Variations in Recrystallization Kinetics of Magnesium Influenced by <11-20>Twinning During the Hot Rolling Process

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Abstract: In this work, we proposed a spatialized temporal method to reveal the structural evolution of Mg during hot rolling process laterally, and then the recrystallization kinetic behavior of Mg affected by twinning during different passes of rolling was reported.The results show that recrystallization occurs preferentially close to the sample boundary, and multiple rolling passes result in a grain size gradient distribution along the sample boundary at an angle, which is related to the roll radius and the strain. In addition, high-angle $<11\bar{2}0>$ tensile twins impede twinning of recrystallized grains, whereas grains without high-angle tensile twins are prone to form twins within the system when DRX occurred, reducing the stressgradient between the recrystallized grains and the parent grains. It is well established that a clear linear correlation exists between the stress gradient and the strain hardening rate, leading to non-uniform deformation-induced strengthening.Through this work, we are hopeful to provide insightsforstress gradient or homogenization of rolled samples by modulating the initial twinning state.

Keywords: Dynamic recrystallization, Magnesium, Hot rolling, Grain refinement, Stress gradient.

1 Introduction

Dynamic recrystallization in Mg usually affected by tensile twinning due to c-axis or perpendicular-to-c-axis forces during plastic deformation[1]. The twins provide the driving force for recrystallization through lattice strain as well as energy stored in grain boundary defects[2]. It is generally believed that a lower dislocation density prevails within the recrystallized grains, which tends to form a strain gradient with the parent crystal, and this strain distribution leads to non-uniform deformation of the recrystallized and non-recrystallized regions in tensile tests, which creates a source of hetero-deformation induced stresses and enhances the strong plasticity of the material[3].However, we find a strain homogenization phenomenon during pure Mg rolling that differs from the above conclusions, and propose a spatialized time continuum approach to analyze the contribution of high-angle $<11\bar{2}0>$ twins to this stress phenomenon.

2 Experimental procedure

Commercially pure magnesium (purity > 99.9%) was selected as the initial material for rolling to investigate recrystallization behavior independently of the second phase influence.The hot rolling temperature was 673K, with the samples preheated at this temperature for 1 hour before rolling, followed by a five minutes re-hold at 673K after each pass. The work roll temperature was 423 K, operating at a speed of 5 r/min with a roll diameter of 130 mm.

Fig.1(a) illustratesthe dimensional shape of a multi-channel hot-rolled pure Mg sample, segmented into four stages according to appliedthe rolling pressure, with each stage corresponding to the thickness $\boldsymbol{h_i}$($\boldsymbol{i}$=0,1,2,3). Additionally, three transitions A, B and C are retained, and the ND directional strain is $\Delta\boldsymbol{\varepsilon_A} = |\boldsymbol{h}_1 - \boldsymbol{h}_0|/\boldsymbol{h}_0 = 30.38\%$, and similarly, $\Delta\boldsymbol{\varepsilon_B} = 30.38\%, \Delta\boldsymbol{\varepsilon_C} = 65.07\%$. For the transitional region of the rolled samples, spatially continuous observations can be used to approximate the temporal evolution of the Mg samples during rolling, known as the spatialized temporal approach, in order to correlate in-situ observations of the recrystallization behavior.Microstructural characterization was conducted using a JEOL JSM-IT800 scanning electron microscopy and an OXFORD electron back scatter diffraction (EBSD) system operatingat an accelerating voltage of 20 kV.

3 Result and discussion

Recrystallization statistics in rolling processes

The spatialized time method combined with the EBSD technique unveils the proportions and evolution of recrystallized grains, substructured grains, and deformed grains in Mg during hot rolling, as depicted in Figs.1 (b1-b8, c1-c5).

The volume fraction of recrystallization increases with the rising downward rolling strain. In the initial stages of rolling, grains deform under stress, generating defects or displacing them, facilitating recrystallization nucleation. However, a significant number of finely deformed grains persisted at the specimen boundaries, attributed to shear forces between the sample boundary and the work roll, along with the strain gradient.

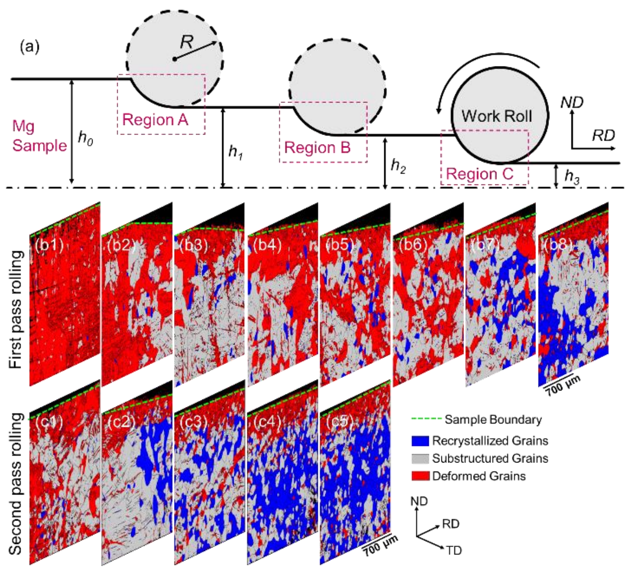

Fig.1 (a) Schematicdiagram of hot rolling and EBSD results show the recrystallization behavior of the first rolling transition zone (b1-b8) and the second rolling transition zone (c1-c5) of Mg samples.

Paradoxical relationship between twins

Further analysis of the recrystallization behavior during the hot rolling process revealed the presence of high-angle tensile twins within the parent grains,as shown in Fig.2, influencing the morphology of the recrystallized grains.

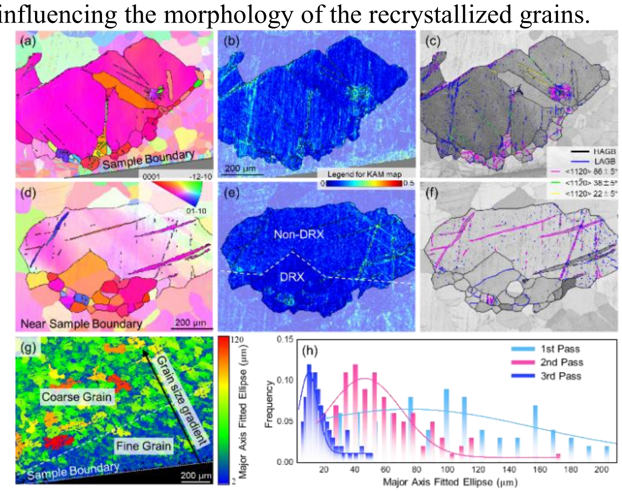

Fig.2 EBSD results indicate the recrystallization behavior of the <11$\bar{2}$0>86° twin-free (a-c) and <11$\bar{2}$0>86° twin systems (d-f), and Figs.(g) and (h) show the grain scale gradient distribution and the grain size statistics during the three rolling passes, respectively.

Within grains with minimal or no <11$\bar{2}$0> 86° high-angle twins, recrystallized grains tend to exhibit a higher density of twins. Conversely, in the recrystallization behavior of grains containing <11$\bar{2}$0>86° grains, there are scarcely any twinswithin the recrystallized grains.Consequently, these grains exhibit lower dislocation densities, creating stress disparities with the parent grains matrix.Additionally, the grain size statistics indicate that recrystallization occurring during the rolling process substantially promotes grain refinement. This refinement effect exhibited non-uniformity, with grains tending to be finer near the sample boundaries,as depicted in Fig.2(g). The grain sizes exhibited a gradient distributionof approximately 30° along the sample boundaries.

4 Conclusion

The spatialized temporal approach proposedin this work offers an avenue for approximatein-situ observation of recrystallization behavior.The existence of <11$\bar{2}$0> twins inhibit the formation oftwins within the recrystallized grains, resulting in an interfacial stress gradient between the recrystallized and non-recrystallized regions.Conversely, parent grains devoid of high-angle twins tend to homogenize interfacial stresses during the recrystallization process.

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