Sintering Stainless Steels with Boron Addition in Nitrogen Base Atmosphere

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Abstract

Due to the increasing use that the stainless steel is getting recently in the nuclear industry, this document proposes the study of the stainless steel 316L with boron addition. With the final product, the properties of the stainless steel 316L (good mechanical properties and high corrosion resistance) with the boron neutron absorption properties are claimed to unify. The P/M technologies allow adding higher boron quantities than with the solidification conventional technologies, where segregation is produced.

Keywords : stainless steels, boron, service performance

1. Introduction

Boron promotes sintering in terms of densification with formation of liquid phase (at 1200 ºC), which results in faster and more efficient sintering kinetics. At sintering temperatures, boron reacts with matrix alloying elements, forming borides that provide an improvement of mechanical properties and corrosion resistance of materials [1], [2]. Nevertheless, presence of eutectic phase on grain boundaries can lead to embrittle the material due to the overhardening caused by solidification of the liquid phase [3], [4], [5].

Commonly, the presence of nitrogen in the sintering atmosphere is considered unfavourable for stainless steels due to sensibilization caused by formation of chromium nitrides that is detrimental to the corrosion resistance of the material. Aiming to prevent it, this work will try to take advantage of the boron eagerness for nitrogen present in the sintering atmosphere, manufacturing in-situ composites [6] with good properties, especially with good wear resistance.

It has been proved that the presence of intermetallic compounds such as γ-TiAl with elements eager for nitrogen, allows stainless steels sintering without the formation of chromium nitrides in this kind of atmosphere [7].

2. Experimental and Results

The study has been carried out with three different materials obtained by the mixture of stainless steel and boron powders in two different proportions (0.75 and 1.5 % wt) in a rotatory ball mill during 30 min. After mixing, properties (apparent density, flow rate) were evaluated. Mixture was uniaxially compacted at 700 MPa, and green density and resistance of the green compacts were measured. Obtained compacts were sintered at two different temperatures (1230 and 1250 ºC), in reducing atmosphere of 90%N_2 – 9.9%H_2 – 0.1%CH_4, during 30 min. Physical properties (sintering density and dimensional change) and mechanical properties (bending strength and hardness) of the sintered materials as well as wear resistance by means of a pin-on-disc test were evaluated. Chemical analysis to evaluate C, N and O amounts have been also carried out.

Complementary to the material study, a microstructural study was carried out in order to explain the obtained results. Wear tracks were also studied by SEM.

The green density increases slightly with boron additions due to better packing caused by lower size of boron particles. As expected, sintering density increases with temperature in all materials due to higher diffusion activity and grain coalescence. Materials with boron addition have shown swelling (higher than 1%) during sintering, while base steel has suffered shrinkage.

Mechanical properties of these materials decrease significantly with boron addition, diminishing bending strength values from 150 MPa (316L) to 40 MPa (boron alloyed stainless steels). Hardness was also evaluated, decreasing significantly with boron addition. Values changed from 151 to 68 HV30. Generally, the values of these properties do not depend on the sintering temperature.

Hence, boron alloyed stainless steels absorb lower amounts of O and C than plain 316L steel, so boron acts as an inhibitor (Table 1). However, greater nitrogen absorption is promoted, which will form boron nitrides and improve wear properties.

Table 1. Variation of the absorbed O, C and N percentages with temperature and boron content.

Element	Sintering Temperature	Materials		
		316L	+0.75%B	+1.5%B
% O	1230 ºC	0.39	0.28	0.37
	1250 ºC	0.97	0.28	0.43
% C	1230 ºC	0.24	0.01	0.01
	1250 ºC	0.17	0.01	0.02
% N	1230 ºC	0.91	1.38	1.6
	1250 ºC	0.92	1.25	1.39

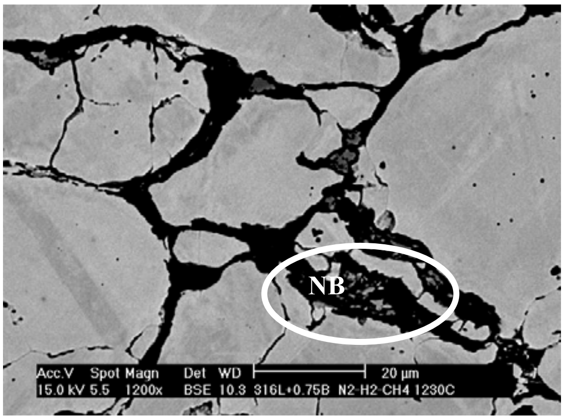

Fig. 1. Microstructure of 316L+0.75%B sintered in N_2-$10H_2$-$0.1CH_4$ at 1250 ºC

Formation of an area with perlitic structure mainly composed by chromium nitrides can be observed through microstructure in all materials. Moreover, 316L steel presents precipitated chromium carbides and nitrides in grain boundaries. Chromium borides and nitrides can be observed in grain boundaries in micrographs of materials with boron addition (Fig. 1). These precipitates cause grain separation and therefore these materials have low density and worse mechanical properties.

Wear study is shown in Fig. 2. Base material suffers erosive wear with little deformation. Material deposits, mainly chromium and iron oxides, appeared in the track.

There is a parallelism between mechanical properties and wear in materials sintered at 1250 ºC, showing the highest wear values the steel with maximum boron content. Materials with boron addition show great decohesion and therefore particles are dragged all together with the subsequent marked material weight loss. In addition, hard particles act as an abrasive third body.

Nevertheless, materials sintered at 1230 ºC show lower wear, due to a larger amount of boron nitride (they have more nitrogen, Table 1). Alloyed steels with 0.75% B show higher wear, when theoretically alloyed steel with 1.5% B should suffer more wear, as all previous studied mechanical properties have shown.

When boron addition is 1.5%, material shows low wear, with the lowest friction coefficient. All abrasion particles remain on the track, increasing hardness and modifying the wear mechanism, turning to erosive since only a minimum amount of the material is lost.

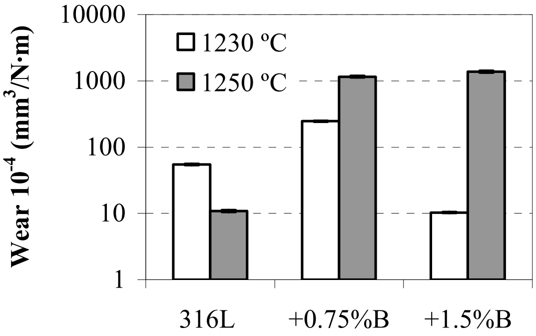

Fig. 2. Wear of studied materials

3. Summary

B avoids C absorption and decreases O_2 amount in the material, but increases N amount.

NB formation in grain boundaries causes material decohesion.

Boron addition changes wear mechanism of materials, turning from mainly erosive wear to abrasive wear, except for 316L+1.5%B steel sintered at 1230ºC in which it is erosive.

NB presence increases wear since it acts as a third body.

Boron additions in these proportions do not impede the stainlessness loss of the steel when sintering takes place under rich nitrogen atmospheres

4. References

1. M. Selecka, A. Salak and H. Danninger: J. Mater. Proc. Tech. Vol. 141 (2003), p. 379.
2. A. Molinari, C. Menapace, J. Kazior and T. Pieczonka: Metal Powder Report Vol. 57 (2002), p. 39.
3..L. Cardamone, J. Liu, T. Potter and R. German: Adv. Powder Metall. & Particulate Mater. Vol. 7 (1999), p. 13.
4. A. Molinari, T. Pieczonka, J. Kazior, S. Gialanella and G. Straffelini: Metall. Mater. Trans. A Vol. 31 (2000), p. 1497.
5. M. Selecka, A. Salak, H. Danninger and L. Parilak, in: *Proceedings of 2000 Powder Metallurgy World Congress*, edited by EPMA, Shrewsbury, UK (2000), p. 16.
6. R. Tandon and R. M. German: Int. J Powder Metall. Vol. 34 (1998), p. 40.
7. F. Velasco, W.M. Lima, N. Antón and J. Abenojar: Tribol. Int. Vol. 36 (2003), p. 547.