

## **Effect of different tempering stages and temperatures on microstructure, tenacity and hardness of vacuum sintered HSS AISI T15**

E. P. R. Lima<sup>1</sup>, M. D. M. das Neves<sup>1</sup>, R. A. Nogueira<sup>1</sup>, L. G. C. de Oliveira<sup>1</sup>, F. Ambrozio Filho<sup>1</sup>.

<sup>1</sup>IPEN-CNEN/SP – Instituto de Pesquisas Energéticas e Nucleares  
Av. Prof. Lineu Prestes nº. 2242, Cidade Universitária, Butantã, São Paulo – SP – Brazil CEP:  
05508-000. E-mail: [emmanuel@epri.com.br](mailto:emmanuel@epri.com.br)

**Keywords:** Powder metallurgy, High speed steels, AISI T15, Heat treatment.

**Abstract.** The purpose of this study is to evaluate the effect of the stages and tempering temperatures on microstructure, tenacity and hardness of the vacuum sintered high speed steel AISI T15. The material was uniaxial pressing at 700 MPa and sintered in a vacuum furnace at 1275°C. After that, different samples of the materials were submitted to the annealing treatment at 870°C, quenching at 1235°C and tempering (single, double and triple) at 540, 550 and 560°C. Concluded the treatments, Rockwell C measurements of hardness were accomplished and, to evaluate the toughness of the material, TRS (Transverse Rupture Strength) tests were done. Later on, the materials were submitted to the metallographic preparation for microstructure analysis in optical microscopy, SEM, EDX and X-ray diffraction. Finally, each property analyzed was evaluated and correlated with the different tempering stages and temperatures accomplished.

### **INTRODUCTION**

The high speed steels receive this denomination due to its capacity to retain high hardness (1000 HV or 65-70 HRC) even if used at the high speed cutting of materials [1]. Another important characteristic of these steels is the capacity to maintain high hardness if submitted a temperature up to 600°C [2]. The microstructure of these materials is composed basically of primary carbides whose main function is to supply protection against abrasive wear and a tempered martensite matrix reinforced by carbides finely dispersed [3]. For containing a high carbon content besides tungsten, vanadium and cobalt, the AISI T15 high speed steel presents an excellent abrasion resistance and a high hot hardness [4].

The AISI T15 high speed steels are usually produced by powder metallurgy techniques. Among the production methods that use this technology, the two more used are: HIP and liquid phase sintering. The first uses high steel powders atomized with inert gas isostatically hot pressed, at temperature and pressure of 1100°C and 100 MPa respectively [5]. In the second technique, the powders are water atomized and uniaxially or isostatically pressed and then sintered under vacuum or protective atmosphere at temperatures of  $1260 \pm 15^\circ\text{C}$ , where occurs the formation of liquid phase [6], favoring, therefore, the mechanisms of diffusion, dissolution and re-precipitation [4].

The sintered steels are thermally treated same as the steels obtained by casting, molding and forming, that means, quenching followed by tempering. The sintered steels tend to answer more quickly and with better previsibility at the heat treatments, due to its more refined and uniform microstructure. In the heat treatments, independently of the processing sequences occur the processes: carbides dissolution, proeutectoid carbides precipitation, transformation of the austenite in martensite and carbides precipitation in martensite.

In this work are evaluate the effects of the stages and tempering temperatures on microstructure, tenacity and hardness of vacuum sintered high speed steel AISI T15.

## MATERIALS AND METHODS

The high speed steel AISI T15 powder water atomized was supplied by Coldstream Inc. and characterized by X- ray diffraction (XRD). The chemical composition of the high speed steel AISI T15 is shown in table 1.

Table 1. Chemical composition of high speed steel AISI T15 powder [wt. %].

Elements	C	W	Co	V	Cr	Mo	Si	Fe
AISI T15	1,59	12,08	4,95	4,91	4,05	0,82	0,28	Bal.

The samples of high speed steel powder were uniaxially cold pressed in metallic matrix at a pressure of approximately 700 MPa. After the pressing, green density measures of the material were done. Soon after, the pressed materials were vacuum sintered with liquid phase, at a temperature of 1275°C ( $\pm 3^\circ\text{C}$ ) for one hour.

Concluded the sintering, density measures of the material were accomplished. Later on, the samples were submitted to the annealing treatment at 870°C for one hour. Finally, distinct samples of the material were air-quenched at 1235°C and submitted to different tempering treatments: single and double at 550°C and triple at 540, 550 and 560°C for one hour. All heat treatments were accomplished in salt bath. Finished the treatments, samples of the materials were milled for determination of hardness Rockwell C (10 measures in each sample) and bend strength in agreement to the ASTM B 528-76 standard specifications.

Finally, the materials were submitted to metallographic preparation (sanding, polishing with diamond paste 1  $\mu\text{m}$  and chemical etching with 4% Picral solution) for accomplishment of the microstructural analysis at SEM and optical microscopy, besides EDX microanalysis. The average grain size, amount and diameter of the carbides were determined by examining micrographs using the “Quantikov” digital analysis method.

## RESULTS AND DISCUSSION

The densities obtained for the pressed samples before and after the sintering presented values of  $6,19 \pm 0,08 \text{ g/cm}^3$  and  $8,07 \pm 0,05 \text{ g/cm}^3$ , that means, 75,21% and 98,06% of the high speed steel AISI T15 theoretical density, respectively.

The XRD pattern of the high speed steel powder shown in fig. 1, indicates that the studied material consists of a ferrite matrix ( $\alpha$ ) with  $\text{M}_6\text{C}$  (rich in W) and MC (rich in V or W) type carbides [7]. It is also possible to observe at the same figure the XRD patterns of the high speed steel quenched at 1235°C and tempered (single and triple) at 550°C. The growth and enlarging of some diffraction peaks, mainly those that corresponds of the MC type carbides, can be justified by the precipitation of these carbides that occurs between 400 and 570°C, mainly during the tempering treatments [8].

The fig. 2 shows micrographs (SEM and optical microscopy) of the high speed steel AISI T15 quenched at 1235°C and single tempered at 550°C, containing MC e  $\text{M}_6\text{C}$  type carbides in a tempered martensite matrix. It is possible to observe in fig. 2a the presence of the eutectic  $\text{M}_6\text{C}$  type carbide (white) in the grain boundary, what indicates the formation of the liquid phase during the sintering. The carbides identification was accomplished by EDX microanalysis.

In samples submitted to the double tempering at 550°C, we can observe that practically there was not alteration in the grain size when compared to the previous case (fig. 3b). However, there is a slight increase of the amount and average size of the carbides (fig. 3a). In figs. 3 and 2, we can observe a great size and morphology dispersion of the carbides, as well as, a larger amount of MC type carbides due to its low solubility during the austenitizing process [1].

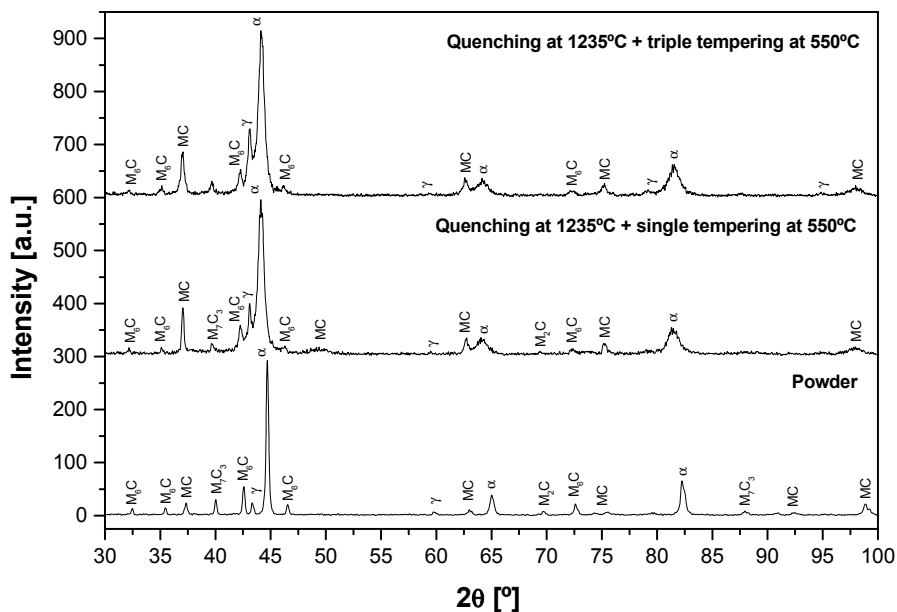


Fig. 1. XRD patterns of HSS AISI T15 samples: powder, vacuum sintered at 1275°C, quenched at 1235°C and tempered (single and triple) at 550°C.

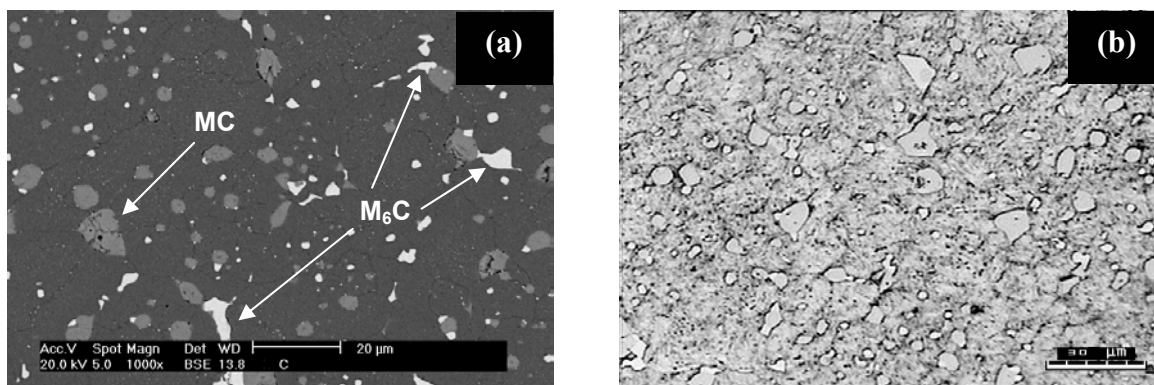


Fig. 2. SEM (a) and optical microscopy (b) micrographs of HSS AISI T15 samples quenched at 1235°C and single tempered at 550°C.

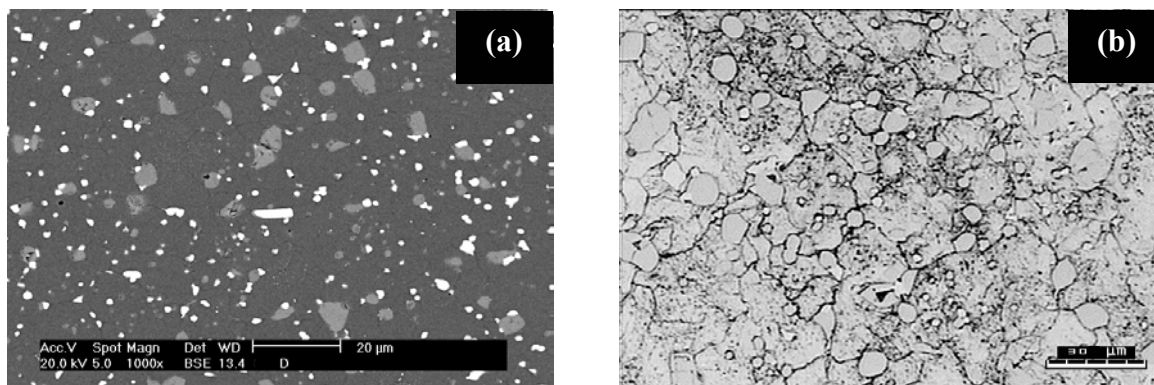


Fig. 3. SEM (a) and optical microscopy (b) micrographs of HSS AISI T15 samples quenched at 1235°C and double tempered at 550°C.

We can observe in fig. 4b a reasonable increase in the grain size, as well as, a soft increase in the size dispersion of the carbides (fig. 4a), what indicates that have had dissolution of some carbides and re-precipitation of others finely distributed at the matrix.

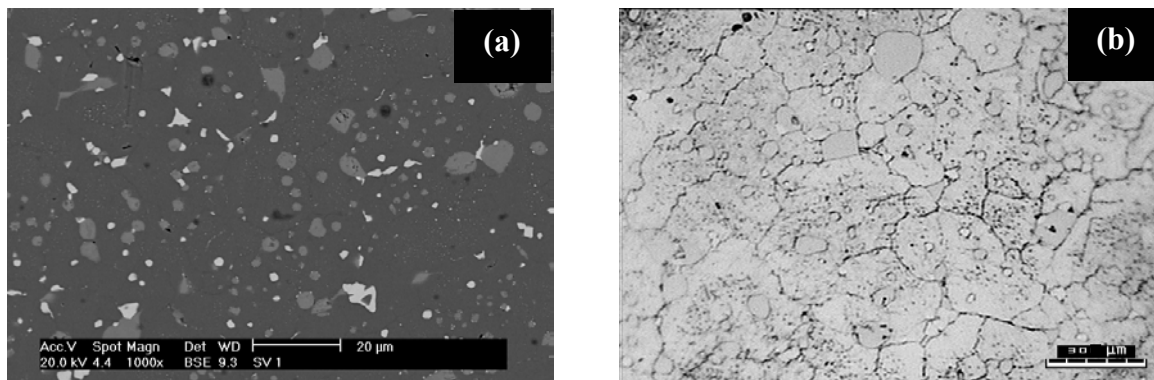


Fig. 4. SEM (a) and optical microscopy (b) micrographs of HSS AISI T15 samples quenched at 1235°C and triple tempered at 550°C.

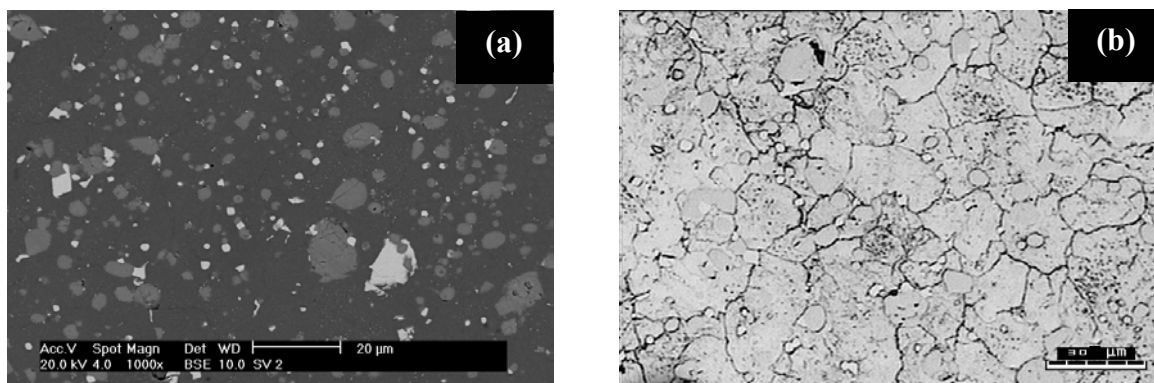


Fig. 5. SEM (a) and optical microscopy (b) micrographs of HSS AISI T15 samples quenched at 1235°C and triple tempered at 540°C.

Due to the tempering lower temperature, samples tempered at 540°C shown a smaller grain size (fig. 5b) than the treated at 550°C (triple tempering). Besides we can observe in fig. 5a that the amount and size of the gray carbides is very larger than the  $M_6C$  (white) type carbides. That can occurs because of the low solubility of the MC type carbides allied to the smallest diffusion in tempering, due to the lowest temperature, increasing even more the difficulty of the carbides dissolution and re-precipitation.

In the samples treated at 560°C (triple tempering), an increase is verified in the grain size and in the amount of  $M_6C$  (white) type carbides, shown in fig. 6. Can be observed, also, that there is a more uniform carbides distribution at the matrix (mainly MC type carbides), besides the smallest dispersion in the carbides size. However, in a general way, the  $M_6C$  type carbides are mainly located in the grain boundary zone.

The results of the measures of the average grain size, diameter and amount carbides are shown in table 2.

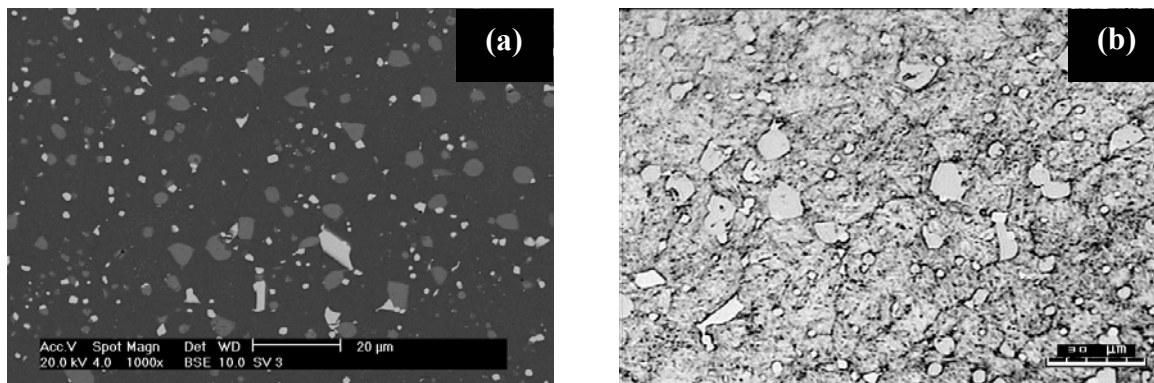


Fig. 6. SEM (a) and optical microscopy (b) micrographs of HSS AISI T15 samples quenched at 1235°C and triple tempered at 560°C.

Table 2. Average grain size, diameter and amount of M<sub>6</sub>C and MC type carbides in high speed steel AISI T15 after tempering heat treatment.

Tempering	Grain size [μm]	M <sub>6</sub> C [%]	MC [%]	Φ Carbides [μm]
Single at 550°C	23,176 ± 3,398	2,93	8,13	1,27 ± 0,66
Double at 550°C	26,918 ± 4,148	3,03	11,75	1,28 ± 0,55
Triple at 550°C	38,811 ± 4,444	3,22	12,65	1,03 ± 0,54
Triple at 540°C	31,048 ± 5,202	3,84	18,00	1,19 ± 0,67
Triple at 560°C	44,372 ± 6,443	3,93	11,76	1,09 ± 0,54

Several authors [3,9] regard the bend strength as an indication of the material tenacity, it means that, as larger is the value of this property, larger is the material tenacity. As, in most of cases, the hardness is inversely proportional to the tenacity, as larger is the material hardness, smaller is the bend strength. The mechanical properties results evaluated in this work, Rockwell C (HRc) hardness and bend strength (TRS), are shown in fig. 7.

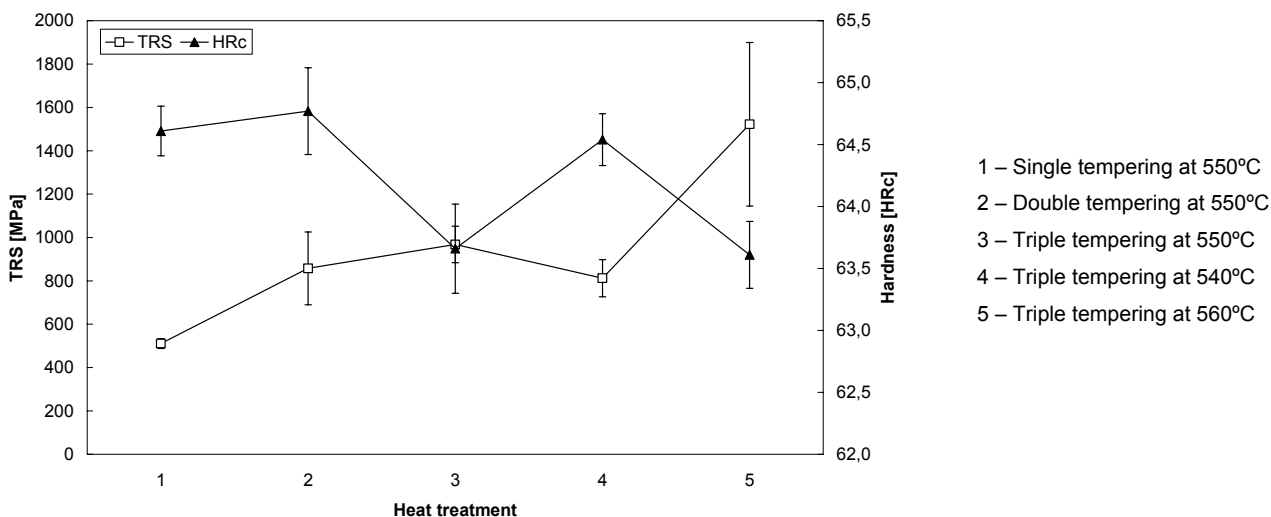


Fig. 7. Graph of the mechanical properties (TRS and Rockwell C hardness) in function of the heat treatments.

From the graph in fig. 7, we can observe that the samples treated at 550°C shown a increasing of the bend strength as increases the tempering stages (single, double and triple). Analyzing the material hardness, we verify that from the first to the second tempering there is a soft increase of this property, which could be related with the  $M_2C$  e  $MC$  type carbides precipitation finely dispersed. This precipitation is responsible for the secondary hardening peak in the high speed steels [8]. However, the value of this property decreases softly in the third tempering, at 550°C. Comparing the results of the samples submitted to the triple tempering (540, 550 and 560°), we observe that as larger is the tempering temperature, larger is the bend strength (TRS) and smaller is the hardness (fig. 7).

## CONCLUSIONS

1. The increase of tempering temperature (triple tempering condition) increases average grain size and decreases hardness;
2. The increase of tempering stages, at same temperature, increases average grain size and amount of  $M_6C$  and  $MC$  type carbides;
3. The increase of tempering temperature (triple tempering condition) and tempering stages, at same temperature, increases the tenacity of the material;
4. The low values of the bend strength (TRS) found in this study can be justified by the high grain size found, in all analyzed conditions.

## REFERENCES

- [1] Hoyle, G., 1988. Butterworth & Co, London.
- [2] Roberts, G. A. and Cary, R. A., 1980. Metals Park: ASM, 4 ed., pp. 627-772.
- [3] Kar, P. K.; Saha, B. P.; Upadhyaya, G. S., 1993. The International Journal of Powder Metallurgy, Vol. 29, n° 2, pp. 139-148.
- [4] Igharo, M., Brewin, P. and Wood, J., 1990. World Conference on Powder Metallurgy, Vol. 1, pp. 266-271.
- [5] Hellmann, P., *et al*, 1971. In H. H. Hausner ed. Modern Developments in Powder Metall, Vol. 4, A, pp. 573-582.
- [6] Bee, J. V., *et al*, 1988. MPR, pp. 170-190.
- [7] Brewin, P. R. *et al*, 1989. Powder Metallurgy, Vol. 32, N° 4, pp. 285-290.
- [8] ASM Metals Handbook, 1991. Heat treating, Vol. 4, pp. 734-760.
- [9] Martins, I. M., Santos, M., Oliveira, M. M. and Carvilhos, H., 1988. Modern Developments in Powder Metall, Vol. 19, pp. 5-20.