

## Effect of tempering temperature on microstructures and properties of niobium and titanium microalloying low carbon bainite steel

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**Abstract.** The effect of tempering temperature on microstructures and mechanical properties of niobium and titanium microalloying low carbon bainite steel was investigated. The results indicate that the mechanical properties change is mainly controlled by the structure evolution, and as the structure evolution during tempering is complex, the mechanical properties do not monotonously increase or decrease with the increasing of tempering temperature.

### Introduction

High strength low carbon bainite steel is a new developed steel, which always shows high strength, high toughness and excellent welding performance, and it has been widely used in the engineering machinery, shipbuilding, oil and gas transmission pipeline, etc. Especially in engineering machinery area, along with the development trends of large scale and lightweight, request for higher yield strength, impact toughness and welding performance of the structural parts has been put forward. At present, the widely used bainite steel with the yield strength of 460 MPa or 550 MPa is mainly prepared by a low cost process named TMCP[1], for the higher yield strength bainite steel, it is widely manufactured by tempering after reheating and quenching process[2]. As the cost of tempering after reheating and quenching is high, so using tempering after TMCP process to instead it is of great significance. During this new process, through reasonable design of rolling and cooling, the high density dislocation that formed during the low temperature severe finishing rolling can be reserved, then the nuclear point during the phase deformation will be increased, the microstructures is refined, after tempering, the comprehensive mechanical properties of the steel will be finally improved[3]. In this paper, niobium and titanium microalloying steel was chosen as the study object, by tempering after TMCP process, bainite steel with higher yield strength was finally prepared, the effect of tempering temperature on microstructures and mechanical properties of this steel was investigated.

### Experimental methods

The experiments were performed in echeng iron and steel Co.,Ltd. The raw materials are billets with the section size of 250 mm×1800 mm, its chemical composition is shown in Table 1. Billets were first heated to 1220°C in walking beam reheating furnace, kept the temperature for more than 30 minutes, and then rolled to 25mm thick plates on four high rolling. The whole rolling were divided into two stages, austenitic recrystallization zone and no austenitic recrystallization zone. In anstenitic recrystallization zone, large pass reduction ratio was used, the total reduction ratio was 68%. In no austenitic recrystallization zone, the total reduction ratio was 60%, among them, the total reduction ration in the last three pass was more than 35%, and the finishing rolling temperature was controlled

above 840°C. After rolling, steel plates were cooled to 300°C by accelerated laminar cooling, and the cooling rate was above 20 °C/s.

Samples with the size of 200 mm × 400 mm were cut from the finished plates, and then tempered in box-type heat treatment furnace under different conditions. With the same tempering time, which was 50 minutes, the tempering temperatures were set at 400°C, 450°C, 500°C, 550°C, 600°C and 650 °C separately. After tempered, the microstructures and mechanical properties of each treated sample was tested. In this paper, the tensile test was conducted on Zwick/Roell Z250 hydraulic servo tensile testing equipment, -20 °C sharpy impact test was performed on SANS ZBC pendulum impact testing machine, microstructures were detected by AXIO optical microscope, and INCA energy disperse spectroscopy was used to analyze the chemical composition of precipitates.

Table1 Chemical composition of the raw material (wt%)

C	Mn	Si	P	S	Mo, Cr	Nb	Ti
0.05	1.65	0.35	0.013	0.008	0.50	0.06	0.03

## Results and discussion

**Effect of tempering temperature on mechanical properties.** The effect of tempering temperature on mechanical properties of the steel plates is shown in Fig 1. As the figure showing, the mechanical properties of untreated plate are: the yield strength (Rp0.2) is 735MPa, tensile strength is 955 MPa, elongation is 12.5% and -20 °C sharpy impact energy is 175 J. After tempering, the corresponding properties change, and they are affected by the tempering temperature. Below 500 °C, both the yield and tensile strength of the treated plate increase, then decrease and finally increase with the increasing of tempering temperature. Above 500 °C, they decrease with the increasing of tempering temperature firstly, and then almost maintain steady as the temperature reaches 600-650 °C. At this steady state, the yield and tensile strength decrease to 650 Mpa and 750 Mpa separately. The changing trends of elongation and sharpy impact energy with the increasing of tempering temperature are generally opposite to that of strength. Below 500 °C, the changing trends of elongation and sharpy impact energy are relatively steady. Above 500 °C, the plasticity and ductility of treated plates are obviously improved. So, considering the comprehensive mechanical properties, the steel plates should best be tempered under 550°C. And under this tempering temperature, the mechanical properties of treated plate are: the yield strength (Rp0.2) is 740MPa, tensile strength is 790 MPa, elongation is 16.5% and -20 °C sharpy impact energy is 250 J. As widely known, the mechanical properties change during tempering is mainly controlled by the structure evolution, such as the recovery of dislocation substructure, desolvation of carbon and precipitation of secondary phase[4]. So, microstructures of treated plates are tested and compared.

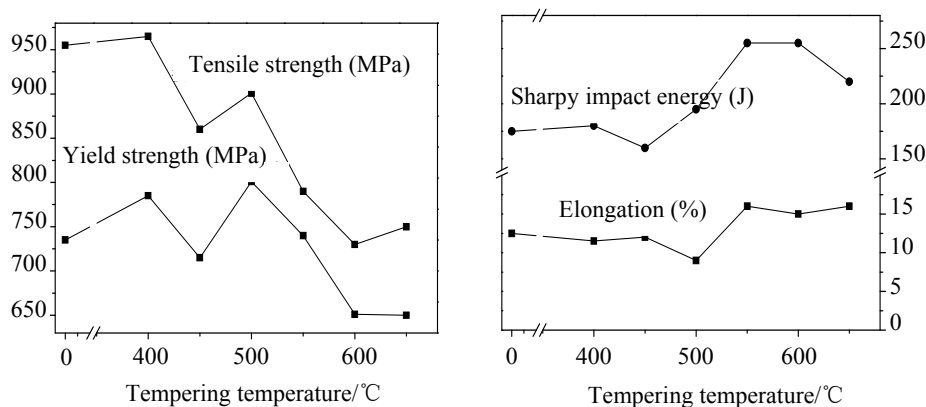


Fig.1 Effect of tempering temperature on mechanical properties of the treated plates

**Microstructure evolution during tempering.** The typical microstructures of plates before (TMCP) and after tempering are shown in Fig.2. As shown in Fig.2(a), before tempering, the structure of steel plate is constituted by lath-shaped bainite, austenite grains' deformation along rolling direction is obviously observed, lots of entangled and lath-shaped bainite distribute among them. Just based on this structure, the strength of the steel is high, but the plasticity and toughness are relatively poor.

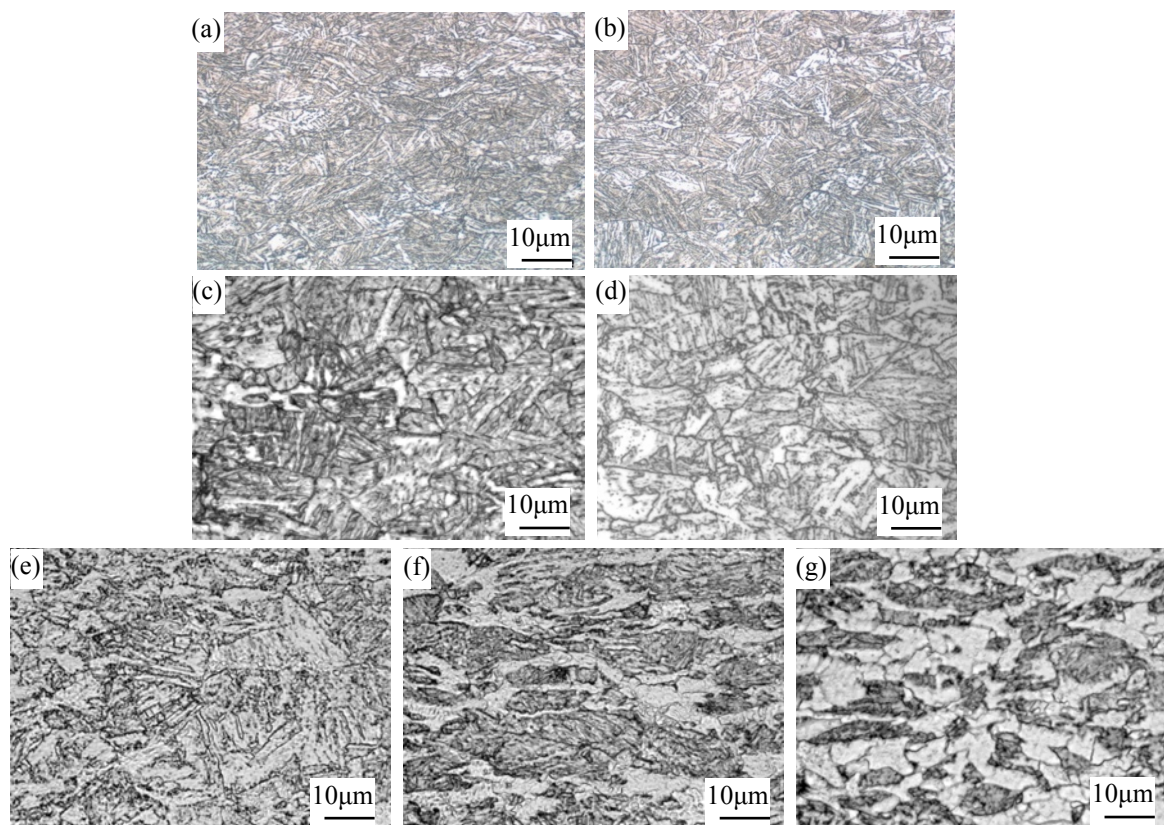


Fig.2 Microstructures of the plates that tempered under different temperatures  
(a) TMCP (b) 400°C (c) 450°C (d) 500°C (e) 550°C (f) 600°C (g) 650°C

When tempered at 400°C, no obvious change of the structure is observed, as shown in Fig.2(b). However, since a certain amount of niobium and titanium are added into this studied steel, after hot rolling, these alloying elements will supersaturatedly solid solute into the steel. When tempered, precipitates will form. Because of pinning effect to the dislocations from these fine and dispersion distributed precipitates (as shown in Fig.3(a)), the strength of the treated steel is undoubtedly enhanced. However, since the tempering temperature is low, recovery is weak, and the precipitates are harmful to the plasticity of steel, so as compared with untreated plates, the elongation of the steel decreases when tempered at 400°C.

Increasing the tempering temperature from 400°C, recovery is enhanced gradually. Due to the movement, merger and restructuring of dislocations, some low angle grain boundaries between lathes disappear, and adjacent lathes merger with each other, then structures are coarsened, as shown in Fig.2(c). Meanwhile, since dislocations density decrease and some substructure are changed during this recovery process, the effect of softening gradually surpass that of precipitation strengthening, then the strength of treated steel decrease. When the temperature reaches 500°C, precipitates precipitate completely, and their size increase to 30nm to 40nm, as shown in Fig.3(b). Meanwhile, the recovery becomes stable under this tempering temperature. Then at this moment, precipitation strengthening lead the yield and tensile strength increase again and reach their maximum values. Furthermore, due to the precipitation of alloying elements, lattice distortion decreases, and then impact toughness of the treated steel is improved slightly.

With the further increasing of tempering temperature, such as to the range from 500 °C to 600 °C, due to the growth of precipitates and desolvation of alloying elements, both precipitation

strengthening and solution strengthening are weakened. Meanwhile, as the tempering temperature is high, recrystallization take place, lath-shaped bainite changes to polygon-shaped ferrite and dislocation defects disappear gradually. Under this condition, softening is undoubtedly enhanced, then the strength of the treated steel decreases sharply[5]. However, because the shape of precipitates change into sphere, lattice distortion decreases and ferrite is formed, the plasticity and toughness of the treated steel plates are improved significantly. When the tempering temperature is above 600 °C, since strengthening and softening achieve balance, so the yield and tensile strength of treated steel almost keep unchanged as the tempering temperature increase continuously. However, as lots of ferrites are formed, the elongation increases slightly, and the structure coarsening lead the impact toughness decrease slightly. Although the size and shape of precipitates in the steel plates that tempered under different temperatures are different, EDS analysis indicates that the precipitated phase are almost the same, as shown in Fig.3(d), both of them are complex carbonitride containing niobium and titanium.

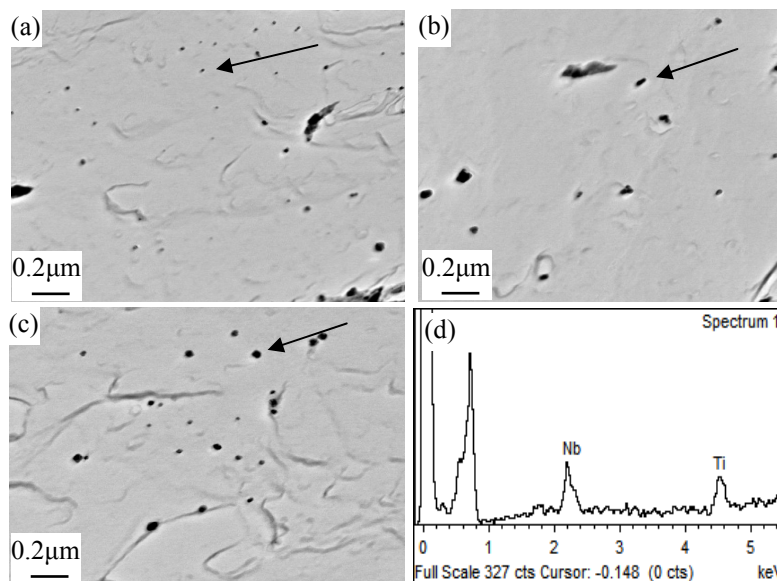


Fig.3 Effect of tempering temperature on precipitates in the treated plates  
(a) 400°C (b) 500°C (c) 600°C (d) energy spectrum

## Conclusions

(1) Tempering temperature has an important impact on mechanical properties of treated steel. Considering the comprehensive mechanical properties, the tempering temperature should best be set at 550°C.

(2) Due to the combined action of precipitation strengthening, recovery softening and alloying elements desolvation, the effect of tempering temperature on mechanical properties of treated steel is complex.

(3) Although the size and shape of precipitates in the steel that tempered under different temperatures are different, the precipitated phase are almost the same.

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