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ScienceDirect
Trans. Nonferrous Met. Soc. China 21(2011) s229−s234
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Effect of hot rolling on grain refining and mechanical properties of AZ40 magnesium alloy

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Received 10 May 2011; accepted 25 July 2011

Abstract: AZ40 Mg alloy thin sheets were prepared by multi-pass hot rolling with the hot-extruded alloy as the starting material. The effect of hot rolling on the microstructure, mechanical properties, and fracture behavior of the alloy was investigated. The results show that the microstructure homogeneity can be improved and the grain size is refined steadily by dynamic recrystallization with increasing rolling passes. As a consequence, the mechanical properties of the as-rolled sheets are improved significantly as compared with the starting as-extruded alloy. By 5 or more rolling passes, the average grain size is reduced to no more than 10 μm, and the yield strength and the tensile elongation of the sheets prepared achieve as high as more than 175 MPa and 20%, respectively, in both the rolling and the transverse direction.

Key words: AZ40 Mg alloy; hot rolling; grain refining; mechanical properties

1 Introduction

Because of their low density, high specific strength, superior damping capacity, and good electromagnetic shielding performance, magnesium alloys are gaining increasing importance for structural applications [1−3]. Indeed, Mg alloys are used more and more in aerospace, automotive, and communication, and portable electronic appliances [4−6]. However, Mg alloys usually present limited workability at room temperature. In addition, most Mg alloys suffer from relatively low mechanical strength as compared with other competing materials such as Al alloys. Therefore, much attention has recently been paid to the improvement of mechanical strength and ductility of Mg alloys [7−11].

It is well known that grain refining is a general way to improve mechanical properties of metallic materials [12−14]. For Mg alloys, it has been shown that both the room-temperature mechanical strength and the plasticity can be significantly improved by grain refining [15−17]. In particular, hot rolling could be used not only to produce Mg alloy sheets that are suitable for the manufacture of complex parts with thin-walled geometries, but also to achieve grain refining and mechanical property improvement. So far, however, most of such studies were concentrated on the AZ31 Mg alloy [18−21]. In the present work, we report a study on the effect of hot rolling on grain refining and mechanical property improvement of an AZ40 Mg alloy.

2 Experimental

The as-hot extruded AZ40 Mg alloy plate billets with a thickness of 12 mm, which was provided by Northeast Light Alloys Co. Ltd., was used as the starting material for hot rolling. The chemical composition of the alloy is shown in Table 1. The rolling experiments were carried out by using a roll mill equipped with an induction heating system to heat the rolls during rolling. In total, 6 passes of hot rolling operations were performed to obtain AZ40 Mg alloy sheets with a final thickness of 1 mm. The major rolling parameters including the billet thickness reduction for each rolling pass were selected as shown in Table 2.

The microstructure and mechanical properties of the alloy subjected to different rolling passes were investigated. The microstructure was observed by using an Olympus optical microscope. To evaluate the mechanical properties, tensile tests were performed at room temperature using an INSTRON-5569 standard testing machine. The tensile specimens, with the

Foundation item: Project (GA09A203-1) supported by Science and Technology Department of Heilongjiang Province, China
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Table 1 Chemical composition of AZ40 alloy (mass fraction, %)

Al	Zn	Mg
4.0	0.2	Bal.

Table 2 Process parameters for hot rolling of AZ40 Mg alloy

Rolling pass	Roll and billet temperature/ °C	Rolling speed/ $(m\cdot s^{-1})$	Thickness reduction/ %	Thickness after rolling/ mm
1	400	2	30.8	8.3
2	400	2	28.9	5.9
3	400	2	28.8	4.2
4	400	2	28.6	3.0
5	300	5	43.3	1.7
6	300	5	41.2	1.0

geometry and dimensions shown in Fig. 1, were prepared from both the starting plate billet and the as-rolled alloy. For all tensile tests, the gauge span was 15 mm, and the strain rate was 1.0×10^{-3} s^{-1}, respectively. The fracture morphology of the tensile specimens was examined by using a S-570 Hitachi scanning electron microscope (SEM).

3 Results and discussion

3.1 Microstructure

Figure 2 shows the microstructures of the starting

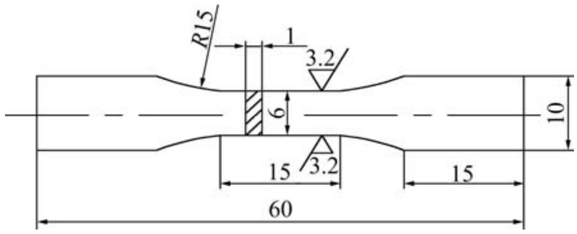

Fig. 1 Geometry and dimension of tensile specimen (unit: mm)

AZ40 Mg alloy billet and the as-rolled sheets obtained by 4−6 rolling passes. It is seen that the starting as-extruded alloy billet is featured by a heterogeneously recrystallized microstructure, with the size of most grains in the range of 10−60 μm (Fig. 2(a)). In comparison, the as-rolled sheets after 4−6 hot rolling passes present a homogeneous, dynamically recrystallized microstructure, and the grain size decreases with the increase of the rolling passes, with the average grain size of the alloy subjected to 4, 5 and 6 rolling passes being about 15, 10, and 8 μm, as shown in Figs. 2(b), (c), and (d) respectively. Obviously, the microstructure homogenization and grain size refining can be attributed to the dynamic recrystallization during hot rolling. In Refs. [18−19], it was shown that for hot rolling of AZ31 Mg alloy a steady grain refining can be achieved by dynamic recrystallization only when the process parameters are well chosen. Since, in the present study, the average grain size of the as-rolled sheets is seen to reduce steadily with the increase of the rolling passes. It is evident that the processing parameters chosen herein

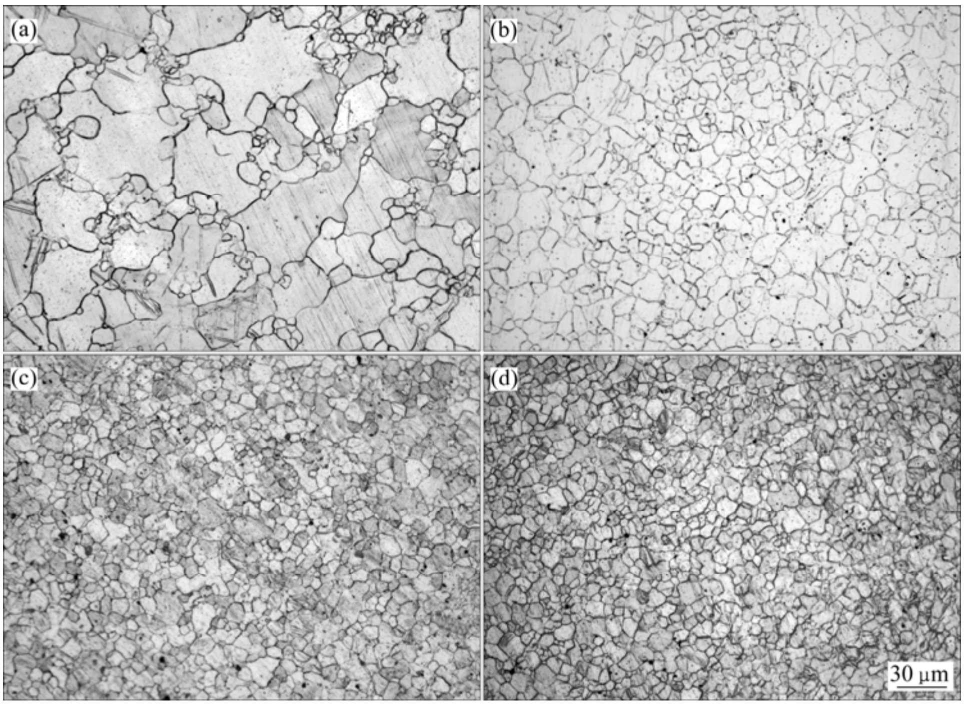

Fig. 2 Microstructures of AZ40 Mg alloy by different rolling passes: (a) Starting billet; (b) 4 passes; (c) 5 passes; (d) 6 passes

are reasonable and of great value for the rolling practice of AZ40 Mg alloy in order to achieve microstructure refining and property improvement.

3.2 Mechanical properties

Figure 3 shows the room-temperature tensile mechanical properties of the starting AZ40 Mg alloy billet and the as-rolled sheets. As shown in Fig. 3(a), the starting as-extruded billet presents obviously anisotropic mechanical properties. In the extrusion direction (ED), the yield strength is only about 100 MPa, but a tensile elongation as high as 20%, together with a strong strain hardening effect, is observed. In contrast, though the transverse yield strength is as high as 230 MPa, the corresponding elongation is only about 13%. This suggests that strong microstructure anisotropy or texture exist in the as-extruded alloy, and the soft orientation for basal slip developed during extrusion must be the same as the extrusion direction. Fortunately, this anisotropy in mechanical properties can be reduced or eliminated by hot rolling. As shown in Fig. 3(b), the anisotropy in mechanical properties was improved significantly after the alloy was subjected to 4 passes of rolling. Indeed, with the further increase of the rolling passes to 5 or more, almost no anisotropy in mechanical properties is observed, as shown in Figs. 3(c) and (d). In addition, both the yield strength and the elongation increase with the increase of the rolling passes. The yield strength and the tensile elongation of the alloy by 5 or more rolling passes achieve the level no less than 175 MPa and 20%, respectively, in both the rolling and the transverse direction. Obviously, this significant improvement in mechanical properties is attributed to the microstructure homogenization and steady grain size refining of the alloy with increasing rolling passes, as shown in Fig. 2.

3.3 Fracture morphology

Figure 4 shows the SEM fractographs of the tensile specimens. As shown in Figs. 4(a) and (b), the fracture of the starting as-extruded alloy is featured by a quasi-cleavage pattern consisting of major cleavage through large grains and some shallow ductile dimples in the cleavage adjoining areas, which is consistent with its relatively poor plasticity. In comparison, though a few small localized cleavages do exist on the fractured surface, the fracture of the alloy after 4 rolling passes is,

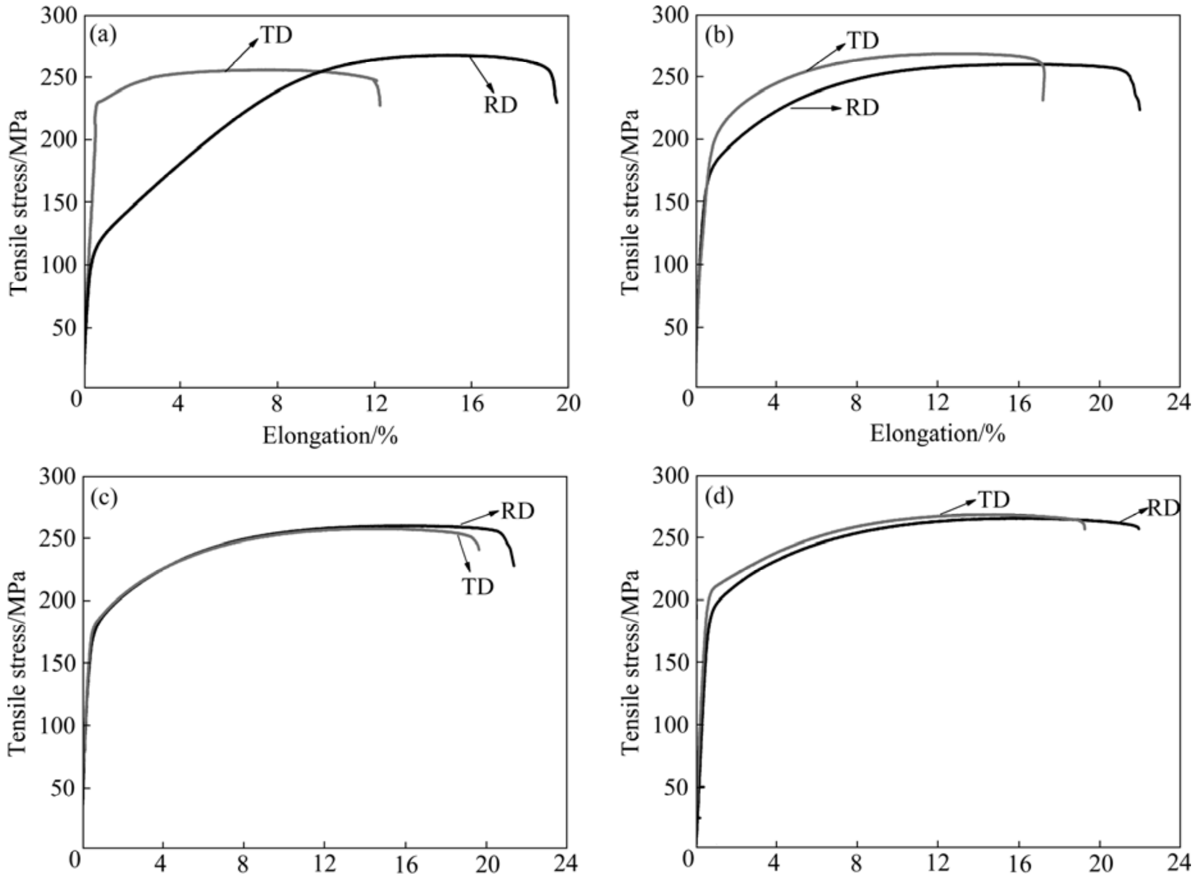

Fig. 3 Room-temperature tensile properties of AZ40 Mg alloy by different rolling passes: (a) Starting billet; (b) 4 passes; (c) 5 passes; (d) 6 passes

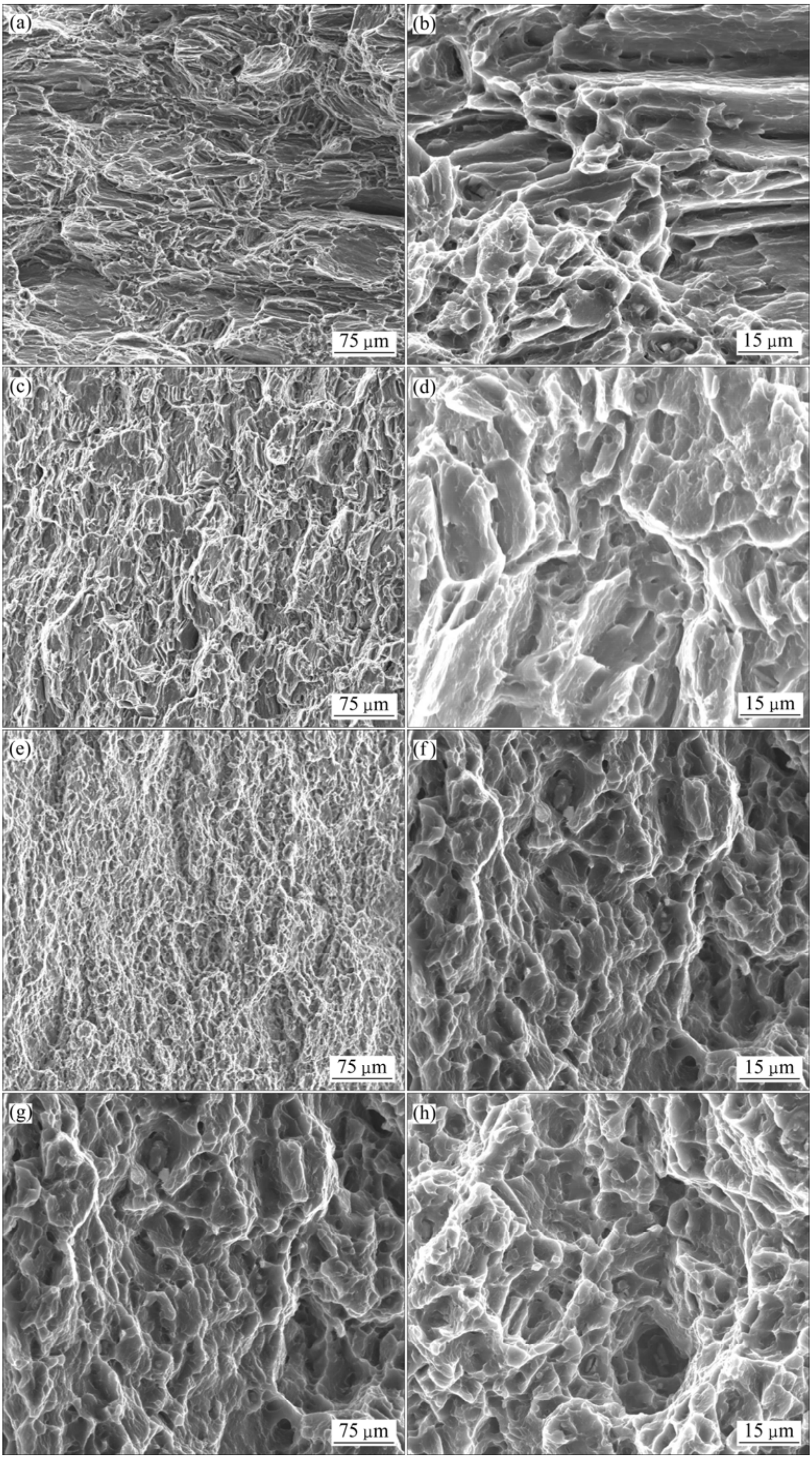

Fig. 4 SEM fractographs of AZ40 Mg alloy by different rolling passes: (a), (b) Starting billet; (c), (d) 4 passes; (e), (f) 5 passes; (g), (h) 6 passes

as a whole, typically ductile, with numerous dimples formed by micro-void coalescence clearly observed, as shown in Figs. 4(c) and (d). In addition, with the further increase of the rolling passes, no localized cleavages are observed, as shown in Figs. 4(e)−(h). Therefore, the tensile elongation of the alloy increases with increasing rolling passes. Of course, this is attributed to the microstructure homogenization and grain size refining, which help to improve the deformation homogeneity and to reduce the internal stress concentration caused by dislocation pile-up within grains during deformation.

4 Conclusions

1) The anisotropy in microstructure and mechanical properties featured by the extruded AZ40 Mg alloy can be improved or eliminated by dynamic recrystallization due to hot rolling processing. Under the rolling conditions in the present study, AZ40 Mg alloy sheets with homogeneous microstructure and no anisotropy in mechanical properties were obtained by 5 passes of hot rolling the extruded alloy.

2) When the rolling conditions is chosen properly, the average grain size of AZ40 Mg alloy can be refined steadily by dynamic recrystallization with the increase of the hot rolling passes. In the present study, the average grain size of the alloy was reduced to no more than 10 μm after 5 passes of rolling processing.

3) Due to the homogenous, fine dynamically recrystallized microstructure, the AZ40 Mg alloy sheets prepared by 5 or more rolling passes present very good mechanical properties, with their yield strength and tensile elongation achieving as high as more than 175 MPa and 20%, respectively, in both the rolling and the transverse directions.

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热轧变形对 AZ40 Mg 合金晶粒细化与力学性能的影响

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摘 要：以热挤压材为坯料，经多道次热轧制备 AZ40 Mg 合金板材。研究热轧变形对合金组织、力学性能与断裂行为的影响。结果表明：随着热轧道次的增加，通过动态再结晶，材料的组织均匀性得到逐步改善，晶粒尺寸持续细化。相应地，热轧板材的力学性能与挤压态坯料相比得到显著改善。经过 5 道次以上热轧制备的 AZ40 Mg 合金板材，其平均晶粒尺寸细化到 10 μm 以下，轧向及横向的室温拉伸屈服强度与伸长率均可分别达到 175 MPa 和 20%以上。

关键词：AZ40 Mg 合金；热轧变形；晶粒细化；力学性能

(Edited by CHEN Ai-hua)