Effect of Ti on microstructure and properties of Ti-Nb microalloyed high strength steels

Qing Yuan[1,a], Guang Xu[1,2,b *], Bei He[1,c] , Yulong Zhang[2,d]

[1]The State Key Laboratory of Refractories and Metallurgy;

Hubei Collaborative Innovation Center for Advanced Steels;

Wuhan University of Science and Technology; Wuhan, 430081, China

[2]State Key Laboratory of Development and Application Technology of Automotive Steels (Baosteel Group); Baoshan; Shanghai, 201900, China

[a]e-mail: 438137485@qq.com [b]e-mail: XuGuang@wust.edu.cn

[C]e-mail: 918353241@qq.com [d]e-mail: zhangyulong@baosteel.com

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Abstract. Three Ti-Nb microalloyed high strength steels with varying Ti contents were refined in laboratory 50 kg vacuum induction furnace. Microstructure observation and TEM analysis were conducted. Tensile tests were performed. The results show that both yield strength and ultimate tensile strength increase with the Ti content, while the elongation has no significant change. The microstructures consist of bainite, ferrite and perlite, and microstructure morphology has no obvious difference. TEM analysis shows that the steel with higher Ti content contains more fine precipitates of (Ti, Nb)(C, N), indicating that precipitation strengthening is the main factor for the improvement of strength

Introduction

Microalloyed steels, widely used in various industries, are normally alloyed by niobium (Nb), titanium (Ti) and vanadium(V), individually or in combination[1]. The strength of microalloyed steels can be improved by a combination of grain refinement and precipitation strengthening resulted from carbonitrides of microalloying elements [1]. In recent decade, there has been a strong interest in using more Ti to reduce adding amount of Nb and V in microalloyed steels because of low price of titanium ore. Steel researchers and production plants, therefore, have paid more and more attention to the development of Ti or/and Ti-Nb alloyed steels to reduce the production cost [2~3]. Some literature on Ti-Nb composite addition high strength steels has been published [4~5]. Akhlaghi[4] etc. studied the effect of thermomechanical processing on the hot ductility of a Nb–Ti microalloyed steel and Banks [5] etc. investigated the influence of Ti on hot ductility of Nb-Ti containing HSLA steels. The type, morphology and distribution of precipitation in Nb-Ti bearing steels have been discussed in literature [6~8]. But few studies concerning the effect of Ti content on microstructure and property have been reported. In the present study, three steels with different Ti content were designed and refined to investigate the effect of Ti content on microstructure and property of Ti-Nb microalloyed steels.

Materials and Experiments

Three steels with varying Ti contents and basically the same Nb content were designed and refined with 50 kg vacuum reduction furnace. The compositions of the tested steels are given in Table 1. Ingots were reheated to 1200 °C and kept for 30 min before hot rolling. Then the ingots were hot rolled to the 12 mm plates on 4-high mill followed by cooling to room temperature at a cooling rate of 10 °C / s. The finishing temperature was 880 °C. The plates were machined to standard tensile test samples and tensile tests were conducted on a universal materials tester. The microstructures of these three steels were analyzed using a Zeiss Axioplan 2 imaging microscope. Precipitates were observed using transmission electron microscopy (TEM) with the second carbon extraction replicas. Carbon extraction replicas were prepared by putting several drops of acetone on metallographic specimens followed by sticking acetate fiber paper on specimens. Acetate fibre paper was torn down after 20 min from specimen and carbon was sprayed on the surface of fibre paper near metallographic specimen side. Then the acetate fibre paper with carbon spray was immersed in the acetone solution for several hours to be completely dissolved and left carbon thin film. The extracted carbon replicas were then rinsed with water and alcohol mixture, placed on the copper grid and dried. Carbon extraction replicas were observed by JEM-2100F field emission transmission electron microscope (FETEM) operated at 120 kV using standard bright field imaging technique.

Table 1. Compositions of three steels (wt %)

No.	Ti	Nb	C	Si	Mn	Cr	N	S
1	0.080	0.062	0.061	0.222	1.77	0.010	<0.007	<0.002
2	0.106	0.070	0.050	0.216	1.80	0.050	<0.007	<0.002
3	0.157	0.074	0.069	0.217	1.78	0.037	<0.007	<0.002

Results

Properties

The standard tensile test samples were machined from hot rolled plates. Tensile tests were conducted on a WAN-10000 materials testing machine. The mechanical properties of three steels are listed in Table 2.

Table 2. The mechanical properties of three steels

No.	Yield Strength/MPa	Ultimate tensile strength /MPa	Total elongation%
1	533	583	31.7
2	558	653	24.2
3	658	763	23.7

It can be seen from Table 2 that the yield strength and tensile strength increased with the increase of Ti content in steels. The basic chemical elements are similar for steels 1, 2 and 3 except for the Ti content. The yield strength and tensile strength of steels increased 25 MPa and 70 MPa respectively when the Ti content increased from 0.080% to 0.106%, while they increased 100 MPa and 110 MPa respectively when the Ti content increased from 0.106% to 0.157%. Therefore, the increase of strength is obvious when the Ti content is increased in the range of 0.080 to 0.157 wt%.

Microstructre

Microstructures of steels were observed using a Zeiss optical microscope and Fig.1 shows the microstructures of three steels. It is clear that microstructures of three steels consist of bainite, ferrite and pearlite, and their microstructures are similar. Austenite first transformed to ferrite and pealite at high temperature during cooling. Untransformed austenite transformed to bainite at low temperature.

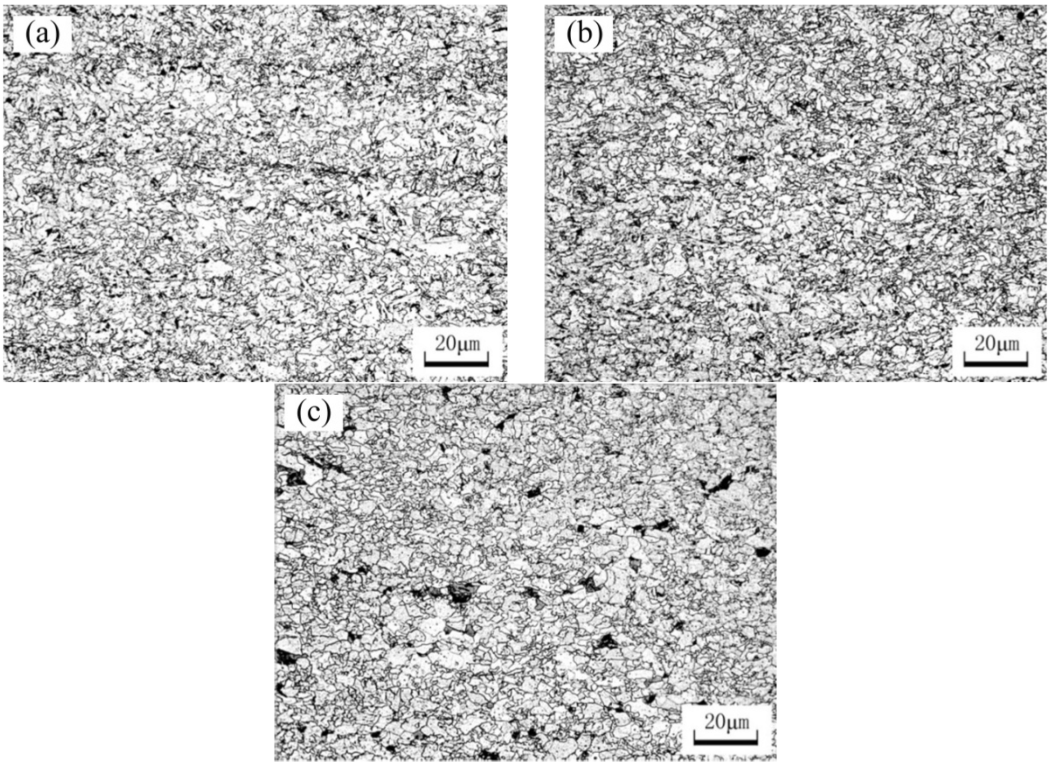

Figure 1. Microstructures of three steels with varying Ti contents, a) 0.080% Ti; b) 0.106% Ti; c) 0.157% Ti

Precipitates

TEM studies of three steels were conducted using JEM-2100FEF transmission electron microscope and the precipitates and particle types for the three steels are given respectively in Figs.2 to 4. It can be seen from TEM analysis that (1) Sample 1, containing 0.080 wt% Ti, has fewer precipitates than other two samples and the precipitated particles are globular composite (Ti,Nb)(C,N) whose size is about 100 to 350 nm while a few particles are from 30 to 100 nm; (2) Sample 2, containing 0.106 wt% Ti, has more precipitates than sample 1, and the morphology, type and size of precipitated particles are basically the same as sample; and (3) Sample 3, containing 0.157 wt% Ti, has the most precipitates among three samples and main precipitated particles are also globular composite (Ti,Nb)(C,N) whose size is about 20 to 70 nm while a few particles are between 70 nm and 200 nm.

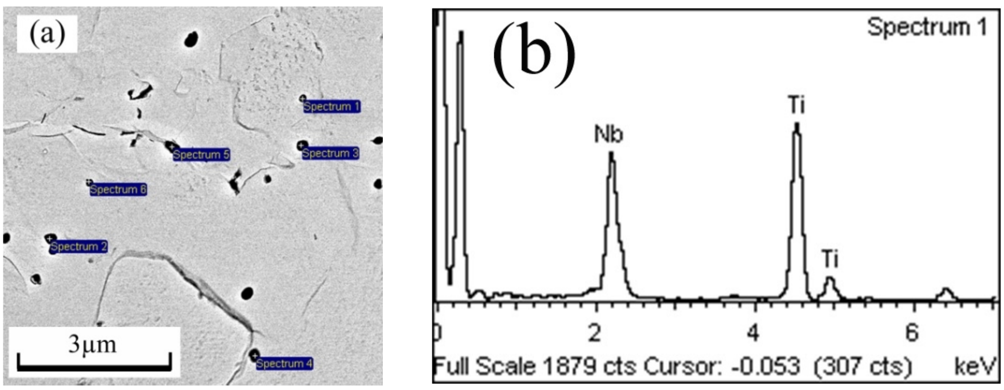

Figure 2. Bright field transmission electron micrographs showing precipitates (a)and energy spectrum (b) in sample 1 with 0.080 wt% Ti.

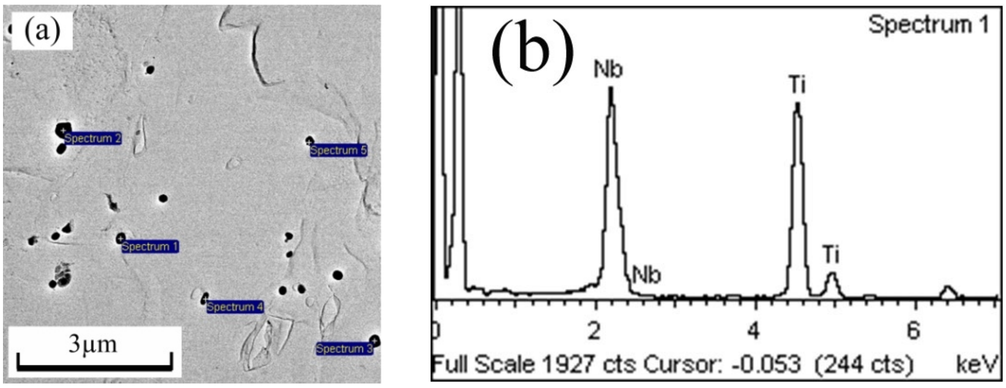

Figure 3. Bright field transmission electron micrographs showing precipitates (a)and energy spectrum (b) in sample 2 with 0.106 wt% Ti.

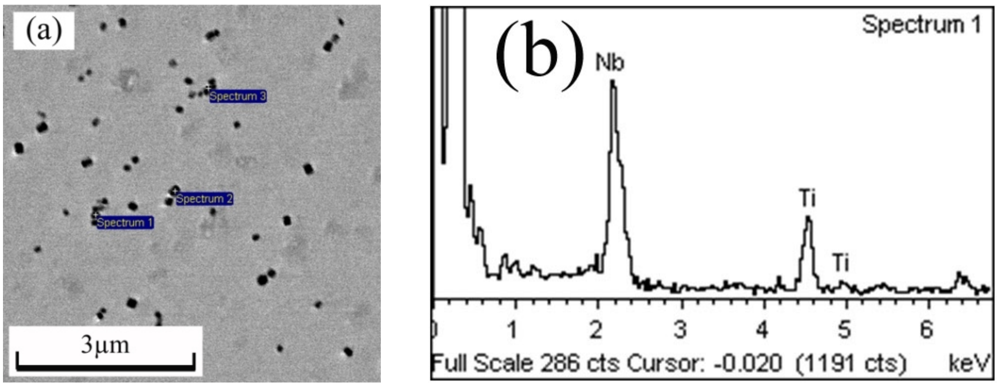

Figure 4. Bright field transmission electron micrographs showing precipitates (a)and energy spectrum (b) in sample 3 with 0.157 wt% Ti.

Discussions

Three steels with varying Ti alloying elemcontents, 0.080, 0.106, and 0.157 wt% respectively, were designed and refined. The chemical compositions of three steels are similar except Ti content. The yield strength and ultimate tensile strength for three steels are illustrated in Fig.5 and Fig.6 shows the relationship between uniform elongation and Ti content. From Fig.5 and Fig.6, we can see that the strength of steels increases with the increase of Ti content, while the elongation decreases with the increase of Ti content.

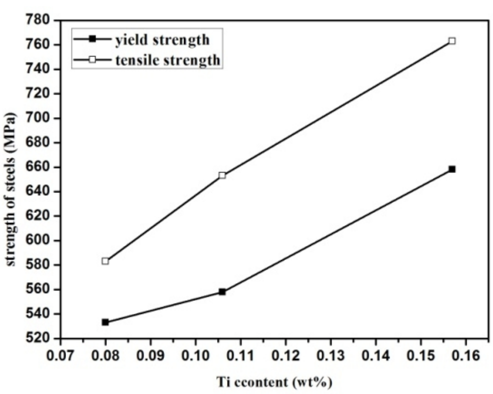

Figure 5. The relationship between yield strength and Ti content

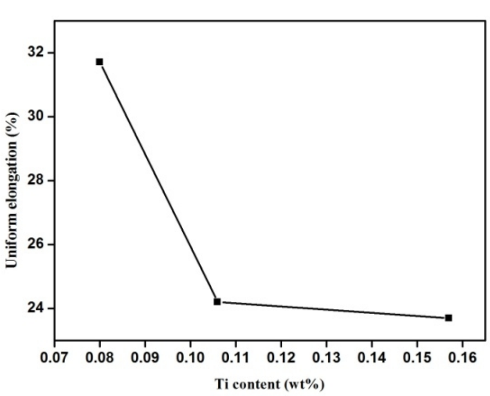

Figure 6. Uniform elongation depending on Ti content

It is well known that the strengthening mechanisms for microalloyed steels include solid solution strengthening, precipitation hardening, grain refine strengthening and dislocation hardening [9]. The microstructures are basically the same for three steels, so grain refine strengthening has no significant difference. Solid solution strengthening should also be same because of the same chemical compositions except for the Ti content. In addition, Dislocation strengthening for three steels should be basically the same due to almost the same rolling and cooling technology. Therefore, the difference of strength among three steels should be caused by precipitation hardening. According to the thermodynamic analyses of carbonitride precipitation of Ti and Nb, carbonitrides of Ti and Nb separated out during hot rolling and cooling processes. Carbonitrides pre-separated out at higher temperature provide nucleation sites for later precipitates at lower temperature. Therefore, it is very difficult to find individual carbides or nitrides of Ti and Nb. As shown in Figs.2~4, the precipitates observed are all composite precipitation of Ti and Nb, i.e. (Ti,Nb)(C,N). Moreover, according to Gladmen et al [10], precipitate strengthening contribution is proportional to particle number and inverse proportional to particle diameter. So the more and finer the particles are, the better the precipitation strengthening is.

As aforementioned, steel 3, containing 0.157 wt% Ti, has more precipitates than other two steels. These precipitates, most of which are between 20nm and 70nm, are globular (Ti,Nb)(C,N) particles. These nanoscale particles impede the dislocation movement during sample deformation to enhance the strength of the steel. On the other hand, steel 1, containing only 0.080 wt% Ti, seperated out fewer particles than steel 2 and steel 3. Corresponding strength is lower than other two Ti-alloyed steels. Therefore, we can get the conclusion from these results that higher Ti content result in more fine precipitates, leading to better precipitation strengthening and higher strength of steels.

It should be noted that in another study it has been found that the strength of steels has a sharp increase when Ti content changes between 0.04 and 0.07 wt% for Ti individual alloyed steels. But in the present study the strength still obviously increases until 0.157 wt % Ti. Perhaps this is due to the difference in compositions. Here steel are compositely alloyed with Ti and Nb. Precipitates of both Ti and Nb can separate out during hot rolling and cooling. Nb precipitates provide addition nucleation sites for carbonitrides of Ti, resulting in more precipitation particles in Ti-Nb alloyed steels compared with single Ti alloyed steels.

Conclusions

Three steels with varying Ti contents were refined and hot rolled. Tensile tests and microstructure observation were conducted. The precipitates were observed using TEM. The results indicate that the strength of Ti-Nb alloyed steels increases with Titanium content. The contribution of Ti content to strength can be attributed to precipitation strengthening. Precipitation strengthening plays significant role in strength improvement until 0.157 wt% Titanium for Ti-Nb composite alloyed steels.

Acknowledgements

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