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Original Research Article

Formation mechanism and control methods of inhomogeneous deformation during hot rough rolling of aluminum alloy plate

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ABSTRACT

The inhomogeneous deformation which appears in hot rough rolling of aluminum alloy plate, reduces rolling output and negatively affects the rolling process. To study the formation mechanism of the inhomogeneous deformation, a finite element model for the five-pass hot rough rolling process of aluminum alloy plate is built. Results show that inhomogeneous deformation distribution in thickness direction causes two bulges at head and tail ends, as indicated by the analysis of the equivalent plastic strain distribution and deformation. However, formation mechanism of the inhomogeneous deformation at head end differs from that at tail end. Changing the end shape and angular rolling are adopted for decreasing the length and width of the crocodile mouth. It can be found that the crocodile mouth can be improved effectively by increasing the central bump length and the rotation angles through simulation and experiments. Then, the combination effect of two methods is simulated and results show that the combination effect is better than respectively using of each method. In addition, combination of two methods can avoid the restricted conditions for respectively using of each method.

1. Introduction

Aluminum alloys have been the preferred lightweight metallic materials since beginning of the 21st century. Hot rough rolling is a critical process in production of aluminum alloy sheets and strips. Aluminum alloy ingots can be rolled into sheets which can be used in aerospace industry [1].

The typical thickness of an aluminum alloy ingot is between 400 and 630 mm. The thickness is considerable and can lead to inhomogeneous distribution in thickness direction of plate at head and tail ends. The elongation of metal near the surface of plate is greater than that at the center. Thus, the end shape appears like an opening mouth instead of a flat plane, as shown in Fig. 1.

If there is no restriction, the inhomogeneous deformation distribution will cause an end shape called lamination or crocodile mouth [2] after multi-pass of rolling, as shown in Fig. 2. The crocodile mouth will be cut completely and negatively affect the yield of aluminum alloy sheets and

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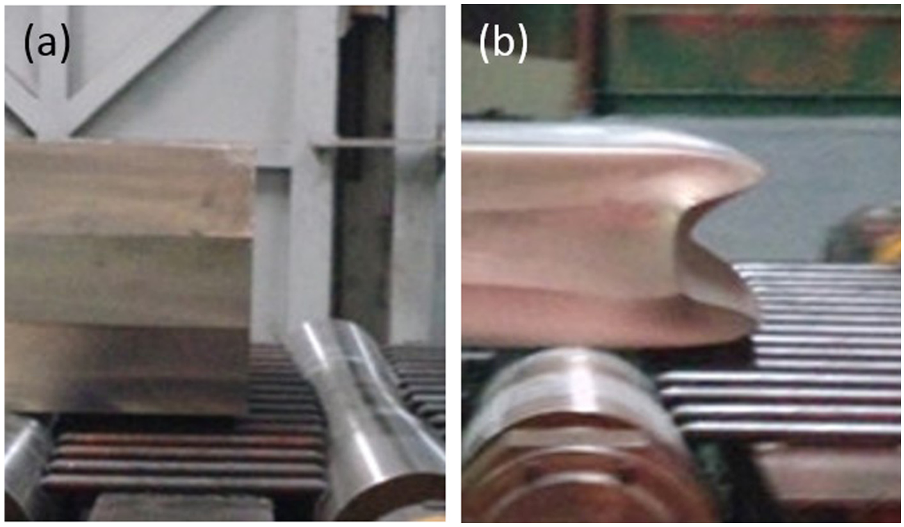

Fig. 1 – End shape of aluminum alloy thick plate: (a) before rolling; (b) after 2nd pass.

strips so its formation mechanism should be studied for improving crocodile mouth.

The plastic deformation of aluminum alloy has been researched for a long time by a large number of scholars. Guan et al. [3] studied a sloping semi-solid rheo-rolling process of Mg–3Sn–1Mn alloy and found that when casting temperature was 670 °C, rolling speed was 52 mm/s and vibration frequency was 60 Hz, the Mg–3Sn–1Mn alloy strip with good properties was produced. Khamei et al. [4] studied the effects of temperature and strain rate on plastic deformation of 6061 aluminum alloy and found that grain was refined and plasticity was better with a larger plastic deformation. Zhang et al. [5] introduced the application of snake rolling in 7075 aluminum alloy rolling process, and analyzed velocity field and strain field in snake rolling process using DEFORM. Novella [6] checked fracture criterion of AA6082 aluminum alloy under hot rolling conditions with experiment and simulation methods.

Besides the research on the microstructure of aluminum alloy, the rolling process of aluminum alloy plates and strips have also been studied widely. Ashtiani et al. [7,8] developed a mathematical model to predict the thermal history and inhomogeneity of temperature through thickness of an aluminum alloy strip using Abaqus/Explicit in three dimensions. Hu [9] optimize the hot rolling schedule of aluminum alloy using the multi-objective optimization algorithm with an adaptive neural network. Yang et al. [10,11] using the algorithm of DE-EDA and chaotic particle swarm for optimizing the rolling schedules of aluminum alloy hot rolling. Ding [12] analyzed the rolling of AM60 sheets using DEFORM and found the effective strain distribution in thickness direction was inhomogeneous. Jiang et al. [13] developed a precision online model for the prediction of thermal crown in hot-strip rolling processes and found the proposed method was effective and had high performance by comparing the prediction values for the thermal crown with the production data in an aluminum alloy hot rolling process.

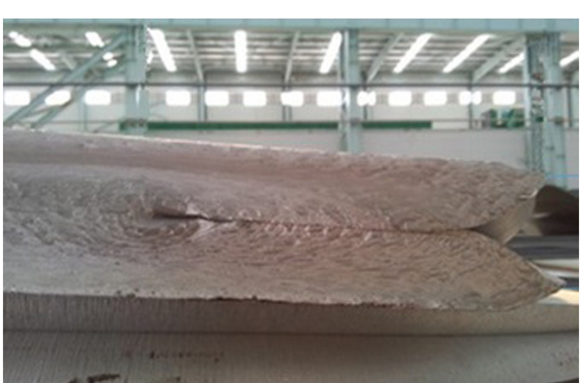

Fig. 2 – The crocodile mouth after multi-pass of rolling [2].

Besides traditional elastoplastic model used widely in simulation of hot rolling, recently viscoplastic model got more attention in deformation of metal. Schindler et al. [14] proposed a novel empirical constitutive law for thermo-viscoplasticity, which considered isotropic strain and strain rate hardening as well as thermal softening. They found that the model was suitable to describe the material behavior of Al2024 accurately over a large range of loading conditions and with the use of the proposed constitutive law, a variety of applications could be modeled. Nellippallil et al. [15] developed a transient thermos-mechanically coupled finite element method based model for single pass hot rolling of AA5083 aluminum alloy. The simulation results indicated that accurate estimates of constitutive behavior of the alloy were critical for precise hot rolling model. Zhou et al. [16] investigated defects that occurred during ring rolling by a 3D rigid-viscoplastic finite element model and analyzed PEEQ, stress, and temperature distributions in different deformation zones. They found that there were strain peaks appearing in the cross-section corners, then forming defects and microstructure damage would appear in cross-section corners due to the high-strain deformation.

However, only a few researchers have focused on the crocodile mouth caused by inhomogeneous deformation distribution in the thickness direction of plate. Liu [2]