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The effect of manganese content on mechanical properties of high titanium microalloyed steels

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ABSTRACT

In this work, in order to achieve an optimum combination of high strength, ductility and toughness of high Ti microalloyed steel, extensive research efforts were exerted to study the effect of soaking temperature, manganese and sulfur content on properties of titanium steels. Precipitation hardening of Ti-bearing steels has been found to vary with different soaking temperature. Higher strength was achieved in these steels at higher soaking temperature due to dissolution of more TiC, $Ti_4S_2C_2$ and little TiN, which lead to re-precipitation of fine carbides with greater volume fraction. The results of transmission electron microscope (TEM)analysis indicates that there were more and finer TiC precipitates coherent or semi-coherent with the ferrite matrix in the high manganese content steel than in low manganese content steel. The marked improvement in strength is also associated with low sulfur content. TiC particles smaller than 20 nm in 8Ti-8Mn steel help enhance strength to higher than 302 MPa compared with 8Mn steel.

1. Introduction

Over the last four decades, the development and application of high strength low alloy steels have been promoted to meet the higher demand of steel properties due to weight reduction in engineering machine [1–3]. The precipitation strengthening mechanism has been known as a useful method for development of new grades of steel with optimized high strength and good ductility [4]. It is well known that the high strength of these steels is derived from Nb, V, Ti carbonitrides precipitates. These precipitates strongly influence the microstructure and mechanical properties of the HSLA steels through grain refinement and precipitation strengthening [5–8].

It is reported that addition of a small quantity of Ti in low carbon steels has been shown to impart inferior welding properties such as cold cracking susceptibility without preheating [9,10]. A large number of studies aimed at researching on the precipitation strengthening mechanism in Ti-Mo microalloyed steels, and the results showed that the contribution of precipitation strengthening for the yield strength was estimated to be approximately 300 MPa, which was attributed to the inter-phase precipitation of nanometer-sized (Ti, Mo) C precipitates [11–13]. In high Ti-microalloyed steels with different content of Mn, it has been suggested that increasing Mn content resulted in the decrease of temperature of $\gamma \rightarrow \alpha$ phase transformation and the kinetics of TiC precipitation at higher temperature. This in turn, led to more TiC particles within 10 nm precipitation in ferrite, thus enhancing the precipitation hardening [14,15]. Addition of a small amount of titanium to low carbon wheel steel made in JingTang Steel can not only refine the grains but also modify inclusions by forming $Ti_4C_2S_2$ and enhance low carbon steels flange elongation.

But the literature concerning the stability of mechanical properties of Ti-bearing steel is scanty. In this investigation efforts have been made to elucidate the influence of different manganese and sulfur contents on TiC precipitation behavior and mechanical properties of Ti low carbon steels. Extensive studies have been carried out on the Ti-bearing steels produced by JingTang steel and selected for their applications in automotive crossbeam structure to better understand microstructure refinement and titanium precipitation strengthening.

2. Experimental procedures

The tested steels were procured from the commercial plate steels with a thickness of 9.8 mm (mm) manufactured through the base oxygen furnace (BOF), vacuum degassing, continuous casting and thermal mechanical control processing (TMCP). The chemical compositions of the tested steels, including a reference C-Mn steel with a base composition of 0.07%C-0.80% Mn, the Ti-microalloyed

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steel with different content of Mn and the high sulfur steel with the composition of 0.07%C-0.81%Mn-0.014%S, were given in Table 1. Specimens (cylinder of Ø8.0 mm × 12.0 mm) were quenched after solution treated at 1250 °C for 3 h in vacuum environment and then quenched by water. The continuous cooling transformation (CCT) was simulated in the Gleeble-2000 simulator after specimens being austenized at 1250 °C for 1200 s, then the specimens were cooled down to 900 °C at cooling rate of 10 °C/s. After 30% reduction in compression at 900 °C, the specimens were continuously cooled at different rates down to room temperature. The cooling rates are 0.2, 0.5, 2, 5, 10, 20, 30, 50 and 80 °C/s, respectively. The critical transformation temperatures (Ar_1, Ar_3) from austenite to ferrite of tested steels with different Mn and Ti content were measured at the cooling rate of 0.05 °C/s. The simulation test processes are shown in Fig. 1(a). TMCP for the steel was worked out according to the CCT microstructure characteristics, the simulation test processes are shown in Fig. 1(b).

In the present investigation an austenitizing temperature of 1260/1220/1180 °C was employed for slab reheating. Then slabs with a thickness of 230 mm were rolled to 45 mm during rough rolling; finish rolling was performed below 950 °C. The finishing temperature, coiling temperature and final thickness of slabs were 880 °C, 620 °C and 9.8 mm respectively and finally coils were cooled about 72 h to ambient temperature. After TMCP, Tensile and Charpy V notch impact specimens were cut from the as-rolled plates in the transverse direction. Impact tests were carried out at the temperature of −20 °C (The −20 °C impact energy requirement of commercial plate steels is over 40 J).

The specimens for optical metallography, which were prepared from the as rolled plates, were mechanically polished and then etched in 3% nitric acid. TEM specimens were produced by cutting slices from the dilatometer specimens, thinning mechanically to 80 μm and finally twin-jet electropolishing to perforation using a mixture of 5% perchloric acid ethanol solution at −30 °C and a potential of 35 V. They were examined on a JEM-2100F field emission gun scanning transmission electron microscope at 200 kV equipped with an energy dispersive X-ray (EDX) spectrometer.

Table 1
Chemical composition of the material (mass%).

Steels	C	Si	Mn	P	S	Alt	Als	Ti	N
8Ti-16Mn	0.07	0.14	1.63	0.011	0.003	0.038	0.035	0.080	0.0031
8Ti-12Mn	0.08	0.15	1.18	0.010	0.004	0.037	0.035	0.078	0.0034
8Ti-8Mn	0.08	0.15	0.78	0.012	0.004	0.038	0.035	0.081	0.0032
8Ti-8Mn-S	0.07	0.16	0.81	0.012	0.014	0.038	0.035	0.08	0.0030
8Mn	0.08	0.15	0.80	0.010	0.003	0.037	0.035		0.0033

3. Experimental results

3.1. Hardenability of the steels

The influence of Mn and Ti concent on the Ar_1 and Ar_3 of experimental steels is shown in Fig. 2(a). A comparison of the Ar_3 and Ar_1 for the 8Mn-steel and 8Mn-8Ti-steel shows that an increase in Ti content improves the Ar_3 and Ar_1 temperatures, about 30 °C respectively. In the 8Ti-steel with different Mn concent, an increase in the Mn content lowers both the Ar_3 and Ar_1 temperatures significantly. For example, the Ar_3 and Ar_1 temperatures for 8Mn-8Ti-steel are 775 °C and 660 °C, respectively, while for the 16Mn-8Ti-steel are 710 °C and 630 °C, respectively. The result shows that an increase in Mn content causes the $\gamma \rightarrow \alpha$ transformation to occur over a wider temperature range, which indicates slower transformation kinetics, that is, an increase in hardenability.

The Fig. 2(b) shows that dynamic continuous cooling transformation behavior for the 16Mn-8Ti steels, constructed from the dilatometry curves, indicates that at cooling rate below 5 °C/s, the polygonal ferrite (PF) transformation occurs first, followed by transformation to pearlite. When the cooling rate is higher than 5 °C/s, the polygonal ferrite (PF) transformation occurs first, followed by transformation to the acicular ferrite and bainite. When the cooling rate is higher than 30 °C/s, there is no polygonal ferrite transformation, but the bainite transformation was observed. The intermediate transformation of all steels studied took place below 600 °C.

3.2. Microstructure of the steels

The slabs with a thickness of 230 mm were rolled to 9.8 mm after reheating at 1260 °C for 3 h. In order to get ferrite-pearlite microstructure, the steels were water cooled to above 620 °C at about 20 °C/s after finishing rolling. The self-tempering temperature was about 630–650 °C during coiling cooled to avoid the present of bainite and widmanstatten ferrite for all studied steels. The coiling cooled rate was about 0.0138 °C/s, the microstructures of steels were shown in Fig. 3.

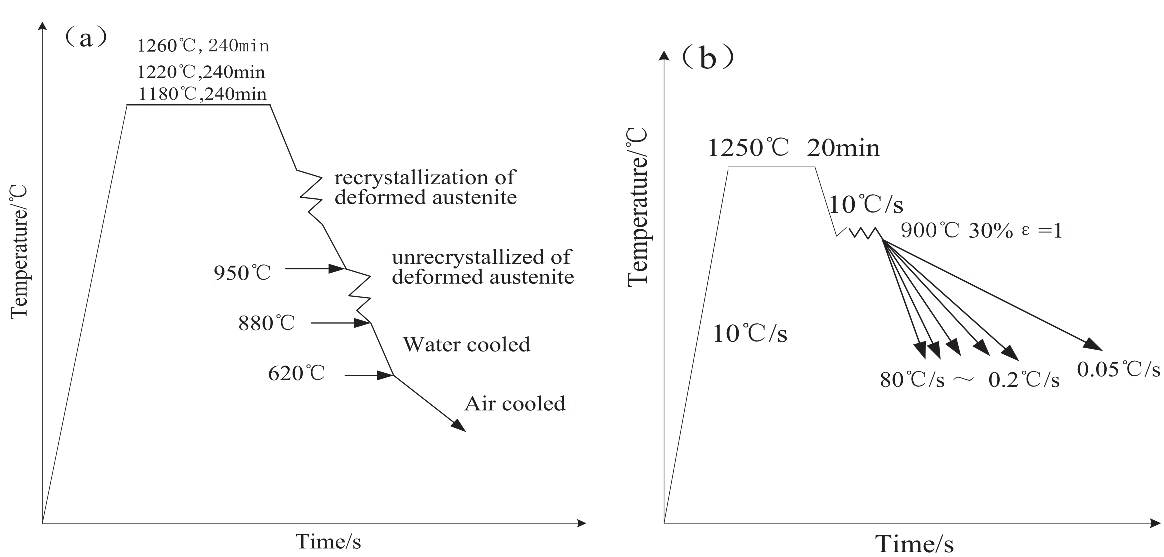

Fig. 1. Schematics of thermo-simulation test processes, (a) control rolling and control cooling processes, (b) continuous cooling process after deformation at 900 °C