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Prediction of austenite grain distribution with FE-based modeling in bar rolling

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For better prediction of the grain size and its distribution in bar rolling, non-isothermal 3-D finite element analysis combined with the austenite grain size (AGS) evolution model available in the literature was performed. To verify the proposed approach, austenite grain size and its distribution in low speed (34 rpm) bar rolling were measured using a laboratory hot bar rolling mill. The measured micrographs revealed that grain size was larger at the boundary than at the interior zone, indicating that metadynamic behavior was dominant at the interior zone while the boundary was affected by static recrystallization.

1. INTRODUCTION

Environmental awareness and fuel economy require the weight reduction of automobile and subsequent strength increase of steel. This trend was accelerated to meet the need for social infrastructure with larger dimensions. In this regard, quantifying the relation between processing conditions and mechanical properties of the final rolled products has been highly desired. So far flat rolling process under the plane-strain deformation condition was mostly investigated. Thus, this study focuses on the bar rolling with multi-axial deformation conditions.

Using hot bar rolling mill, the austenite grain distributions were investigated for AISI1020 (S20C) steel. A series of numerical simulations was conducted for predicting austenite grain evolution of AISI1020(S20C) steel and the results were compared with the measured ones to investigate the validity of the numerical AGS modeling. The influences of process variables on AGS distribution were also examined for multi-pass processes. In this investigation, the uniformity and homogeneity of the grain size distribution were taken as characteristic parameters for predicting and controlling the grain size distribution.

2. EXPERIMENTAL

To measure austenite grain distribution in the low speed bar rolling, several rolling experiments were carried out in a single pass pilot mill, using AISI1020(S20C). Fig. 1(a) illustrates the schematic for preheating-rolling-quenching experiment process employed. To measure the thermal responses of the workpiece, three K-type thermocouples were inserted into the specimen as Fig. 1(b). The specimen was soaked in the reheating furnace for 20 minutes and then transferred to the roll guide at slightly higher temperature than the rolling temperature. The specimen was pushed into the roll gap when the target temperature was reached. After rolling it was maintained at the rear supporting plate for the given holding time (2, 5, and 20 sec). Then it was quenched in the water bath and cooled by stirring. Austenite grain distribution on the cross section was measured and average grain sizes at the interested points were calculated with the planimetric method according to ASTM standard E112 [1].

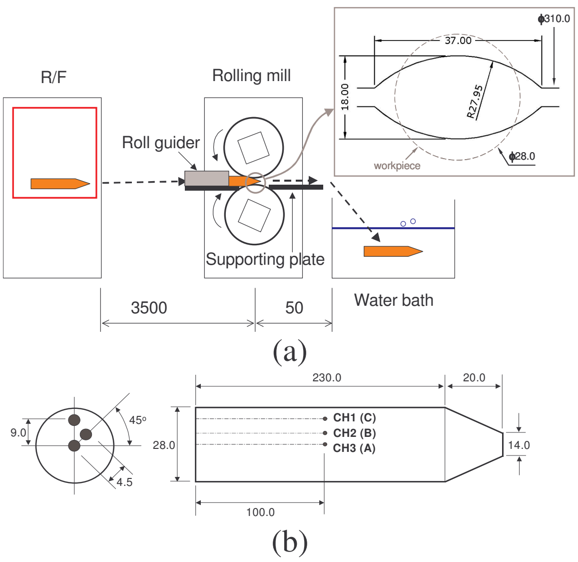

Fig. 1 (a) Experimental set-up and (b) thermocouple positions in the workpiece (unit: mm).

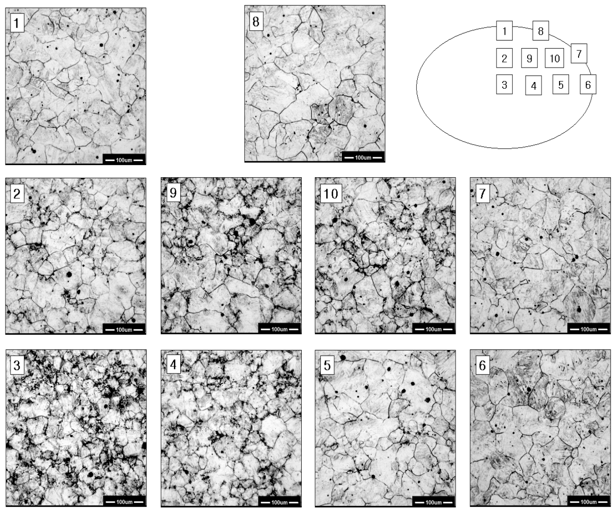

Fig. 2 Austenite grain distribution at the cross-section of the quenched specimen (T = 1000 ^{o}C, hold time = 20 s) (The numbers in elliptic section corresponds to the numbers in the micrographs).

Fig. 2 shows the optical micrographs at 10 points on the cross-section of the deformed workpiece when AISI1020(S20C) specimen was rolled and quenched after 20 seconds elapsed. More grain refinement was observed at the inner zone (Positions 2, 3, 4, 5, 9, and 10) than at the boundary (Positions 1, 6, 7, and 8). These overall distributions were also observed when the interpass time before quenching was set to be 2 and 5 seconds.

3. GRAIN SIZE PREDICTION

To get better understanding of the microstructural changes, a hot torsion test-based AGS evolution model was adopted and was integrated with the finite element analysis as Fig. 3. The AGS model proposed by Hodgson and Gibbs [2] was used to model the microstructural behaviors of AISI1020(S20C), which is applicable to a wide range of C-Mn steel and HSLA steel.

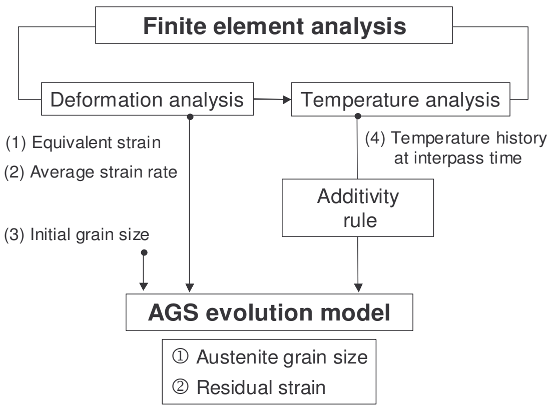

Fig. 3 Integration of the FE analysis with the AGS evolution model by Hodgson and Gibbs [1] .

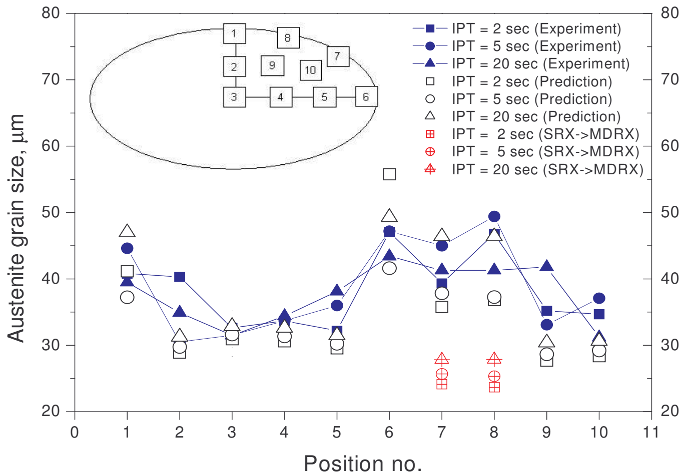

Fig. 4 Comparison of experiment and prediction at 10 positions at the workpiece cross-section.

3.1. Outline

To determine the process parameters such as strain, strain rate, and temperature, three-dimensional finite element program [3-5] was developed and applied. In this program, the equivalent strain and time-averaged equivalent strain rate were given as deformation parameters. To apply the AGS model to the transient thermal conditions, the additivity rule was applied. The thermal history obtained from the FE analysis was discretized into isothermal steps and all the kinetic equations were applied at each time interval.

3.2. Verification

In Fig. 4 predicted local AGS was compared with the experimental results. Although some discrepancies were observed, the overall trend of the local AGS distribution was in agreement with the measurement. The predicted AGS value at the center (Position 3) was almost identical to the measurement.

4. APPLICATION

Based on the above verification of current approach for a single pass, the AGS characteristics in multi-passes were investigated. For a systematic investigation of the effect of process parameters on the AGS distribution, two criteria indicating the average grain size (F_1) and grain size deviation (F_2) were proposed. Grain size minimization is important but the homogeneous feature of the grain size distribution is also of great importance since the locally irregular grain sizes can severely deteriorate the overall strength of the rolled bar in service.

As an example of multi-pass rolling sequence, a new rolling process was designed as shown in Fig. 5, which transforms the 50 mm round specimen into 20 mm round bar. Initial workpiece temperature and rolling speed were chosen as major parameters because they are normally controllable in a existing roll pass schedule. Their effects on the two criteria were examined by changing the roll speeds from 30, 90, to 150 rpm and the initial workpiece temperatures from 1100, 1000, 950, to 900 ^{o}C. In total 12 cases (3×4) were simulated and the final AGS predictions were summarized in Fig. 6.

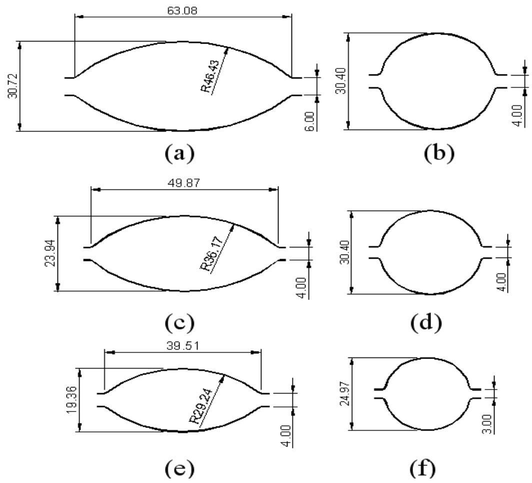

Fig. 5 Designed roll geometries with six-pass sequences: (a) pass 1, (b) pass 2, (c) pass 3, (d) pass 4, (e) pass 5, (f) pass 6.

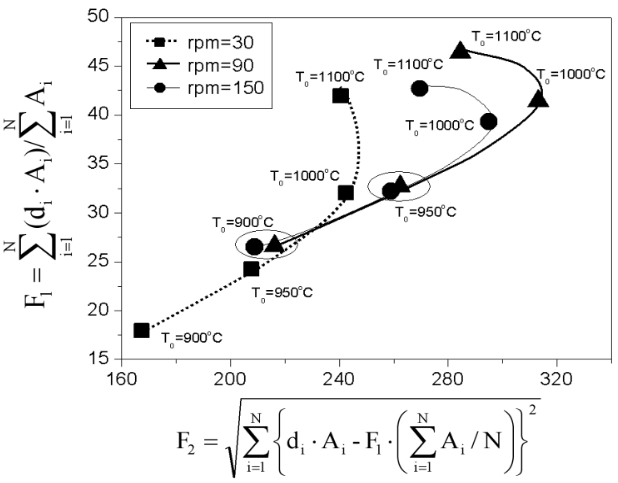

Fig. 6 Variations of average grain size and grain size deviation at the sixth pass with initial rolling speed and initial temperature.

When the temperatures were between 900 °C and 1000 °C, the temperature decrease reduced the two criteria simultaneously. When the rolling speed was 30 rpm, the most grain refinement was obtained. Thus, under the rolling condition of 900 °C and 30 rpm, the average grain size was refined up to 18 μm. Although two variables affected the grain size evolution, the temperature was found to be more significant parameter for the grain size control.

5. CONCLUSIONS

Local AGS distributions in low speed bar rolling were studied through rolling experiments. For better understanding of the AGS distribution, finite element analysis was combined with AGS model to obtain local grain distributions. Following conclusions were arrived at:
(1) In round-oval rolling of AISI1020(S20C), more grain refinement was obtained at the interior zone of the rolled specimen than at the boundary region.
(2) Current numerical approach showed quite a good agreement with the experimental result.
(3) In the multi-pass rolling sequence, if the initial temperature could be reduced, both the AGS refinement and homogenization could be obtained.

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