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Research Paper

Central infiltrated performance of deformation in ultra-heavy plate rolling with large deformation resistance gradient

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HIGHLIGHTS

- A rolling method with large deformation resistance gradient is proposed.
- FEM is studied considering effect of oxide scale thickness and specific heat changing.
- Equivalent strain with large temperature gradient gradually moves to the central part of the plate.
- Average ferrite grain size at the center of the plate decreases and mechanical properties increase.

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ABSTRACT

To solve the problem of poor infiltrated performance at the center of ultra-heavy plate, rolling method with large deformation resistance gradient was investigated. FEM was used to study the formation law of the temperature field which considers effect of oxide scale thickness and specific heat changing in thickness direction, then temperature distributed regularity with different heat transfer coefficients in thickness direction of the plate was obtained. Effect of temperature gradient as well as reduction ratio on the equivalent strain was studied in ultra-heavy plate rolling process with large deformation resistance gradient. Numerical simulation showed that the equivalent strain of ordinary rolling mainly occurred on near surface of ultra-heavy plate; nevertheless, the equivalent strain of plate rolling with large deformation resistance gradient does not occur on near surface but gradually moved to the central part of the plate as heat transfer coefficients increase. Experimental results have shown that the average ferrite grain size at the center of the plate can be decreased from 27.51 μm to 22.92 μm when reduction ratio is 10% and even decrease to 19.05 μm when reduction ratio increases to 20%, which results in a significant increase in mechanical properties. The equivalent strain increases by 0.18 from experiment work and 0.1411 from FEM as the reduction ratio increasing from 10% to 20%, so the equivalent strain have the same variation trend.

1. Introduction

Central defect is one of the most intractable quality problem in manufacture of ultra-heavy plate, which results in quality problems such as quality instability, substandard mechanical properties, failure of the fracture surface and so on [1–3]. Large reduction in ultralheavy plate rolling process is often used to decrease the central grain size and improve mechanical properties [4–7], but the deformation in thickness direction is asymmetrical and the compression ratio at the center is too small in ultra-heavy plate rolling process, so it is significant to increase the deformation of ultra-heavy plate in the center part, which can improve the microstructure property of the plate center as well as the deformation uniformity in thickness direction [8]. Deng and Zhao [9] indicated that the critical reduction to close the rectangle crack in a 140 mm thick plate is 14%, but the internal pores and cracks are difficult to close in the ultra-heavy plate rolling process. In the 1990s, continuous forging was used with a pair of anvils installed in the strand before complete solidification, which can squeeze out solute-enriched liquid in the mush zone and improve the center porosity and internal cracks [10]. But this method is more suitable for ingots than continuous casting.

Rolling technology with large deformation resistance gradient is a rolling process with a nearest fast cooling equipment ,during which the plate temperature of center part is still high but surface temperature decrease very quickly. When rolling process starts, temperature of the upper and lower surfaces is lower than that in the central part, the deformation resistance becomes larger and the deformation is not easy to happen. But temperature in the center part

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Table 1
Material parameters.

Parameters	Roll	Plate
Young's modulus (GPa)	210	117
Density (kg/m^3)	7850	7850
Poisson's ratio	0.3	0.36

is higher, in which deformation is more prone to happen [11,12]. This will cause the deformation to go deep into the center part of the ultra-heavy plate and increase the quality of the center part. In addition, large deformation resistance gradient of ultra-heavy plate can also reduce the dual drum shaped defect and improve rolling yield of finished products.

In this paper, FEM was used to investigate the generation rules of the temperature field and the performance of deformation in thickness direction of ultra-heavy plate, which considers effect of oxide scale thickness and specific heat changing in thickness direction. Then, experiment with large gradient of deformation resistance was carried out under laboratory conditions so as to verify the accuracy of the analysis, by which the influence rules of infiltrated performance can be obtained. The work explores the influence of the temperature gradient on the microstructure and mechanical property in the center of the plate with different reduction ratios, and proposes an innovative ultra-heavy plate rolling process for effectively eliminating this casting flaw and improving plate properties.

2. FEM model and experimental method with temperature gradient

2.1. FEM by DEORM-3D and mathematical model

To simulate actual rolling process in ultra-heavy plate rolling on gradient temperature conditions, similar geometrical characteristic and boundary conditions of experiment are carried out because of laboratory mill limitation. The continuous casting slab is 100 mm thick, 120 mm wide, and 400 mm long; diameter of work roll is 600 mm, length of work roll is 500 mm. Although the width spread may affect strain distribution to some extent in thickness direction, the trend of strain in thickness direction will not be changed, and the strain change induced by spread is a transverse component. So the lateral spread was therefore ignored in the analysis of experiments [13,14]. A rigid material model was used for work roll, and its deformation was neglected. The main material parameters are listed in Table 1. Temperature distributions across the slab thickness were calculated by DEFORM-3D, which takes 1/4 of the slab for numerical simulation because the rolling process is symmetrical; element numbers are 20, 100 and 144 respectively in thickness direction, width direction and length direction as shown in Fig. 1.

The coefficient of friction has a large impact on the hot rolling process; its calculation accuracy can not only affect the forecasting precision of rolling load but also affect the metal floating law of plate. Large temperature gradient increases the range of surface temperature of plate and the coefficient of friction between the plate and roll changes significantly with surface temperature of ultra-heavy plate, so measurement experiment of friction coefficient is carried out on laboratory conditions and the result of which is shown in Fig. 2.

Oxide scale thickness will increase during the process of heating in furnace, transporting in the roll table as well as rolling in the plate mill, and it will influence the heat transfer process of the steel plate, so it is meaningful to study the changing process of oxide scale thickness; diagram of oxide scale thickness as time changes is shown in Fig. 3.

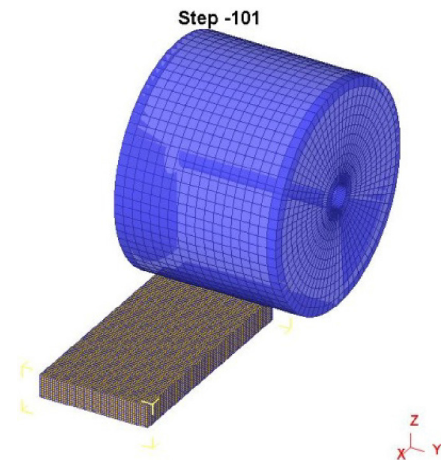

Fig. 1. The finite element model and grid division.

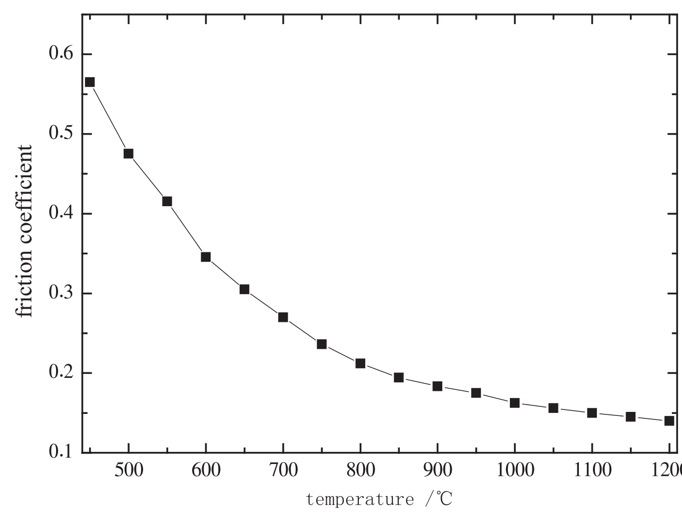

Fig. 2. Coefficients of friction with different temperatures.

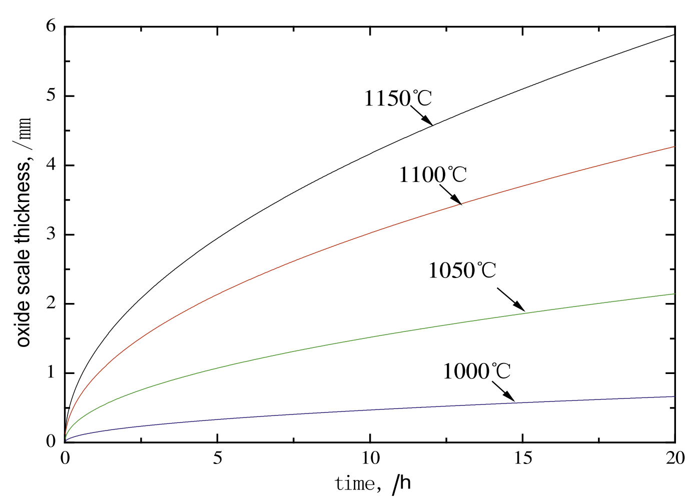

Fig. 3. Diagram of oxide scale thickness as time changes.