Journal of University of Science and Technology Beijing
Vol.8(2001), No.3, p.224

A Special TMCP Used to Develop a 800MPa Grade HSLA Steel

Chengjia Shang, Xuemin Wang, Xinlai He, Shanwu Yang, Yi Yuan

Material Science and Engineering School, University of Science and Technology Beijing, Beijing, 100083, China

(Received 2000-11-10)

Abstract: The effect of relaxation after finished rolling on structures and properties of four microalloyed steel with different content of Nb and Ti was investigated. By alloy designing and control rolling + relaxation-precipitation-control phase transformation (RPC) process, a new 800 MPa grade HSLA plate steel could be obtained, the microstructure is composite ultra-fine lath bainite/martensite. The tempering process and mechanical properties of this kind of HSLA steel were investigated. The yield strength can achieve 800 MPa, and the ductility and impact toughness is satisfied.

Key words: HSLA steel; microstructure and mechanical properties; TMCP (thermomechanical control process); RPC

1 Introduction

Iron and steel materials will still be the main structural materials in the 21st century. In China, the output of crude steels is more than 100 million tons per year, but the high performance steels can not meet the requirement of domestic market. Since 1999, "New generation of iron and steel material" research project was arranged by Chinese government. One of the subject scopes is developing and investigating the metallurgical mechanism of 800 MPa grade high strength low alloy steel, the yield strength of steel will be increased from 400 to 800 MPa [1].

HSLA steel has been widely used in many areas, the superior mechanical properties and weldability are the advantages of this kind of steel. Thermomechanical control process (TMCP) has been applied in producing HSLA steel for many years. Micro-alloying (Nb,Ti, B, ect.) plays an important role during TMCP [2]. The accelerated cooling/or direct quenching is a technique which has been employed to produce high strength and toughness steels [3, 4]. In this paper, by alloy design and employ a special TMCP: two steps controlled rolling and relaxation-precipitation-control phase transformation (RPC) after final rolling, a 800 MPa grade high strength and toughness plate is obtained which has an ultra-fine composite microstructure.

2 Experimental

The composition of the steels is listed in **table 1**. The steels were melted in a 25 kg vacuum induction furnace. The ingots were soaked at 1 150 ℃ for 2 h and forged to 42 mm thick. The slabs were austenized for 2 h at 1 150 ℃ and controlled rolling (CR) to 6 mm by 5 passes (two passes in recrystallization region, three passes under no-recrystallization temperature (NCT)). The rolling schedule is listed in **table 2**. The TMCP and tempering process of steels is as follows.

Table 1 Composition of the steels (mass fraction)

%

Heat	C	Mn	Si	Nb	Ti	Mo	Ni	Cu	B
1-1	0.060	1.68	0.37	0.058	0.020	0.30	0.22	0.30	0.004 0
2-1	0.031	1.74	0.16	0.094	0.057	0.31	0.25	0.29	0.000 9
2-3	0.036	—	—	0.091	0.080	—	—	—	0.001 0
2-6	0.035	—	—	—	—	—	0.33	—	0.002 0

Note: S<0.005%, P<0.010%.

Table 2 Rolling schedule

Pass number and cooling	1	2	3	4	5	Water cooling
Final thichness / mm	23	15	11	8	6	—
Reduction / %	44	35	27	27	25	—
Rolling temperature / ℃	1 150	1 000	930	860	830	750
Waiting time between final pass and water cooling / s	—	—	—	—	—	20–40

Process (1): After two phase controlled rolling, the rolling finished at 830 ℃, the steels were relaxed (air cooled) for 20–40 s, then accelerated cooling (cooling rate more than 20 ℃/s) to room temperature. The steels were tempered at 500–710℃ for different time (i. e. CR-RPC-T).

Process (2): Controlled rolling as same as above, after final pass rolling, the steel was cooled to room temperature in air. The as-rolled plate was reheated at 930 ℃ and quenched, then tempered at 630 ℃ (RQ-T).

Tensile specimens have an original thickness of plate (cross section is about 6 mm×25 mm). The Charpy notch impact tests were done at room temperature, −20 ℃ and −40 ℃ respectively. The microstructure was observed by optical microscope (OM), scanning electron microscope (SEM) and transmission electron microscope (TEM).

3 Results and Discussion

3.1 Microstructure

The microstructure of as rolled plate of heat 2-3 steel processed following Process (1) is shown in **figure 1**.

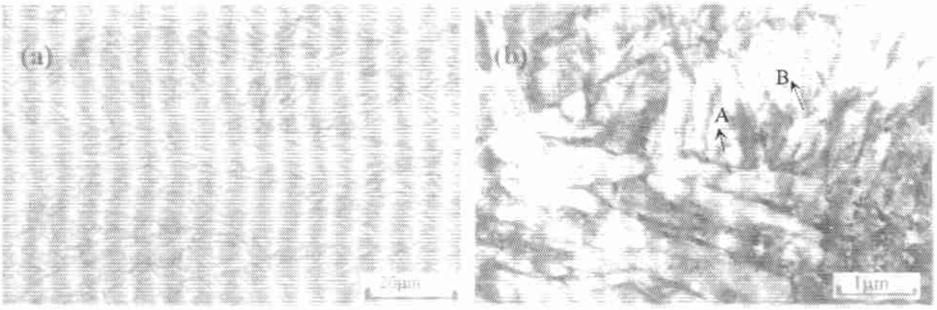

Figure 1 The as-rolled microstructures of heat 2-3 steel followed Process (1), (a) OM; (b) TEM.

Figure 1(a) shows that the prior-austensite grains are flattened/pancake like after ausforming, the microstructure is a composite structure of granular bainite, lath bainite and martensite. The deformed grain consists of several irregular packets, each packet partitioned into some parallel laths of bainite /marsensite. Figure 1(b) is a TEM photograph of the steel. It shows that, in same grain, the laths do not lay in same direction, the length of lath is about 4–6 μm, the width is about 0.3 μm. Figure 1 (b) also shows that several laths have a tendency to align themselves parallel to one another in a small region of grain. About 3 to 4 laths (0.3 μm width/lath) exhibit a block characteristic morphology (1 μm width) in optical micrograph as shown in figure 1(a). The blocks as shown in figure 1(b) by arrows A and B are separated by high angle boundaries. The fine dimension blocks and packets as shown in figure 1 will improve the mechanical properties of steel. Reference [5] has also indicated that the basic microstructural unit controlling the strength and toughness of matrix is known to be the packets and blocks, and refinement of packets and blocks will improve the mechanical properties of the steel.

Figure 2 shows the microstructure of heat 2-3 steel after tempered at 500 ℃and 690 ℃ for 3 h. It shows that after 500 ℃ tempering, the packet size is not enlarged, the laths in packet are coalesced. After tempering at 690 ℃ for 3 h, the packet size and blocks width grow obviously, but the microstructure does not change basically, it is still granular bainite and lath bainite. Figure 2(c) is the morphology of heat 2-1 steel following Process (2). After re-quenched and tempered at 630 ℃ for 2 h, the microstructure is mainly recrystallized granular bainite. The flatten grain induced by deformation under NCT has been recovered.

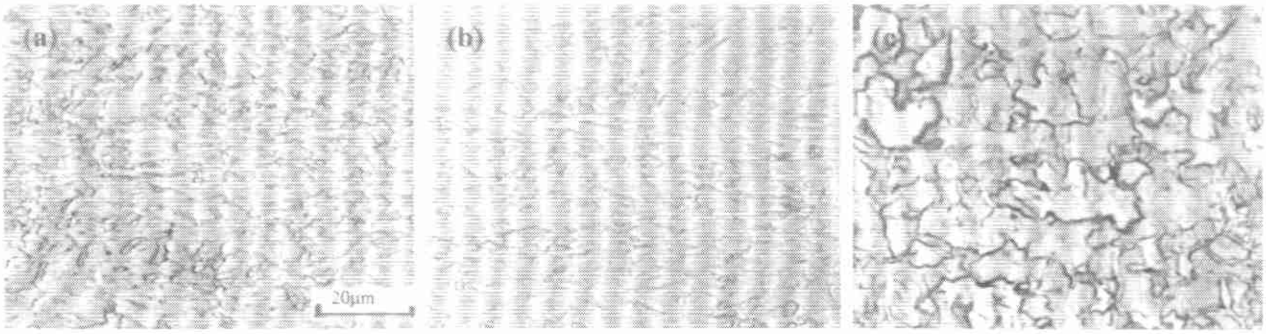

Figure 2 The microstructure of heat 2-3 steel after tempered at (a) 500 ℃; (b) 690 ℃ for 3 h and (c) 2-1steel after RQ-T treatment.

3.2 The mechanical properties

(1) The strength comparison of difference processes.

The composition of heat 2-2 steel is designed as same as heat 2-1, and they were manufactured following Process (1) and (2) respectively. **Figure 3** shows the tensile strength of these two kinds of steels after various tempering time at 630 ℃. It can be seen that the tensile strength of heat 2-1 steel after RQ-T is about 650 MPa, and the heat 2-2 steel after CR-RPC-T is more then 850 MPa. **Figure 4** shows the difference of yield strength of heat 2-1 and heat 2-3 steels, it also shows that the yield strength of RQ-T steel is about 600 MPa and RPC-T steel is about 800 MPa. These results indicate that the tensile strength and yield strength after RPC-T treatment is both about 200 MPa higher than that of RQ-T steel,the CR-RPC-T process can increase the strength about 30% comparing with RQ-T process. The yield strength of this kind of HSLA after RPC-T process can achieve more then 800 MPa.

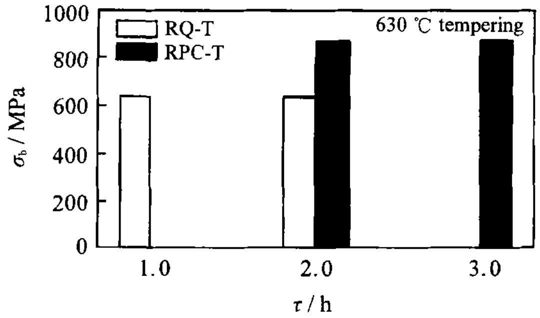

Figure 3 Tensile strength (σ_b) of RQ-T and RPC-T processed steels.

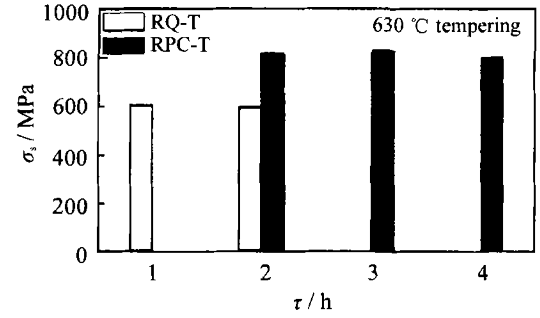

Figure 4 Comparison of yield strength (σ_s) of RQ-T and RPC-T processed steels.

(2) Tempering curve of hardness.

Figure 5 are the hardness of heat 2-2 and heat 2-3 steel tempered at different temperatures for 1 h. The difference of two steel is the content of Nb. Figure 5(a) shows that after tempered from 500 to 710 ℃, the hardness of heat 2-2 steel decreases from as-rolled state about 300 to 240 Hv, but there is a peak at the temperature range about 625 ℃. When temperature is higher than 650 ℃, the hardness decreases obviously. Figure 5(b) shows the hardness peak of heat 2-3 steel appears at 575 ℃ which is higher than that of heat 2-2 steel and moves to the left, the hardness decreases remarkably when tempering temperature is higher than 600 ℃. As the Nb content in heat 2-3 steel is higher than heat 2-2 (0.091% and 0.05% respectively), the hardening temperature is different. The difference of hardening peak perhaps is induced by precipitation at TMCP and tempering. When tempering time increases to 3 h, the hardness decreases smoothly when tempering from 500 to 625 ℃ as shown in **figure 6** for steel 2-3. When the temperature is higher than 650 ℃, the hardness drops sharply but higher than 200 Hv. The aging characteristic of heat 2-3 steel at 650 ℃ is shown in **figure 7**. When time is more than 1 h, the hardness decreased with increasing tempering time. The microstructure of RPC processed steel is stable. Unless tempering at 650 ℃ for more than 5 h, the microstructure is mainly bainite.

(3) The mechanical properties during tempering.

The mechanical properties of heat 2-3 steel change with tempering temperatures are shown in **figure 8**. It shows that after tempering at various temperatures for 1.5 h, the strength decreases while the tempering temperature is increased. When the tempering temperature is lower than 650 ℃, the yield strength is more than 800 MPa, even tempered at 675 ℃, the yield strength is more than 750 MPa. The ductility of every sample is more than 15%. **Figure 9** shows the influence of tempering time on the mechanical properties of heat 2-6

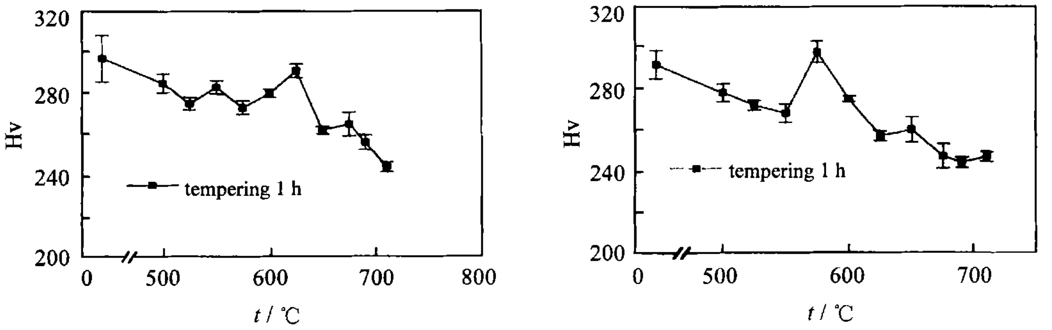

Figure 5 Hardness vs. tempering temperature of (a) 2-2 steel and (b) 2-3 steel.

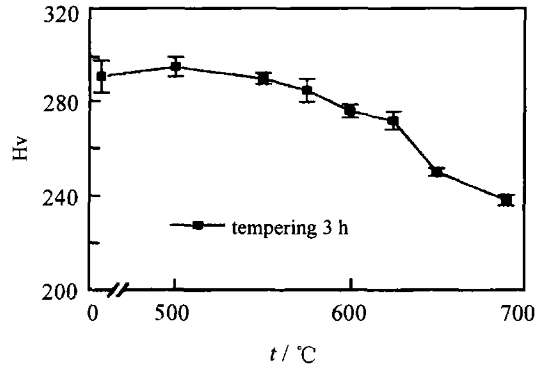

Figure 6 Hardness vs. tempering temperature of 2-3.

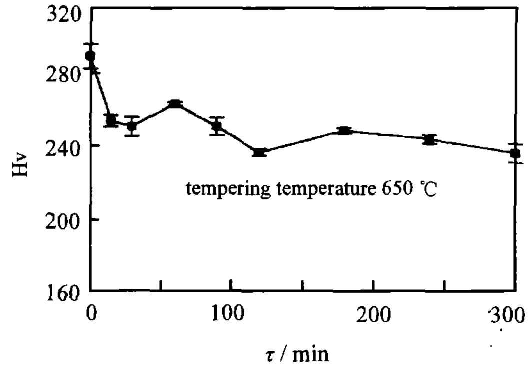

Figure 7 Hardness vs. tempering time of 2-3 steel.

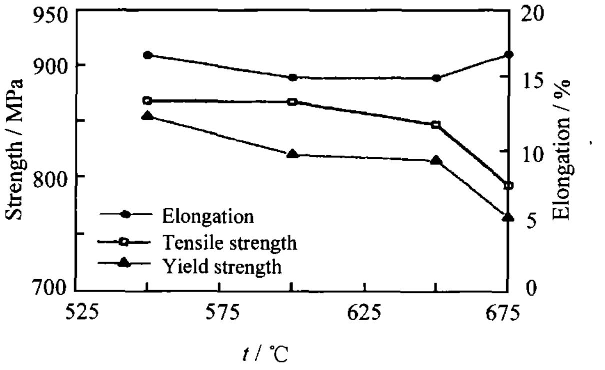

Figure 8 The mechanical properties vs. tempering temperature of 2-3 steel within 3 h soking.

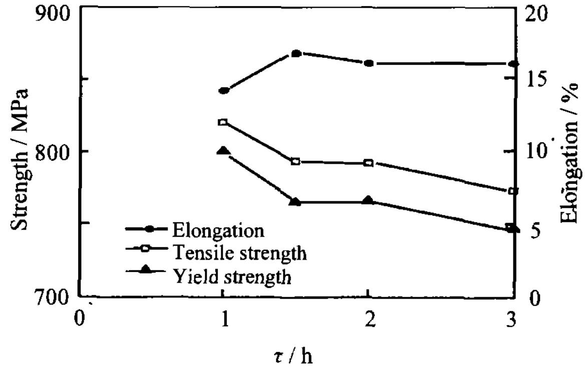

Figure 9 The mechanical properties vs. tempering time of 2-6 steel, tempering at 675℃ for 1 to 3 h.

steel. It shows that tempering at 675 ℃ for 1 to 3 h, the yield strength decreased, but the ductility is more than 16% when tempering time is longer than 1.5 h. The above results indicate that after RPC process and tempered at 600–675 ℃ for 1.5–3 h, yield strength can reach 750–800 MPa, and the ductility is more than 15%.

The impact energy at room temperature, −20 ℃ and −40 ℃ of heat 1-1 steels after tempering at 650 ℃ for 2 and 3 h are shown in **figure 10**. It shows that the longitudinal impact energy is more than 60 J (specimen size: 5 mm×10 mm×55 mm) at −40 ℃. The FATT is lower than −40 ℃. The transverse and longitudinal impact energy of heat 2-3 steel at −40, −20 and 20 ℃ after tempering at 675 ℃ for 3 h is shown in **figure 11**. It shows that the transverse impact energy 50% less than the longitudinal results, otherwise the transverse impact energy at −40 ℃ is still more than 36 J.

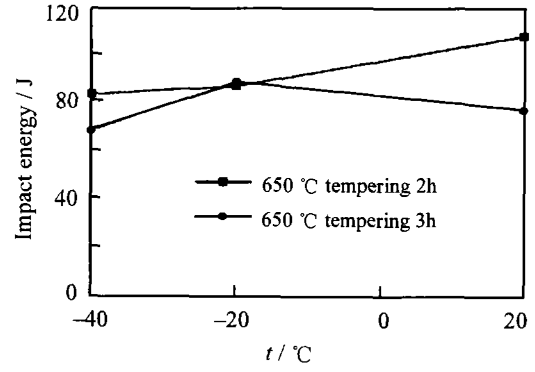

Figure 10 The longitudinal impact energy of 1-1 steel (specimen size 5 mm×10 mm×55 mm).

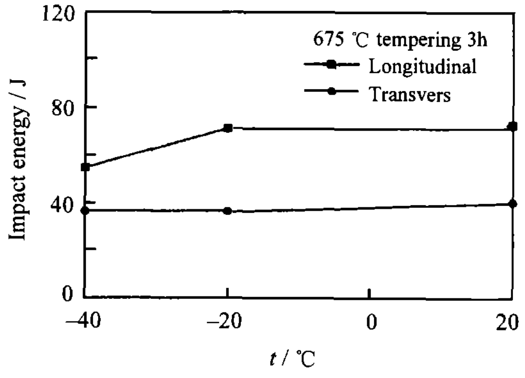

Figure 11 The longitudinal and transvers impact energy of 2-3steel after tempering.

4 Conclusions

(1) An ultra-fine composite microstructure of HSLA steel can be obtained by alloy design and CR+RPC process. The microstructure is composed mainly of bainite and less martensite. The lath is composed of sub-lathes that contain a high dislocation density, the length of sub-lath is about 4–6 μm, the width is about 0.3 μm.

(2) During tempering the hardness decreases with the increasing tempering temperature, there is a hardening phenomenon at a certain temperature range and tempering time. The optimum tempering temperature is 600–675 ℃, and the tempering time is in the range of 1–3 h.

(3) The mechanical properties of ultra-fine composite microstructure steel is perfect, the yield strength is 750–800 MPa, the ductility is more than 15% and the longitudinal impact energy of half size specimen (5 mm×10 mm×55 mm) is 75–100 J at room temperature and more than 68 J at −40 ℃.

References

[1] Y. Q. Weng: [in:] *Proceedings of the International Workshop on Innovative Structure Materials for Infrastructure in 21st Century*. Tsukuba, Japan, 2000, p. 11.

[2] A. J. DeArdo: [in:] T. Chandro, T.Sakai eds.: *THERMEC'97*. TMS, Warrendale, PA, 1997, p. 13.

[3] I. Kozasu: [in:] P. D. Southwick ed.: *Accelerated Cooling of Steel*. TMS, Warrendale, PA, 1986, p. 15.

[4] I. Kozasu: [in:] T. Chandro, T. Sakai eds.: *THERMEC'97*. TMS, Warrendale, PA, 1997, p. 47.

[5] T. Maki: [in:] K. A. Talor, S. W. Thompson, F. B. Fletcher eds.: *Physical Metallurgy of Direct-quenched Steels*. TMS, Warrendale, PA, 1993, p. 3.