Hot Ductility of Ti/Nb-added 800MPa Grade Weathering Steel

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Abstract. The hot ductility behavior of two kinds of 800MPa grade Ti/Nb-added weathering steel has been investigated by using Gleeble3500 thermo-mechanical simulator. The tensile strength (TS) and reduction in area (RA) were acquired to draw hot ductility curve and hot strength curve. SEM fractographs and microstructures of the tensile specimens were analyzed. The results show that the occurrence of the third brittle zone was related to the formation of film-like ferrite phase along the prior austenite grain boundary. Moreover, the addition of alloy elements has a big influence on hot ductility. Deep ductility trough was observed for niobium added titanium containing steel, while titanium containing steel free of niobium shows excellent hot ductility.

Introduction

As an important part during steel production, continuous casting technique has many advantages such as simplifying production process, increasing metal recovery rate, saving energy and meanwhile, improving the quality of slab to some extent. The most essential reason of cracks in solidified shell is the variation of mechanical behavior of the slab at high temperatures [1]. Therefore, by fully studying the hot ductility of new steels, determining the plastic trough, developing a reasonable casting and rolling process and eliminating cracking tendency, the quality of the new steels can be conserved [2].

The hot ductility behavior of two kinds of 800MPa grade Nb/Ti-bearing steel has been investigated. The study focuses on hot-rolling process,in order to analyze the components influence on hot ductility, establish and improve the basic research for the continuous casting and rolling process.

Experimental

The high temperature tensile tests of two experimental steels were completed on Gleeble-3500 thermo-mechanical simulator. Table 1 shows the chemical composition of the test steels. Nb and Ti were composited added in steel B. The casting slab was processed into Φ10mm×120mm standard cylindrical tensile test samples, both the ends of the sample were processed into M10×1.5mm. The samples were heated to 1350˚C at a rate of 10˚C/s holding for 100s, then cooled to the test temperature at 5˚C/s holding for 30s, and subsequently tensiled with a constant true strain rate of $0.001s^{-1}$. Fig.1 is schematic diagram of thermo-mechanical cycle of hot tensile test.

Generally, the reduction of area (RA) is used in the assessment of the quality of the hot ductility. The fracture surfaces were examined with HITACHI SU-1500 scanning electron microscopy (SEM). The microstructure was observed and analyzed by Nikon LV150 type optical microscope(OM).The precipitations were observed and analyzed by JEM-2010F transmission electron microscope(TEM).

Table 1 Chemical composition of the test steels（wt.%）

Steel	C	Si	Mn	Al	Nb	Ti	P	S	N
A	0.12-0.18	0.03	1.2-1.6	0.045	-	0.024	0.021	0.013	0.004
B	0.12-0.18	0.46	1.2-1.6	0.038	0.021	0.030	0.026	0.014	0.004

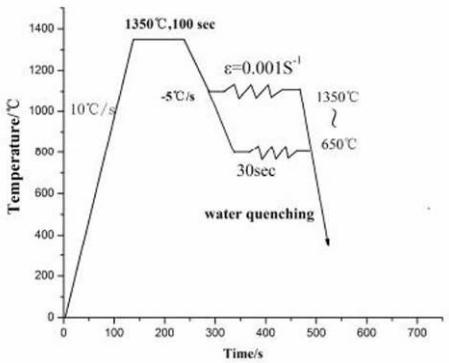

Fig. 1 Schematic diagram of thermo-mechanical cycle.

Results and Discussion

Hot Ductility and Strength

Fig.2 is the hot ductility curves and tensile strength curves of test steels. It is common believed that hot ductility is good with the RA in excess of 60%, and the slab is not easy to crack [3]. The experimental steels had good ductility at 850˚C<T<Tm. The ductility trough of steel A and steel B appears in the temperature range of 700˚C-800˚C and 650˚C-800˚C respectively, as shown in Fig.2 (a). Obviously, niobium added titanium containing steel has a much deeper and wider ductility trough, while titanium containing steel free of niobium shows better hot ductility. The presence of lots of precipitations in the straightening operation is harmful to the Nb-bearing steel [4]. Chiaki OUCHI et al investigated the influence of Nb on hot ductility, and it is found that the ductility trough became deeper and wider with the increase of Nb [5]. The result of this study is consistent with the literature.

Fig.2 (b) is the tensile strength curves of test steels. The tensile strength increases as temperature decreases for the steel, when temperature dropped to 750 ℃, tensile strength raises up quickly.

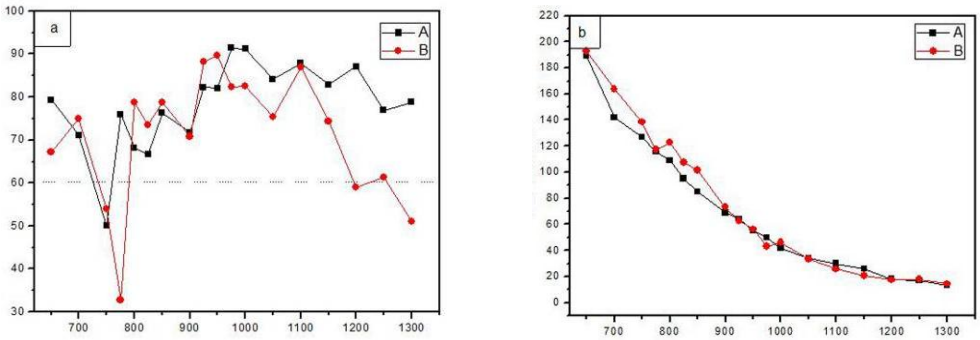

Fig.2 Hot ductility curve (a) and tensile strength curve (b) of test steels.

Microstructure and Fracture Morphology

Fig.3 is the microstructure of experimental steels at the third brittle zone. White film-like proeutectoid ferrite forms along the prior austenite grain boundaries [6], as shown in Fig.3. Research [7, 8] shows that the main reason of the appearance of the third brittle zone is related to both the embrittlement of austenite grain boundary and the film-like ferrite formed along the prior austenite grain boundaries. The former is caused by precipitation of AlN, TiN, NbCN etc. The latter is due to the strength of ferrite is only 1/4 of that of austenite [9]. Thus, deformation mainly occurs in the film-like ferrite distributed in the austenite grain boundary. The microvoids gather together in the ferrite and lead to the cracks of grain boundary, as shown in Fig.4 [10].

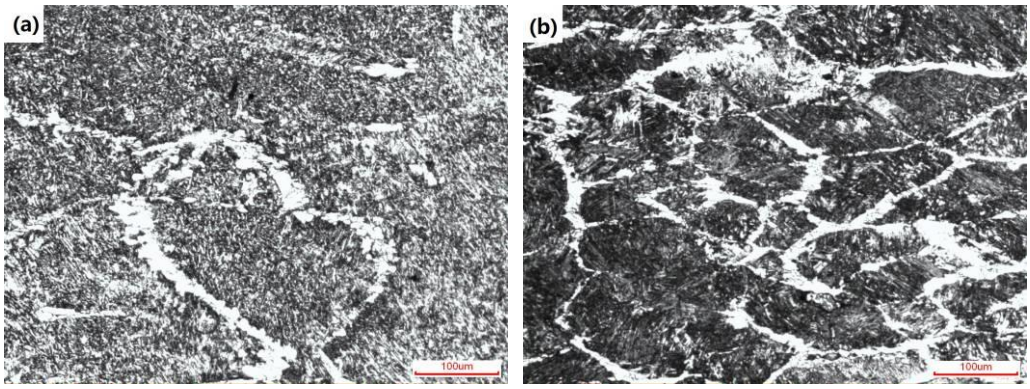

Fig.3. Microstructures of test steel near to the fracture surface. (a) A750˚C-50%,(b) B775˚C-32%.

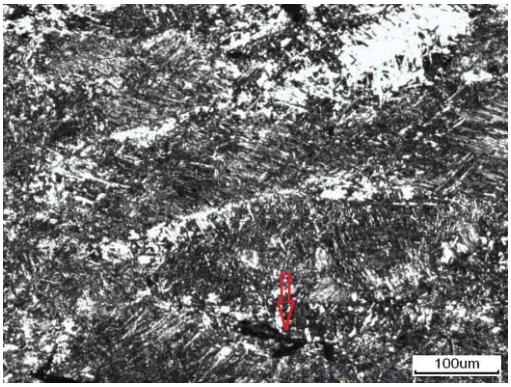

Fig.4. Microstructure of cracks in fracture samples of steel B.

Fig.5 is the fractograph of hot tensile test samples at different temperature. A typical ductile fracture pattern with many deep dimples is shown in Fig.5 (a) and (b). It can be inferred that transgranular fracture occurs at this temperature. Grain boundaries migrated easily during deformation owing to dynamic recrystallization occurred at high temperature, and cracks are difficult to initiate. As test temperature drops to 750˚C, the fracture shows typical intergranular fracture morphology in Fig.5(c) and (d), where the ductility is poor.

Fig.6 is the TEM micrograph and EDS spectrum of a precipitate in steel B deformed at 750˚C. The size of the precipitates which surrounded by cavities is greater than 1μm. The precipitate is confirmed to be Ti/Nb compounds with N. Ti is a beneficial element to hot ductility because it weakens the adverse effects of Nb [11]. TiN has lower solubility in austenite under high temperature, thus, it can be easily precipitated in priority. Owing to the higher precipitation temperature of TiN than Nb(C,N), the precipitation of Nb(C,N) decreases with the addition of Ti[12].

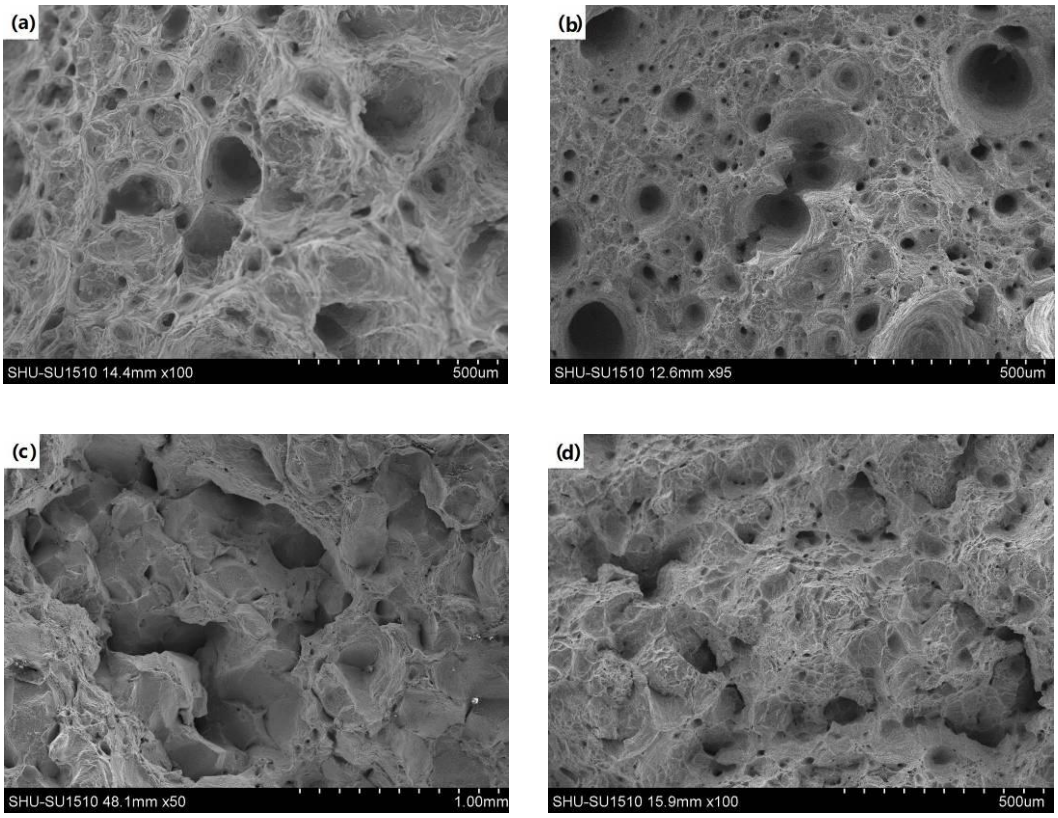

Fig.5. SEM fracture micrographs of the specimens（a）A-950˚C,（b）B-1050˚C,（c）A-750˚C,（d）B-750˚C.

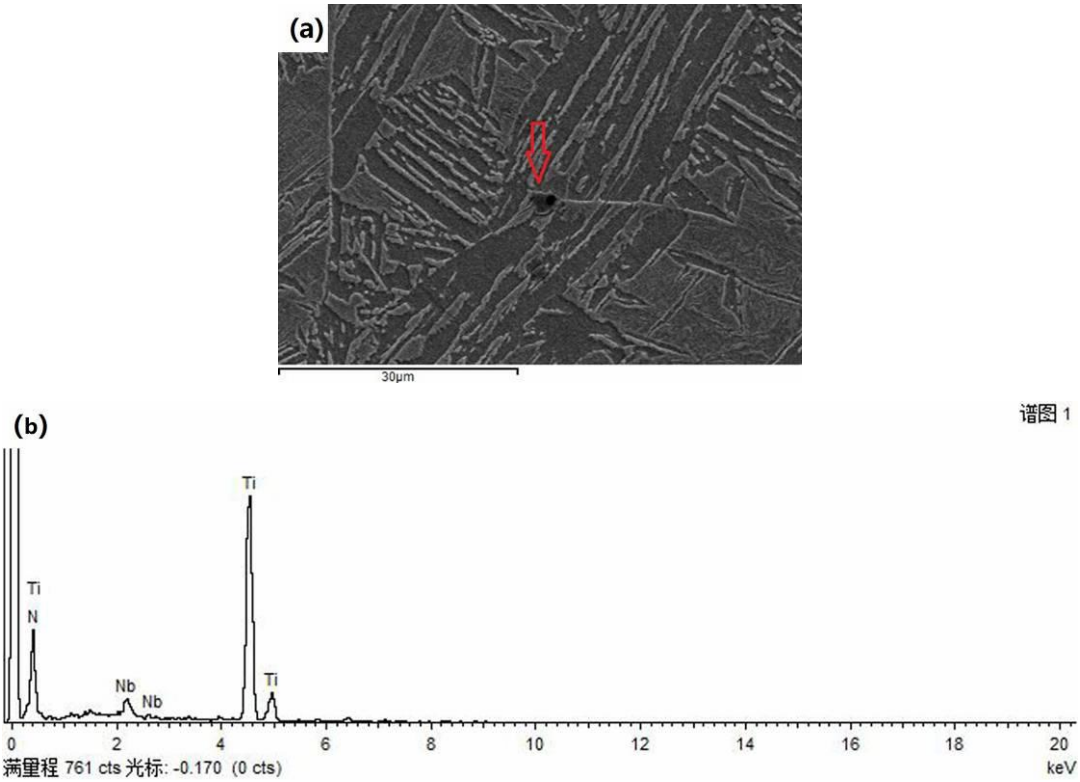

Fig.6. TEM micrograph and EDS spectrum of a precipitate in steel B at 750˚C.

Conclusions

(1) The test steels both had good ductility at 850 ℃-Tm. The straightening temperature should be kept over 850 ℃. The ductility trough of steel A and steel B appears in the temperature range of 700˚C-800˚C and 650˚C-800˚C, respectively.
(2) The occurrence of the third brittle zone was related to the precipitation of film-like ferrite along the prior austenite grain boundary. The fracture morphology was brittle intercrystalline fracture and tensile sample showed poor ductility at the third brittle zone.
(3) Alloy elements enormously affect hot ductility. Deep ductility trough was observed for niobium added titanium containing steel, while titanium containing steel free of niobium shows excellent hot ductility.

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