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Surface microstructure control of microalloyed steel during slab casting

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ABSTRACT

Lots of work has been done to investigate slab surface microstructure evolution during continuous casting in order to improve hot ductility and avoid transverse cracks. The slab surface microstructure after continuous casting was characterized by optical microscopy, and the precipitation behavior was investigated by transmission electron microscopy. At the same time, the mechanical properties of the slabs were measured using a Gleeble 1500D thermal simulator and the transformation temperatures were examined by means of a thermal dilatometer. The experimental results show that homogeneous microstructure without film-like ferrites and chain-like precipitates at grain boundary can be obtained through surface intensive cooling and transverse cracks do not occur on the slab surface. For the experimental steel, fine ferrite can form at slab surface when the water flow rate is larger than 1560 L/min at vertical section. As the distance to surface increases, microstructure turned to ferrite and pearlite. Moreover, nano-size carbonitrides precipitated in the ferrite grain and the size was larger at the junction of the dislocations. The mechanical experiment results show that the hot ductility of the sample deformed at 650 °C was better than that of the sample deformed at 750 °C. The reason is that film-like ferrite formed at the grain boundary in the sample deformed at 750 °C. Thus, the slab must be cooled quickly below A_{r3} to prevent the occurrence of film-like ferrite and transverse cracks on the slab surface during casting.

1. Introduction

It is well known that surface transverse cracks are prone to occur during slab continuous casting at the secondary cooling zone for the microalloyed steel because of the induced strain concentration at film-like ferrite and chain-like precipitates[1-6]. Lots of researches have been done to avoid the occurrence of transverse cracks through surface microstructure control method[7,8] or chemical composition control method[9-13]. The results of Kato et al.[1] proved that the slab surface microstructure without film-like ferrite could be controlled by adopting intensive cooling until less than A_3 transformation temperature just below mold and subsequently reheating up to 977 °C in secondary cooling for the low alloy bearing steel[1]. However, until now, transverse crack problem still exists for the microalloyed steel and lots of materials are wasted in many steel plants. The difficulty is that the cooling rate is hard to control. Owing to the low contents of C and microalloying elements, the critical cooling rate is large and film-like ferrite is prone to form along austenite grain boundaries. Thus, a method to avoid the formation of film-like ferrite and chain-like precipitates should be investigated. Moreover, the nucleation mechanism of the precipitates must be studied to obtain nano-size carbonitrides uniformly distributed within the grain.

Tensile test has been found very useful in assessing cracking susceptibility of a steel. Up to now, tensile tests have been adopted by many researchers to simulate continuous casting process[14]. In other words, whether transverse cracks occur in the slab continuous casting process can be testified through hot tensile tests. Meanwhile, different microstructures susceptibility to cracking can also be investigated[15,16]. Particularly, tensile tests can be performed on the sample with different microstructures and at various temperatures to find the optimum processing parameters for continuous casting. Thus, tensile tests were performed to investigate the cracking susceptibility of a microalloyed steel in this paper.

2. Experimental

The chemical compositions of the experimental

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microalloyed steel are shown in Table 1. Firstly, refined molten steel was cast into a mold to produce slab with section size of 360 mm×2350 mm. When reaching the mold exit, the experimental slab was intensively cooled by water with flow rate of 1560 L/min at vertical section. The cooling water temperature was 30 °C and the experimental casting speed was 0.65 m/min. Finally, the sample was intercepted from the surface and interior of the as-cast slab. The microstructures of the samples were observed by optical microscopy (OM) and transmission electron microscopy (TEM) to investigate the nucleation mechanism of the ferrite and precipitation behavior under surface intensive cooling conditions. Traditional slab cooled with water flow rate of 375 L/min at vertical section was also studied for comparison.

Table 1
Chemical composition of experimental steels (wt.%)

C	Si	Mn	P	S	Nb	Ti	V	Al_s	Fe
0.160	0.179	1.471	0.015	0.002	0.017	0.012	0.052	0.035	Balance

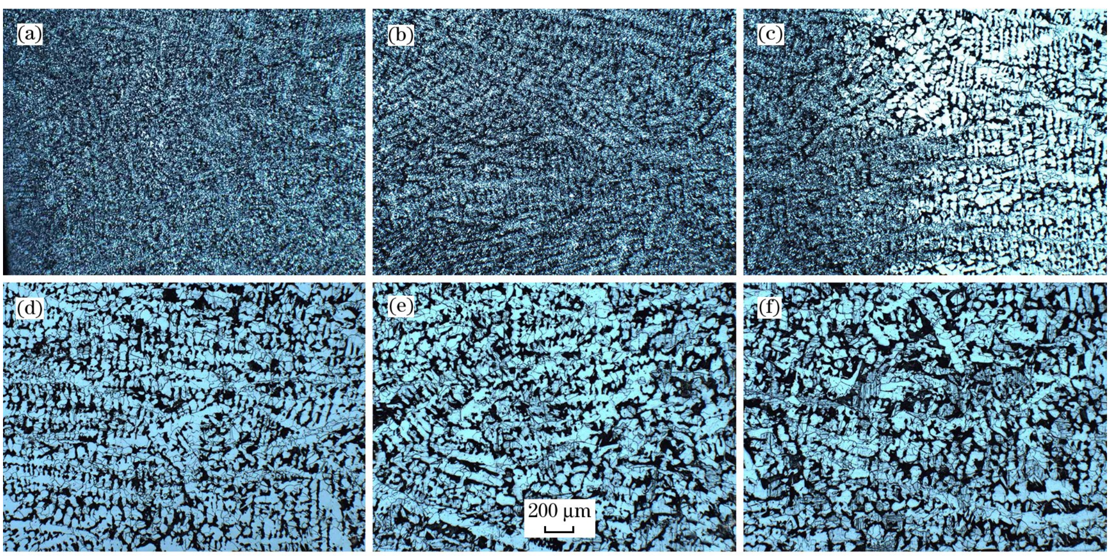
The transformation temperature was measured by means of a thermal dilatometer. Firstly, the sample with size of ϕ10 mm×15 mm was heated to 1250 °C and held for 10 min, then cooled to 25 °C at different cooling rates from 0.2 to 20 °C/s and water quenched. Through measuring the inflection point of the experimental curves, the transformation temperature can be identified.

Tensile tests were performed on a Gleeble 1500D thermal simulator. The samples were intercepted from the as-cast slab and machined to ϕ10 mm×110 mm. In order to obtain different microstructures, the samples were heated to 1350 °C, held for 1 min, and then cooled to 600, 650, 700, 750, 800, 850, 900, 950, and 1000 °C respectively at the cooling rate of 3 °C/s. The hot tensile tests were performed on the samples with different temperatures with the strain rate of 1×10^{-3} s^{-1}. The cracking susceptibility of the steel was evaluated by the reduction of area.

3. Results

3.1. Microstructure observation

In this experiment, the microstructure of the continuously cast slab which was cooled with intensive cooling at vertical section during the secondary cooling was observed by OM. In order to know the microstructure variations from surface to interior, the slab microstructures with different depths to the slab upper surface were studied (Fig. 1). The depth was 0, 2, 4, 6, 8, and 10 mm, respectively. Fig. 1 shows that the microstructure was fine ferrite at the slab surface. The ferrite size was about 2 μm. As the distance to the slab surface increased, the ferrite size became large and lots of pearlite formed. Owing to the large cooling rate, there were almost no dendrites formed at the slab surface. However, in the slab cooled with traditional cooling at vertical section



(a) 0 mm; (b) 2 mm; (c) 4 mm; (d) 6 mm; (e) 8 mm; (f) 10 mm.
Fig. 1. OM photographs of intensively cooled samples at different locations beneath slab upper surface.