Improvement of the Mechanical Properties of 30MnB5 Wear-Resistant Steel by Subcritical Annealing and Water Quenching, Improving Its Life Cycle Analysis

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Abstract

Life Cycle Analysis (carbon footprint) is currently a criterion that should accompany the selection of materials and processes. This research proposes a heat treatment for carbon steels with boron and manganese that reduces processing time and saves energy. It is a question of replacing the conventional hardening and tempering treatment with a single stage of subcritical annealing and hardening. This can be achieved thanks to the presence of boron in the steel, which significantly increases its hardening capacity. Thus, 30MnB5 carbon steel, with a very short subcritical annealing time and water hardening, competes in advantages with other wear-resistant steels such as RAEX450. The Life Cycle Analysis (carbon footprint) is very favorable and, its mechanical properties very advantageous, within the field of application of these steels. The obtaining of a dual-phase ferrite-martensite structure, with this heat treatment, allows very positive mechanical characteristics and adaptable to a variety of possibilities.

Keywords: Boron steel; Wear resistant steels; Dual phase structure; Life cycle analysis

Introduction

Today, the trend in all fields is to design treatments and operating methods that have the lowest possible environmental impact. The Life Cycle Analysis (LCA) of a process is vital to decide on its goodness or not. The heat treatment of steels requires high energy consumption. Sometimes, these processes are also slow, require high temperatures and sometimes long periods of time. For some time now, we have been trying to design an alternative treatment to the hardening and tempering of steels, which will compete with it by improving the Life Cycle Analysis, reducing process times and economic costs.

With the subcritical annealing and water quenching treatment of wear-resistant steels, we have tried to prove that this is possible. We have done it with a particular case, which serves as a model for other cases, with 30MnB5 boron steel, comparing the mechanical results obtained, and its improvement of the Life Cycle Analysis, with a classic of the wear-resistant steels, such as RAEX450 steel, widely used in the current industry.

Initially, the two steels have different chemical compositions that make it clear that 30MnB5 steel has a better life cycle analysis than RAEX450, which is alloyed with Cr, Ni, Mo. Likewise, the alloying elements added to the RAEX450 increase its price above 30MnB5, which does not contain them (Table 1).

In order to achieve water quenching from temperatures around 750°C and for very short annealing times of around 15-20 minutes, the steel must be formulated with elements that considerably accentuate the hardenability, such as boron and/or manganese. The steel chosen, 30MnB5, has boron and appreciable amounts of manganese, without any other alloying element, always ensuring that its ACV is not unfavourable (Table 1) [1-6].

With the water quenching of these steels, a dual phase ferrite-martensite structure is obtained that is very favourable for obtaining excellent mechanical characteristics, shortening the annealing temperature and avoiding the subsequent tempering stage [7,8].

As a final result, comparing the results of the mechanical tests with those of classic wear-resistant steel, RAEX450, there is an improvement in the mechanical characteristics including its wear resistance. It can be assured that 30MnB5 carbon steel, with boron and manganese, competes with the steels of the RAEX series and with a more favorable Life Cycle Analysis (LCA).

Experimental Technique

RAEX450 steel is purchased from the factory heat treated. The heat treatment to which it is subjected at source is an annealing at 900°C with subsequent tempering in water and tempering at 900°C. Its technological applications are those of a steel with an excellent performance as resistant to wear. It is a boron-manganese steel alloyed with chromium, nickel and molybdenum. It has excellent hardening penetration (RUUKKI RAEX450).

The 30MnB5 steel, selected for this investigation, is an unalloyed boron-manganese steel. Its technological applications are the same as for the RAEX450 (ArcelorMittal).

The specimens used in the investigation have been cut and machined according to the standard of each test (Figure 1). The heat treatments carried out on 30MnB5 steel were carried out in a Carbolite muffle, mod. ELF-11/148 series S336RB, at a subcritical annealing temperature of 770°C, for 10, 15, 20, 25 and 30 minute times, and then hardened in water.

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	%C	%Si	%Mn	%P	%S	%Cr	%Ni	%Mo	%B
30MnB5	0.30	0.30	1.30	<0.035	<0.035	-	-	-	0.0030
RAEX450	0.26	0.80	1.70	<0.025	<0.015	1.50	1.00	0.50	0.005

Table 1: Chemical composition of the steels studied.

Figure 1: Research specimens, cut and machined.

Figure 2: Microstructure of RAEX450 steel, factory-treated, tempered martensite.

For microhardness measurements, a Vickers FUTURE-TECH FM-700 microhardness tester with a variable load of 10 kg to 100 kg was used.

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

For tribological tests, the specimens were roughened to a Buehler 600 grit sandpaper. They were then subjected to the wear test on a CENT UMT Multi-Specium Test System-Pin-on-Disk tribometer, using the ASTM International G99-95a(2000)e1 protocols with a tungsten carbide pin.

Results

The RAEX450 steel is received already heat treated with a water quench from 900°C and a final tempering at 500°C, carried out in the factory (RUUKKI RAEX450). In this state, its hardness is 43HRC and its microstructure is of tempered martensite (Figure 2).

The 30MnB5 steel has a receiving structure of iron carbides aligned in rows, partially globulized, in the plastic forming direction, in a matrix of elongated ferrite crystals in the same direction (Figure 3).

The treatments applied to 30MnB5 steel were a short duration subcritical annealing, followed by water quenching. Table 2 shows the subcritical annealing times and the hardness achieved. For all treatments, the heating temperature was 770°C, varying the permanence time from 10 minutes to 30 minutes.

The microstructure obtained, in all cases, is dual phase ferrite-martensite, varying the proportion of both phases, depending on the treatment time. It is interesting to see how the Vickers microhardness of the ferrite and martensite phase varies with the heat treatment time (Table 3 and Graph 1).

As the hardness varies with the treatment time, so do the basic mechanical properties of modulus of elasticity, yield strength, mechanical strength and ductility (elongation) (Table 4).

It is clear that with the subcritical annealing and water quenching treatment, excellent mechanical characteristics are achieved for 30MnB5 steel. For 15 minutes of treatment, values of resistance,

Figure 3: Microstructure of 30MnB5 steel in its receiving state.

Temperature (°C)	770	770	770	770	770
Time (min)	10	15	20	25	30
Hardness (HRC)	51	57	54	54	52

Table 2: Different subcritical annealing times and HRC hardnesses obtained.

Time (min)	10	15	20	25	30
Martensite (HV)	450	670	663	665	701
Ferrite (HV)	101	159	151	155	172

Table 3: Variation of the Vickers microhardness of the ferrite and martensite with the treatment time.

elasticity and elongation are obtained that are better than those obtained for the RAEX450, tempered from 900°C and tempered at 500°C. In addition, the hardness value obtained is 57HRC for 30MnB5 compared to 43HRC for RAEX450. This makes 30MnB5 steel superior to RAEX450 in its industrial applications as wear-resistant steels. This has been demonstrated by tribological tests performed on both steels, following ASTM International G99-95a(2000)e1 with a tungsten carbide pin.

These tests confirm that the coefficient of friction of steel 30MnB5, with a subcritical annealing treatment of 15 minutes at 770°C and water quenching, is more favourable with a value of 0.54 than that obtained for RAEX450, which is 0.63. The mark left by the tungsten

Steel	Modulus of elasticity (GPa)	Yield strength (MPa)	Mechanical strength (MPa)	Elongation (%)	Hardness (HRC)
RAEX ₄₅₀	212	1000	1300	6	43
30MnB ₅ (10 min)	210	1100	1300	6	51
30MnB ₅ (15 min)	206	1400	1600	5	57
30MnB ₅ (20 min)	208	1350	1500	3	54
30MnB ₅ (25 min)	210	1300	1450	3	54

Table 4: Relationship between treatment times and mechanical properties.

carbide pin is abrasive for 30MnB5 steel, as opposed to the mark left by the RAEX450 which is adhesive.

The dual-phase structure of 30MnB5 steel has proven to be more mechanically convenient than the tempered martensite structure of the RAEX450. All this has to be associated with the fact that 30MnB5 steel also has a more favourable Life Cycle Analysis (carbon footprint) than the RAEX450.

Conclusions

It has been shown to be a carbon steel containing small amounts of boron and manganese, 30MnB5, can replace RAEX450 as wear-resistant steel, saving alloy elements (chrome, nickel, molybdenum), manufacturing times and direct energy savings. This has a significant influence on its Life Cycle Analysis (carbon footprint), which allows

30MnB5 steel treated by subcritical annealing and water quenching to replace the RAEX450, advantageous in terms of time and cost savings and, by far, more favourable Life Cycle Analysis (carbon footprint).

It has been proven in this investigation that the mechanical properties of 30MnB5 steel, treated by subcritical annealing and water quenching, exceed those of alloyed RAEX450. It even improves its performance, typical of these steels, in its most notable applications of wear-resistant steels. The steel 30MnB5, presents a more favorable coefficient of friction of 0.54 against 0.63 of the steel RAEX450.

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