Numerical Simulation of Aluminum Alloy Hot Rolling using DEFORM-3D

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Abstract—The flow stress behavior of 6016 aluminum alloy was studied by single-pass high temperature compression experiment on Gleeble-1500 thermal-mechanical simulator and the derivational constitutive equations was prepared for the computer simulation. Numerical model of 5182 aluminum alloy hot rolling was built using DEFORM-3D. By compared the measured value with the predictive value, we found the model error was blow 5% and it's good enough for the actual production needs. Based on the 5182 model, the 3D numerical model of 6016 aluminum alloy was built and can provide theoretical parameters in design of the actual production process.

Keywords: DEFORM-3D, hot rolling, numerical simulation

I. INTRODUCTION

Rolling force is one of the important force-power parameters in metal hot rolling process, accurately prediction of the rolling force of the rolling process is great significant for establishing a reasonable rolling schedule and to fully exploit the potential of rolling mill. It’s very high practical value [1-5] for developing reasonable aluminum rolling schedule to establish accurate rolling force model in making reasonable process schedule, to determine the rolling force and force-energy parameters of aluminum rolling process rapidly and accurately. In present the researches of numerical simulation of hot-rolling process, such as rolling force mathematical model, are in most cases for steel rolling, not or rarely for aluminum rolling as reported.

DEFORM-3D is a finite element methods (FEM) software based on process simulation, specifically designed to analyze three-dimensional (3D) metal flows in metal deforming process, to provide valuable process analysis data, and to analyze materials flow and temperature distribution related in the forming process [6].

In this paper, to utilize finite element software, DEFORM-3D, a 6016 aluminum alloy hot strip rolling force model was established based on experimental model of deformation resistance of aluminum and process parameters from an aluminum plant. And the 5182 aluminum rolling force prediction model was established by modifying the material parameters related to the model of rolling force and the four-stand rolling forces was predicted, that would provide the basis for actual production of aluminum alloy strips.

II. DEFORMATION RESISTANCE MODEL OF ALUMINUM

A. Experimental results

Experimental material is 6016 aluminum alloy, cylinder prepared by cutting the size φ10 mm × 15 mm. The specimens carried out homogenization process in the box-typed resistance furnace: 550 °C heat preservation for 12 hrs and afterwards water quenching released. Compression test was performed on the Gleeble-1500 thermal simulation machine. Before compression process, both ends of a cylindrical specimen filled with a lubricant mixture of 75% graphite +20% mesitylene oil +5% nitrate trimethylbenzene grease to reduce friction on the compression interface. Experimental temperature in test ranged at 300 ~ 500 °C, strain rate at 0.1 ~ 10 s⁻¹, the total compression strain 0.8 (true strain). The specimens treated immediately by water quenching after deformation ended.

High temperature deformation behavior of materials can be described by flow stress equation. The classical models are Zuzin and Browman model, Zener-Hollmon parameter model, Slater relational model, etc. [7-8]. In this paper, the 6016 aluminum alloy deformation resistance model’s built according to Zener-Hollmon parameter model format, as follows:

\[
\sigma = \frac{1}{0.0183} \ln \left( \left( \frac{Z}{2.62 \times 10^7} \right)^{\frac{1}{\gamma}} + \left( \frac{Z}{2.62 \times 10^7} \right)^{\frac{2}{\gamma}} + 1 \right)^{\frac{1}{\gamma}}
\]

(1)

where, \(Z = \delta \exp \left( \frac{270257}{RT} \right)\)

(2)

B. Verification of the constitutive model

Deformation resistance model accuracy of aluminum alloy has the most important influence on prediction of rolling force. To examine the accuracy of the constitutive equation of flow stress, comparison of the true stress - true

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strain curve, the measured to model-based predicted values of the 6016 aluminum alloy in isothermal deformation condition, at 1 s⁻¹ of strain rate and at 300 ~ 500 °C of deformation temperature, was made, as shown in Figure 1.

Figure 1 demonstrates that there is a good agreement of the predicted curve with the corrected experimental curve. Figure 2 shows the error analysis diagram of the flow stress at strain rate of 1s⁻¹ and at temperature of 300 ~ 500 °C, it can be seen that errors of the predicted compared with the experimental, are less than 7%, that means, the deformation resistance model’s precision meets the requirements of engineering application. This provided the basis for setup of the finite element models and simulation of rolling process in following sections.

III. FINITE ELEMENT MODEL

In order to reduce the amount of calculation, the rigid plastic physical model of 1/4 geometry can be chosen as finite element model due to symmetrical characteristic of the plate rolling process, as shown in Figure 3.

In process simulation the last calculation step of the previous stand will be treated as the beginning of the next following stand, avoiding the problem of not to be bitted as a result of the tiny deformation of rolling plate due to step nonsequence. Both the rolls and rolling piece models, which were built up via the UG software, were imported into DEFORM-3D. During simulation process, the rolls assumed as rigid body, no deformation during rolling process. The rolling plate, AA5182 aluminum alloy, adopted rigid plastic material constitutive relation, the rolling temperature ranged from 283 °C to 219 °C. Detail model parameters set in Table 1.

Table 2 shows the process parameters of the rolls and plate for the four-stand continuous rolling process. F1 ~ F4 corresponds to 1st to 4th stand, respectively.

Table 3 shows the material parameters for 6016 and 5182 aluminum alloy.

A. The 5182 aluminum alloy simulation contrast to experimental
Figure 4 shows prediction curve of rolling force for the 5182 aluminum alloy, in contrast to experimental rolling force (in average), a, b, c and d corresponding to F1, F2, F3 and F4 stand of the rolling mill line, respectively.

It can be perceived from figure 4, the simulated roll force curve is in steady during rolling simulation process, that means, rolling force can be predicted preferable. In the figure the dashed rolling force curves indicate average actual rolling force in production, in contrast, the real curves represent the predicted value of every simulation step. Figure 5 shows the comparison of the predictive value of rolling force, in average, with the measured. And error of predicted values compared to measured average in the figure, less than 5% among the four stands, indicates predicted values are in good agreement with the measured, in other words, the roll force model has high accuracy.

B. The 6016 aluminum alloy simulation and prediction

The rolling force prediction model of 6016 aluminum alloy were established based on 5182 aluminum alloy. The process parameters and structure parameters of rolling plate and rolls, with the same size, were described as above. Calculated rolling force prediction curves of 6016 aluminum alloy shown in Figure 6, a, b, c and d corresponding to F1, F2, F3 and F4 stand of the rolling mill line, respectively. The figure indicated simulation of rolling force of this alloy is steady during rolling process. It can provide a theoretical basis and analysis methods for design and development of 4-stand continuous rolling process parameters of 6016 aluminum alloy.

V. CONCLUSION

(1) 6016 aluminum alloy deformation resistance model, obtained by experimental and regress, validated high accuracy of the model, can provide the basis for the finite element simulation.

(2) A 5182 aluminum alloy rolling force model was established, by compared the simulation predicted value
with the actual production process average both can be in
good agreement with, errors below 5%.
(3) The rolling force prediction model of 6016
aluminum alloy were established in the same way which
applied to 5182 aluminum alloy. Simulation rolling force
predicted curve can provide a theoretical reference to design
and development of 4-stand continuous rolling production
process parameters of 6016 aluminum alloy actually, that
needs to be verified in the following further researches.

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