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MICROSTRUCTURE AND PROPERTY ANALYSIS OF HIGH STRENGTH ULTRA-FINE LOW CARBON BAINITIC STEEL

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Abstract. The ultra-fine acicular ferrite/bainite compound microstructures were obtained by proper chemical composition design and optimizing Thermo Mechanical Control Process technology (TMCP). The microstructure and mechanical experiments, including tensile and impacting tests, were conducted. The results indicated that the flattening and refinement of austenite grain was the main factor to the change of mechanical performance, such as impacting energy. The size of bainitic bundle less than 1 μm and the average flattening thickness of austenitic grain less than 5 μm were obtained. Meantime its tensile strength R_m was above 1000 MPa, total fracture elongation *A* is greater than 14%, and Charpy notched impact energy A_{KV} reached above 120 J at a temperature of 30 below zero (-30 °C).

1. INTRODUCTION

Nowadays high strength micro alloyed steel was required to have both high strength and good toughness to fulfill its potential application. Microscopic structure refinement can help improve these properties of strength and toughness. Obviously, the development of high strength steel over 900 Mpa needs more guarantee on toughness. Only the higher toughness control can help these high strength steel adapt to the engineering machinery and high grade pipe line environment [1-3].

By utilizing of optimized mechanical heat treatment process technique on the experimental rolling mill, the austenite grain became flatter to a considerable extent and superfine bainite lath beams were obtained under a wide range of cooling condition. This improving technology introduced by this article can make a nice match between high strength and its corresponding toughness. Meanwhile this success results have supplied technical reference for the industry to innovate its products.

2. EXPERIMENTAL MATERIALS AND METHODS

The steel, used for experiment, was smelted in a 50 kg vacuum induction furnace and then cooled in air after vacuum pouring. The ingot steel was forged into square ones. Its chemical composition via weight percentage is: C 0.039, Si 0.34, Mn 1.94, Ti 0.018, the impurity P 0.0052, S 0.0014, N 0.0080, O 0.0066, and the total amount of micro-alloying elements Ni, Cu, Mo, Nb, B is about 1.4%.

Experiments were conducted by controlled rolling and controlled cooling(CR and CC) using two-high reversing mill as shown in Fig. 1, meanwhile the industrial compression ratio is simulated and two-stage compression ratio is optimized, of which the compression ratio of non-recrystallization were 3,4,5,6,7,8. The heating temperature of square ingots in the furnace was controlled at 1230 °C for

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Table 1. Temperature control of steel rolling experiments (°C).

starting rolling at recrystallization zone	finishing temperature	fine rolling starting temperature	fine rolling finishing temperature	starting cooling temperature	finishing cooling temperature
1180-1200	1110-1130	980-1000	800-820	800-820	350-370

1.5 hours heating. The main parameters of controlled rolling and controlled cooling can be seen from Table 1. The metallographic observation was carried out under the Olympus metallographic microscope BX41M.

3. RESULT AND DISCUSSION

3.1. Microstructure analysis of CR and CC steel plates

A variety of intermediate microstructure transformations occur during the continuous cooling process for low carbon micro-alloyed steels [4,5]. The low carbon bainite steel designed in this study is of Mn-Mo-Nb-B series. Under the testing system, the microstructure change of the low-carbon bainite steel was analyzed. By comparing the experiment with the simulated continuous cooling procedure, the former interior structure is much finer with no obvious sub-structure was found in their microstructure view due to non-uniform of austenite grain flattened.

The microstructure of the longitudinal cross-section along the rolling direction was shown in Fig. 2. Its compression ratio is 8.0. Inside the longitudinal cross section there exists an obvious deformation zone, where the austenite grain gets flattened along the rolling direction and the thickness changes unevenly from several to dozen microns in range. The flatten austenite grains are mainly composed with lath bainite (LB) and a small quantity of granular bainite (GB) which were often pressed to laths. It was found that the acicular ferrite (AF) independently existed in the grains with a wide thickness which presented some needle-like structures and divided the lath structure into parts. When the squashed thickness turns smaller, these three kind structures are compressed in a very narrow space, so the photograph feathers of the three become difficult to distinguish each other.

The metallurgical microstructure on three orthogonal surfaces of steel is shown in Fig. 3. In the direction of the vertical longitudinal section paralleling to the rolling direction the original austenite grains is squashed. In the austenite grains,

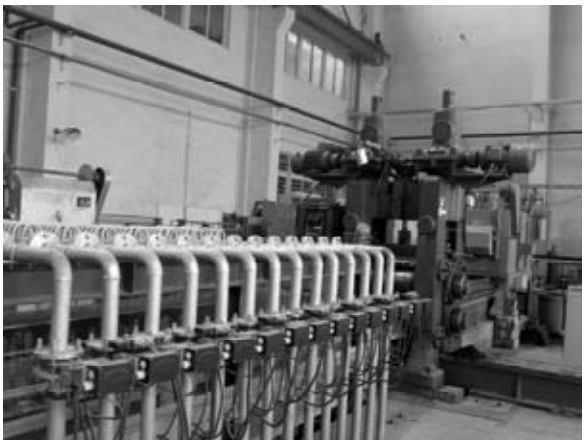

Fig. 1. Two-high reversing mill.

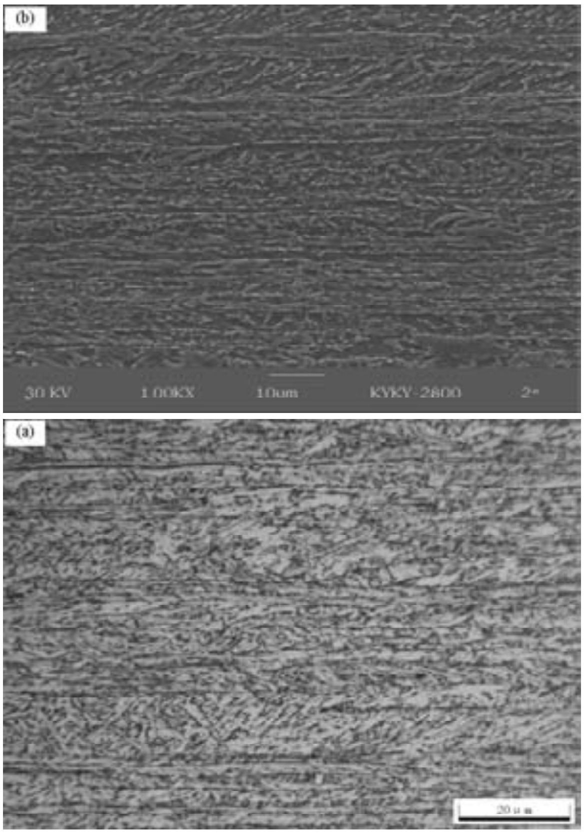

Fig. 2. Ultra-fined acicular ferrite/bainite microstructure of as rolled Mn-Mo-Nb-B steel. (a) OM, (b) SEM.

Fig. 3. Three dimension orthogonal microstructure of Mn-Mo-Nb-B low carbon bainitic steel.

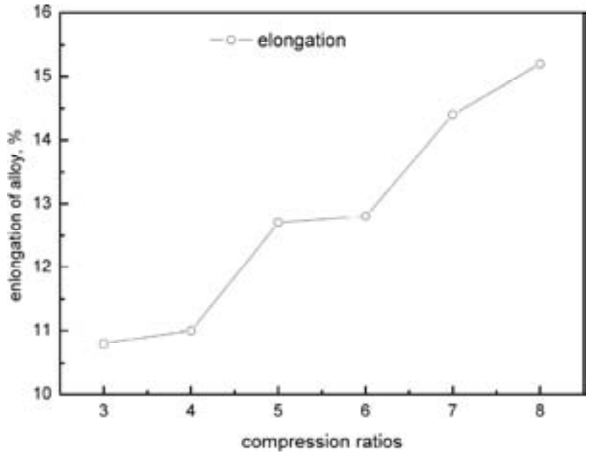

Fig. 5. Effect of compression ratios on total elongation.

there are mainly composed of lath bainite (LB) and a small amount of granular bainite (GB). Occasionally there exists acicular ferrite. The detail of rolling cross section is not very obvious, but the microstructure is consistent with that in the rolling longitudinal section. Significantly the microstructure of rolling plane is different from the other two planes, the structure presents round-pie shape of **uneven sizes,** the white base is granular bainite compressed, and the other is lath bainite.

3.2. Mechnical properties tests

The rolling reduction of non-recrystallization zone is closely related to the structure properties after rolling. The compression amount change directly presents the flattening degree of the original austenite, that is, the thickness value of flattened austenite grains. The relationship among the

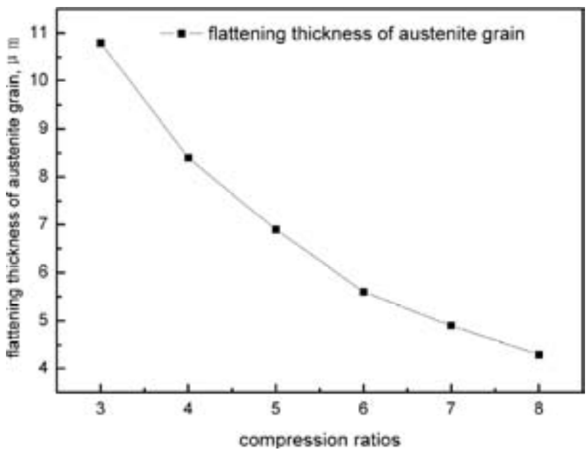

Fig. 4. Effect of compression ratios on the flattening thickness of austenite grain.

compression ratio, the flattening thickness of austenite grain and its corresponding elongation is shown in Figs. 4 and 5. From the two figures in can be seen that compression ratio play an important role in the thickness value of flattened austenite grains and its elongation.

As shown in Fig. 4, it is clear that the thickness of flattening austenite grain decreases with the compression ratio increases. From the compression ratio 3 to 8, the decreased tendency is gradually slowing down. When the compression ratio is greater than 7, the flattening thickness drops to 5 μm.

On the contrary, with the compression ratio raised, the elongation increased. When the compression ratio is 7, the reduction was increased above14%, as shown in Fig. 5.

The relationship among the flattening thickness of grain, tensile strength and impact toughness is shown in Figs. 6 and 7. Fig. 6 showed that the tensile strength presents a upward trend with the grain thickness decreasing, although they behaves some fluctuations. The temperature of impacting tests was selected the lower one, -30 °C. The change of impact energy also showed increasing tendency regularly. Under the condition of flattening thickness of austenite grain 3 μm, the charpy impacting energy is the minimize. When the flatten degree of grains is less than 5, the impact energy (-30 °C) reached above 120 J, the tensile strength stayed steady above 1000 Mpa, as shown in Fig. 7.

Compression ratio had a great effect on mechanical performance, but it was not the essential reason. The decrease of flattening degree caused by compression ratio is the main reason that the mechanical properties including the strength and toughness increases. Once the width of flatten grain reduced, the grains would became fine resulting in

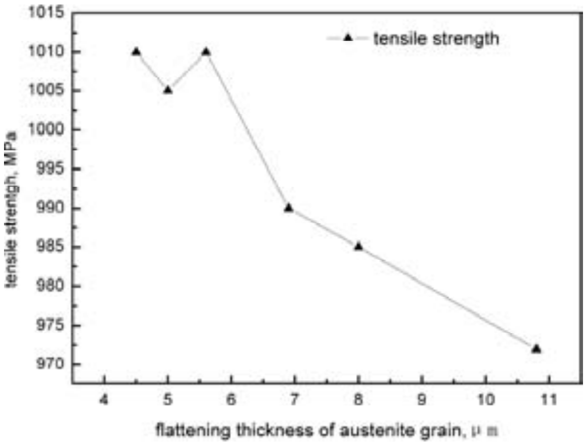

Fig. 6. Effect of flattening thickness of austenite on the tensile strength.

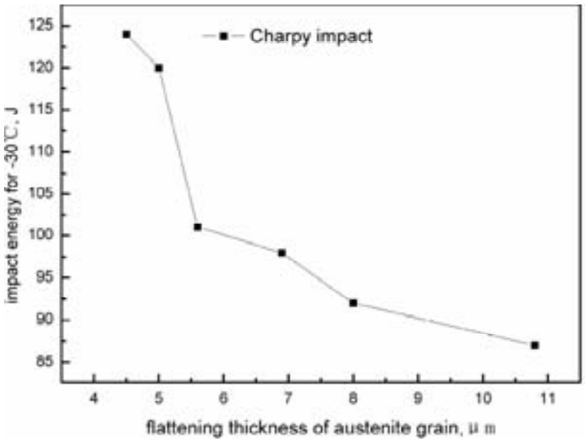

Fig. 7. Effect of flattening thickness of austenite on Charpy notched impact.

much more grain boundary. More grain boundary inhibited the movement of dislocation and caused the increasing of tensile strength.

4. CONCLUSIONS

CR and CC experiments were conducted to obtain the ultra-fine acicular ferrite/bainite compound microstructure which improved the mechanical performance. The improvement depends on compression ratio of austenite grains. Using TMCP technology with optimizing process the size of bainite bundles less than 1 μm and the average flatten thickness of austenitic grain less than 5 μm were obtained.

A comprehensive study indicated that tensile strength R_m was greater than 1000 MPa, the elongation fraction was all above 14%, Charpy notched impact toughness A_{KV} exceeded 120 J at the temperature of 30 below zero(-30 °C) condition. It is a good match between high strength and good toughness. This success can help improve the use area of high strength steel in some specific place.

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