EFFECTS OF HIGH TEMPERATURE AUSTENITIZATION ON FRACTURE TOUGHNESS OF C-Mn-B STEELS

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Measurements of fracture toughness on C-Mn-B microalloyed steels quenched from high austenitizing temperatures (950-1350°C) have been carried out using short rod and standard three point bending specimens. The values of toughness obtained for the same heat treatment with the different specimens have been very similar, ranging from 71 to 101 MPa $m^{1/2}$ for different heat treatments. Although high austenitizing temperatures result in coarse austenite grain sizes, this effect has only a negligible influence on fracture toughness. Fractographic analysis carried out on broken specimens have shown mainly transgranular fracture mechanims with quasicleavage regions close to ductile (dimpled) ones.

INTRODUCTION

Direct quenching from the finishing forging temperature (ausforging) is becoming an important process for saving energy in the production of heat treated components. However, at the high forging temperatures used, recrystallization is fast (1) and a substantial grain growth after recrystallization (2) can take place before the component is actually quenched. Although several works have shown an increase of the fracture toughness for conventional low alloy steels: AISI 3140, 4130, 4140, 4330, 4340, 300M and several BS grades, quenched from high austenitizing temperatures (3-16), results about the influence of high temperature austenitizing for C-Mn-B steels were not found in the literature, and even it was a controversy about the embrittlement effect of boron in steel (17). In the present work the influence of the high temperature of austenitizing on the strength and fracture toughness, measured using two techniques: "short rod" and three point bending, of a C-Mn-B steel is studied. Charpy tests, fractographic analysis and the evolution of inclusions with austenitizing temperature is also carried out.

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EXPERIMENTAL PROCEDURE

C-Mn-B steels were supplied by Patricio Echeverría S.A. , Legazpia, in form of hot worked strip 20mm thick, rolled from billets obtained by continuous casting. Table I shows the chemical composition of the steel. Tensile, Charpy, "short rod" (12 mm diameter and 18 mm long) and conventional three point bending fracture toughness specimens (13 mm of thickness) were machined from the strip. Short rod fracture tests, as reported by Barker (18) does not require previous precracking, and as described elsewhere (19) fracture toughness is worked out from the maximum load and specimen geometry factors. Fractographic examination was performed on fracture surfaces in a Philips 501B scanning electron microscope. As-polished specimens were used to measure the inclusion volume fraction, using point counting by optical metallography. Polished specimens after etching with nital were used for optical metallography. Austenite grain size was measured after etching the quenched specimens with a saturated solution of pricric acid in water with some drops of Teepol added. Particles inhibiting grain growth were analysed using extraction replicas, which were observed in a Philips CM12 STEM unit.

RESULTS AND DISCUSSION

Fig. 1 shows the evolution of austenite grain size as a function of the austenitising temperature. It is observed that the grain size grows in a nearly continuous form from around 30 μm at 950°C, presenting a plateau of around 50 μm between 1050 and 1100°C and reaching 140 μm at 1300°C. The small grain size found at 950°C is due to the presence of some AlN found in extraction replicas in addition to the TiN found also at this and higher temperatures. The measured grain sizes closely agree with the limiting grain sizes proposed by Gladman equation (20) for the volume fraction and size of inhibiting particles measured on specimens quenched after austenitization for diferent temperatures (21).

Fig. 2 shows a micrograph of the typical lath martensite microstructure found in this material after quenching. A small but important growth of packet size with temperature has been observed (21).

Table II summarises the 0.2% proof stress, the ultimate tensile strength and the reduction of area obtained from the tensile tests carried out on specimens quenched from different austenitizing temperatures. Fracture toughness measured using "short rod" specimens for the same heat treatments are also shown in Table II. Some results after two step quenching and quenching and tempering are also included. It is clearly

apparent from the table that in general increasing the austenitizing temperature has not a marked influence on strength, but ductility, as measured by area reduction, slightly decreases with austenitizing temperature. Long time intermediate holding on two step quenching produces also a decrease in ductility, while a significative decrease in strength and increase in ductility is observed after tempering. On the other hand, a slight, although consistent increase in fracture toughness with austenitizing temperature is observed. A decrease in fracture toughness is observed after two step quenching, being this decrease larger the longer the intermediate holding time. After one hour tempering at 200 and 350°C, fracture toughness clearly increases. On the contrary, by using higher austenitizing temperatures a decrease of Charpy absorbed energy is produced, being this effect more marked after two step quenching, as shown in Fig. 3. The improvement in K_{Ic} observed after high temperature austenitization, although modest compared with previous results (3-16), in the present case, can be atributed also to a long list of factors: a) total absence of ferrite and bainite ; b) presence of interlath austenite and c) dissolution of carbides and inclusions, among others. Points a) and b) are under investigation, but in relation to point c), it is worth emphasizing that the main inclusions are TiN particles (as shown in Table III) an due to their high stability, only a slight decrease in their content is observed. This agrees with the only slight increase in fracture toughness observed in the present case. The decrease observed also in this case on Charpy impact energy, in spite of the increase of K_{Ic}, can be explained in the way suggested by Ritchie and Horn (13) and also by Cao and Lu (22). The increase in K_{Ic} is a consequence of the increase of the distance between the void initiating particles ("characteristic distance" for ductile fracture), while the decrease in Charpy absorbed energy is associated with the reduction of critical fracture strain at high austenitizing temperatures and for long holding times in two step quenching, consistent with the observed decrease in ductility. The decrease in K_{Ic} for long holding times during two step quenching has been observed also by other authors (23) and has been attributed to the increase volume fraction of twinned martensite and segregation of impurities to grain boundaries (13).

Additional fracture toughness tests were carried out to compare the results obtained by the "short rod" procedure with the conventional notched three point bending technique proposed in the ASTM E399-83 standard. The specimens were heat treated exactely in the same manner and the results are very close when compared, as shown in Table IV.

Fractography obtained from fractured "short rod" specimens shows a transgranular fracture mechanism with the presence of quasicleavage regions (see Fig.4a) together with dimpled ductile regions (see Fig. 4b).

These fracture modes were observed also by other authors (22) in specimens quenched after high temperature austenitization. It is worth emphasising that only in a specimen austenitized at 1300°C a small region of intergranular fracture was observed.

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Table I. Chemical Analysis of the C-Mn-B steel . Weight Percent.

C	Mn	Si	S	P	Al	Ti	B	N
0.27	1.2	0.23	<0.02	<0.02	0.043	0.064	0.0027	0.0080

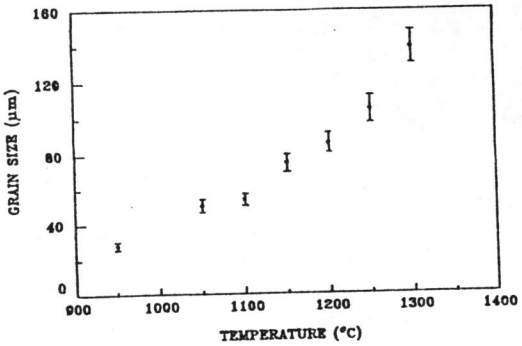

Fig. 1. Effect of austenitizing temperature on austenite grain size.

Table II. Mechanical Properties after Several Heat Treatments.

Temperature (°C)		0.2% Proof Stress (MPa)	UTS (MPa)	Area Reduction (%)	Fracture Toughness (MPa√m)
950		1390	1900	22	78
1200		1220	1790	25	84
1250		1330	1780	-	93
1300		1260	1800	18	87
1350		1270	1810	18	89
1200 + 950	1/4 h	1253	1800	23	92
	1h	1360	1870	12	79
1300 + 950	1/4 h	1440	1800	23	77
	1h	1300	1840	18	75
Q + T 1300 + 200		1250	1680	45	101
Q + T 1300+350		1160	1380	41	97
Q + T 1300 + 400		1120	1300	45	-
Q + T 1300 + 450		940	1120	48	-

Table III. Volume Fraction and Size Inclusions.

Temperature (° C)	F_v x 10^{-4} TiN	F_v x 10^{-5} SMn	Mean Size (μm)	
			TiN	SMn
950	4.7	5.9	3.4	18 x 0.6
1300	3.6	2.8	3.0	18 x 0.6

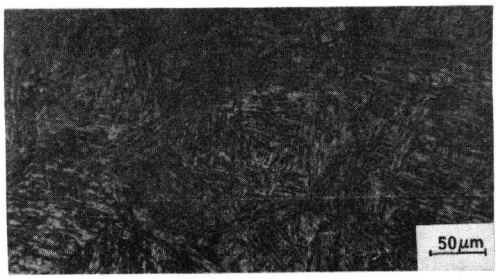

Fig. 2. Optical micrograph of lath martensite in a specimen directely quenched from 1300°C.

Table IV. Comparison of Fracture Toughness values obtained by Short Rod and Three Point Bending Techniques.

Temp. (°C)	K_{IC} (MPa$\sqrt{m}$) Short rod-Barker	K_{IC} (MPa$\sqrt{m}$) Three Point Bending
950	89	82
1100	91	90
1200	80	80

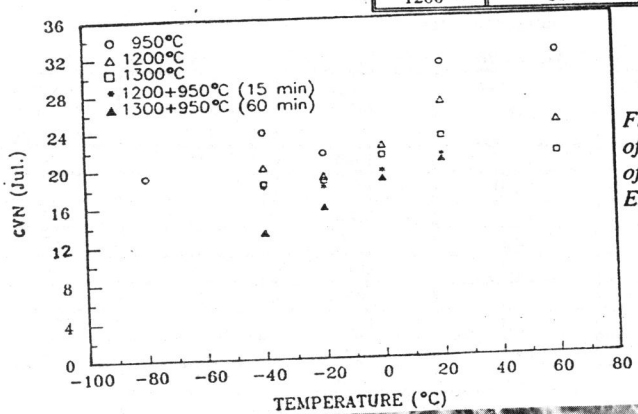

Fig. 3. Influence of heat treatement of Charpy Impact Energy Curve.

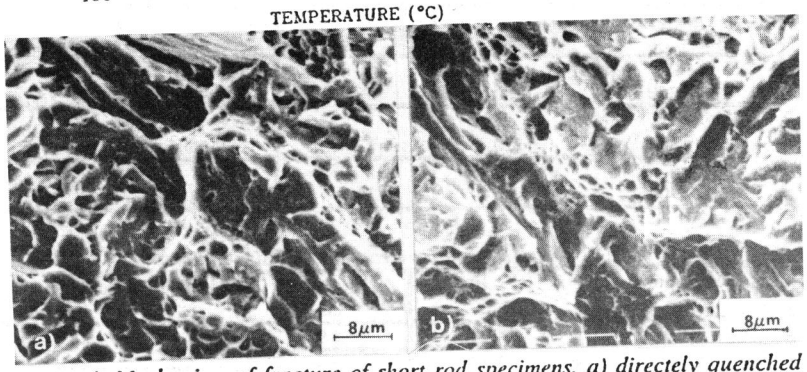

Fig. 4. Mechanism of fracture of short rod specimens. a) directely quenched from 1350°C. b) step quenched 1200°C + 950°C/15 min.