the destabilization at 1100°C and subsequent tempering treatments, it can be seen less visible damage to the surface as seen in Fig. 9b, d. The best wear resistance of the high chromium white irons specimen subject to the destabilization at 1100°C and subsequent tempering treatment can be explained by fine carbides in its microstructure (Fig. 3). In such microstructure it is difficult for the abrasive particles to remove a larger parts of the matrix first and makes the carbides exposed. Instead of the wear by the removal of both phases which is likely a slower process Fig. 9 b, d. There was an exception, it was recorded that the high chromium white irons specimens contain a fine carbides have a very good wear resistance

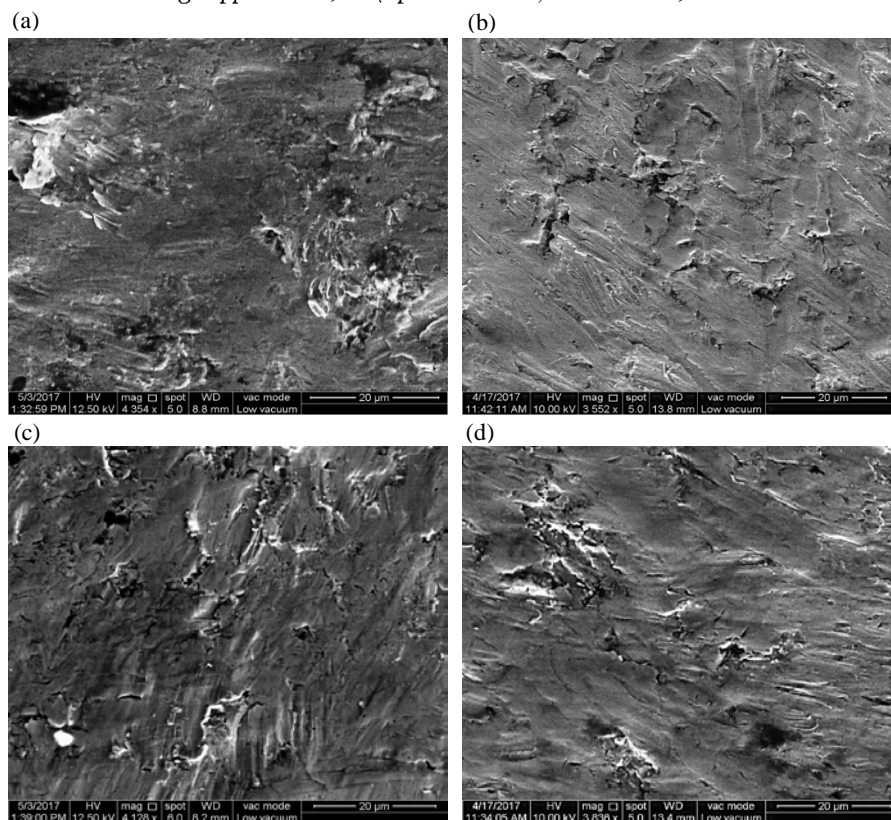


Fig. 9: a, b) SEM show worn surface of 27 wt.% Cr iron in the destabilization heat treated at 950 and 1100°C and subsequent tempering at 400°C by the 600-800 μm silica sand slurry, respectively (c, d) After destabilization heat treated at 950 and 1100°C and subsequent tempering at 400°C by the 400-600 μm silica sand slurry, respectively (Llewellyn *et al.*, 2004; Higuera-Cobos *et al.*, 2016), the effect of a such microstructure on erosive wear agree with the current results where that the specimen destabilized at 1100°C and subsequent tempering treatment exhibits the best wear resistance and also a microstructure with the finer carbides.

CONCLUSION

The microstructure of the heat-treated 27 wt.% Cr irons consists of Cr₇, C₃ carbide within a tempered martensitic matrix. After destabilization and tempering, the hardness was increased as compared with annealed condition. Specimens subjected to the destabilization heat treatments at 1100°C and subsequent tempering treatment had a higher wear resistance than those destabilized at 950°C and tempered. The wear resistance of high chromium white irons in the presence of silica sand increased with decreasing the carbides size in the microstructure. Larger silica sand particles caused more wear damages than the smaller one.

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