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Comparative Life Cycle Analysis (LCA) Study on Two Wear-Resistant Boron Steels: RAEX450 and 30MnB5

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Abstract

The inter-critical annealing and water quenching heat treatment proposed by us is a practical example of environmental sustainability applied to wear-resistant boron steels. In this research we try to compare the LCAs of two wear-resistant steels, a RAEX450 widely used in the industry today and cheaper 30MnB5 boron steel without alloy elements. The 30MnB5 steel has been given an inter-critical annealing and hardening treatment and the RAEX450 a conventional annealing and hardening treatment. The mechanical properties achieved are similar to or better than those of boron steel; but the energy savings with this steel and its environmental impact are notably more positive for the environment.

The LCA of the heat treatment applied to 30MnB5 is significantly more positive than that applied to RAEX450, without affecting its mechanical properties as wear-resistant steel.

Keywords: Life cycle • Environment • Steels • Mechanical properties • Wear

Introduction

We live in the era of "Industry 4.0", or the Fourth Industrial Revolution, always taking into account when the first Industrial Revolution (1760-1840) took place. Within this industrial revolution the reduction of environmental impacts has become a universal priority. Industrial growth must be proportional to the growth of clean technologies. The study of Life Cycle Assessment (LCA) is key in all phases of the ecological and economic sustainability of an industrial product or service.

The inter-critical heat treatment proposed by us is a practical example of economic and environmental sustainability applied to wear-resistant boron steels. In this research we tried to compare the LCAs of two wear-resistant steels, a RAEX450 and a 30MnB5 boron steel, which was subjected to an inter-critical treatment. This inter-critical treatment improves the LCA by lowering the treatment temperatures, saving the heat energy used and reducing the procedure time, obtaining the same mechanical characteristics and even better in some aspects such as wear resistance and toughness. We are going to see all this in front of a typical example in the industry as they are the steels RAEX450, resistant to the wear, with a typical heat treatment of heating to 900ºC during 30 minutes, hardening in water and later tempering to 600ºC during 120 minutes.

This inter-critical heat treatment that we apply to 30MnB5 steel consists of heating to 770ºC for 15 minutes with subsequent hardening in water. In this way, the tempering phase is cancelled and the temperature and annealing time are reduced.

By using this boron steel without alloy elements, which is an economic and environmental improvement, it has at the end of its treatment a better resistance to wear than the alloy RAEX450 steel, for the application for which it has been designed, improving, in addition, the toughness.

In addition to the energy and process time savings, a mechanically very advantageous dual martensite-ferrite structure is obtained.

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Our LCA study will be applied under the door-to-door concept, not from the cradle to the grave.

Technical Proposal and Advantages

Our technological proposal has been to act in classic heat treatments, trying to improve them and also with the fixed goal of improving the environmental impact. In the case we are investigating boron steels resistant to wear, we think that the classic heat treatment of hardening and tempering was excessive in terms of fuel consumption. Boron, due to its very high hardenability, could be used to obtain dual phase ferrite-martensite type structures.

The first thing we thought of was to use boron steel, with a low carbon content, allowing only the influence of this element to appear without the presence of other alloying elements.

The applications of these steels are, almost always, using them in flat sections: plates, sheets, tubes, discs, etc., of a not very big section and resistant to the wear, and of great hardness, reason why the minimum radius Jominy must not be very big.

Two expensive boron steels of great current industrial interest have been selected for this study: RAEX450 steel and boron steel without alloys, 30MnB5. For the 30MnB5 steel, a novel heat treatment proposed by us has been used: an inter-critical annealing at 750ºC for 15 minutes and subsequent quenching in water. RAEX450 steel retains its conventional heat treatment of annealing at 900ºC for 30 minutes, water quenching and final tempering at 600ºC for 120 minutes.

The final structure of both steels is different. While RAEX450 steel has a classic structure of tempered martensite, 30MnB5 steel shows a dual phase structure of ferrite-martensite. The mechanical properties are similar, although with an improvement by the steel 30MnB5. These improvements are more noticeable in the hardness and, consequently, in its resistance to wear, which is the purpose of using these steels for wear.

Figure 1 shows the martensitic structure of RAEX450 steel and Figure 2 shows the dual phase ferrite-martensite structure. As it is evident, the characteristics of the two steels are different and compete with each other, being more positive those of the dual steel. All this has been verified in our research [1-5].

A summary of the mechanical properties of both steels is shown in Table 1. The RAEX450 steel with conventional treatment of quenching in

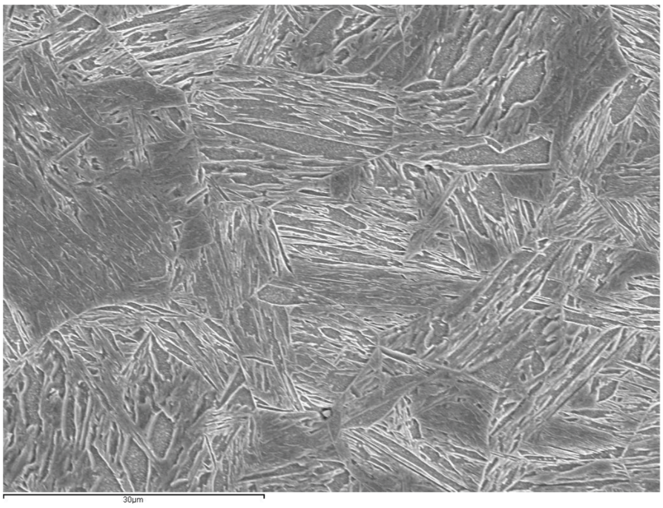

Figure 1. Micrograph showing the martensitic structure of RAEX450 steel.

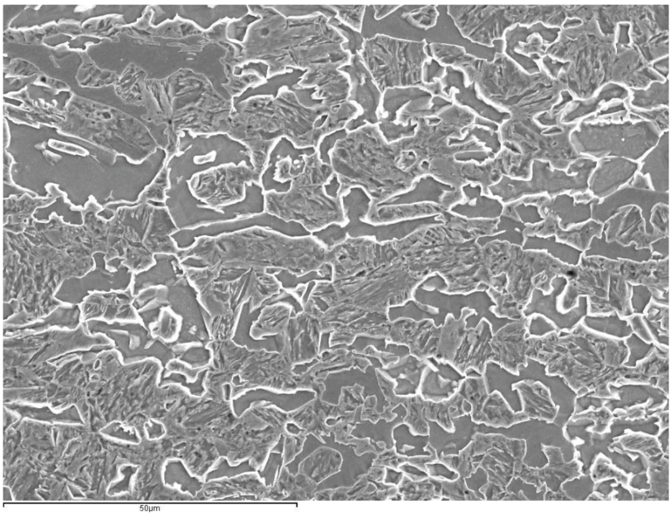

Figure 2. Micrograph showing the dual phase ferrite-martensite structure of 30MnB5 steel.

Table 1. Summary of the mechanical properties of both steels.

	Resistance (MPa)	Elongation (%)	Wear Resistance (Coefficient of friction)	Hardness (Vickers)
RAEX450	1300	6	0.63	573
30MnB5	1600	5	0.54	632

water from 900ºC for 60 minutes and tempering at 500ºC for 30 minutes, and the 30MnB5 steel with inter-critical treatment of heating to 750ºC for 15 minutes and quenching in water.

As you can see, 30MnB5 steel is equal or superior to RAEX450, with the heat treatments described. At first sight, we can see how the inter-critical treatment of 30MnB5 steel is more positive in terms of manufacturing times, and we are going to prove that it is more positive to the environment in terms of CO_2 emissions. Taking into account the treatment temperatures and duration times, it is possible to calculate the cubic metres of CO_2 generated and the energy consumed in the two processes applied to these wear steels.

Determination of CO_2 release during heat treatment of 30MnB5 steel and RAEX450 steel in a homogenized furnace

For a preheated and homogenized furnace, the release of CO_2 is determined only as a function of the heating time of the parts and their respective hardening. For this purpose, we start by determining the amount of CO_2 released during the heat treatment of RAEX450 steel.

Determination of the release of CO_2 during the heat treatment of RAEX450 steel in a homogenized furnace

Based on the heat capacity formula:

$Q=m \cdot C_p \cdot \Delta T$

where:

- Q is the amount of heat received by the steel.
- m is the mass of the steel.
- Cp is the specific heat or heating capacity of the steel.
- T is the temperature variation.

In this case we know that the heat capacity of steel is 0.486KJ/kg-K and the mass of reference steel is 1000 kg. For a hardening heat treatment of RAEX450 steel at a temperature of 900ºC and a tempering at 500ºC, the amount of heat required for each treatment can be calculated.

In this way, considering the temperature used in the hardening T_1=1173 K and the temperature used in the tempering T_2=773 K, the amount of heat can be determined, obtaining the following results in Table 2.

On the other hand, taking into account that the CO_2 emission factor in fossil fuels is 1 Kw/h = 0.35 kg of CO_2 [6,7] and the treatment times for hardening and tempering are 0.5 h and 2 h, respectively, we have in Table 3.

In short, for a complete hardening and tempering treatment of RAEX450 steel, the amount of CO_2 emitted would be the sum of the emissions from both treatments, the total value being 100 4kg.

Determination of the CO_2 release during the heat treatment of 30MnB5 steel, in a homogenized furnace

We start again from the formula of the calorific capacity:

$Q = m \cdot C_p \cdot \Delta T$

Table 2. Amount of heat can be determined.

Temperature (K)	Q (KJ)	Q (Kw/h)
1173	570078	158.35
773	375678	104.35

Table 3. Treatment times for hardening and tempering.

Temperature (K)	Time (h)	Q (Kw/h)	Furnace (Kw)	CO_2 emission (kg)
1173	0.5	158.35	79.175	27.4
773	2	104.35	208.7	73

Table 4. Heat capacity of the steel.

Temperature (K)	Q (KJ)	Q (Kw/h)
1043	506898	140.8

Table 5. CO_2 emission factor in fossil fuels.

Temperature (K)	Time (h)	Q (Kw/h)	Furnace (Kw)	CO_2 emission (kg)
1043	506898	140.8	35.2	12.32

Table 6. Current cost of electricity.

Steel	CO_2 emission (kg)	Costs (€)
RAEX450	100.4	15.3
30MnB5	12.32	2

Table 7. Difference in costs of energy consumption for the mentioned steels.

Steel	Time (h)	Q (Kw/h)	CO_2 emission (kg)	Costs (€)
RAEX450	2.5	158.35	100.4	15.3
30MnB5	0.25	140.8	12.32	2

In this case, the heat capacity of the steel is 0.486KJ/kg-K and the mass of reference steel is 1000kg. For an inter-critical heat treatment of 30MnB5 steel at a temperature of 770ºC, the heat quantity determined in Table 4.

On the other hand, taking into account that the CO_2 emission factor in fossil fuels is 1Kw/h = 0.35kg of CO_2 [6,7] and the treatment time 0.25h, we have in Table 5.

Difference in heat treatment emissions of 30MnB5 and RAEX450

To determine the difference in CO_2 gas emissions between an inter-critical annealing treatment of 30MnB5 steel versus a hardening and tempering treatment of RAEX steel, we calculated the difference:

m=100.4-12.32=88.08 kg de CO_2 emission.

That is, by eliminating the tempering stage and performing an inter-critical annealing treatment, 30MnB5 steel can save a CO_2 emission into the atmosphere of 88.08kg.

Determination of the change in energy costs of RAEX450 steels and 30MnB5 boron steels

Taking into account that the current cost of electricity is 1kw/h = 0.1527 EUR [8], the energy cost for RAEX450 and 30MnB5 steels would be as given in Table 6.

Therefore, the difference in costs of energy consumption for the mentioned steels will be 13.3 EUR, that is, for each ton treated, 13.3 EUR would be saved, in each procedure (Table 7).

In short, inter-critical annealing treatment is more sustainable, economical and environmentally friendly.

Conclusions

Some interesting criteria can be deduced from the proposed research. With non-alloy anti-wear steel, only with boron and manganese, 30MnB5, it is possible to obtain a cheaper material, with lower manufacturing costs and with mechanical performance similar to RAEX alloy anti-wear steel.

It is a matter of intervening in the heat treatment process. With RAEX450 steel, such as the treated one, a hardening heat treatment is carried out, consisting of an annealing at 900ºC for 30 minutes and subsequent hardening in water. Then, a tempering treatment is carried out at 600ºC for 120 minutes.

Our proposal to improve this material and its environmental impact and economic performance is to use a non-alloy wear-resistant steel, 30MnB5, which is more economical and has less environmental impact, with an inter-critical annealing heat treatment of 770ºC for 15 minutes and subsequent quenching in water, with the consequent cost savings and much lower gas emissions (CO2). All this without loss of mechani

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8. https://tarifasgasluz.com/comercializadoras/endesa/precio-kwh cal characteristics and with some improvement in its application as wear-resistant steel.

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