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Austenite Grain Growth Behavior after Recrystallization Considering Solute-Drag Effect and Pinning Effect

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In this study, a predictive model was developed to estimate the austenite grain growth behavior after recrystallization during hot rolling of microalloyed low-carbon steels. The features of the model are as follows: (1) the solute drag effect of not only niobium (Nb) but also molybdenum (Mo) was assessed, (2) the Nishizawa formula was used to quantify the pinning force of titanium (Ti) nitride instead of the Zener formula, and (3) the formula for driving force in grain growth for tetradecahedral grains was used instead of that for spherical grains. Austenite grain size calculated by the model was in good agreement with that obtained from experimental results.

INTRODUCTION

High strength and excellent toughness at low temperatures have been required for line pipe steels to achieve safety and reliability in pipelines for oil and natural gas transportation. Control of austenite grains during hot rolling is effective for improving the toughness of steels by grain refinement. In particular, it is important to suppress grain growth after rolling in the recrystallization region for austenite grain refinement, and it is also important to retard recrystallization during rolling in the non-recrystallization region for increasing the austenite grain boundary area and the formation of a deformation band.

To obtain austenite grains with these desirable characteristics, alloy elements such as niobium (Nb), titanium (Ti), and molybdenum (Mo) are added to steels. These steels are called microalloyed steels. It is well known that grain growth and recrystallization are affected by these alloy elements because of the solute-drag effect of solute atoms and the pinning effect of particles. A model of recrystallization that incorporates the solute drag and pinning effects was proposed (Zurob et al., 2001). This model took account of only the solute-drag effect of Nb atoms on mobility, and the Zener formula was used to quantify the pinning force in this model (Smith, 1948). Although numerous empirical relations have been developed to describe the kinetics of recrystallization in microalloyed steel (Sellars and Davies, 1980; Yoshie et al., 1987), the model proposed by Zurob et al. (2001) is a physics model of recrystallization kinetics having a solute-drag effect and pinning effect. The model is more expandable to various cases than empirical relations because the model treats the physical constants. For example, it is possible to describe the recrystallization behavior by using the model instead of empirical relations, although the chemical compositions of steels greatly vary. The predictions of this model were in excellent qualitative agreement with experimental results as well as empirical relations. Although a good formulation of recrystallization has been proposed, a model that considers the solute-drag and pinning effects on grain growth behavior after recrystallization has not been proposed.

This paper describes a model of grain growth that considers the solute-drag effect, pinning effect, and driving force of grain growth, where the latter takes into account the grain shape.

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KEY WORDS: Line pipes, recrystallization, grain growth, solute-drag effect, pinning effect, model, alloy element.

EXPERIMENTAL PROCEDURE

The chemical composition of the steel used in this study is shown in Table 1. The steel was melted in a 300-kg vacuum furnace and rolled to a thickness of 100 mm. The austenite grain growth was investigated using a hot-deformation simulator. Specimens for the simulator, with a diameter of 8 mm and length of 12 mm, were cut from the hot rolled plates.

The test conditions of the hot processing simulator are shown in Fig. 1. These specimens were reheated at 1,150°C or 1,300°C for 600 s and cooled to the deformation temperature (1,050°C or 1,150°C). Once the temperature was stabilized, a compression test was conducted at a strain rate of 5 s^{-1} and a true strain value

C	Nb	Ti	Mo	N	Others
0.040	0.029	0.015	0.170	0.0032	Si, Mn, Ni

Table 1 Chemical compositions of tested steel (mass percent)

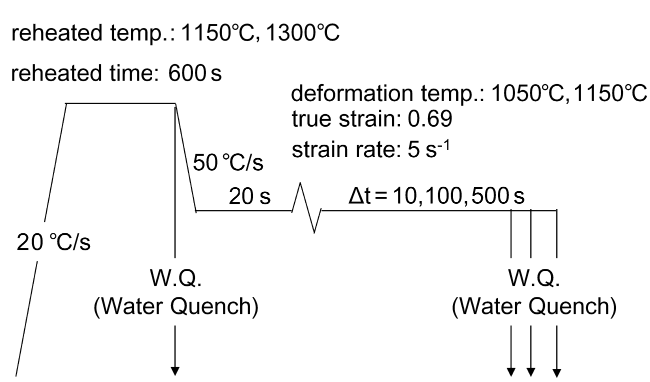

Fig. 1 Test conditions of hot processing simulator