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Influence of the Heat Treatment on the Microstructure of AISI T15 High Speed Steel

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Abstract: The thermal history before the final heat treatment (hardening) of high speed tool steels affect the microstructure and, consequently the final properties of the tools. The influence of quenching temperature on the mean austenite grain size and size distribution and volume fraction of the primary carbides, MC and M_6C, in AISI T15 samples prepared by hot isostatic pressing and liquid phase vacuum sintering was quantitatively investigated. The quenching temperatures were 1135, 1160, 1185, 1210 and 1235°C. The mean austenitic grain size as well as the distribution and the volume fraction of the MC and M_6C primary carbides have been determined by analyses of the scanning electron micrographs using the Quantikov quantitative method. Specimens prepared either by hot isostatic pressing or by vacuum sintering show no modification in the mean grain size for increasing quenching temperature. Similar behavior was found for the measured carbide mean size. The mean size and the volume fraction of the MC and M_6C carbides were similar for the hot isostatic pressed specimens. For the vacuum sintered specimens, on the other hand, the MC carbides present larger mean size and volume fraction, besides a larger fraction of coarse carbides (1,5-3μm). The main results show that the quenching temperature increase of the AISI T15 steel does not influence both the mean grain and carbide sizes.

Introduction

High speed steels used in the manufacture of cutting tools are iron alloys containing tungsten, molybdenum, vanadium, and chromium carbides. During their solidification, different types of carbides can be formed, and the most important ones are M_6C and MC, where M stands for metal. The presence of these carbides depends on the cooling rate and on the concentration of different elements in the steel [1]. That presence considerably affects the properties of those steels in two ways [1-4]: firstly, partial dissolution of the carbides in the matrix during austenitization affects the properties that depend on the matrix composition, like hot hardness; secondly, the carbides themselves affect the mechanical properties, especially the wear resistance.

The final (hardening) heat treatment of high speed steel tools consists of austenitization, quenching, and tempering. In this context, some important microstructural aspects such as austenite grain size, type, volume fraction, and size distribution of primary carbides require evaluation.

The quenching temperature has an effect on the austenite grain size and consequently in the tool properties [5-6]. For instance, a previous work reported that an austenite grain refinement allows a substantial tool performance improvement of the high speed M1 and M2 tools under intermittent cutting condition [5]. Effects of the austenite grain size on the performance under continuous cutting conditions were not found. A toughness increase in a T1 steel was also confirmed by Gill [7] and substantial increase in rupture strength in M2 steel with austenite grain refinement was observed by Bungardt e Mülders [8].

The thermal history before hardening treatment also affects the austenite grain size. For instance, the type of annealing treatment given to high speed steels before hardening has a profound influence on the austenite grain size after hardening. In temper annealing (sub critical annealing) the as quenched martensite or the as hot worked steel (almost transformed to martensite during cooling) is heavily aged at temperatures below the A1 temperature. In transformation annealing the steel is heated just above the austenitization temperature (A3 temperature) followed by cooling and isothermal holding at temperatures below the A1 temperature. Both processes result in the formation of carbides aggregates in a ferrite matrix [5,6,9]. Both annealing treatments can provide refined austenite grain size, but the temper annealing is more effective, probably due to the smaller size of secondary carbides [5]. It has also been observed that the austenite grain size increased proportionately by increasing the mean primary size mean primary carbide spacing [5,9].

Volume fraction, shape, size, and size distribution of primary carbides (MC and M_6C) after quenching depend on the austenitization temperature, the steel composition, and steel preparation method. In general, as the volume fraction of primary carbides increases, higher hardness will be observed, the wear behavior improved, and the toughness lowered.

Materials and Methods

Starting materials were hot isostatic pressed (commercial) and vacuum sintered AISI T15 high speed steels. This steel was received in the annealed condition, processed by slowly heating to 870°C and held for two hours, cooled to 760°C and held for 4 hours, followed by air cooling to room temperature (transformation annealing). The sintered steel was prepared by compacting water atomized T15 powders with 800MPa and sintered under vacuum at 1270°C, followed by cooling to room temperature inside the furnace. This kind of cooling after sintering provides a microstructure with carbides in a matrix of martensite and retained austenite.

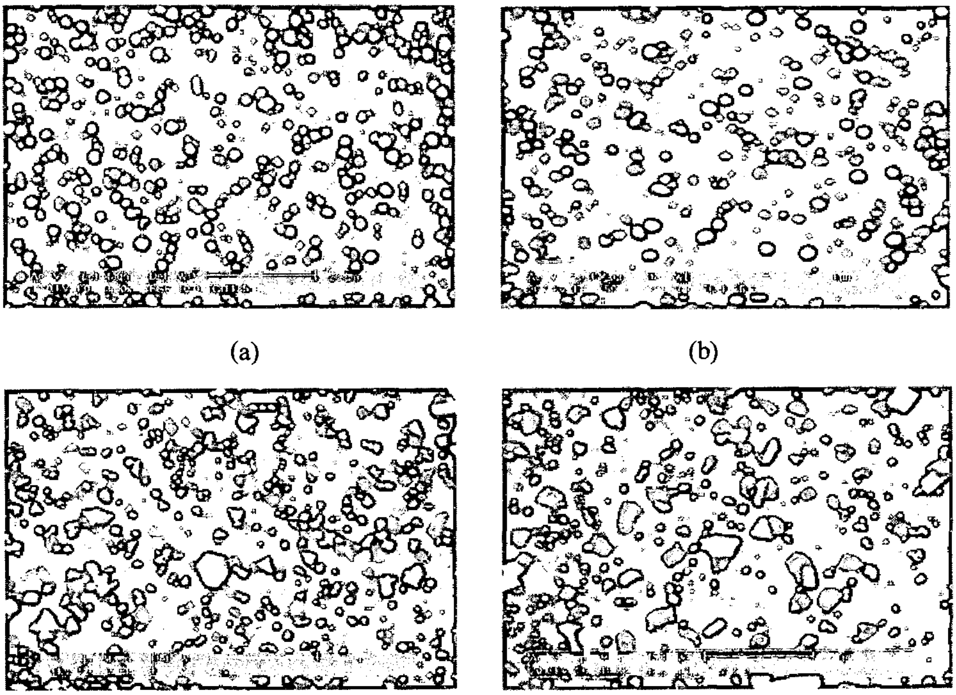
Samples with dimensions 12.7X12.7X3 mm^3 were held at 1135, 1160, 1185, 1210, and 1235°C for 2 minutes followed by air quenching.

Quenched samples were polished to 1μm diamond paste, etched in a 3% nital solution and examined at a scanning electronic microscope (magnification of 1500X).

Mean austenite grain size, volume fraction of carbides, and mean primary carbide sizes (M_6C and MC) were measured by using a quantitative digital analytical method, Quantikov [10] over the micrographs. About 200 grains were measured, corresponding to four different regions in each specimen to obtain, statistically, representative results. Four different areas were also evaluated to measure the carbide parameters.

Results and Discussion

Fig. 1 presents typical quenched of hipped and sintered T15 high speed steels microstructures observed by scanning electron microscopy (SEM). The prior austenite grain boundaries, the M_6C (white), and the MC (gray) primary carbides are revealed. The identification of MC carbides is very difficult because their color is similar to that of the matrix. The use of backscattered electron image (composition image) helped to distinguish the M_6C (white) from the MC (gray) carbides. The shapes of carbides found in the hipped steel are more round meanwhile in the sintered steel are more angular and polyhedrical.



(a) (b)

(c) (d)

Fig. 1: Scanning electron micrographs of etched AISI T15 steel samples quenched at 1135 and 1235°C: (a) and (b) hipped; (c) and (d) vacuum sintered.

Carbides

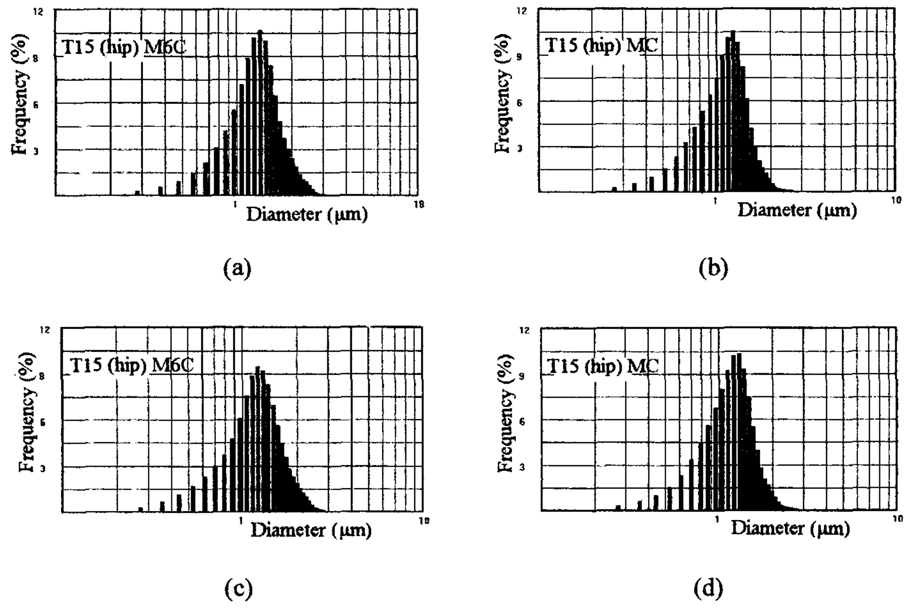
Table 1 presents the mean size and volume percentage of the carbides in quenched samples.

The amount of carbides is roughly the same at all quenching temperatures. Table 1 also shows that the hot isostatic samples have almost the same mean size and volumetric fractions of M_6C and MC carbides. The vacuum sintered samples presented MC carbides with mean size and volumetric fractions higher than the hipped samples.

Table 1: Mean size (μm) and volume percent of M_6C and MC carbides in hot isostatic pressed and vacuum sintered AISI T15 steels after quenching at different temperatures.

Quench.	Hip T15					Vacuum Sintered T15				
Temperature (°C)	M_6C (μm)	M_6C (%)	MC (μm)	MC (%)	Total (%)	M_6C (μm)	M_6C (%)	MC (μm)	MC (%)	Total (%)
1135	1.3	5.0	1.0	3.3	8.3	1.0	6.7	1.6	5.3	12.0
1160	1.2	4.7	0.9	3.9	8.6	1.0	4.7	1.3	6.8	11.5
1185	1.2	4.6	1.1	3.9	8.5	0.8	3.8	1.6	6.0	9.8
1210	1.2	3.8	1.0	4.5	8.3	0.8	4.1	1.1	4.8	8.9
1235	1.1	3.2	1.0	3.6	6.8	1.0	6.9	2.0	5.2	12.1

Fig. 2 shows the distribution histogram of M_6C and MC carbides in the hot isostatic pressed steel quenched at 1135 and 1235°C.



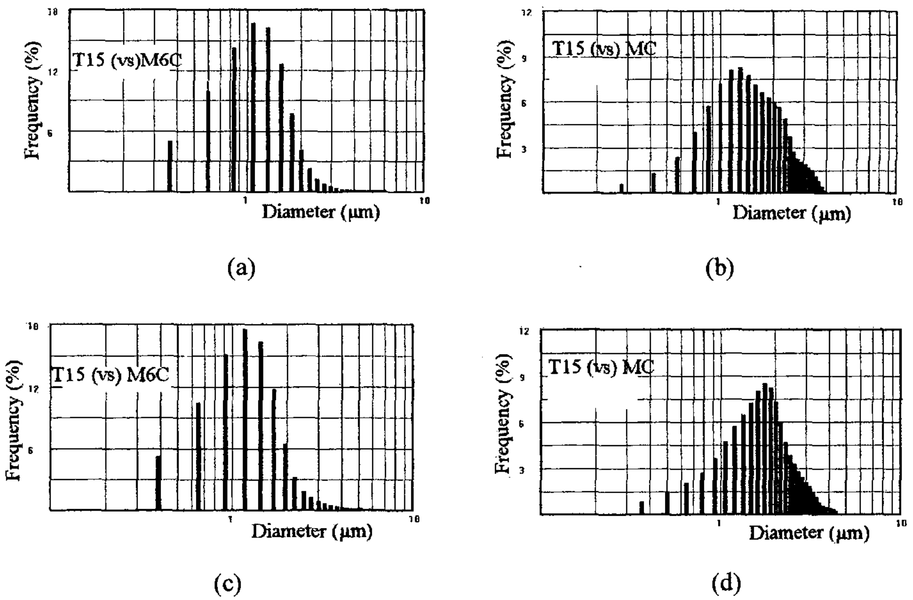
(a) (b)

(c) (d)

Fig. 2 Distribution histogram of M_6C and MC carbides in the hot isostatic pressed steel quenched at 1135 and 1235°C.

The mean sizes and the distribution curves are similar for both carbide types without any influence of increasing of tempering temperature.

Fig. 3 shows the histograms for vacuum sintered specimens



(a) (b)

(c) (d)

Fig. 3: Size distribution of M_6C and MC carbides on vacuum sintered AISI T15 steel, tempered at 1135°C (a) and (b) and, at 1235°C (c) and (d).

. It has been verified that the mean size and distribution of M_6C carbides of the T15 high speed steel are similar for both hipped and vacuum sintered samples. The results for the MC carbides show an increase of the mean size and a larger fraction of 1,5-3µm carbides.

Austenite Grain Size

Table 2 shows the mean grain size for different austenitization temperatures.

Table 2: Austenite mean grain size at different quenching temperatures for hot isostatic pressed and vacuum sintered AISI T15 steels

Quenching temperature	Grain size (µm)	
	Hip	Vac. Sint.
1135	6.0 ± 0.2	4.8 ± 0.2
1160	6.0 ± 0.4	6.0 ± 0.5
1185	5.6 ± 0.2	5.0 ± 0.3
1210	6.2 ± 0.2	6.0 ± 0.2
1235	6.6 ± 0.1	4.7 ± 0.6

The results show that the mean size of the austenitic grain of the vacuum sintered and hipped samples does not change with the increase of the quenching temperature.

Moreover the mean size of the vacuum sintered samples is smaller even if one takes into account the average mean deviation. This can be due to grain growth inhibition as a result of the enhanced number of large size carbides.

Conclusions

1) The austenitic mean grain size of both hot isostatic pressed and vacuum sintered AISI T15 steels did not increase with the increase of quenching temperature.
2) The increase in the quenching temperature did not influence the mean size and the volume fraction of the M_6C and MC carbides.
3) The M_6C and MC carbides of hipped samples showed similar mean sizes and size distributions.
4) Vacuum sintered and hipped samples presented similar M_6C carbide mean sizes and size distributions. The mean size and the volume fraction of the MC carbide were larger in the vacuum sintered samples.
5) Vacuum sintered samples showed a reasonable content of coarse carbides (1,5-3μm).

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