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Recrystallization Behavior Design for Controlling Grain Size in Strip Rolling Process

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Abstract: To promote effectively dynamic recrystallization and obtain a homogeneous distribution of ultrafine grain size in strip finish rolling process, the behavior of static and dynamic recrystallization must be appropriately designed to provide an ultrafine austenite microstructure without mixed grain size. The design of rolling schedule was analyzed based on the control of the recrystallization behavior to achieve ultrafine grain size in the strip rolling process of niobium microalloyed steel. The experimental simulations were presented to validate the twice dynamic recrystallization design to achieve ultrafine grain size control.

Key words: twice dynamic recrystallization; critical strain; dynamic recrystallization; ultrafine grain size

The key advantage of high-grade of line-pipe steels is high toughness at low temperature (−60 ℃) with high strength, which can be achieved by refining the grain size. The grain size can be refined by dynamic recrystallization or/and strain-induced phase transformation. With the progress of modern technologies, the refinement of grain size by dynamic recrystallization is more interesting in industrial processing, using which a finer grain size than that by strain-induced phase transformation can be obtained[1]. Ferrite grain size can be refined by preferred nucleation in the grain boundary of ultrafine dynamically recrystallized austenite microstructure, which provides a high nucleation rate and nuclei density[2,3]. To obtain ultrafine austenite grain size, the dynamic recrystallization must be promoted under the condition of large Zener-Hollomon parameter Z, which corresponds to a large strain rate and a low rolling temperature. However, on the other hand, the large Z is associated with a large critical strain for dynamic recrystallization. While this large strain can be obtained in laboratory by single pass large reduction[1,4], it is not possible in industrial practice, especially with a coarse initial grain size. In industrial application, the large strain should be only accumulated pass by pass in multipass rolling process. In this case, the time-temperature-deformation schedule must be designed properly to promote dynamic recrystallization at the required pass to the exclusion of partial static recrystallization during the interpass time to eliminate the mixed grain size.

To obtain ultrafine austenite grain size, the strain accumulation should be large enough to overcome the large critical strain for dynamic recrystallization associated with large Z. The critical strain for dynamic recrystallization is closely related to Z and also to the initial grain size of roughing. The coarser the initial grain size, the larger is the critical strain for dynamic recrystallization[5]. When the critical strain for dynamic recrystallization is very large because of the coarse initial grain size of roughing, it is impossible to obtain large enough strain accumulation to promote dynamic recrystallization because of the limitation of the practical mill condition. In this case, the design of multi-times dynamic recrystallization or/and a combination of static and dynamic recrystallization will be required to resolve this problem.

When partial static recrystallization occurs during the interpass time before the final dynamic re-

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crystallization, mixed microstructure will invariably result with a larger grain size from static recrystallization and a finer one from dynamic recrystallization[6]. This mixed microstructure will impair the toughness properties of the steels. In the design of the rolling schedule, the recrystallization behavior must be designed to promote dynamic recrystallization without partial static recrystallization during interpass time in multipass rolling process to eliminate the mixed grain size. Finally, the design of pass reduction must assure the total reduction to meet the final thickness requirement of the products.

In summary, the design of industrial applicable rolling schedule for the control of ultrafine grain size through dynamic recrystallization is a complicated optimization process in which the thermodynamic and kinetic behaviors of static and dynamic recrystallization, the effect of the initial grain size on the recrystallization behavior, the limitation of mill capability, the requirement thickness of product as well as the shape control must be considered comprehensively.

1 Experimental

High temperature performance (HTP) steel with a composition in mass percent (%) of C 0.026, Mn 1.49, Nb 0.097, Si 0.15, P 0.012, and S 0.001 was used for experimental investigation. The experimental database generated by Lutz-Meyer and his co-worker was employed for modeling analysis. The critical strain for static recrystallization and the experimental validation of the modeling results were investigated by WUMSI (Warm-UMform-Simulator), a computer-controlled thermal-deformation simulator in Max Planck Institute, Dusseldorf, Germany. The grain size was determined using optical metallography.

2 Results and Discussion

2.1 Effect of initial grain size on critical strain for dynamic recrystallization

To promote dynamic recrystallization, the strain accumulation should be large enough to overcome the critical strain for dynamic recrystallization. The calculation of critical strain for dynamic recrystallization is basically required to design the rolling schedule for the control of ultrafine grain size, which is closely related to the parameter Z as investigated in Ref. [6]. Furthermore, according to Fernández A I and his co-workers, the critical strain for dynamic recrystallization is also a function of the initial grain size of roughing[6]. Based on the analysis in Ref. [5] and the experimental database generated by Lutz-Meyer in HTP steels[7], the critical strain for dynamic recrystallization can be estimated from Eqn. (1).

$$\varepsilon = d_0^{0.147}(0.0299\ln Z - 0.598) \quad (1)$$

where ε is critical strain for dynamic recrystallization; and d_0 is initial grain size.

To prevent the partial static recrystallization during the interpass time, the critical strain for static recrystallization is an important parameter for rolling schedule design. The critical strain for static recrystallization is determined by the experiments on WUMSI and is combined with the analysis of the effect of the initial grain size, which was calculated as expressed in Eqn. (2).

$$\varepsilon' = d_0^{0.147}(-3.15\times 10^{-3} T + 3.774) \quad (2)$$

where ε' is critical strain for static recrystallization; and T is temperature, K.

2.2 Design of recrystallization behavior for ultrafine grain size control

The dynamic recrystallization for the grain size control was designed at the 6th pass just before the last pass in a seven-pass finishing processing based on the assumption that the last pass with small reduction could be used as a skin pass to affect the shape control. Also, the strain in the last pass introduced adequate dislocations, which provides an additive effect of grain refinement by strain-induced phase transformation along with ultrafine austenite grain size.

To promote the dynamic recrystallization at the 6th pass, static recrystallization during the interpass time in multipass rolling processing should be minimized to keep a possibly large pass deformation for accumulated strain. However, incomplete static recrystallization during the interpass time causes a mixed grain size[8], which affects the toughness properties at low temperature. Thus, the static recrystallization should be suppressed during the interpass time, i.e. the rolling schedule must be designed to only promote dynamic recrystallization without the occurrence of static recrystallization during the interpass time to obtain homogeneous ultrafine austenite grain size. To meet this requirement, the pass reductions must be designed just below the critical strain for static recrystallization at each pass. In the rolling schedules proposed for industrial simulations, the rolling temperature win-