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Study of microestructure and tempered martensite embrittlement in AISI 15B41 steel

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Abstract

In this paper we show that the evolution of the microstructure due to heat treatment for hardening and tempering of a commercial IRAM - IAS 15B41 boron steel, equivalent to AISI 15B41, is consistent with the mechanical behavior of materials and associated fracture mechanisms. The 15B41 steel alloy contains elements that influence the martensitic transformation. Such influence allows the formation of a needle shaped martensite whose thin slats and global shape close together. Such quenching microstructure leads to the precipitation of very fine carbides at low tempering conditions, which are very close together. On the other hand, at high tempering conditions the precipitated carbides are significantly larger and are not coherent with the iron matrix. These microstructures highlight the tensile strength of tempered steel, but also cause a noticeable loss of notch toughness when tempering around 350°C, which weakens the steel's impact resistance.

*Keywords: steel; tempered martensite embrittlement; microstructure; carbide precipitation;

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1. Introduction

The phenomenon of temper embrittlement of a martensite phase in steels is linked to effects of composition and microstructure. In particular, when tempering during one or two hours this phenomenon is called Tempered Masrtensite Embrittlement (TME) and is characterized by a drop in the impact toughness after tempering in a range of temperatures from 250°C to 450°C. In the current work it is exhibited as the heat treatment, quenching and tempering, modifying the microstructure of AISI 15B41 and therefore its mechanical behavior. The results show that tempering produces the recovery of the ferric matrix. Annihilates the abundant substructure called "forest dislocations" present in the martensite by quenching effect and causes segregation of carbon atoms from interstitial sites of the crystal cell. These atoms would leave the interstices stacked around the crystal lattice defections or would precipitate as carbides. When the annealing temperature is high enough these carbides grow and become incoherent precipitating with the iron matrix.

The variation of hardness, yield stress and impact toughness as a function of tempering temperature shows that the 15B41 steel responds to the classic mode of the TME, Briant and Banerji, 1978 or Lescano et al., 1995.

This study shows that the boron is not a remedy for this embrittlement and chemical composition of this steel leads to an acicular martensitic structure with very thin slats. This fact influences the precipitation of carbides due to tempering, and therefore the mechanical behavior of the material.

2. Material and experimental procedure

We used a commercial steel AISI 15B41, provided by the firm SCANIA ARGENTINA S. A. Its chemical composition is reproduced below in Table 1.

Table 1: The chemical composition of AISI 15B41 studied.

Alloying element	C	Mn	Si	Ti	B	N	Cr	S	P	Al
Weight percent	0.42	1.37	0.26	0.04	40ppm	72ppm	0.39	0.030	0.023	0.030

Squared-section pieces of a AISI 15B41 steel normalized bar (10 mm. wide by 55 mm long) were fragmented.

Such pieces were subjected to the following heat treatment protecting the decarburization: Austenitizing (880°C) in air during 45 minutes, quenched in oil car SAE 20W40 at room temperature (20°C) and tempering immediately for 1 hour in normal atmosphere at different temperatures. Chosen tempering temperatures were 100°C, 200°C, 250°C, 300°C, 350°C, 400°C, 450°C, 500°C and 550°C.

From the given material, heat-treated specimens were prepared for conventional mechanical tests. Each test was performed three times verifying the similarity of the values obtained and recording the average values. The mechanical tests were performed at room temperature under the premises of CIMM - INTI Cordoba: impact (Charpy - V) of hardness (Rockwell C) and traction.

After performing different heat treatments on the material, the resulting microstructure was observed under an optical microscope, with the use of metallographic techniques involving standard mechanical polishing and attack with Nital - 5%. Subsequently carbon replicas were built from some of them and were observed with a transmission electron microscope, in-INTA IFFIVE Cordoba. Finally metallographic samples were used for crystallographic study.

3. Results and discussion

3.1 Microstructure

The 15B41 Steel is among the group of low alloy and high strength. Its best properties are obtained when the steel is hardened and tempered. High strength and hardness, with a high ratio between the yield strength and fracture stress as well as good ductility properties, toughness and fatigue resistance. Boron in small quantities has a marked effect on the hardenability and in many cases can replace the conventional alloy (which must be added to a greater extent with a much higher cost).

Martensite observed by light microscopy is typical of steels with 0.4% carbon. It was acicular (composed of slats) with the presence of somes plaques. In the photographs that make up Figure 1 shows how the typical appearance of the quenching martensite is lost due to tempering. The acicular shape forming zigzag groups at 60°, typical of quenching martensite, fade and disappear completely from the tempering of 300°C. Etching reveals that these contrasts pass globular appearance. A salient fact is that from the 250ºC - 300°C the change is radical, showing the recovery of the iron matrix.

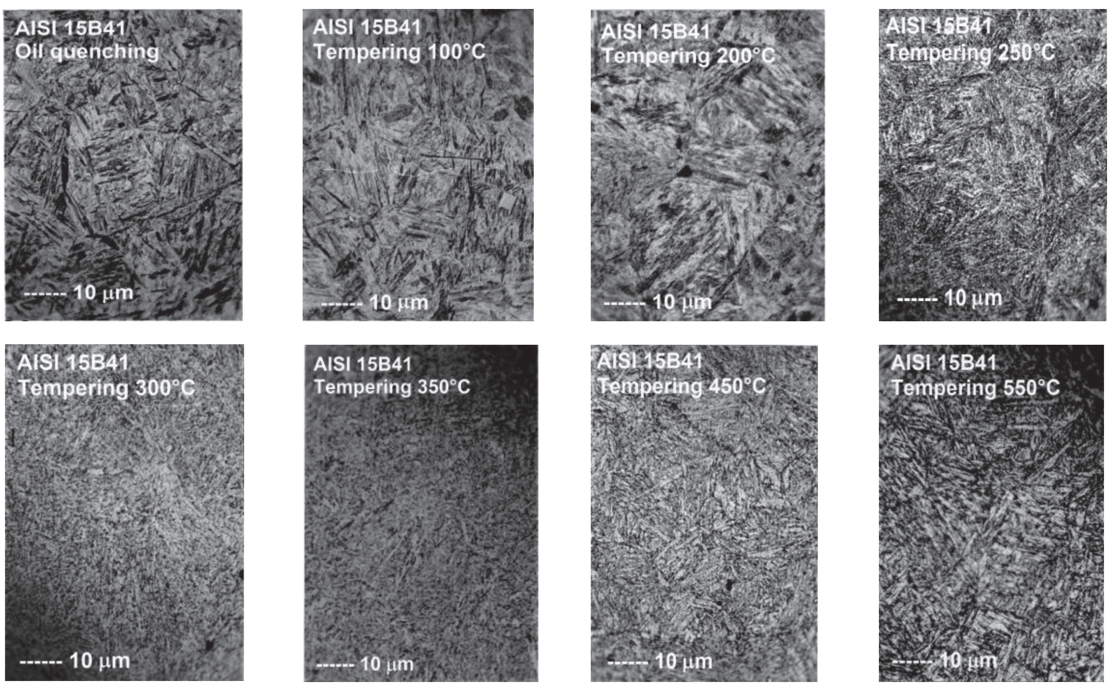


Figure 1: Microstructure of 15B41 steel austenitizing at 880°C for 1 hour in air, oil quenching and tempering for 1 hour at 100°C, 200°C, 250°C, 300°C, 350°C, 450°C and 550°C.

Martensite slats contain a tangled dislocation substructure that fits into microscopic cells of an average width of 2.500 Å with typical density of 0.3 to 0.9 x 1012 cm/cm3, Speich and Swan, 1965. Tempering heat treatment causes the destruction of these dislocations, and therefore the recovery of the ferric matrix. Furthermore, causes the precipitation of carbides.

3.2 Mechanical testing

Figure 2 shows the variation of the hardness, yield stress and notch toughness depending on the tempering temperature. Both yield stress and hardness decreases monotonically with increasing annealing temperature. Not so with the notch toughness. The curve shows a minimum between 300°C and 400°C, which is the characteristics TME trough. This result shows that boron addition is not a remedy for TME in this steel.

During the testing of Charpy-V impact, which severely restricts the plasticity, the crack can spread rapidly and appear brittle fracture modes. This situation is even more severe for the tempering of 250°C - 400°C, since for them particles are the shaped needles and the matrix is hardened yet.

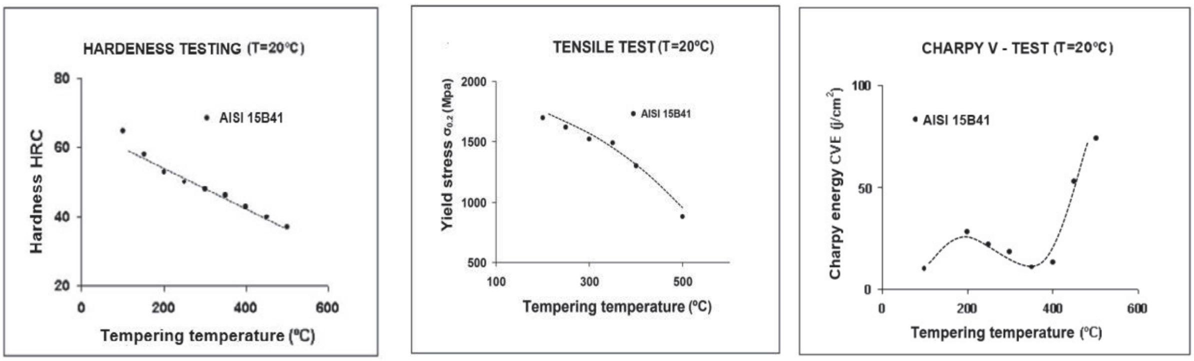


Figure 2: Hardness, yield strength and notch toughness versus tempering temperature for AISI 15B41 steel.

3.3 X-ray diffaction and observations of carbon replicas using electron microscopy

The crystallographic study conducted determined that the family of planes {200} type undergoes compressive deformation for the components of Miller index (200) and (020) and tensile deformation for the component (002). Assuming no preferred orientation of crystals, the interplanar distance, measured by X-ray diffraction, corresponds to an average value which will display a deviation by compression with respect to the same family of planes of the iron. As shown in Figure 3, the heat treatment effectively produces a variation of the interplanar distance coincident with those predicted. This can be attributed to the deformation of the crystal lattice caused by the carbon in solution. Furthermore, from the tempering temperature of 300°C, is remarkable change in the interplanar distance between the quenched martensite and tempered martensite, which indicates that from this tempering the carbon atoms in solution are very few. On the other hand, the study was not sensitive enough to detect retained austenite.

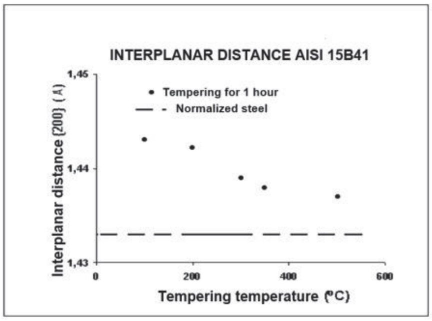
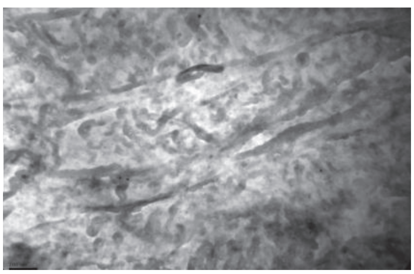


Figure 3: Variation of {200} interplanar distance with the tempering temperature

The study by Krauss, 1983, shows that for steels with composition (wt%) 0.4% C, a fine dispersion of carbides ε precipitated during the first stage of tempering, and between 250°C and 700°C cementite precipitates. Tempering temperatures between 250°C to 400°C the Fe3C precipitates in the form of needles of both the interior and in its edge slat. For temperatures above 400°C these particles are enlarged and rounded. These results are consistent with the appearance of the replicas of the microstructure of 15B41 steel. Replication allows some particles to extract and copy to your background details of the microstructure. Figure 4 (a) shows a replica of a bar of quenched martensite. It can be seen at the bottom of the reply, the tracks due to a large number of defects. In Figure 4 (b) shows the replica of the microstructure corresponding to the tempering of 200°C. It reaches to notice the precipitation of very small particles, many of them associated with the traces of the defects mentioned above. Figures 5a, 5b and 5c show the distribution of cementite precipitated by tempering 300°C, 350°C and 450°C respectively. Clearly the growth and thickening of the precipitates rises as the tempering temperature.

(a)



(b)

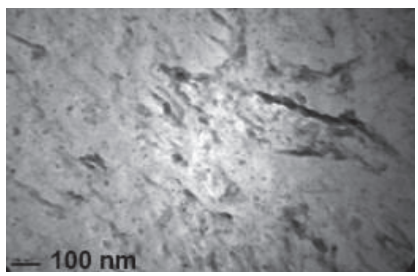


Figure 4: (a) replica of the microstructure of hardened steel AISI 15B41. 80000x. and (b) replica of the microstructure of AISI 15B41 steel hardened and tempered at 200°C. 80000x.

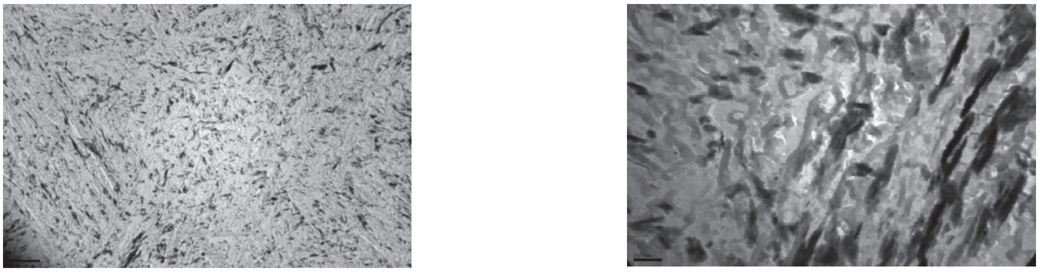


Figure 5a: Replica of the microstructure of AISI 15B41 steel hardened and tempered at 300°C. 10000x and 80000x.

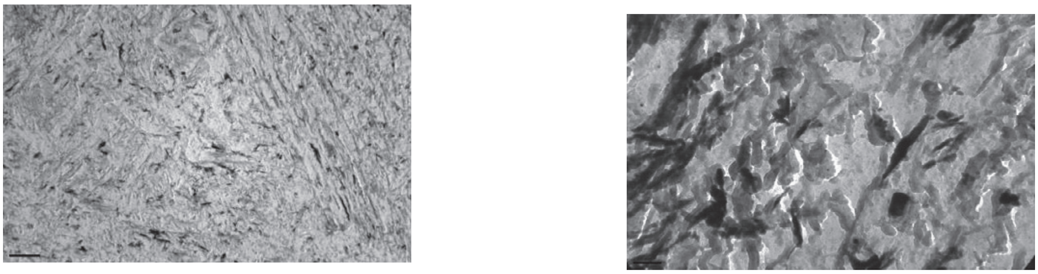


Figure 5b: Replica of the microstructure of AISI 15B41 steel hardened and tempered at 350 ° C. 10000x and 80000x.

Figure 5c: Replica of the microstructure of AISI 15B41 steel hardened and tempered at 450 ° C. 10000x and 80000x.

The martensite laths are very fine and close together. The precipitated particles grow with increasing annealing temperature, and it is evident that the "bottom" of the replica is smoother for the tempering of 450°C to 300°C. This allows that for the tempering temperature of 300°C the substructure of dislocations is still important. Also, for this temperature tempering has occurred carbon ejection from the interstitium crystal cell, as indicated by the study of X-ray diffraction.

As published in 1995 by Lescano et al., the different fracture modes of these materials are related with the variation of impact toughness due to tempering. Nevertheless, intergranular fractures become noticeable only in the TME trough. Between 200°C and 300°C the drop in the absorbed energy is associated with the transgranular brittle mechanism of fracture (quasi-cleavage).

For propagation of cleavage in steels Smith, 1966, and Almond, Timbres and Embury, 1969, show that the fracture stress σF is inversely proportional to film thickness of cementite, directly proportional to the ferrite grain size, taken as the stacking length of the dislocations which presses the carbide and influenced by the friction that gives the crystalline cell.

The removal of particles by replication is incomplete and not suitable for measuring the distribution and size. Probably the particles may have a thickness of less than 10 nm to the tempering temperature of 200°C, grown to 50 nm to the tempering temperature of 300°C and above 80 nm from the tempering temperature of 350°C. On the other hand the width of the slats is about 200 to 500 nm.

The observations show that for the tempering temperature from 200°C to 350°C the matrix is hardened. Under the conditions of Charpy-V the high speed of deformation prevents a substantial plastic deformation of the specimen, except that the softening is large. Therefore the fine dispersion of carbides present in the tempering temperature of 200°C is favorable to the toughness of the material, whereas for the tempering temperature of 300°C and 350°C carbides have grown to a critical size in thickness. This size is equal to the critical crack size necessary for the rapid propagation of the fracture through the prior austenite grain or the edge weakened by impurities. For tempering from 450°C the particles are rounded and have ferrite recovery. Then the fracture will occur by growth and coalescence of microvoids.

4. Conclusions

The AISI 15B41 steel presents the classic mode of TME. The addition of Boron is not a remedy for TME in 15B41 steel. The steel chemical composition leads to an acicular martensite structure with thin slats and close together. These very narrow slats influence the distribution of carbide precipitates due to tempering, and therefore the mechanical behavior of the material.

References

Almond, E. A., Timbres, D.H. and Embury, J.D., 1969, Proc. 2nd Int. Conf. on Fracture, Ed. P.L.Pratt, London, Chapman and Hall, p266.

Briant, C.L. and Banerji, S.K., 1978, “Intergranular Failure in Steel: The Role of Grain Boundary Composition”, Int. Met. Rev. 4, p164.

Krauss, G., 1983, Proc. Conf. Phase Transformations in Ferrous Alloys, The Metall. Society of AIME, Philadelphia, p101.

Lescano, D., Mancini, R., and Lanzillotto, C., 1995, “Evaluation of tempered martensite embrittlement in AISI 15B41 steel”, Journal of Materials Science Letters, 14, p1241.

Smith, E., 1966, Proc. Conf. Physical Basis of Yield and Fracture, Inst. of Physics and Physical Soc. Oxford, p36.

Speich, G.R. and Swan, P.R., 1965, “Yield strength and transformation substructure of quenched Iron-Nickel alloys”, J.Iron Steel Inst., 203, p480.