FRACTURE TOUGHNESS OF TOOL STEELS USING CHEVRON NOTCHED SPECIMENS

A. Villellas*, R. Ríos*, A. Martínez* and G. Campos*

Fracture toughness properties from two High Speed Steels have been measured with chevron-notched rod specimens. Fracture toughness values ranging from 10 to 15 MPa $m^{1/2}$ for the powder metallurgy steel, and from 8 to 23 MPa $m^{1/2}$ for the conventional processed steel, have been obtained for different tempering temperatures. Crack jump and smooth crack growth behaviour have been observed on fracture tests depending on the heat treatment. Microstructure of alloys has been investigated by SEM and EDX. Likewise fractography studies have shown that all specimens have fractured by a quasicleavage mechanism, sometimes related with primary carbides.

INTRODUCTION

Powder Metallurgy Tool Steels (PMTS) are now widely used due mainly to the uniform composition and to the more fine and uniform dispersion of primary and secondary carbides before and after heat treatment and the lower austenitising temperatures needed to put into solution part of the primary carbides before quenching. Hardness is the property which describes the performance of these alloys, but fracture toughness is becoming a very important parametre to control the quality of these steels. Conventional fracture toughness (K_{Ic}) tests follow the ASTM E 399-83 standard (1), and a fatigue precrack is needed to perform the test. More recently, a new standard, the ASTM E 1304-89 (2), to measure the fracture toughness with small chevron-notched samples, based on Barker work (3,4), has been developed. In this test it is not necessary to create a fatigue crack, and the fracture toughness is more simple and easy to obtain.

* Department of Ciencia de Materiales e Ingeniería Metalúrgica, Universidad de Zaragoza, Zaragoza, Aragón, Spain

EXPERIMENTAL PROCEDURE

Two high speed steels, one conventional (M2, Böhler S600) and one from powder metallurgy (Böhler S790 Isomatrix), have been investigated. Chemical compositions in the as received state of both steels are shown in Table 1. Materials were adquired in rod form.

TABLE 1 - Chemical compositions of the two high speed steels (weigth %)

Steel Type	C	Si	Mn	Cr	Mo	V	W	N	O .
S600 (M2)	0,92	0,29	0,25	3,92	4,70	1,72	6,13	-	-
S790 (PM)	1,31	0,50	0,30	4,20	5,0	3,0	6,30	0,055	0,008

The PM high speed steel samples were heated on several steps up to 1180 ºC and were held at this maximum temperature about 2 minutes. After quenching in oil, specimens were tempered three times; each tempering treatment lasting 2 hours. Several different tempering temperatures were selected: 450, 530 and 610 ºC. The conventional M2 steel samples followed the same procedure, but in this case the austenitising temperature was 1250 ºC. Three samples from each treatment were tested for the fracture toughness measurement for both steels. Fracture toughness experiments were performed on 19 mm in diametre chevron-notched rod specimens. The other specimen dimensions are related with the diametre, as indicated in the ASTM E 1304 standard. Tests were carried out on a servohydraulic Instron 8032 testing machine, with 100 kN of maximum load capacity, under stroke displacement control. Stroke velocity was 0,01 mm s^{-1} in all tests, and several unloading and reloading cycles were applied to each specimen and graphs of mouth opening versus load were recorded during the tests. From the graphical records and with the calculation procedures indicated in the standard, the fracture toughness values (K_{IvM} and K_{Iv} when it was possible) were estimated.Microstructure and fracture surfaces were analised using the Jeol JSM 6400 scanning electron microscope. Carbide identification was carried out with the Link eXL-10 energy dispersive spectroscope attached to the electron microscope.

RESULTS AND DISCUSSION

From the fracture toughness tests it has been observed that the crack growth curves are those typed "smooth crack growth", and they occur for the two steels and for all the heat treatments, with the exception of the as-quenched state for the conventional steel; in this latter case, the curve is that termed "crack jump curve". These two curve types follow different calculation procedures in order to estimate the possible fracture toughness parametres: K_{Iv}, calculated with a critical load which is not coincident with the maximum load, and K_{IvM}, calculated with the maximum load. In most part of tests, only the K_{IvM} parametre has been calculated. The other fracture toughness parametre requires certain conditions to be satisfied in the manipulation of the resultant curves, and they have not been attained (Campos and Martínez (5)). In Table 2 are shown the complete set of fracture toughness and Rockwell hardness results for the two steels and after the heat treatments. These results are the mean values of three tests.

TABLE 2 - Hardness (HRc) and Fracture Toughness (MPa √m) results

		Tempering temperature		
Property	As-quenched	450 ºC	530 ºC	610 ºC
S600 (M2)				
K_{IvM}	18,5	23,7	7,9	8,6
K_{Iv}	-	23,7*	-	-
HRc	61	57	58	60
S790 (PM)				
K_{IvM}	12,6	14,7	11,0	12,0
K_{Iv}	11,2	-	10,4**	11,0**
HRc	65	62	63,5	59,5

* Value obtained with one specimen. ** Value obtained with two specimens

With chevron-notched specimens, similar fracture toughness values have been obtained when compared with other values obtained with other fracture toughness tests. Horton and Child (6), with a conventional M2 steel, have obtained K_{Ic} values around 18 MPa √m in the as-quenched state, with a maximum toughness after tempering at 400 ºC of 21-22 MPa √m. Measurements in this case were made with the crack perpendicular to the carbide bands. At the maximum hardness level, K_{Ic} values down to 15-16 MPa √m. In this work with the M2 steel, and with the crack parallel to the carbide bands, fracture toughness values are similar to those of Horton and Child, and the drop up to 8 MPa √m due to secondary carbide precipitation is larger than in that of Horton and Child. Furthermore, in this work, when tempering at 610 ºC is not observed an increase in toughness, this increase in toughness is observed in the Horton and Child work. After tempering, the general lower level of fracture toughness of the PM steel when compared with the conventional steel, as it is observed in this work, is a consequence of the shorter inter-particle spacing in the PM steel, as Child (7) has shown with a M2 and ASP 23 (PM) steels. The results are in relative agreement with other from literature. Urrutibeaskoa *et al.* (8) have obtained values ranging between 14,1 and 19,7 MPa √m after tempering between 550 and 620 ºC for a T15 PM steel. Amador *et al.* (9) gives K_{Ic} values for a M2 type PM steel after sintering between 460 and 620 ºC of around 15,8 to 17,1 MPa √m. Microstructure was analysed with SEM-EDX and different carbide distributions were observed. Primary carbides are homogeneously dispersed in the PM steel matrix after tempering at 450 ºC, Figure 1, whereas in the conventional steel carbides are viewed as both isolated and grouped in clusters in the transverse direction, and aligned in bands in the longitudinal direction; in this latter case the dispersion is not homogeneous after the same tempering treatment, Figure 2. These figures represent the other tempered states as well. In Figures 3 and 4 are shown the different carbide types present in both steels (after 530 ºC tempering). White particles are M_6C carbides due to the high Molybdenum and Tungsten and low Vanadium contents, and the grey particles are MC carbides due to their elevated Vanadium content. These big carbides are reported in other experimental works, like that of Palma *et al.* (10). The fracture surfaces of the broken test specimens show a quasicleavage fracture mechanism. The fracture surface roughness is larger in the conventional steel than in the PM steel, as it is shown in Figures 5 and 6, after 530 ºC tempering.

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REFERENCES

(1) ASTM. Standard E 1304 - 89. 1990. ASTM, Philadelphia, USA.

(2) ASTM. Standard E 399 - 83. 1990. ASTM, Philadelphia, USA.

(3) Barker, L.M. Int.J.of Fracture, 15, No 6, 515, 1979.

(4) Barker, L.M. Development of the short rod method of Fracture Toughness measurement. TerraTek International Report, 1980.

(5) Campos, G. and Martínez, A. Internal Report, CPS Universidad de Zaragoza, Zaragoza, 1995.

(6) Horton, S.A. and Child, H.C. Metals Technology, 10, 245, 1983.

(7) Child, H.C. Heat Treatment of Metals, 2, 33, 1983.

(8) Urrutibeaskoa, I. *et al.* Private Communication, 1995.

(9) Amador, J. *et al.* Private Communication, 1995.

(10) Palma, R.H., Urrutibeaskoa, I., Martínez, V and Urcola, J.J. J. Materials Science, 27, 2026, 1992.

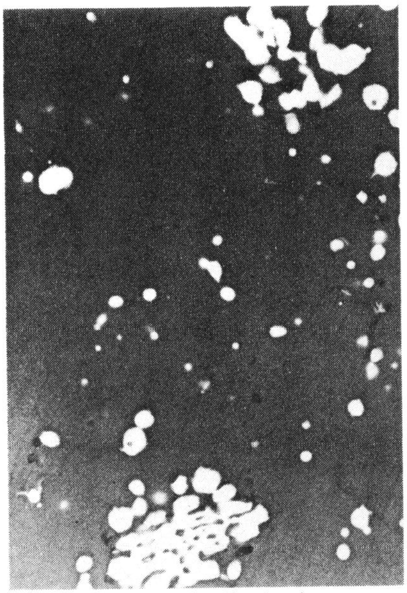

Figure 1 Carbide distribution in conv. HS Steel (x 1520)

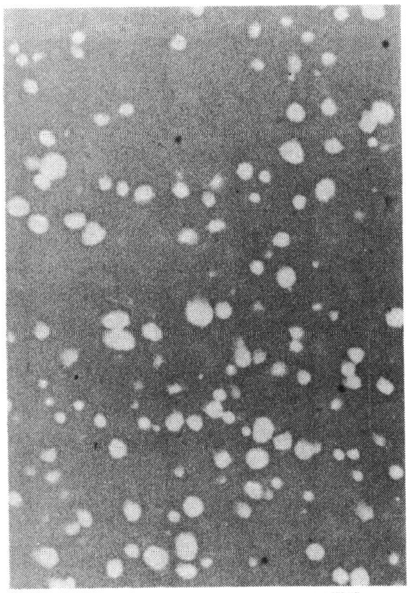

Figure 2 Carbide distribution in PM HS Steel (x 1520)

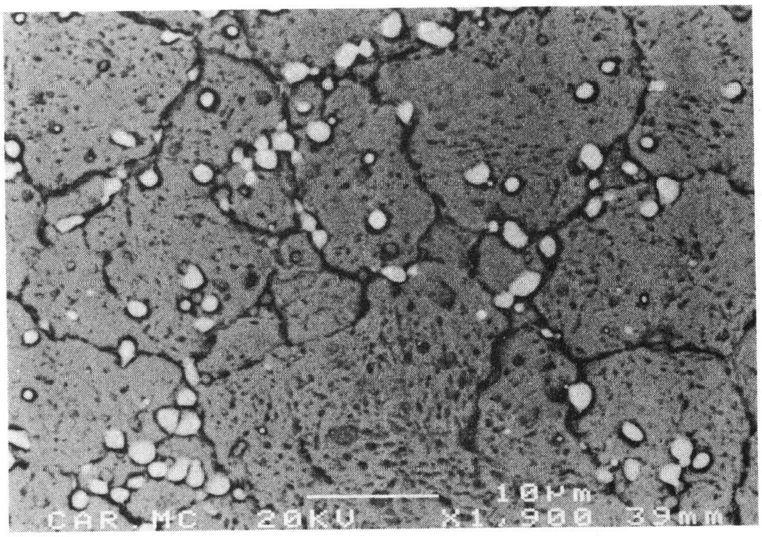

Figure 3 MC and M_6C Primary carbides in the conventional HS Steel (x 1520)

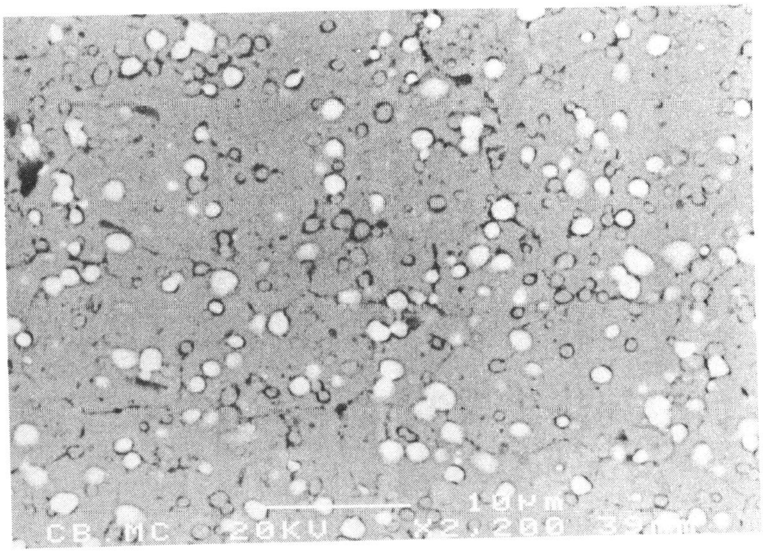

Figure 4 MC and M_6C Prymary carbides in the PM HS Steel (x 1520)

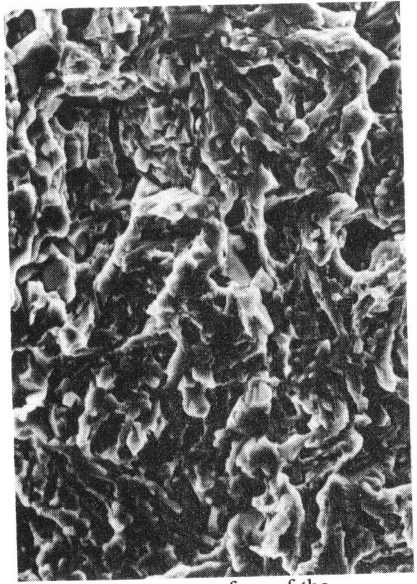

Figure 5 Fracture surface of the conv. HS Steel (x 1520)

Figure 6 Fracture surface of the PM HS Steel (x 1520)