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Effects of Cooling Rate and Isothermal Holding on Precipitation Behavior During Solidification of Nb-Ti Bearing HSLA Steels

Hyun Jo Jun and C. G. Park
Department of Materials Science and Engineering, Pohang University of Science and Technology
Pohang, Korea

K. B. Kang
Technical Research Laboratories, POSCO, Pohang, Korea

ABSTRACT

The effects of the cooling rate and isothermal holding on precipitation behavior during solidification have been investigated in 0.063C-0.017Ti-0.056Nb HSLA steels. The precipitates identified in an as-cast slab were semidendritic, dendritic or rod-like Nb-rich (Nb,Ti)(C,N). The morphology and chemistry were quite different when these precipitates formed after reheating and/or hot-rolling processes. No precipitation has been observed at the end of the solidification and the continuous cooling down to 800°C. ICP and TEM analyses indicated that most of the Nb and Ti was mainly precipitated into carbonitrides by the isothermal holding at a temperature range of 900° to 1000°C. In the case of a continuous casting process, the isothermal holding region corresponds to a certain flat cooling region, probably due to the latent heat of solidification. The Nb-rich carbonitrides formed during solidification are associated with the microsegregation of Ti and Nb in the interdendritic region.

INTRODUCTION

Micro-alloying elements in steels, such as Ti, Nb and V, can facilitate grain refinement through precipitation in austenite, and contribute to dispersion hardening through precipitation in ferrite during or after $\gamma \rightarrow \alpha$ transformation. Especially, titanium has frequently been added to high-strength, low-alloy (HSLA) steels to enhance the control of austenite during the welding or reheating process. In addition, TiN precipitates of a suitable size can suppress austenite grain coarsening in subsequent high-temperature processes such as welding or reheating, thus improving the toughness of final steel products (Cuddy, 1983). Multi-micro-alloying, then, can lead to the formation of complex compounds, which can influence the mechanical properties of the HSLA steels.

Very large precipitates could also be found in Nb-Ti HSLA steels produced by a continuous casting process (Chen, 1987; Zhou, 1996). It is, however, unlikely that these large precipitates can play any useful role in refining grain size. Instead, their harmful effects on the distribution and formation of smaller precipitates can weaken the role of Nb and Ti as grain refiners during the subsequent reheating and hot rolling processes (Hong, 2003).

The objectives of the present study are both to identify the precipitates formed in a continuously cast slab, and to examine the effects of post-solidification cooling on the precipitation behavior in Nb-Ti bearing HSLA steels.

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KEY WORDS: Precipitate, carbonitride, solidification, cooling rate, isothermal holding.

EXPERIMENTALS

Materials

Table 1 gives the chemical composition of the investigated slab. POSCO (Pohang Iron & Steel Co. Ltd.) produced the slab of Nb-Ti bearing HSLA steel.

Simulation for Solidification and Cooling

Simulation of the solidification and cooling was conducted using the Gleeble 3500 system (Dynamic System Inc.). Rod samples 120 mm in length and 10 mm in diameter were machined from the 1/4 and 3/4 positions of the slab thickness. The quartz tube was used for shielding the sample during the melting and solidification processes. The samples welded with an R-type thermocouple were heated from room temperature to melting temperature (1470°∼1480°C). In order to fully dissolve Nb and Ti in steels, the melt was held for 3 min and cooled down as follows, as shown in Fig. 1: (1) Cooling to 800°C at various cooling rates (10°, 100°, 200°, 300°C/min) followed by water quenching in order to identify the effect of the cooling rate on precipitation, and (2) cooling to various holding temperatures from 700° to 1200°C at the cooling rate of 100°C/min, followed by isothermal holding for 30 min in order to evaluate the precipitate-forming temperature.

Quantitative Analysis and TEM Observations of Precipitates

The quantitative amount of Nb and Ti precipitated was measured using inductively-coupled plasma (ICP) spectroscopy. At first, a few grams of samples were electro-chemically dissolved, and then filtered with a polycarbonate membrane fil-

	C	Si	Mn	Nb	Ti	N
Slab	0.063	0.2	1.58	0.056	0.017	0.006

Table 1 Chemical composition of investigated slab (wt.%)