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Deformation and Evolution of Microstructure and Texture during High Speed Heavy Rolling of AZ31 Magnesium Alloy Sheet

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Abstract

An AZ31 magnesium alloy sheet was rolled to 71% by one pass operation at 473K at a rolling speed of 500m/min. During rolling, the mill was suddenly stopped and the sheet was withdrawn from the gap of work rolls. The evolution of microstructure and texture of the AZ31 magnesium alloy sheet during rolling deformation was revealed by observing microstructure and texture at the plane perpendicular to the transverse direction from the entry to the exit of the zone of deformation of the withdrawn sheet. Grains with their orientation other than basal texture preferentially deform at the initial stage of rolling deformation. Dynamically recrystallized grains are observed in the deformation zone. The double peak texture developed during recrystallization.

Introduction

Magnesium alloy is the lightest metal among practical alloys and is helpful for weight saving of transportation vehicles and electronic equipments. In addition, it has excellent properties such as high-specific strength, high rigidity, good recycling potential, high damping capacity and high shielding efficiency of electromagnetic wave. Because of these properties, magnesium alloy is expected to be used widely.

Magnesium sheets are usually produced by rolling from cast slabs. In cold rolling, applicable reduction in thickness is less than 10% due to the low workability at room temperature. Therefore the thickness is mostly reduced in hot or warm rolling. In the process, multi-pass operation with small reduction accompanied by intermediate annealing is employed to suppress edge cracks or fracture of the material and to maintain the workability [1, 2]. Rolls are often heated to minimize the temperature drop. Because of these all the procedures, fabrication of magnesium alloy sheets is less productive and magnesium alloy sheets are more expensive than cast magnesium products as well as other metal sheets. If the productivity is improved, they should be used in quantity, especially in automotive industries.

It is necessary to provide sheets at a low price to apply magnesium alloy widely as structural materials. Rolling is the most appropriate process to mass-produce sheets at a low cost. However, as mentioned before, the efficiency of production is low and cost is high in rolling of magnesium alloy, due to its low ductility below 473K coming from its hexagonal crystal structure and inactiveness of non-basal slip systems.

The present authors succeeded in single pass large draught rolling of various magnesium alloy sheets below 473K without heating rolls by rolling at the speed higher than 1000m/min. In high speed rolling, heat transfer from a sheet to rolls was prevented due to the very short duration where the sheet and rolls were in contact, so the temperature of the sheet efficiently rose by plastic working and deformability even at cold or warm rolling region became comparable to hot rolling. Furthermore, this process was performed under high strain rate condition or high Zener-Hollomon parameter condition, so the sheet obtained by high speed rolling had fine grained microstructure of which the mean grain size was 2-3μm, and had good mechanical properties too [3-5]. For these advantages, the high speed rolling is a promising process to produce high-quality rolled magnesium alloy sheets at a low cost.

However, the mechanism that makes one pass large draught rolling possible and the evolution of microstructure and texture during high speed rolling are not fully understood. In this study, we tried to observe the evolution of microstructure and texture of the sheet during rolling by interrupting rolling and freezing the microstructure. We performed experimental high speed rolling of AZ31B magnesium alloy. During rolling, the mill was suddenly stopped and the sheet was withdrawn from the work rolls immediately. The evolution of microstructure and texture of the AZ31 magnesium alloy sheet during rolling deformation was revealed by observing microstructure and texture at the plane perpendicular to the transverse direction from the entry to the exit of the zone of deformation of the withdrawn sheet.

Experimental Procedures

A two-high laboratory rolling mill with ϕ530mm rolls shown in Fig.1 was used. The rolling speed can be changed from 200m/min to 2600m/min. Detailed specification can be found elsewhere [6, 7], where the authors studied microstructure and texture evolution of steels and other metals systematically.

Commercial 3.0mm thick AZ31B (Mg-3.2%Al-0.77%Zn-0.34%Mn) extruded sheets produced by Sankyo Material, Inc. were received. 30mm wide 300mm long specimens were cut from the sheets and subjected to the rolling experiment. The initial microstructure was covered by equiaxed grains of which mean

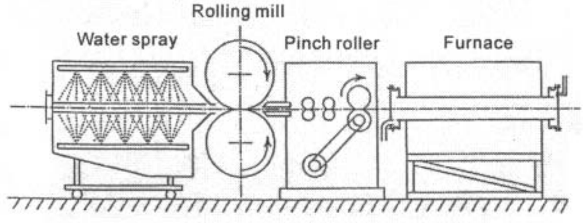


Fig.1. Illustration of high-speed rolling mill used.

grain size was 18μm. The grain size was inhomogeneously distributed ranging from 10 to 50μm.

Prior to the rolling, a specimen was held for 15 min at 473K in an electronic tube furnace, then supplied to the mill through the pinch roller. The rolling conducted in single-pass operation with reduction in thickness of 71%. The peripheral speed of the rolls was 500m/min. The estimated strain rate during 70% rolling is 4.9×10^2 s^{-1}. The rolls were neither heated nor lubricated. The rotating rolls were suddenly stopped during rolling and specimen was quenched immediately by cold (room temperature) rolls that are in contact with specimen. The rolled part of specimen was quenched by the water spray closely attached to the exit of the mill.

Microstructures on longitudinal section (TD plane) were observed by an optical microscope. The EBSP measurement by FE-SEM was performed also on TD plane.

Results

Partly Rolled Sheet

The shape of TD plane of the rolled and interrupted (partly rolled) sheet is shown in Fig.2. The length of contact arc is longer than calculated value (23.6mm) because of roll flattening. The areas at which microstructure and texture are observed on TD plane are indicated by small numbered squares. Reductions at several positions calculated from the thickness at that point are also given in Fig.2.

Change of Microstructure along Rolling Direction

Figure 3 shows the microstructure of the partly rolled sheet. At the middle stage of rolling deformation (a), a lot of deformation bands inclined about 45° to the rolling direction are introduced and initial crystal grains are divided to small grains. At the final stage of rolling deformation where reduction in thickness comes to 71%, the deformation microstructure prevails while fine recrystallized grains appear. Just after rolling, 12mm from the roll exit, recrystallization is completed and microstructure with fine equiaxed grains develops.

Change of Crystal Orientation along Rolling Direction

Figure 4 shows the change of IPF map of partly rolled sheet drawn by TSL-OIM software along rolling direction. The IPF maps shown here are drawn from the data (Kikuchi line) obtained from grains free from deformation microstructures. Deformation microstructures are indicated in black. These IPF maps are closely related to Fig.3. At the middle stage of rolling (a), initial grains are divided by deformation bands. Almost all the grains are oriented their 0001 plane parallel to the sheet plane in the initial stage. At the final stage of the rolling (b), initial grains are not observed and deformation microstructure prevails. A large number of fine recrystallized grains appear among deformation microstructure. These recrystallized grains nucleated during rolling because they are observed in the part of sheet just between the rolls. It suggests that dynamic recrystallization occurs during high speed large draught rolling. At the exit of the roll gap (c), the fraction recrystallized increases from (b), while deformation microstructure remains. Similar to the final stage of deformation, almost all the grains align their 0001 plane parallel to the sheet plane. After rolling, 12mm from the exit (d), recrystallization is completed. From these OIMs, for the formation of completely recrystallized equiaxed microstructure in the sheet heavily rolled

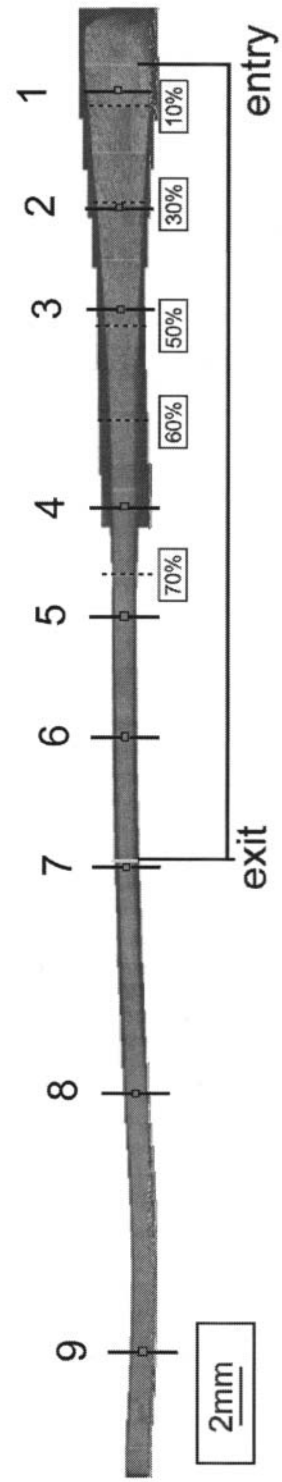
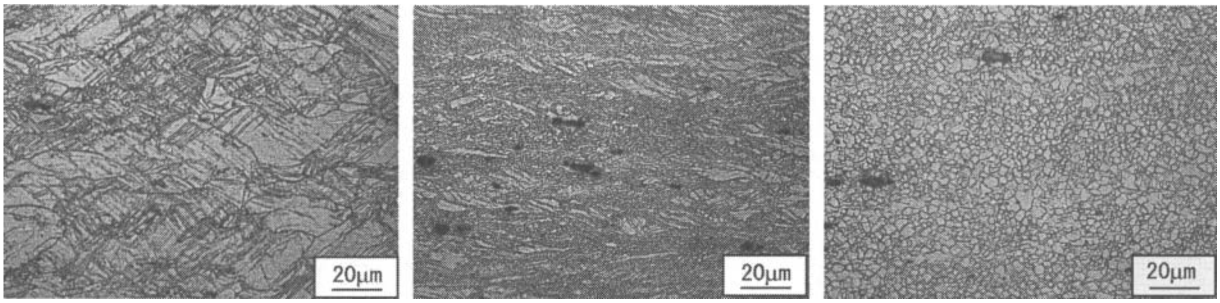


Fig.2. Shape of TD plane and the positions of observation of the sheet by interrupted rolling.



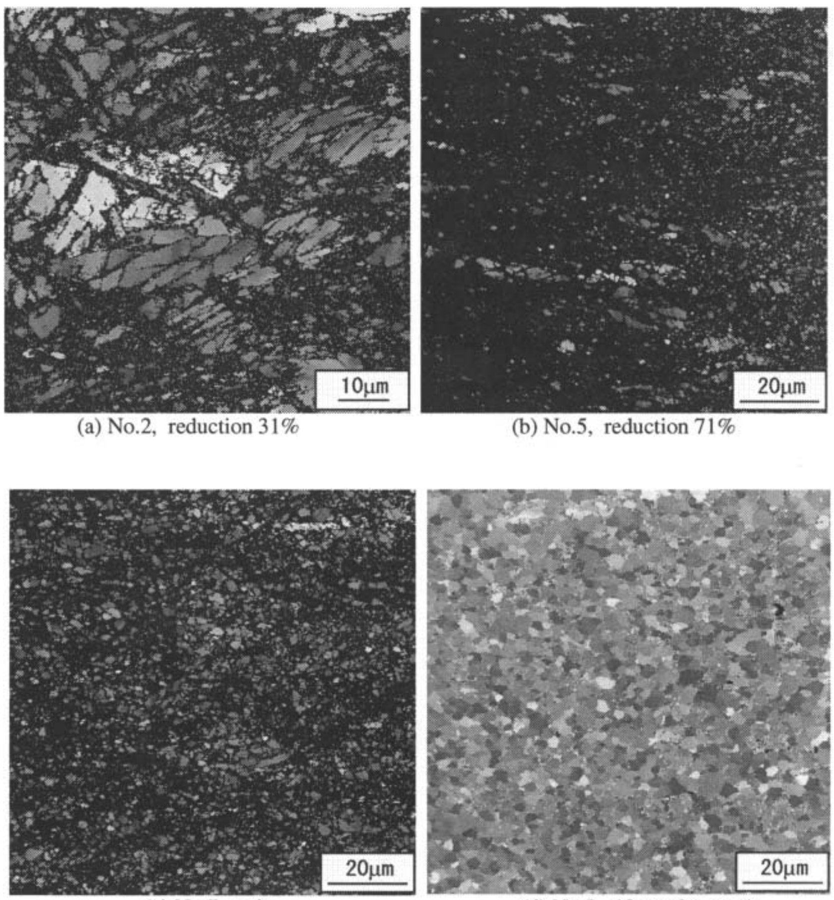
(a) No.2, reduction 31% (b) No.5, reduction 71% (c) No.8, 12mm from exit

Fig.3. Change of microstructure with the progress of rolling deformation.

by high speed rolling, contribution of static recrystallization cannot be disregarded.

After rolling, grains with orientations other than 0001 parallel to the rolling plane (colored in green or blue) that are not observed in the sheet at the roll gap appear here and there. The growth of grains other than basal orientation occurs during static recrystallization after rolling.

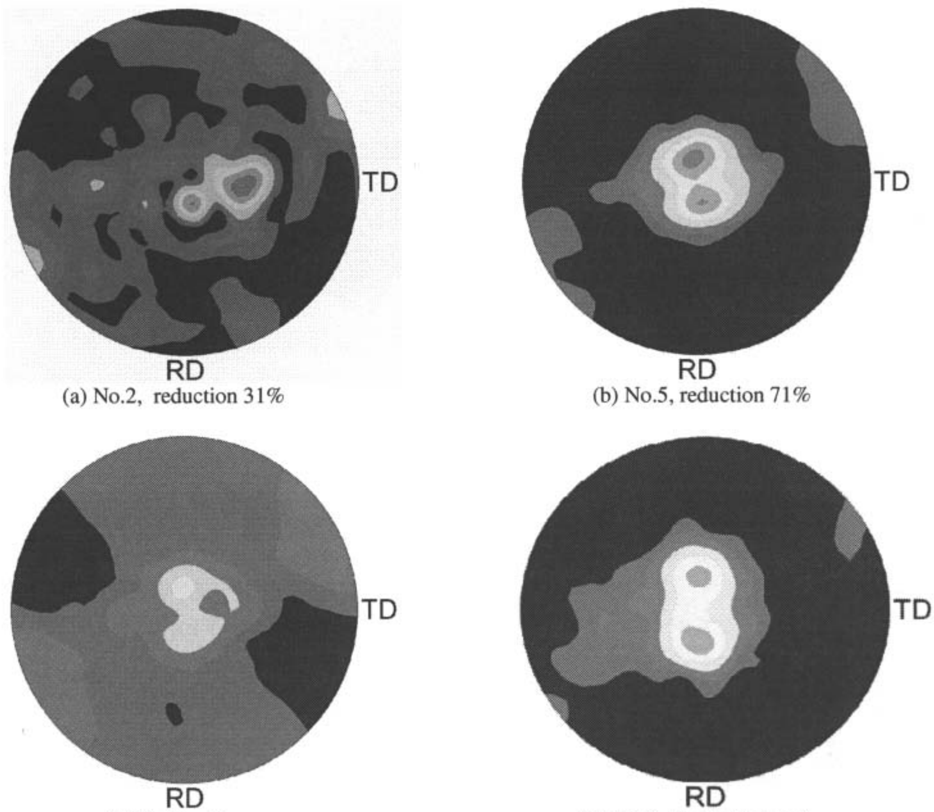
The change of pole figures drawn from the OIM data with the progress of rolling is shown in Fig.5. At the middle stage (a), 0001 peak shifts from ND to TD direction, which is the orientation resulting from extrusion texture originally formed in the specimen. At the final stage (b), 0001 peak splits to double peaks on RD axis originating from recrystallized grains. With the progress of recrystallization, the intensity of 0001 peak and the interval between two peaks increase. However, pole figures (b) and (c) only show the orientation of recrystallized grains. The



(a) No.2, reduction 31% (b) No.5, reduction 71%

(c) No.7, exit (d) No.8, 12mm from exit

Fig.4. Change of IPF map with the progress of rolling deformation.



(a) No.2, reduction 31%
(b) No.5, reduction 71%
(c) No.7, exit
(d) No.8, 12mm from exit

Fig.5. Change of 0001 pole figure with the progress of rolling deformation.

orientation of deformed grains (colored black in IPFs) could not be obtained in the present study. The pole figures of heavily rolled sheets drawn by X-ray diffraction indicates that the orientation of deformed grains shows single 0001 peak elongated towards RD direction at ND position [4]. The texture with two 0001 peaks on RD axis, so called double peak texture, is the typical texture formed in magnesium alloy sheets recrystallized by high speed rolling to high reduction in one pass operation. These pole figures indicate that the static recrystallization just after rolling plays an important role in the formation of the texture of heavily rolled and recrystallized magnesium alloy sheets.

Conclusions

The evolution of microstructure and texture of the sheet during high speed large draught rolling was observed by sudden interruption of rolling operation followed by freezing of the microstructure. The results are summarized as follows.

1. The dynamically recrystallized grains are observed in the sheet deformed in the roll gap.
2. The static recrystallization proceeds in very short time after completion of rolling. The growth of grains with orientation other than near basal texture occurs during static recrystallization.
3. The recrystallized grains show the double peak texture with two 0001 peaks on RD axis and it develops after rolling.

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