MICROSTRUCTURE CHARACTERIZATION AND IMPACT BEHAVIOR OF A LOW CARBON BAINITIC STEEL

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ABSTRACT

A microstructure composed of polygonal ferrite, granular bainite, bainitic ferrite and martensite was produced in a low carbon steel microalloyed with Nb, V, Ti and B. A controlled rolling schedule with accelerated cooling was used to reach this objective. After the thermomechanical processing the samples were submitted to three start cooling temperatures (750, 700 and 650°C) and ten cooling rates in each case (0.03, 1.3, 3.4, 7, 11, 20, 40, 60, 80, 100°C/s). In the interval of cooling rates from 1.3 to 11°C/s, the amount of MA constituent was increased. The mechanical behavior of the steel, studied through the absorbed energy in the impact test at -20°C decreased with increasing cooling rate, but they did not depend on the start cooling temperature.

INTRODUCTION

HSLA (High Strength Low Alloy) low carbon steels, with bainitic and multiphase microstructure, has been investigated by several scientific works in the last two decades. These steels are used in the naval ships construction industry and for manufacturing large diameter pipes for oil and gas transportation. Bainitic and multiphase microstructures can be produced in a large variety of HSLA low carbon steels through appropriate chemical composition and thermomechanical processing(1).

The most important variables to control accelerated cooling are the cooling rate and the start and finish cooling temperatures. The best condition of these variables depends on the chemical composition and thermomechanical processing, because the hardenability and austenitic conditioning of steel during controlled rolling can influence the microstructural evolution and the mechanical properties(2). Accelerated cooling after controlled rolling have been used to obtain grain refinement and to improve low temperature transformations products, as bainite and MA constituent(3). The MA constituent contributes with its strengthening effect to tensile strength but it impair the toughness(4).

This work has been investigated the effect of cooling rate and start cooling temperature on the microstructure, mainly the volume fraction of MA constituent, and impact energy of a HSLA low carbon bainitic steel.

EXPERIMENTAL PROCEDURE

The chemical composition of the steel investigated is indicated in table I. This steel contains 21 ppm of B and is microalloyed with Nb, Ti, V and Ni. The presence of B and the high Mn content have a strong influence to improve bainitic hardenability, causing the formation of a multiphase microstructure. This steel was developed by a national steel plant and was used as hot rolled.

Table I - Chemical composition of Nb-V-B steel investigated (weight %).

C	Mn	Si	P	S	Al	Nb	V	Ni	B	Ti	N
0.08	1.70	0.25	0.021	0.002	0.029	0.033	0.058	0.17	0.0024	0.026	0.0048

The controlled rolling process with accelerated cooling was carried out on a 500 kN laboratory mill, with 200 mm diameter rolls and rolling speed of 25 m/min. The specimens 19 mm thick slab were reheated at 1200°C for 20 minutes, rolled with four pass schedule to 9 mm gauge sheets, resulting in a total reduction of 74.7% true strain. The reductions above T_{nr} (no-recrystallization temperature) were 38% and below T_{nr} were 37%. The finish rolled temperature was 825°C.

The critical temperatures values of controlled rolling, T_{nr}, A_{r3} ($\gamma-\alpha$ transformation temperature) and B_s (bainite start transformation temperature), were experimentally determined using hot torsion tests, based on the relationship between mean flow stress and temperature and by dilatometric tests without deformation. The values determined were T_{nr} = 945°C, A_{r3} = 760°C and B_s = 638°C[5].

The rolled specimens were cooled down by an accelerated cooling system device, developed and assembled to this work. The design consisted of top and bottom double banks of spray nozzles which provided angularly directed fan shaped water sprays. The cooling conditions consisted of ten cooling rates (t_r) (0.03, 1.3, 3.4, 7, 11, 20, 40, 60, 80 and 100°C/s) and three starting cooling temperatures (T_i) (750, 700 and 650°C). These cooling rates are average values for the temperature range from 800 to 500°C and were registered in a Omega Eng. INC interface with a thermocouple embedded in the mid-width, mid-thickness of the sample.

Transverse sections from the rolled specimens were examined by optical, scanning electron, transmission electron and atomic force microscopy after careful metallographic preparation. The microstructure was revealed using nital 2% or 4% and LePera[6] etchants. The mechanical properties were evaluated from impact energy, using a Heckert machine and the temperature tests were conduct at -20°C. The data represent the mean of 3 tests for each condition.

RESULTS AND DISCUSSION

The figure 1 illustrates the final microstructure of the steel Nb-V-B obtained after controlled rolling with cooling begun in 700°C and rate of 11°C/s. The figure 1 (a) shows the microstructure composed of polygonal ferrite and granular bainite contends particles of MA constituent. In this case, the particles were revealed by the coloration of white tonality due to LePera etchants. Details of these particles can be verified in the figures 1 (b) and 1 (c). In the superior part of the figure 1 (b), these particles show equiaxed (irregular) morphology, without a preferential orientation, while in the center of the same figure the particles of MA constituent are elongated and fine, with an acicular aspect, some parallel ones to each other and with the same orientation. In agreement with the scale of the figure 1 (c), it is observed that the width of some particles of MA constituent with acicular morphology can reached 0.3μm. The figure 1 (d) illustrates a lath of ferrite of the granular bainite contends a cellular substructure of dislocations.

During the cooling from 700°C after the controlled rolling, as the rate increase from 1.3 until 11°C/s, the amount of granular bainite formed in the final microstructure increase. The carbon rejected by the ferrite diffuses for the neighboring austenite not transformed, increasing its concentration. Thus, this not transformed austenite had its hardenability increased. Therefore, as larger as the cooling rate,

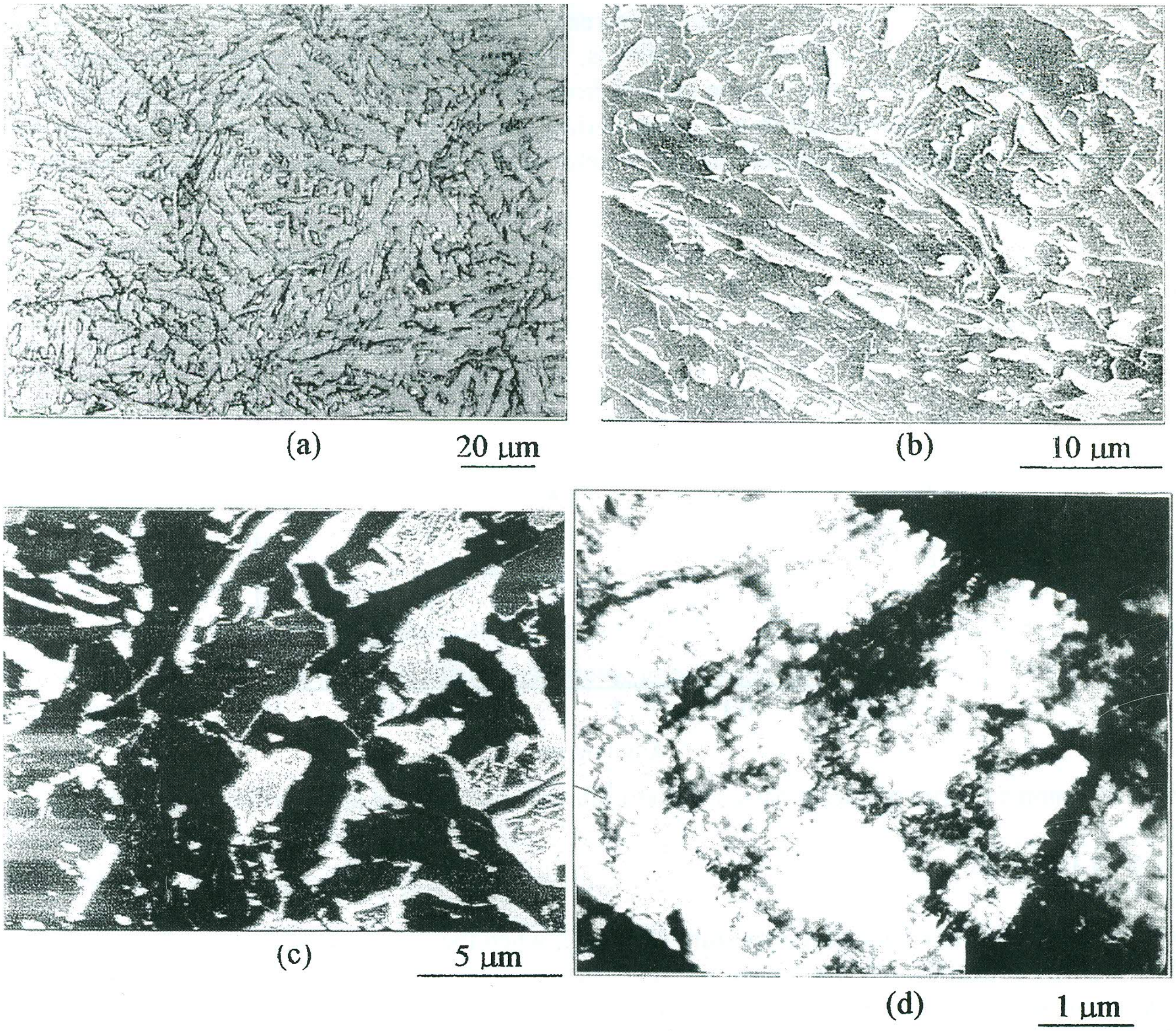

Figure 1-Microstructure of Nb-V-B steel after controlled rolling with accelerated cooling. Start cooling temperature (T_i) = 700°C and cooling rate (t_r) = 11°C/s. (a) OM, 500X, LePera. (b) SEM, 2000X, Nital 4%. (c) AFM, 4000X, Nital 2%. (d) TEM, 13400X, bright field.

smaller the available time to the transformations controlled by diffusional processes, and larger the amount of available austenite for the shear mode of phase transformation. The austenitic region with larger concentration of carbon became MA constituent. The bainite and MA constituent formed in higher rates (11°C/s) generated a high density of mobile dislocations in the ferrite. This can have been contributing to the increase in the density of free dislocations and in the total density of dislocations, promoting the formation of cells with walls contends entangled dislocations, as the figure 1 (d) illustrates. Therefore, it can be concluded that the cellular substructure of dislocations shown in the figure 1 (d) was formed during the phase transformation of austenite in granular bainite due to residual tensions.

The figure 2 shows as the rate (t_r) and the start cooling temperature (T_i) modified the toughness of the steel Nb-V-B, evaluated through the absorbed energy in the impact Charpy test at -20°C. It is observed in the figure 2 that the temperature T_i had little influence on the toughness of the steel, unlike the cooling rate. When the cooling rate increase from 0.03 up to 100°C/s, the absorbed energy decreased 70%. In the interval from 1.3 to 20°C/s, the fall of the absorbed energy with the increase of the rate was around 45%, while in the interval from 20 to 100°C/s it was smaller, close to 33%. In the first interval, the microstructure was characterized by the increasing amount of constituent MA with equiaxed morphology. This fact caused the deterioration of the toughness of the steel Nb-V-B.

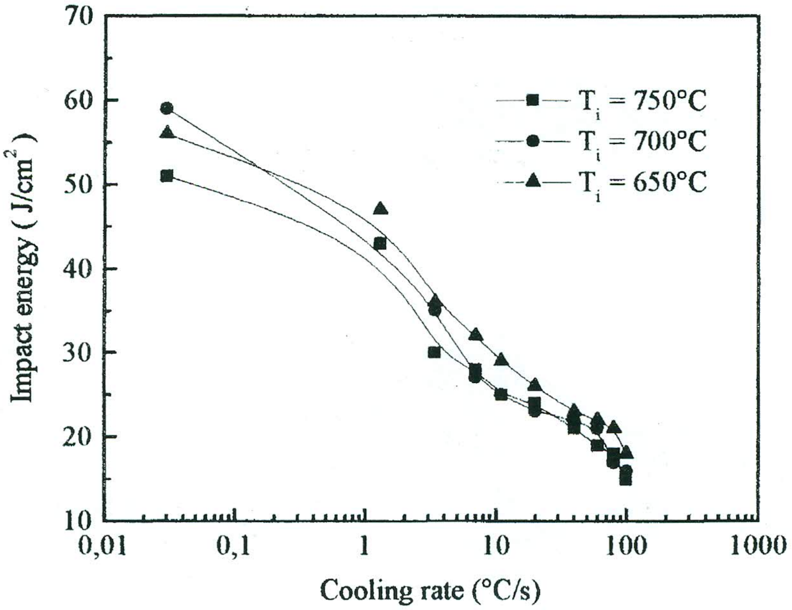

Figure 2-Impact energy of specimens cooled at different cooling rates and start cooling temperatures

CONCLUSIONS

- Considering the start cooling temperature of 700°C, when the rate increased from 1.3 up to 11°C/s the volumetric fraction of MA constituent increase. In this interval of rates, the particles of MA constituent show equiaxed (irregular) morphology.
- A cellular substructure of dislocations was identified, using transmission electron microscopy, in the final microstructure of the steel Nb-V-B processed, as a consequence of the phase transformation of the austenite in several microstructural constituents.
- The absorbed energy in the impact Charpy test at -20°C decreased with increasing cooling rate and it did not suffer influence of the start cooling temperature. However, the change in the fall of the absorbed energy was dependent of the cooling rate interval. From 1.3 to 20°C/s, due to MA constituent, the decrease in the absorbed energy was larger than from 20 to 100°C/s, although this last interval has presented the smaller values of toughness.

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