

Comparison of Three Ni-Hard I Alloys

Ö. N. Doğan¹, J.A. Hawk¹, and J.Rice²

¹U.S. Department of Energy, Albany Research Center, Albany, Oregon

²Texaloy Foundry Co., Inc., Floresville, Texas

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Abstract

This report documents the results of an investigation which was undertaken to reveal the similarities and differences in the mechanical properties and microstructural characteristics of three Ni-Hard I alloys. One alloy (B1) is ASTM A532 class IA Ni-Hard containing 4.2 wt. pct. Ni. The second alloy (B2) is similar to B1 but higher in Cr, Si, and Mo. The third alloy (T1) also falls in the same ASTM specification, but it contains 3.3 wt. pct. Ni. The alloys were evaluated in both as-cast and stress-relieved conditions except for B2, which was evaluated in the stress-relieved condition only. While the matrix of the high Ni alloys is composed of austenite and martensite in both conditions, the matrix of the low Ni alloy consists of a considerable amount of bainite, in addition to the martensite and the retained austenite in as cast condition, and primarily bainite, with some retained austenite, in the stress relieved condition. It was found that the stress relieving treatment does not change the tensile strength of the high Ni alloy. Both the as cast and stress relieved high Ni alloys had a tensile strength of about 350 MPa. On the other hand, the tensile strength of the low Ni alloy increased from 340 MPa to 452 MPa with the stress relieving treatment. There was no significant difference in the wear resistance of these alloys in both as-cast and stress-relieved conditions.

Introduction

Ni-Hard I is a trade name for cast Fe-Ni-Cr-C alloys which are classified as Class I Type A in Standard Specification for Abrasion Resistant Cast Irons [1]. These cast irons are used extensively in applications requiring superior wear resistance. These applications include crushing and grinding ores, mixing concrete, pulverizing coal, and rolling metals. Ni Hard I alloys contain about 44 volume percent M_3C type carbides embedded in an iron matrix [2]. Their solidification begins with formation of proeutectic austenite followed by a eutectic reaction of liquid \rightarrow austenite + M_3C [2,3]. Upon cooling to room temperature, austenite partially transforms to martensite [4,5].

The purpose of this investigation is to determine whether variations in the Ni content or the concentration of other alloying elements changes the strength and wear resistance of Ni-Hard I type white cast irons. Three alloys were tested in this work: a 4.2 wt. pct. Ni alloy (B1), a 4.1 wt. pct. Ni alloy with higher Cr, Si, and Mo (B2), and a 3.3 wt. pct. Ni alloy (T1).

Experimental Procedures

The alloys were induction melted and cast in sand molds to produce 25 mm x 51 mm x 203 mm (1" x 2" x 8") bars. Some of the bars were given a stress-relieving treatment. This treatment included heating the bars to 150°C (300°F) in 3 hours and holding at temperature for 2 hours. The temperature was then raised to 250°C (480°F) in one hour, and the bars were held there for 2 hours before they were cooled in furnace.

Chemical compositions of the alloys are listed in Table 1. The chemical compositions of the alloys were determined by wet chemistry (Mn, Cr, Si), inductively coupled plasma (Ni, Mo), combustion infrared detection (C), and atomic spectroscopy (P, S, Cu). Microstructural characterization of the alloys was performed using optical and scanning electron microscopy. Specimens were polished by the usual metallographic preparation techniques and etched with Vilella's reagent before examination.

The tensile strength of castings was determined using a three-point bend test. A MTS mechanical testing machine with a load cell capacity of 23,000 kg (50,000 lbs) was used. The ramp rate of the cross head was $2.12 \times 10^{-5} \text{ ms}^{-1}$ (0.05 inches per minute). The bars were surface ground and tested unnotched. Four castings in each category were tested. The distance between the two supports was 144.5 mm (5.69 inches). Load at failure was recorded, and the modulus of rupture was

Table I. Chemical compositions of chill samples in weight percent.

Alloy	C	Si	Ni	Cr	Mo	Mn	P	S	Cu
B1	3.32	0.80	4.17	2.09	0.01	1.00	0.021	0.014	0.13
B2	3.25	1.42	4.05	2.91	0.25	0.63	0.036	0.016	0.06
T1	3.21	0.52	3.27	2.07	0.27	0.48	0.034	0.009	0.03

calculated from the following equation [6]:

$$M = \frac{3PL}{2bd^2} \quad (1)$$

where P is the load at rupture, L is the distance between supports, b is the width of specimen, and d is the thickness of specimen.

Abrasion resistance of the alloys was determined using a pin abrasion test. Pin abrasion wear tests utilized the pin-on-drum apparatus; details of this test procedure are described elsewhere [7]. The pin-on-drum abrasive wear test involved high-stress, two-body abrasion, in which one end of a cylindrical pin specimen was moved over an abrasive paper. In this study 150 grit garnet (80-100 μm abrasive particle size; Vickers hardness of 13.1 GPa), a naturally occurring mineral, was used to determine the volume abrasive wear of the white cast irons. For these wear tests, a 6.35 mm diameter pin sample was pressed against the drum with a normal force of 66.7 N, corresponding to an average surface pressure of 2.11 MPa on the wearing surface of the pin. The pin was rotated at a peripheral speed of 5.65×10^{-3} m/s (17 rpm), while the drum rotated at a speed of 4.5×10^{-2} m/s (1.7 rpm). The wear path was 1.6 meters per drum revolution.

Each abrasive wear test required two runs--one for the test specimen and a second for a standard specimen. After each test specimen had been run, the standard specimen was also run under identical conditions, but with its wear track exactly between the tracks left by the test specimen. The standard material was a low-alloy steel, ASTM A514, with a Brinell hardness of 269. The wear of the standard specimen was used to correct for small variations in the abrasiveness of the abrasive cloth from lot-to-lot and within a given lot.

After a specimen break-in cycle of four revolutions, wear data were collected after 10 revolutions, equivalent in magnitude to a sliding distance of 16 m. Two sets of tests were performed for the specified number of drum revolutions for each material. The weight loss of the sample and the standard pin was measured after each test, and the results were averaged. Abrasion data were calculated as both the volume wear rate (volume loss of sample / sliding distance) and the wear factor (volume loss of sample / volume loss of standard pin).

Brinell hardness measurements were performed on the ground surfaces of the castings. For each indent, a load of 3000 kg was applied through a 10 mm diameter WC ball for 15 seconds. Five indents were made on each specimen.

Results And Discussion

Microstructure

The as-cast microstructure of Ni-Hard I alloys containing higher Ni (B1 and B2) consists of M_3C type carbides in a primarily austenitic matrix, with some lenticular martensite. The stress relieving treatment modifies the matrix to various degrees in the different alloys, whereas the primary carbides remain unchanged. Alloys B1 and B2 differ slightly in the coarseness of the microstructure, as shown in Figures 1 and 2, with B2 having the coarser structure. Also, in the stress-relieved condition, granular bainite constituent was observed in the matrix of B2 to a much larger extent than in B1 (Figure 3).

In the as-cast condition, the matrix of the T1 alloy consists of austenite, lenticular martensite, and a granular bainite, as shown in the SEM micrograph in Figure 4. Metallographic observations suggest that, during continuous cooling from the solidification temperature, the martensite plates form first in austenite, followed by the formation of granular bainite at lower temperatures. The amount of granular bainite in the T1 alloy is much greater than that observed in the B alloys. The stress relieving treatment changes the matrix structure of T1 quite significantly (Figure 5). During this treatment, a lower bainite

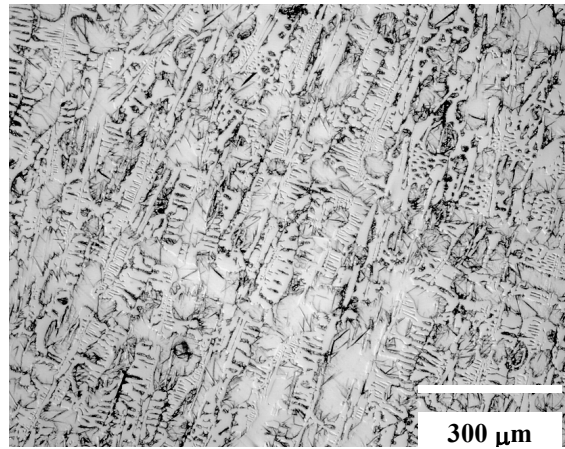


Figure 1: Optical micrograph of casting B1 showing general microstructure in the stress-relieved condition.

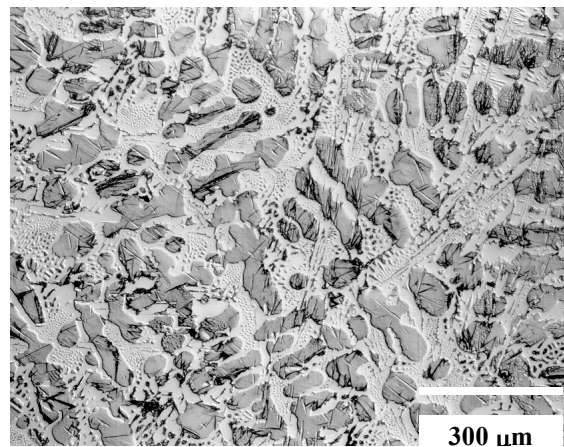


Figure 2: Optical micrograph of casting B2 showing general microstructure in the stress-relieved condition.

phase forms. It appears that the lower bainite sheaves form on the former martensite phase.

Tensile Strength

The tensile strengths of the castings, as obtained from the three point bend test, are listed in Table 2. The B1 alloy has a strength of about 350 MPa in both the as-cast and stress-relieved condition. The strength of B2 is 427 MPa in the stress-relieved condition. The higher strength of B2, as compared to B1 is probably due to the greater extent of granular bainite formation. This alloy was not tested in the as-cast condition. On the other hand, T1 alloy showed a dramatic increase in tensile strength, from 340 MPa to 452 MPa, with the stress relieving treatment. This increase in the tensile strength may be due to transformation of some of the austenite phase into lower bainite. Overall, the stress-relieved T1 has the highest tensile strength among the alloys tested.

Abrasion Resistance

Table 2 lists the abrasion rates (inverse of abrasion resistance) of the alloys as determined using the pin abrasion test. The abrasion rates are listed as the volume loss (mm^3) of the specimen as it travels a distance of 1 meter on the abrasive paper. The abrasion rates of the three alloys in the as-cast and the stress-relieved conditions are very similar. It is interesting to note that although the tensile strength changes with variations in composition (from B1 to B2 and to T1) and with the stress relieving treatment (within T1), the abrasion resistance remains essentially the same. This result suggests that the abrasion resistance of these alloys is a strong function of carbide content and that it is not influenced by the changes in the matrix which were introduced by the variations in chemistry and thermal treatment in this work. Compositional changes and thermal

treatment employed in this work modify the matrix of castings as discussed above but do not change the primary carbide structure.

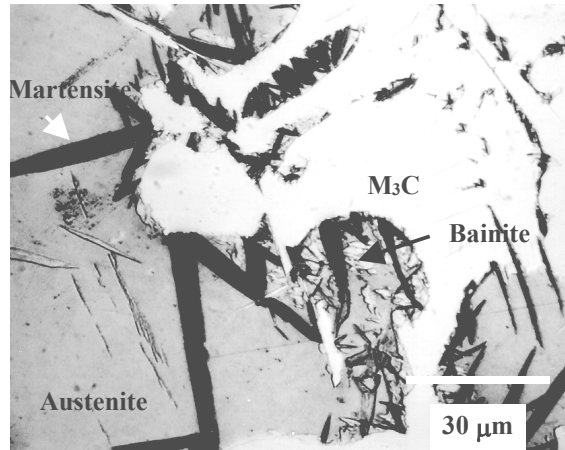


Figure 3: Microstructure of B2 in the stress-relieved condition.

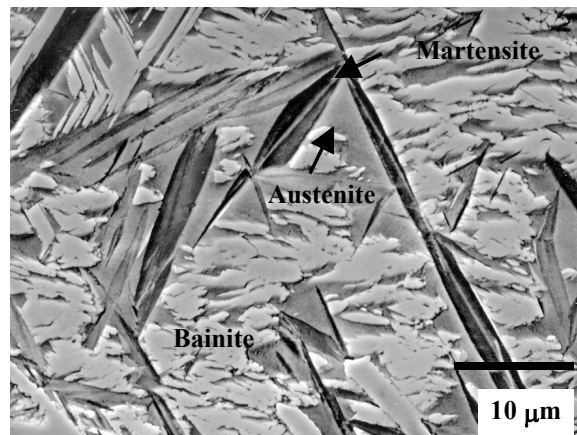


Figure 4: Secondary electron image of alloy T1 in the as-cast condition.

Table II. Mechanical properties of castings.

Alloys	Tensile Strength (MPa)	Wear Rate (mm ³ /m)	Wear Factor	Hardness HB
B1 as cast	351±12	0.21	0.25	512
B1 stress relieved	350±9	0.26	0.24	514
B2 stress relieved	427±16	0.25	0.22	462
T1 as cast	340±23	0.25	0.21	646
T1 stress relieved	452±24	0.25	0.22	614

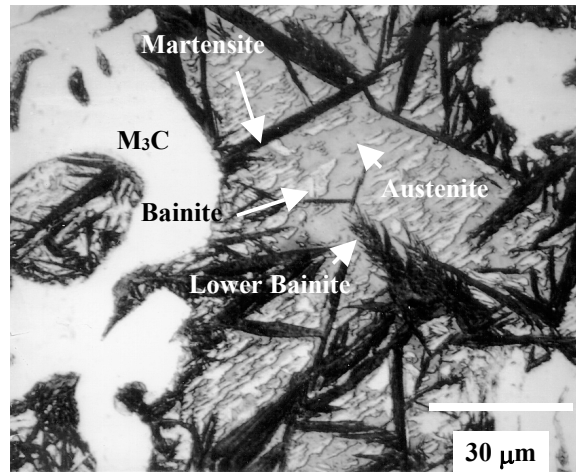


Figure 5: Optical micrograph of alloy T1 after stress relieving.

Conclusions

1. Compositional variations in the Ni-Hard I type castings employed in this investigation changed the matrix structure of the alloys. However, the primary carbide structure was not influenced by these variations.
2. The stress relieving treatment modified the matrix of the T1 alloy. A lower bainite phase formed from retained austenite during this low temperature treatment. Essentially the matrix of the alloy became martensitic-bainitic with some retained austenite. The primary carbide structure was unaffected by this treatment.
3. The tensile strength of the modified (T1) alloy increased significantly above the standard Ni-Hard alloy with the stress relieving treatment.
4. The abrasion resistance of the three Ni-Hard I alloys investigated were essentially the same. Neither the compositional variations nor the stress-relieving treatment had a significant effect on the abrasion resistance.

Acknowledgments

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References

1. ASTM A532-93, Annual Book of ASTM Standards, vol. 01.02, (1999).
2. G. Laird II, "Microstructures of Ni-Hard I, Ni-Hard IV, and High Cr White Cast Irons," *AFS Transactions*, 99 (1991), 339-357.
3. R.T. Warren and B. Chicco, "The Fe-Rich Corner of the Metastable C-Cr-Fe Liquidus Surface," *Metallurgical Transactions A*, 16A (1985), 1541-1549.
4. G. Laird II, R.R. Brown, and R.L. Nielsen, "Factors Affecting Eutectic Solidification of Cr-Ni (-Si-Mn) White Cast Irons," *Materials Science and Technology*, 7 (1991), 631-642.
5. M.N. Tomovic, D.V. Mihajlovic, and M.M. Radulovic, "Microstructure Characteristics of Isothermally Treated Ni-Hard Cast Iron," *AFS Transactions*, 97 (1988), 339-346.
6. ASTM C674-88, Annual Book of ASTM Standards, vol. 15.02, (1994).
7. R. Blickensderfer and G. Laird II, *Journal of Testing and Evaluation*, 16 (1988), 516-526.