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Materials

Carbides/nitrides precipitates in a C-Mn strip by CSP technology

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Abstract: The carbides/nitrides precipitates in ferrite grains, on grain boundaries and dislocations were investigated on a hot-rolled C-Mn strip (0.16wt%C-1.22wt%Mn-0.022wt%Ti) produced by the CSP (compact strip production) technology using TEM and X-ray energy dispersive spectroscopy. The Pickering's equation for the contribution of precipitates to the yield stress was also discussed. It is shown that there are numerous fine and dispersive precipitates TiC in the ferrite grains, on the grain boundaries and dislocations. Also there are a small amount of coarser Ti(C, N) particles and TiC particles associated with MnS. Precipitation strengthening on steels produced by the CSP technology is significant.

Key words: CSP technology; C-Mn steel; carbides/nitrides precipitates

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1 Introduction

Since the first CSP (compact strip production) plant was commissioned at Nucor Steel in Crawfordsville in 1989, the CSP technology has brought hot-strip production a remarkable step forward [1], This technology shows significant differences from conventional rolling processes especially the high supersaturation level of microalloying elements in the as-cast austenite [2]. Although Y.L. Kang *et al.* made a lot of extensive researches on low carbon steels [3-8] and some others on low carbon steels microalloyed with Nb [2, 9-10], there are less researches on Carbon-Manganese steels microalloyed with Ti. In this paper, the chemical composition, morphology and distribution of the precipitates in one hot-rolled carbon-manganese strip containing 0.022wt%Ti produced by the CSP line were investigated using H-800 TEM and X-ray energy dispersive spectroscopy (EDX) fixed on JEOL 2010 HRTEM (High Resolution Transmission Electronical Microscope). The carbides/nitrides precipitation behavior in the CSP process has also been discussed.

2 Material and experimental procedure

The material investigated was a carbon-manganese hot-rolled strip (ZJ510L-B) produced by the CSP technology at Guangzhou Zhujiang Iron and Steel Co. in China. The chemical composition is given in **table 1** and the mechanical properties in **table 2.** From table 2 we can conclude that the mechanical properties of ZJ510L-B strip are very good. The specimens were cut from the hot coil (5.0 mm gauges) produced in the 6-stand finishing train with a reduction of up to 90% using thin casting slabs (50 mm). Thin foils and carbon extraction replicas were prepared to investigate the precipitates. The size of the precipitates d_P and the particle density n_s were measured on TEM micrographs, using an image analyser with Imagetool software.

Table 1 Chemical composition of the tested strip wt%

C	Si	Mn	S	P	Ti	Al	N	Cu	Ni	Cr
0.16	0.3	1.22	0.003	0.015	0.022	0.037	0.0039	0.10	0.035	0.026

Table 2 Mechanical properties of ZJ510L-B strip

Direction	σ_s /MPa	σ_b/MPa	σ_s / σ_b	δ_5	HRB	Hv
Transversal	411	584	0.70	34.40	76	142
Longitudinal	398	585	0.68	34.60	76	142

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3 Results and discussion

3.1 TEM observations

Figure 1 shows the precipitates present on the carbon extraction replicas. The precipitates have square or rectangle geometries, and are fine and dispersive. The statistical particle diameter shows that 72.34% of precipitates are less than 10 nm in diameter, 94.21% less than 20 nm and the mean particle diameter d_p is about 9.1 nm, in the range of 3-170 nm. The statistical mean particle density n_s is 2.74×10^{13} m^{-2}, in the range of 1.23×10^{12}-$1.29\times10^{14} m^{-2}$.

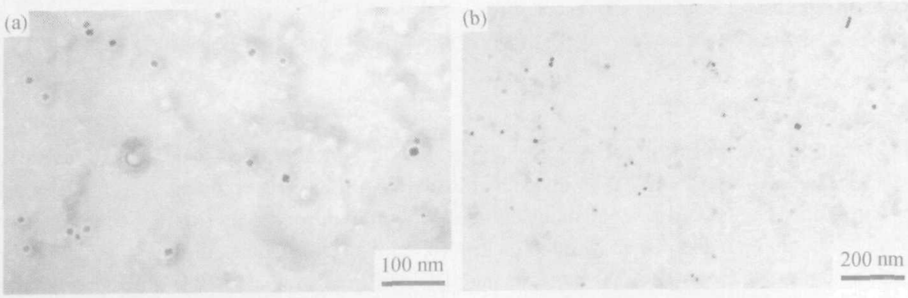

Figure 1 TEM micrographs of the precipitates present on the carbon extraction replicas.

TEM thin foils observation shows that there are more precipitates formed in the ferrite matrix than on the grain boundaries, as shown in figures 2(a) and (b). Most of the precipitates formed in the ferrite matrix are located on or near the dislocations, as shown in figure 2(a).

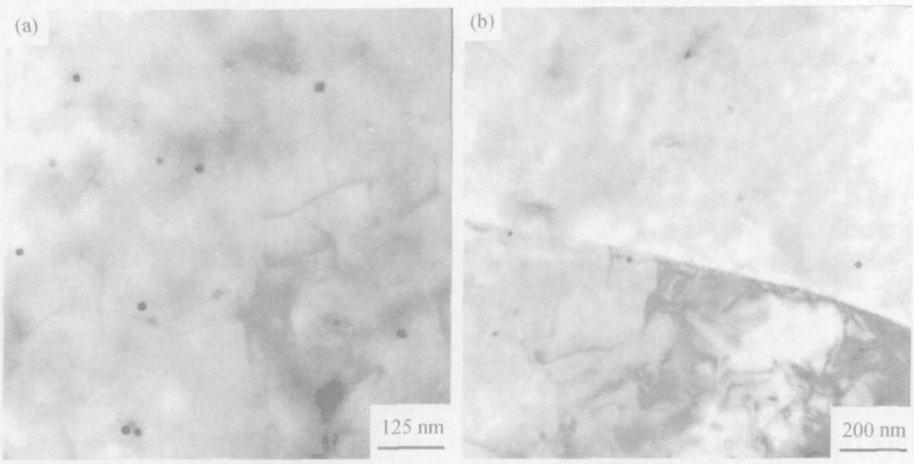

Figure 2 TEM micrographs of precipitates present on the thin foils: (a) intragranular precipitates; (b) precipitates on the grain boundary.

3.2 EDX analyses

On all the spectra, carbon and copper peaks were always detected. They are attributed respectively to the carbon of the replicas and to the copper grids on which the replicas are put. As a consequence, these two elements can not be quantified. The results of EDX analyses show that most of the precipitates smaller than 30 nm are TiC particels, as shown in figure 3(c). Figures 3(a) and (b) show their different morphologies.

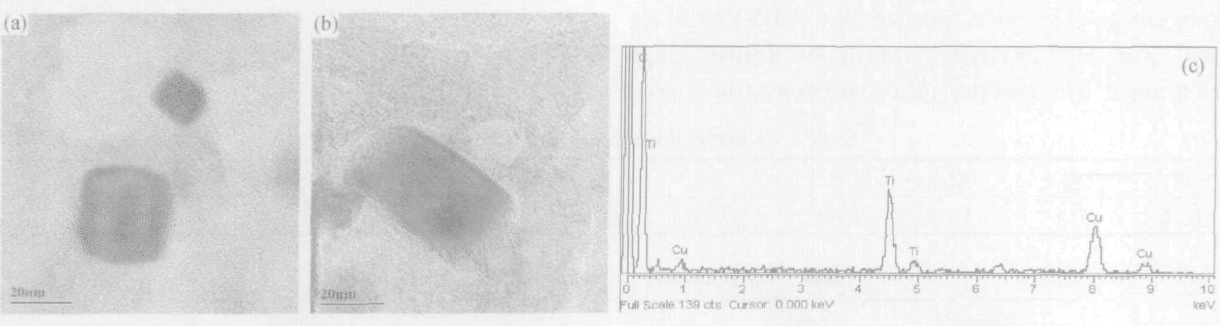

Figure 3 HRTEM micrographs of TiC precipitates present on the carbon extraction replicas: (a), (b) different morphologies of TiC precipitates; (c) EDX spectrum.

Two types of coarser precipitates (larger than 30 nm, about 5% in the total particles) are observed in the carbon extraction replicas. The one is TiN/Ti(C,N) particles, as shown in **figure** 4. and the other is TiC particles associated with MnS, as shown in **figure 5,** both types of precipitates are rich in titanium. The big particle in figure 4(b) has an irregular geogmetry. In figure 5(a), the larger one is the TiC particle associated with MnS.

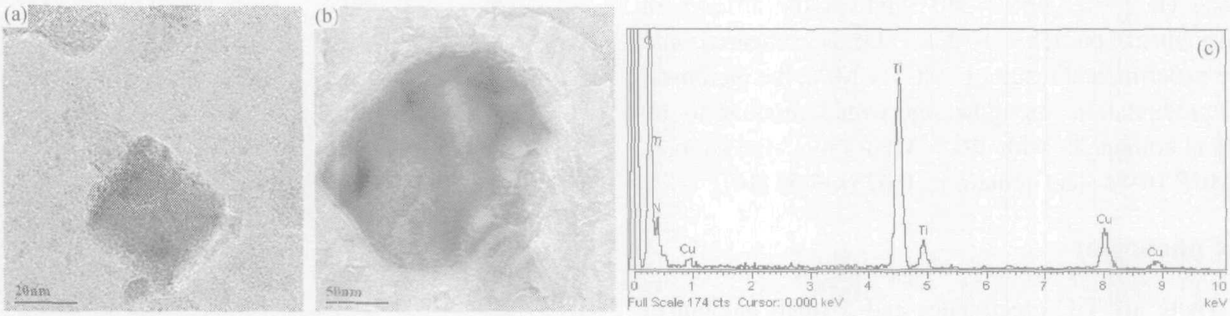

Figure 4 HRTEM micrographs of Ti-rich TiN/Ti(C,N) precipitates present on the carbon extraction replicas: (a), (b) different morphologies of Ti-rich TiN/Ti(C,N) precipitates; (c) EDX spectrum.

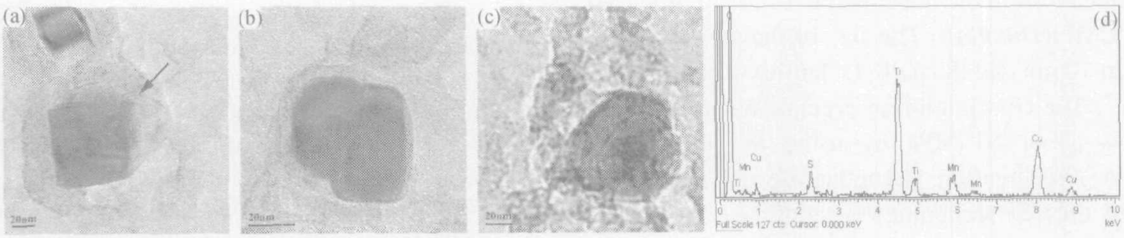

Figure 5 HRTEM micrographs of precipitates present on the carbon extraction replicas: (a), (b), (c) different morphologies of the TiC particle associated with a MnS particle; (d) EDX spectrum.

3.3 Dissussion

The present investigations show that the precipitates in C-Mn steel containing 0.022wt%Ti produced by the CSP technology are dominant TiC particles and a small amount of coaser Ti rich TiN/Ti(C, N) particles and TiC particles associated with MnS. Y.Li [11] *et al.* reported that in two low carbon steels microalloyed with V-N and V-Ti-N by TSDR (thin slab direct rolling) process, no major precipitation occurred between the start of rolling and the end of the 4th pass. In their research, they also observed a small amount of VN particles associated with MnS after 1050°C equalization in a V-N steel. So it would be expected in ZJ510L-B steel that those two types of coarser precipitations commence nucleation after equalization or during hot rolling. Due to their big size and rich titanium content, TiN/Ti(C, N) particles and TiC particles associated with MnS should precipitate before the fine and numerous TiC particles. Also, the two kinds of coarse precipitates were retarded by the CSP line's unique heat-cycle because there is supposed to be low preferential precipitation site on the austenite grain boundary due to large austenite grain size [12] and most of titanium remains in supersaturation after the soaking process [13]. The tested steel's mass ratios (%Ti/%N=5.64), comparing with that of K. Kunishige's experiments, may also result in a small amount of TiN/Ti(C, N) precipitates [13]. According to K. Kunishige's results, in the low titanium steels (less than 0.015wt%Ti) processed by HDR (hot direct rolling), the steels containing nitrogen more than 40×10^{-6} (the mass ratio, %Ti/%N<3.75) are strengthened mainly by the non-embrittling type TiN which precipitates during hot rolling. When the nitrogen content is less than 20×10^{-6} (the mass ratio, %Ti/%N>7.5), the embrittling type TiC which precipitates after hot rolling becomes the dominant factor in the strengthening. In the tested steel, there are 0.022wt% Ti and 39×10^{-6} N. It would be expected that in this low nitrogen content steel, TiC precipitetes after hot rolling become the dominant precipitation and there will be a small amount of TiN/Ti(C,N) particles precipitate during the hot rolling.

In the CSP process, however, the strengthening effect by the TiC and/or TiN precipitation may be much enhanced by its unique heat-cycle [13]. In the tested steel the main precipitation strengthening factor is the TiC precipitation after hot rolling which can be estimated by the Pickering's equation [14]. The yield strength (in MPa) in the absence of precipitation strengthening, as a function of chemical composition and ferrite grain size:

$$\sigma=15.4(3.5+2.1[\%Mn]+5.4[\%Si]+23[\%N_f]+1.13d^{-1/2}),$$

where [%Mn], [%Si], and $[\%N_f]$ are the mass fraction of manganese, silicon, and free nitrogen respectively, and *d* is the ferrite grain diameter, mm. Inserting the composition of the steel given in table 1 and the ferrite grain size 6.3 μm [15] into the above equation gives a basic yield strength of 340 MPa for the absence of carbonitride particles. If this value is compared with the experimental result of 398-411 MPa, the increment of precipitation strengthening would amount to 60 MPa, compared with 26.7 MPa in a conventional TMCP 16Mn steel containing 0.025wt%Ti [16].

4 Conclusion

There are TiC precipitates and a small amount of TiN/Ti(C,N) particles and TiC particles associated with MnS in the ferrite grains, on the grain boundaries and dislocations in the hot-rolled C-Mn strip produced by the CSP technology. The size of the precipitates is less than 10 nm and the particle density is about 2.74×10^{13} m^{-2}. The contribution of precipitates to the yield stress is about 60 MPa by using the Pickering's equation. Precipitation strengthening on steels produced by the CSP technology is significant.

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