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Improved Wear Resistance of Boron Steels by Subcritical Annealing and Hardening with Production Cost Savings and Lower Environmental Impact

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Abstract

Boron steels are very interesting as wear resistant materials. In this research we propose a boron steel without alloys, 30MnB5, with a new thermal treatment that exceeds the mechanical characteristics of conventional treatment. The 30MnB5 steel, with the new sub-critical annealing and water quenching heat treatment, also exceeds the RAEX450. The new treatment has important advantages, such as: energy savings and reduction of costs and manufacturing times. It also has a more favourable ACV than 30MnB5 with conventional heat treatment and RAEX450. Its wear resistance is significantly improved compared to the classic heat-treated 30MnB5 and the RAEX450.

Keywords: Boron steel; Heat treatment; Metallographic structures; Mechanical properties

Introduction

The hardness obtained after hardening of these steels in water makes them particularly suitable for applications where high resistance to wear is required.

The use of these steels allows reductions in the weight of very considerable structures, up to 40% in weight compared to several types of steels, among others, compared to HSLA (High Strength Low Alloy). Its fatigue resistance is also much higher than HSLA, from 40% to 60%.

They have an excellent performance for hardening in water, which results in environmental impact, compared to other carbon steels [1-10].

The applications of boron steels, after the thermal treatment of hardening in water, are directed to agricultural or public works machinery, mining, cutting equipment, etc., as a suitable material because of its resistance to wear.

Two types of boron steels have been used in this study: one carbon steels, 30MnB5 (UNE-EN 10083-3:2006) and one slightly alloyed RAEX450. RAEX450 steel, we have used it as a reference material, because our aim is to propose 30MnB5 steel, without alloy, as a prototype for its best LCA (Life Cycle Analysis) [11,12], since it lacks alloying elements, such as chromium, nickel and molybdenum. It also affects the price.

A new water quenching heat treatment has been designed for these steels, which represents an innovation. It is a matter of achieving hardening from a low temperature, such as 750°C, and with a very short cycle heating, from 10 to 15 minutes. It is a subcritical hardening from the binary field of existence ferrite+austenite. The structure obtained is binary, formed by ferrite and martensite [12]. The relative percentages of these phases provide a great variability in the mechanical properties; depending, only, on the variables temperature and time. This makes the annealing stage unnecessary. It is an important success because it reduces annealing times and a stage in the hardening and tempering process, reduces production costs and has a very favourable environmental impact [12]. It is even possible to improve some of its mechanical properties. All this was evident in the work published by García and Criado [12], in which the mechanical properties obtained for this thermal treatment of subcritical annealing and hardening of boron steels were compared with 30MnB5. The mechanical properties were of a similar order to those obtained by conventional hardening and tempering treatment, but with certain improvements in toughness and hardness. In this research, steel 30MnB5, is treated by means of the new sub-critical annealing and hardening heat treatment and we have tried to see its wear behaviour, which is the industrial use of these boron steels. To see its improvement in terms of wear resistance, we have chosen RAEX450 steel as a reference, whose application as wear-resistant steel is widely used.

Experimental Technique

Two types of boro-manganese steels have been selected for this research: 30MnB5 (UNE-EN 10083-3:2006) and RAEX450 001-01-01 (SSAB?s Certified Partner). The 30MnB5 is a carbon steel of high wear resistance in its quenching state and the RAEX450 is an alloyed boron-manganese steel with similar mechanical performance. The chemical composition of both steels is shown in Table 1.

	30MnB5	RAEX 450
C	0.3	0.26
Mn	1.3	1.7
P	<0.035	0.025
S	<0.035	0.015
Si	0.3	0.8
Cr	0.95	1.5
Ni	-	1
B	0.003	0.005
Mo	-	0.5

Table 1: Compositions of steels (% by mass content): 30MnB5 and RAEX 450.

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They were acquired in the form of wire rod drawn wire, steel 30MnB5, up to diameters of 7.02 mm, 8.84 mm and 12.79 mm (Figure 1). RAEX450 steel was acquired in the form of an 8 mm thick plate (Figure 2), with heat treatment of hardening and tempering, ready to be used in the typical industrial applications of these steels: hardened from 900°C and tempered at 500°C.

From these starting materials were obtained samples that were heat treated in a Carbolite muffle, model ELF-11/148 series S336RB, with thermal capacity of 1100°C.

For micro-hardness measurements, a Vickers FUTURE-TECH micro-hardness tester was used, model FM-700, with a variable load from 10 kg to 100 kg.

The Rockwell-C hardness determination has been carried out on a universal hardness tester OFFICINE GALILEO, model A200, with a 150 kg load, using the Brale diamond cone tip penetrator.

For tribological tests, the specimens were roughed to a sandpaper of 600 grams per square inch, then subjected to the wear test on a CENT UMT Multi-Specium Test System Pin-On-Disk tribometer, taking as a reference the ASTM International G99-95a(2000)e1 standard with a tungsten carbide pin [13].

Figures 3 and 4 show the type of samples tested, extracted from the reception materials (Figures 1 and 2), used for heat treatments and hardness, micro-hardness, tribology and metallography tests.

Figure 1: Wire rods of boron steel (30MnB5) drawn wire.

Figure 2: Alloyed boron steel sheet RAEX 450.

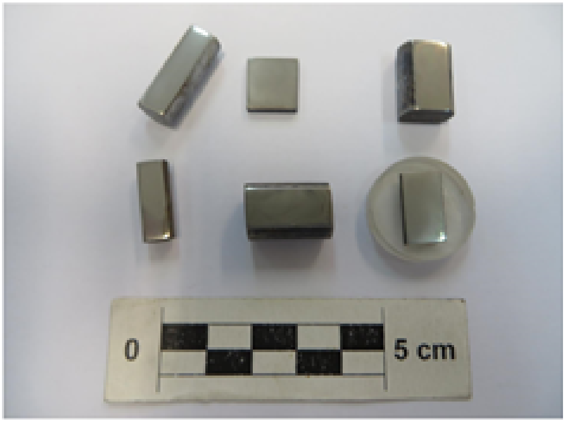

Figure 3: Used specimens of boron steel 30MnB5.

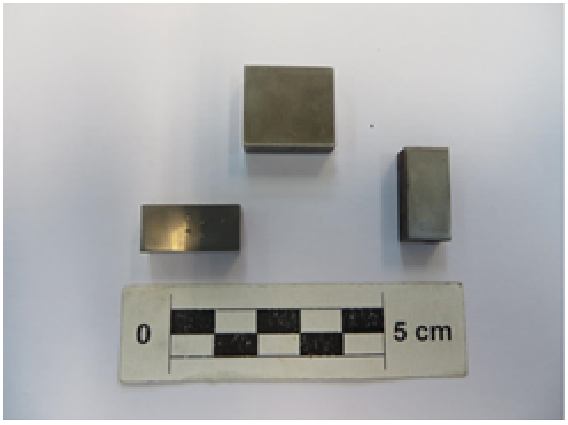

Figure 4: Used specimens of boron steel RAEX450.

Results and Discussion

RAEX450 steel was received with heat treatments already carried out directly by the trading company. They come with the mechanical properties derived from the conventional industrial thermal treatment applied to this type of steel, quenching in water from 900°C and tempering at 500°C. In that state the hardness found is 43HRC.

The non-alloy boron steel, steel 30MnB5, was subjected to subcritical annealing heat treatments at 770°C, variable time and hardening in water (Table 2). Without further heat treatments, they were tested. This demonstrates significant energy savings and process times.

The microstructure of the steels studied is the result of the heat treatment undergone. The RAEX450, which is already heat-treated, has a tempered martensitic structure (Figure 5). The unalloyed boron steel, 30MnB5, in its receiving state, presents a microstructure of iron carbides in scolonies distributed in a ferritic matrix of elongated grains, produced by the drawing process (Figure 6). This steel, treated by subcritical annealing at 770°C for 15 minutes and tempered in water, has a dual-phase microstructure with alternating martensite crystals of ferrite crystals (Figure 7).

Temperature (°C)	**Times** (minutes)	**Hardness** (HRC)
770	10	51
770	15	57
770	20	54
770	25	54
770	30	52

Table 2: Hardness of steel 30MnB5, depending on subcritical annealing time.

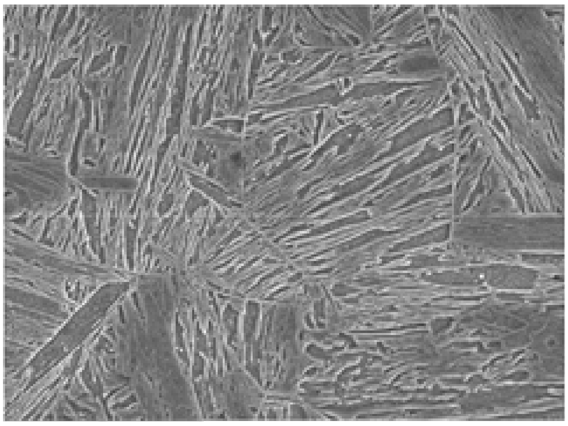

Figure 5: Microstructure of RAEX450 steel tempered from 900°C and tempered to 500°C. A structure of tempered martensite is observed.

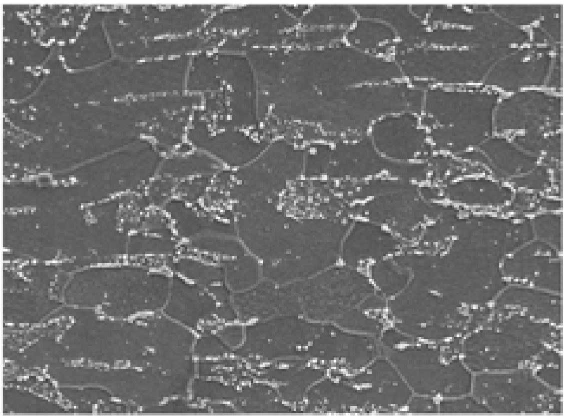

Figure 6: Microstructure of steel 30MnB5 in receiving state. Iron carbide colonies are observed in a ferritic matrix, which corresponds to a hot-drawn structure.

The hardnesses obtained with these steels are suitable for industrial use, such as wear resistant steels. The factory heat-treated RAEX450 has a Rockwell hardness of 43HRC, while the non-alloy steel 30MnB5, with the different subcritical annealing times at 770°C and hardened in water, has hardnesses reflected in Table 2.

The steel 30MnB5 selected for other tests is subcritical annealing at 770°C, for 15 minutes and hardened in water, which has a hardness of 57HRC.

In this research, we have considered the wear behaviour of both RAEX450 and 30MnB5 to be very important, with our subcritical annealing treatment, as this is the main application of these wear-resistant steels. The aim is to see if, with the subcritical annealing treatment of 770°C, during 15 minutes and quenching in water, an improvement in the coefficient of friction of steel 30MnB5 compared to the reference material, RAEX450, is observed. Tribological testing has been done under ASTM International standard G99-95a (2000)e1, with a tungsten carbide pin. The results obtained, after statistical study, give values for the coefficient of friction of 30MnB5 of 0.54 and, for the RAEX450 of 0.63.

The justification for these values, which stand out as the best coefficient of friction for steel 30MnB5, is not that it is associated with higher hardness (57HRC), since the excellent toughness of 30MnB5 is demonstrated [12] with subcritical annealing and tempering treatment. This acceptable toughness for such high hardness is due to the dual phase ferrite-martensite microstructure.

The traces left by the tungsten carbide pin are of a different nature (Figures 8 and 9). In Figure 8, the wear pattern left by the tungsten carbide pin on 30MnB5 steel with subcritical annealing and water quenching is abrasive; whereas in Figure 9, the wear pattern left by the tungsten carbide pin on RAEX450 steel is clearly adhesive.

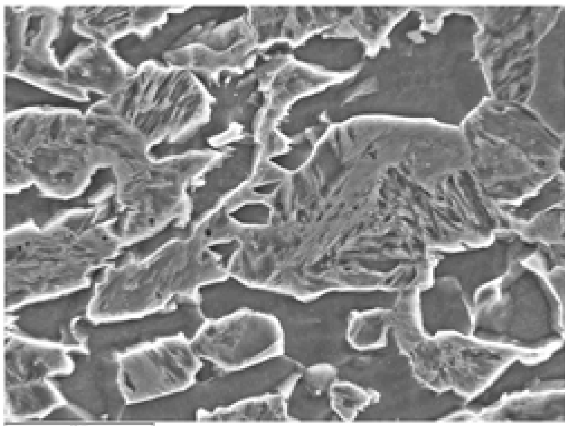

Figure 7: Microstructure of steel 30MnB5 after subcritical annealing at 770°C for 15 minutes and tempered in water. A dual structure of martensite and ferrite is observed.

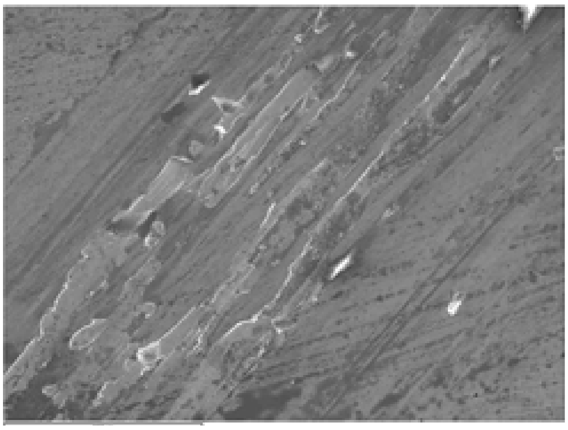

Figure 8: Wear pattern of steel 30MnB5 (recognized 770°C, 15min; hardened in water). The print has abrasive wear morphologies.

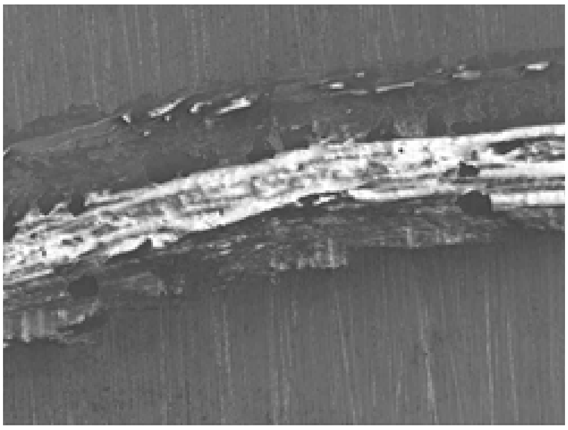

Figure 9: Wear pattern of RAEX450 steel (Recognized 900°C; hardened in water; tempered 500°C). The print has adhesive wear morphologies.

Conclusions

Boron steel 30MnB5, due to its chemical composition, presents a more favourable LCA (Life Cycle Analysis) than RAEX450 steels.

The heat treatment of steel 30MnB5 requires less time and a lower annealing temperature (770°C) than RAEX450 (900°C) and 30MnB5 itself by the current conventional method. The proposed new sub-critical annealing and water quenching treatment does not require the RAEX450 tempering stage at 500°C for an extended period of time. Also, steel 30MnB5, according to the conventional treatment, needs this tempering stage after quenching in water, which our proposed treatment does not require.

Substantial energy savings occur during subcritical annealing, at a lower temperature and at the same time as those used conventionally for RAEX450 or 30MnB5 itself. The saving of the tempering stage means a very considerable advantage of the proposed new subcritical annealing treatment compared to the conventional treatment being used.

This very considerable energy saving results in a very favourable LCA for the proposed treatment of subcritical annealing.

The mechanical properties that are obtained with the new treatment, are of the same order or improved, to which they are obtained with the conventional thermal treatment of annealing, hardening and tempering. The cause that justifies this behaviour is the obtaining of a dual phase structure, consisting of a ferrite matrix with martensite crystals.

In this research we have found a greater hardness (57HRC) of 30MnB5, with the proposed new treatment, compared to RAEX450 with conventional treatment (43HRC). This translates into a lower coefficient of friction of 0.54 for 30MnB5 steel compared to 0.63 for RAEX450 steel. Therefore, the wear behaviour is improved and, in addition, without loss of toughness by the 30MnB5.

Considering that the wear-resistant applications of these steels, an industry using plates and other medium thickness products is applied, 30MnB5 steel, treated with the proposed new heat treatment, is a strong competitor for RAEX steels, in all fields.

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