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Evaluation of Mechanical Properties and Microstructure of a High Carbon-vanadium Tool Steel Produced by Powder Metallurgy

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Abstract

Tool steels have important participation in the worldwide market of steels. They are used by metal-mechanical industry as cutting tools, molds, punches, etc. Because the use is of great responsibility, it is important to discuss the relationship between microstructure and mechanical properties. The starting material was powder of a commercial tool steel with the composition (wt%) 2.5%C, 5.25%Cr, 0.9%Si, 9.75%V, 0.5Mn, 1.3%Mo and balance Fe. The samples were obtained by hot isostatic pressing (hip) process, and than were austenitizing at 1120°C and submitted to tempering in the temperature range varying from 430° to 550°C. The aim of this work was to evaluate the correlation between heat treatment, microstructure and mechanical properties. Results of toughness and hardness are presented.

1. Introduction

Tool steels are widely used for punches and dies for metal forming. During industrial process the contact between the tool and the work material, especially the surface of the tool is submitted to high stresses that can result in failure. Inclusions and carbide particles [1], and surface defects [2] are known to nucleate fatigue cracks.

Ingot casting followed by hot working is the conventional route to produce tool steels. The alloying elements present in the steel tend to segregate and to form a network of carbides during solidification. So, the ingot has a heterogeneous structure. In powder metallurgy method the melt is rapidly solidified in the atomization process. The powder is hot isostatic pressed, and the material is more homogeneous, fine grained and the carbides are smaller and better distributed than these obtained by casting [2, 3]. For this reason powder metallurgy is considered a great advance in production of tool steels that are used after had been submitted to a sequence of heat treatments: austenitizing, quenching and tempering. The properties of this material are highly dependent on heat treatment. The carbon content of this steel is closely controlled for the formation of the wear resistant carbides and to achieve sufficient matrix hardness [4].

The most relevant microstructural elements present in tool steels are primary carbides, annealed carbides that were not dissolved during austenitizing and the tempering austenite embedding carbides that are frequently coherent with the matrix. Because martensitic structures are brittle, tempering is fundamental to recover a more toughness structure [5].

It is a common practice in industry to specify heat treatments based mainly in the final hardness of the material. Nevertheless for the same value of hardness steel can present differences in plastic flow, tensile strength, fatigue resistance, depending on the heat treatment cycle applied. Thus the selection of the heat treatment is a relevant technological aspect in the performance of tool steels.

The aim of this work was to correlate microstructures, mechanical properties and heat treatments of high carbon-vanadium tool steel for cold work application and to determine the heat treatment able to promote the best relationship hardness-toughness.

2. Experimental Procedure

The starting material was a commercial tool steel powder with the composition (wt%) 2.5%C, 5.25%Cr, 0.9%Si, 9.75%V, 0.5Mn, 1.3%Mo and balance Fe, obtained by X-ray fluorescence. The samples were produced by hot isostatic pressing (hip) process. The specimens for mechanical testing were austenitized at 1120°C for 8 min, quenched and than triple tempered for 2 h in the temperatures 430°, 525° and 550°C, as it can be seen in Table 1.

Table 1: Heat treatment cycles

	Temperature (°C)	Time (min)	cycles
Pre-heating	400 850	120 20	-
Austenitizing	1120	8	-
Cooling	520	16	-
Tempering	430 525 550	120 120 120	3 3 3

Samples of the as-received material, quenched and tempered were observed in optical and scanning electron microscopes (SEM) coupled with energy dispersive X-ray analysis (EDS) in order to characterize the microstructure. Nital 3 % was used to reveal the microstructure. Fracture surface of Charpy impact tests were also observed in SEM. Rockwell hardness tests were carried out to evaluate the effect of each heat treatment. At least five samples were measured for each hardening condition.

3. Results and Discussion

In Fig.1a it can be seen the microstructure of the as-received steel. It consists of a matrix of ferrite embedded with fine carbides. Figs. 1b-d show the microstructure of the steels quenched and triple tempered at 430°, 525° and 550°C respectively. The microstructure consists of tempered martensite and carbides. Optical microscopy observations of specimens submitted to hardness treatments do not show significant difference in the size and distribution of carbides.

After quenching, part of the austenite transform into martensite, and another part remains as retained austenite. Subsequently, after tempering treatments, the retained austenite transform into martensite [4], and is submitted to solid state reactions, loosing its tetragonality, and carbide precipitation occurs. The hardness and tempering resistance increase.

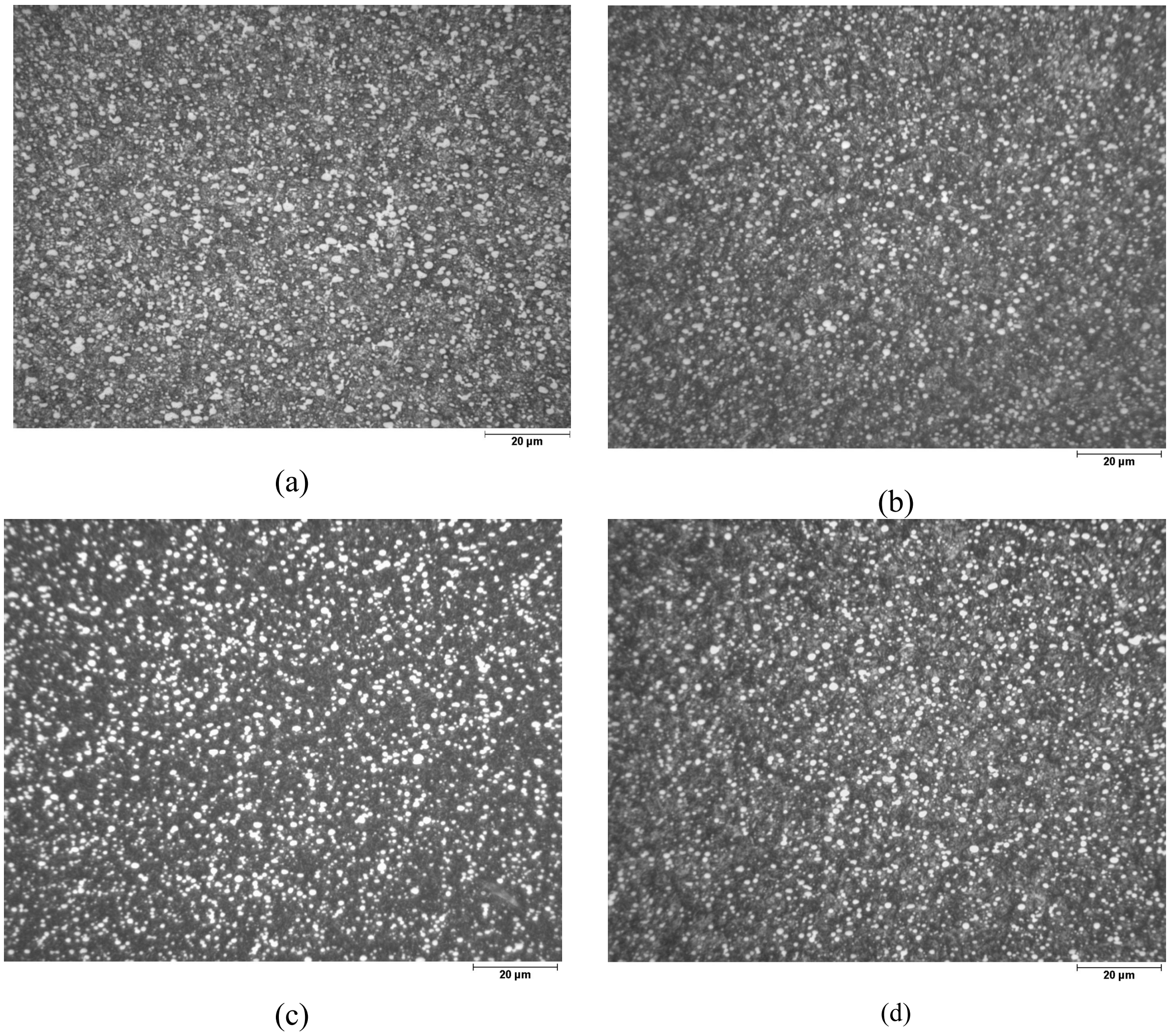
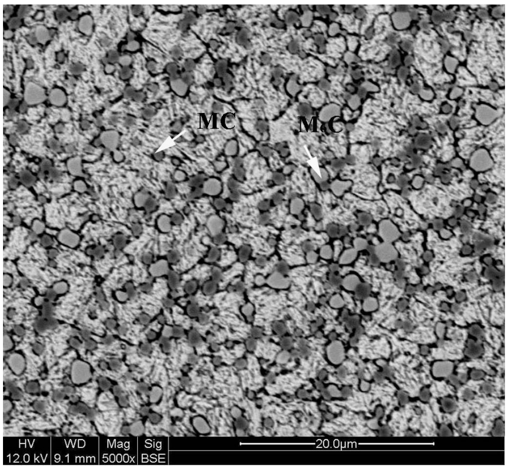
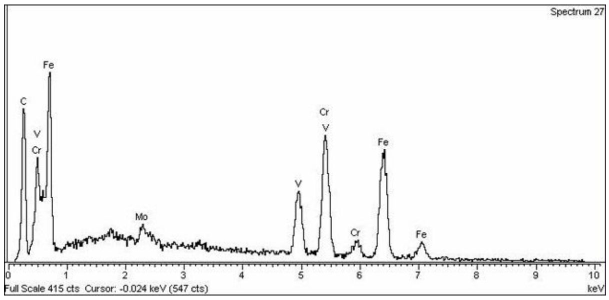


Figure 1: Longitudinal sections of tool steels. (a) as-received; (b) quenched and tempered at 430°C; (c) quenched and tempered at 525°C; (c) quenched and tempered at 550°C.

Fig 2a shows the cross-section of the steel quenched and tempered observed by SEM. EDS analysis, Figs. 2b-d, were used to identify the carbides MC and M_6C. The M_6C type carbide is predominantly rich in molybdenum but also contains chromium and vanadium. The MC type carbide corresponds almost entirely to vanadium carbide, which is extremely hard and abrasion resistant.



(a)



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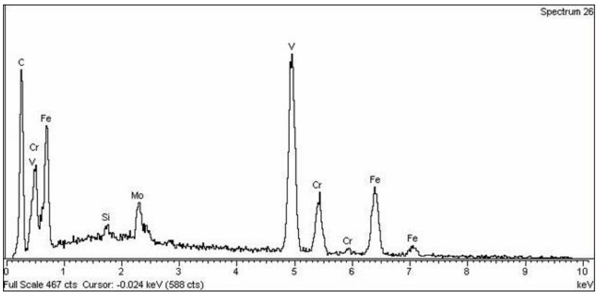

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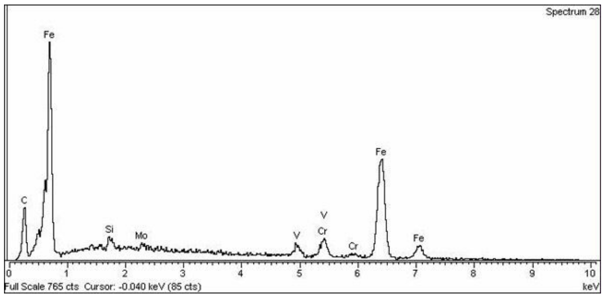
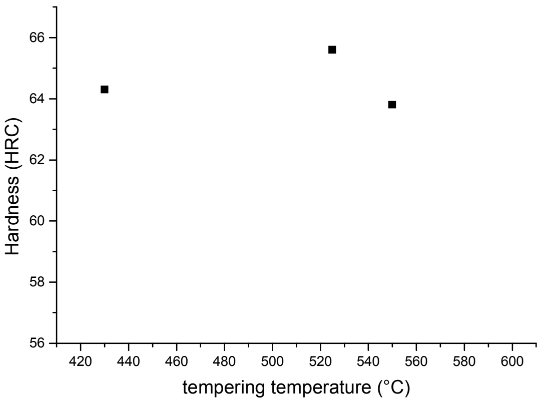
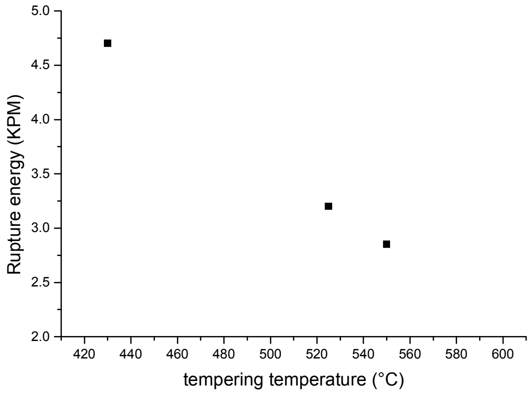


(d)

Figure 2: (a) Cross-section of the tempered steel. Etch.Nital 3%; (b) EDS of primary carbides; (c) EDS of secondary carbides; (d) EDS of the matrix.



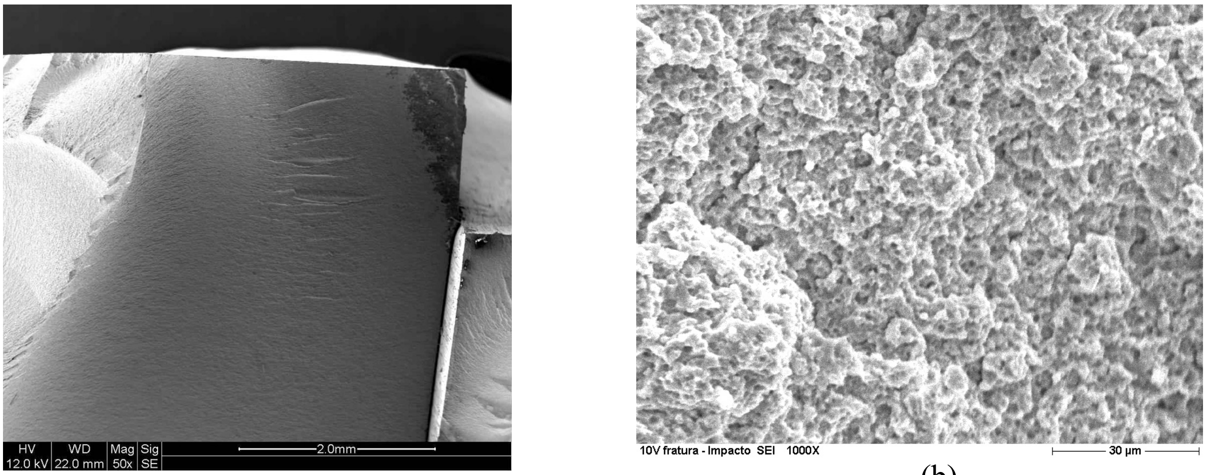
(a)



(b)

Figure 3: Effect of tempering temperature on the hardness and rupture energy of samples.

Fig. 3a shows the effect of tempering temperature on the hardness of the steel. It can be seen a secondary endurance near 525°C. The precipitation of vanadium carbides should occur in a temperature higher than that for the molybdenum rich carbides precipitation. It was also observed a softening in the temperature of 550°C, even if elements as vanadium and molybdenum were present. This behavior is probably related to austenitizing temperature/time that was not enough to completely dissolve the carbides. Fig. 3b shows the rupture energy as a function of tempering temperature. It can be seen that the higher the tempering temperature, the lower the absorbed energy in the impact test.



(a) (b)

Figure 4: Fracture surface of tool steel quenched and tempered. (a) general view; (b) higher magnification in crack region.

The exam of the fractured surface of a sample submitted to Charpy test showed brittle fracture with shell aspect typical to this class of materials quenched and tempered, as it can be seen in Fig.4. The fracture mechanism is “quasi cleavage” with specific characteristics because this material has besides the martensitic ferrous matrix, the complex carbides of high hardness and high volumetric fraction that participate of the fracture process.

4. Conclusions

1. The microstructure of tool steels quenched and tempered consists of tempered martensite and carbides. Optical microscopy observations of specimens do not show significant difference in the size and distribution of carbides.

2. It was observed a secondary endurance near 525°C tempering temperature, and a softening in the temperature of 550°C. This behavior is probably related to austenitizing temperature that was not enough to completely dissolve the carbides.

5. References

[1] T.Lund; S.A.Johansson; L.J.P. Olund, “Nucleation of fatigue in very low oxygen bearing steels. Bearing steels in the 21st century, ASTM STP (1998), p.124.
[2] F.Meurling; A. Melander; M. Tidesten; L.Westin,. **International Journal of Fatigue**. 23 (2001), p.215.
[3] O.O.Araújo Filho; F.Ambrozio Filho; M.D.M.Neves; O.C.S.Ribeiro; C.H.L.Silv,a **Materials Research**,8, 2 (2005), p.173.
[4] K.E.Pinnow; W.Stasko; J.J.Hauser; R.B.Dixon. “Properties of advanced high vanadium wear/corrosion resistant PM tool steel”. In:**New materials processes experiences for tooling**. Ed. H.Berns; M.Hofmann; L.-A.Norstrom; K.Rasche and A.-M.Schindler, 1992.
[5] W.Shizhong; Z.Jinhua; X.Liujie; L.Rui, **Materials and Design**, 27 (2006), p. 58.