Heat Treatment in High Cr White Cast Iron Nb Alloy

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Wear resistance of high Cr white cast irons can be improved by means of heat treatment. This type of cast iron alloy may present a microstructure with retained austenite. The amount of retained austenite changes with the applied heat treatment, which will have an influence on wear properties. The purpose of this work was to study the influence of several parameters such as quenching and tempering temperatures and subzero treatment in the wear performance of the high Cr white cast iron Nb alloy. In this way, the performance was evaluated using pin-on-disc abrasion test. The worn surface was examined by scanning electron microscopy, and the main wear mechanisms were identified. The microstructural characterization was also performed with carbide identification. This Fe alloy has proven to be good for applications in mining and alcohol-sugar industries.

Keywords cast iron, wear resistance, white iron

1. Introduction

White cast iron alloys have been used for their hardness and abrasion resistance, aiming to reduce damage from the abrasion wear. Applications for these alloys include the mining industry, rolling mill, pieces of earthmoving equipment, coatings of pumps, shredder hammer tips of sugar cane, *etc.* In these cases, the pieces and equipment suffer wear and then they need maintenance and repair. This results in great expense.[1–5]

Because soil has sand silica particles that are very hard, between 900 and 1000 HV,[1,6,7] the equipment that works with earth suffers very intensive abrasion wear. Among alloys for these applications, there are high chromium white cast iron alloys that can also have significant additions of Ni, Mo, V, and Nb. These elements have increased hardness and have also improved toughness.[8–12]

In order to get high hardness and abrasion resistance properties, both chemical composition and heat treatment are important, the latter being as important as the former. The heat treatments usually used are hardening, with oil or air quenching, and subsequent tempering. Sometimes subzero cryogenic treatment is needed for substantial lowering of the amount of retained austenite after quenching. Great amounts of retained austenite may result in a substantial decrease in the hardness after quenching.[13,14]

Abrasive wear resistance depends on matrix characteristics and volumetric fraction and the form of the carbides and their distribution in the matrix. In this type of alloy, M_7C_3 and M_3C (M = Fe, Cr, or Mn) and MC (M = Nb, V, or Mo) carbides are formed.[9,11,15]

The arrangement of matrix with carbides gives special properties for this alloy in applications that need high hardness and abrasion resistance and also good toughness. This association of characteristics is only possible after appropriate heat treatment.[5–8,12,13,16]

In this work, different austenitization and tempering temperatures were used to obtain a range of hardness, toughness, and abrasion resistance. Removal of the subzero cryogenic treatment to reduce stress was suggested.

2. Methodology

The material used in this work was a high chromium white cast iron Nb alloy. This alloy was cast in sand molds. The chemical composition is shown in Table 1.

In the present work, four better austenitization temperatures were selected based on the results produced for hardness.[17] The sample of 900 °C was excluded. A similar procedure was adapted with the tempering temperature. Among 400, 450, 500, 550, and 600 °C for different times, 450 °C for 6 hours was chosen. For quenching, forced air and oil (60 °C) were used. The subzero, cryogenic treatment was done with liquid nitrogen for 1/2 hour.

Hardness tests, abrasion tests, metallography optical, and SEM (Scanning Electron Microscope) were carried out in samples for each step of heat treatment. Hardness tests were made in a Rockwell C scale (150 kg) with the average among eight measured.

Abrasion tests were made in pin-on-disc. An abrasive paper (180# SiC) was used under the disc, and the pin was the sample. Samples were weighed every 200 turns.[7,18] The total number of turns was 1600, corresponding to 720 m.

Charpy tests were done for some of the heat treatments. Samples were polished and etched with Vilella, Nital (5%) e Behara[19] for identification of the matrix and carbides. The MEV was done to help the microstructural identification and also for analysis of the worn surface.

3. Results and Discussions

The alloy as cast showed austenitic matrix and scattered carbides (Fig. 1). Hardness measures gave values of about 50 HRC.

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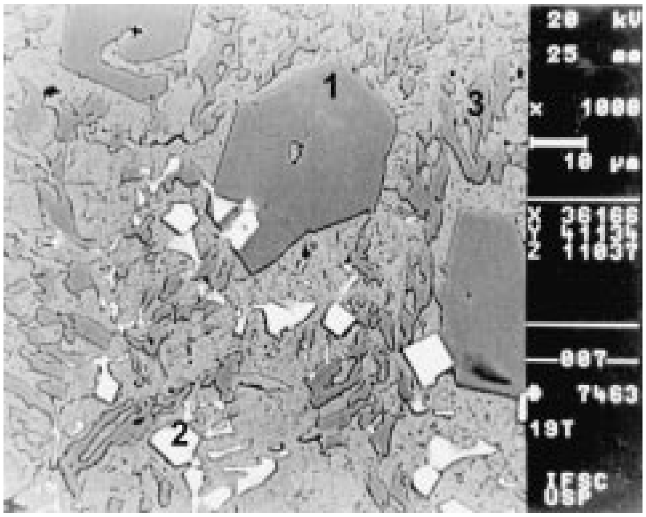

Fig. 1 Microstructure of A1 alloy as cast. MEV. Nital 5%

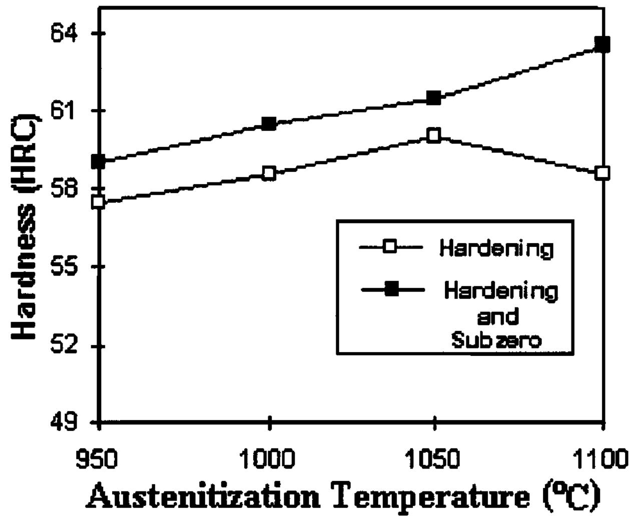

Fig. 2 Austenization temperature *X* hardness. Time in the temperature: 3 h-air quenching

Table 1 Alloy chemical composition (%)

	Elements (%)							
Alloy	**C**	**Si**	**Mn**	**Cr**	**Mo**	**Nb**	**V**	**Fe**
Al	4	1.6	0.75	27.5	0.83	5.02	0.4	bal

Hexagonal carbide (1) M_7C_3, massive carbide (2) NbC, and eutectic carbide (3) M_7C_3 can be seen in Fig. 1. These carbides were identified by MEV (R-X emission).

Low hardness values close to those of the alloy as cast were obtained with austenitization temperatures lower than 950 °C. When the austenitization temperatures increase to 1050 °C, higher hardness values are obtained because carbon diffusion in the austenite is improved.[6,8,13,20] This austenite is transformed in a higher carbon martensite, which is harder.

Temperatures above 1050 °C cause a hardness decrease with values close to those of the alloy as cast. This low hardness is due to retained austenite whose amount increases with the austenitization temperature.[7,14,20] After subzero cryogenic treatment, the hardness increases because the matrix is now almost totally martensitic.

Hardness values for different austenitization temperatures are shown in Fig. 2 either with or without subzero treatment.

An alternative heat treatment was carried out in order to reduce the retained austenite, without using subzero cryogenic treatment. In the treatment, the austenite homogeneity is obtained with solubilization at 1100 °C for 3 h. After lowering the temperature to 850 °C, the samples stayed at this temperature for 1 h.

The quenching was done in oil at 60 °C. In order to check whether the retained austenite was eliminated, some samples underwent subzero cryogenic treatment. The hardness measurements confirmed the same values in both situations. This means that the alternative treatment was efficient to reduce the retained austenite. The same procedure was done using 800 and 750 °C as intermediate temperatures. Table 2 presents the heat treatment procedures and the hardness results.

Table 2 Hardness values after different intermediate temperatures

Austenitization temperature (°C)	Time (h)	Intermediate temperature (°C)	Time (h)	Hardness after quenching (HRC)	Hardness after subzero (HRC)
1100	3	850	1	60	60
1100	3	800	1	60	60
1100	3	750	1	60	60

Table 3 Heat treatment and hardness values

Sample	Heat treatment	Hardness (HRC)	SD
T1	950 °C (3 h)-quenching: blowed air-tempering: 450 °C (6 h)	58	0.38
T2	1000 °C (3 h)-quenching: blowed air-tempering: 450 °C (6 h)	59	0.51
T3	1050 °C (3 h)-quenching: blowed air-tempering: 450 °C (6 h)	60	0.20
T4	1050 °C (3 h)-quenching: blowed air-subzero treatment (1/2 h)-tempering: 450 °C (6 h)	61	0.35
T5	1100 °C (3 h)-750 °C (1 h)-quenching: oil 60 °C-tempering: 450 °C	60	0.30

The tempering was done in the samples after the different heat treatment cycles. Hardness values confirm the carbide precipitation (hardening precipitation) for some sample during tempering.[8,20] In Table 3, hardness results of some selected samples are shown. Samples T1 to T5 were used for abrasion tests (pin-on-disc). The results showed that the mass loss decreases as the hardness increases (Fig. 3).

One should note that for treatment T5, with hardness 60 HRC, the mass loss was smaller in relation to treatment T3,

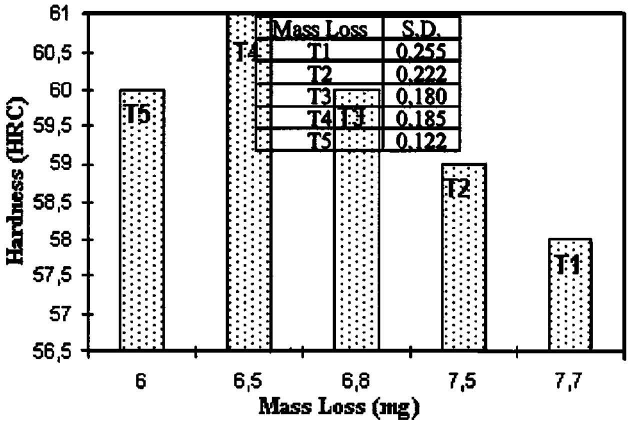

Fig. 3 Hardness *x* mass loss, as a function of the heat treatment quoted in Table 3

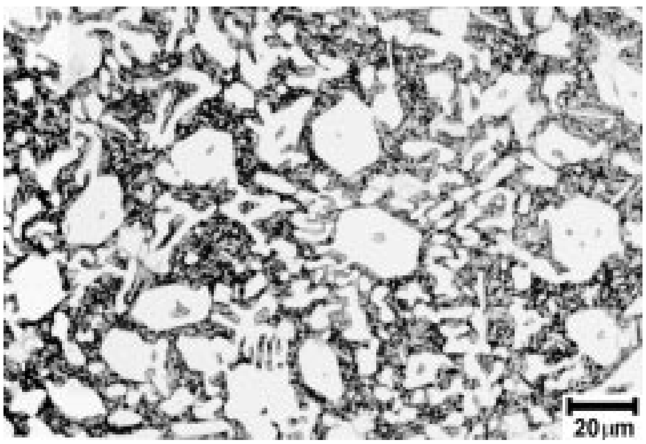

Fig. 4 Photomicrograph of alloy A1-heat treatment sample A1-3 (Table 3). Etching: Behara-900×

Fig. 5 Photomicrograph of alloy A1, by MEV, after two body abrasion tests. Heat treatment: sample T2 (Table 3)

Table 4 Impact energy as a function of the type of heat treatment

Sample	Heat Treatment	Hardness (HRC)	Impact energy (J)	SD
A1-0	As cast	50	12.13	2.14
A1-2	1100 °C (3 h)-750 °C (1 h) quenching: oil 60 °C tempering: 450 °C (6 h)	60	8.48	0.95
A1-1	1050 °C (3 h) quenching: blowed air tempering: 450 °C (6 h)	60	5.54	0.55
A1-3	1050 °C (3 h) quenching: blowed air subzero treatment (1/2 h) tempering: 450 °C (6 h)	61	2.07	0.66

with the same hardness, and also smaller than treatment T5, which produces better resistance to abrasive wear, probably owing to better dispersion and/or precipitation of carbides in the matrix.

The microstructure of the alloy with treatment T2 in Table 3 is shown in Fig. 4, in which the presence of hexagonal carbides M_7C_3 and M_3C are noticed in a predominantly martensitic matrix[6,7,15] and also monocarbide type NbC.

For the other heat treatment, nearly the same microstructure was predominant; this microstructure is shown in Fig. 4. Table 4 shows the variation of toughness for alloy A1 as a function of the different heat treatments. Table 4 further shows that the subzero treatment in sample A1-3 provided high hardness to the alloy. However, the toughness of the alloy as cast (sample A1-0) is probably due to the accumulation of stresses involved in the process of transformation from retained austenite to martensite by the subzero treatment.

In the treatment of sample A1-1, where retained austenite was partially transformed into martensite during tempering, the impact energy was higher than that of sample A1-2, including quenching from a lower temperature, provided a value of toughness close to the state as cast, and higher than the previous samples; sample A1-1 also has a better resistance to abrasion.

For better understanding of the abrasive wear process, some samples of alloy A1 were observed in MEV after being tested. Figure 5 and 6 show the surface of alloy A1 after having been submitted to wear test type pin-on-disc. Figure 5 shows the presence of pits (1), cracks (2), and splinters (3) in the sample after abrasion test. The phenomenon of spalling is also observed, and its occurrence is attributable to the coalescence of microcracks, which cause the breakage of the surface.[7] Figure 6 shows grooving followed by "kneading" of the material (1), which is a typical process of repeated microgrooving.

The material displaced to the side edges of the groove produced by the abrasive is bent (or folded), probably by the action of another abrasive. The presence of pits (2) can also be noticed as a consequence of the abrasive process.

These mechanisms are characteristics of brittle materials.[7] However, in this work, it is not possible to state that the presence of microcracks is a consequence solely of the wear process, because the surface of the samples was not observed before tests.

The presence of different wear micromechanisms involved in the abrasion process confirms the idea that the micromechanisms of wear may occur in a combined fashion within a material, demonstrating the complexity of the abrasive wear tribology

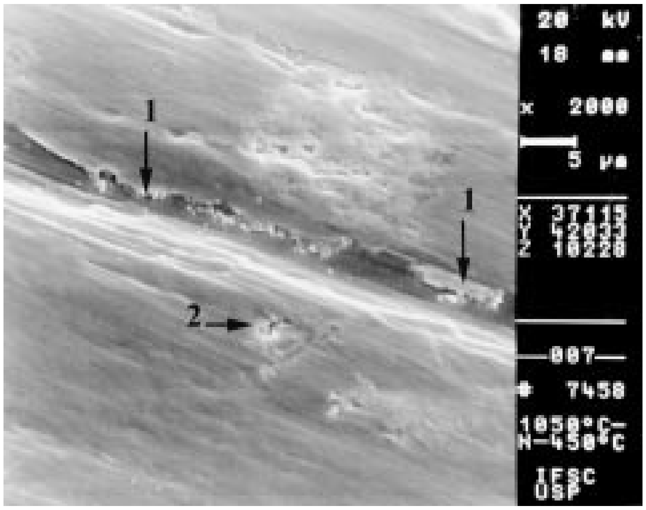

Fig. 6 Photomicrograph of alloy A1, by MEV, after two body abrasions tests. Heat treatment: sample T4 (Table 3)

mainly when materials with high heterogeneity are involved, such as in the case of this type cast iron.

4. Conclusions

- The wear resistance behavior of the alloy as cast (A1) was modified by heat treatments that promoted the matrix transformation from austenite in martensite. Hardness and metallography tests confirmed this transformation.
- Higher austenitization temperatures promote more effective carbide dissolution and larger amounts of retained austenite; consequently, the subzero cryogenic treatment is needed.
- The best abrasion resistance performance occurred after T5 (Table 3) heat treatment of the A1 alloy. Associations of effective carbide dissolution (high austenitization temperature), a small amount of retained austenite, and the decrease of stress during quenching (low intermediate temperature) lead to this improved performance.
- The same way the T5 heat treatment caused the best toughness performance, it also showed the best relationship among hardness, wear abrasion, and toughness.
- Subzero cryogenic treatment can be eliminated using the T5 heat treatment. With lower gradient temperature between sample and quenchant, the stress is decreased.
- Wear resistance evaluation confirmed that the greater hardness does not always result in lower mass loss.

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