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Effect of Extrusion Conditions on Microstructure and Texture of Mg-1% Mn and Mg-1% Mn-1.6% Sr Alloys

Hemant Borkar, Mihriban Pekguleryuz

McGill University, Mining and Materials Engineering, 3610 University Street,
Montreal, QC, Canada H3A 2B2

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Abstract

Mg-1% Mn (M1) and Mg-1% Mn-1.6% Sr alloys have been subjected to hot extrusion and the effect of extrusion conditions on the microstructure and texture has been investigated. Addition of Sr to M1 alloy refines the extruded microstructure. Two different ram speeds of 4 mm/s and 8 mm/s and two different temperatures of 300°C and 350°C have been used in the study. The extent of recrystallization increases with increasing ram speed. The texture of extruded M1 weakens with Sr addition. The mechanism of texture weakening is suggested to be PSN with formation of new grains having orientations different than that of parent grains.

Introduction

Despite their low density, wrought Mg alloys have limited applications due to low ductility and poor formability at room temperature. This is due to the limited number of slip systems in the hexagonal close packed (HCP) Mg alloys [1]. Another problem associated with Mg alloys is the strong fiber texture which is developed after extrusion in which the c-axis aligns perpendicular to the extrusion direction [2]. This leads to anisotropic behavior of deformed materials thus limiting their widespread applications.

Several methods have been attempted to improve the performance of wrought alloys such as the reduction of grain size [3], the activation of non basal slip by alloying (e.g Li addition) [4] and randomization or weakening of texture with RE elements (e.g Ce, Nd addition) [5-7]. Strontium has proven to be good grain refiner in Mg alloys thereby improving mechanical properties [8-10]. The Mg-Sr precipitates may also affect recrystallization during hot extrusion of Mg alloys containing Sr.

The deformation behaviour and the formation of new grains during recrystallisation is of importance for the control of microstructure and texture and therefore the properties of extruded profiles. The recrystallization behavior is closely related to the temperature and the strain induced during extrusion.

The current paper investigates the effect of extrusion conditions and effect of 1.6% Sr addition to Mg-1%Mn (M1) alloy by studying the microstructure and texture of extruded samples.

Experimental Procedure

Mg-1%Mn (M1) and M1-1.6%Sr alloys were cast using 20kW, 5kHz induction furnace under protective gas mixture of SF_6/CO_2. Casting was done at 740 °C in preheated cylindrical shaped steel dies. 5 cm long, 2.5 cm dia extrusion samples were machined and subjected to extrusion at 300°C and 350°C and at ram speeds of 4mm/s and 8mm/s in lab-scale 100 Ton hydraulic press. Extrusion ratio of 1:8 was used in the experiments.

The samples for optical microscopy were obtained in such a way that the extrusion direction is parallel to the plane of the samples. Nikon Epishot 200 optical microscope equipped with Clemex optical image analyser was used for microstructure investigation. The samples for texture studies were obtained from cross sections of extrusions in such a way that the extrusion direction is perpendicular to the plane of the samples. The texture of these samples was measured with X-Ray diffraction using Bruker Materials Analyser texture goniometer equipped with Cu Ka radiation.

Results and Discussion

Microstructure

The stereoscopic images of M1 and M1-1.6Sr extruded at 350°C at ram speeds of 4 mm/s and 8 mm/s are shown in Figure 1. These figures depict the material flow during extrusion. Grain refining is observed with Sr addition to M1 in the samples extruded at both the speeds.

Microstructures of M1 and M1-1.6Sr extruded at 350°C at 4 mm/s speed are shown in Figure 2. Recrystallized grains originating at the grain boundaries of elongated parent grains can be observed in the microstructure of M1(Figure 2a). Deformation is accompanied with twins which can be spotted in the microstructure. Presence of twins can be attributed to the coarse grain structure of M1 as larger grain size promote increased twinning activity. M1-1.6Sr shows refined microstructure with presence of Mg-Sr intermetallic stringers elongated in the extrusion direction (Figure 2b). Twins are not observed in this microstructure. The recrystallized grains are seen to be associated with stringers.

At higher ram speed, the M1 (Figure 3a) shows similar microstructure to that of M1 at lower speed. M1-1.6Sr (Figure 3b), on the other hand, shows extensive recrystallization associated with Mg-Sr stringers. New grains are seen to be originating from the stringer and grow until they reach another stringer or grain boundary. This kind of recrystallization is called particle stimulated nucleation (PSN) of recrystallization. It has been observed in aluminium[11,12] and magnesium alloys[13] in which particle size of around 1.5 to 2 μm are sufficient to induce PSN.

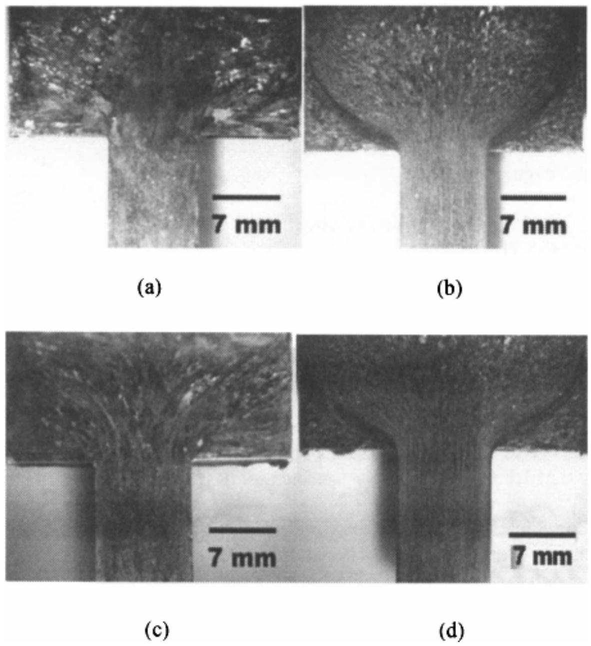


Figure 1. Stereoscopic images of extruded samples at 350°C
(a) M1, 4 mm/s speed (b) M1-1.6Sr , 4 mm/s speed
(c) M1,8 mm/s speed (d) M1-1.6Sr, 8 mm/s speed

In the process of PSN, deformation zones occur at the particles and can act as nucleation sites for recrystallization since they have high dislocation density and fine sub-grains. Higher ram speed in extrusion imposes higher strain and hence degree of recrystallization is higher in the samples extruded at higher speeds.

An increase in ram speed leads to an increase in the surface temperature of the billet. This increases homogeneity of deformation. The increase of ram speed from 4mm/s to 8 mm/s was found to improve properties (YS) slightly in ZK30 alloy but a further increase in speed to 16 mm/s led to the occurrence of grain growth and secondary recrystallisation, which lowers the properties[14]. In the current studies, both M1 and M1-1.6Sr alloys show improved surface quality after extrusion at higher ram speed of 8 mm/s.

Texture

The inverse pole figures of M1 and M1-1.6Sr extruded at 300°C and 350°C and at constant ram speed of 8 mm/s are shown in Figure 4 and Figure 5. The inverse pole figures are in extrusion direction which means that the axis of the figure is parallel to the extrusion direction. In M1 alloy extruded at 300°C (Figure 4a), the texture is mainly concentrated near $\langle 10\bar{1}0\rangle$ and $\langle 11\bar{2}0\rangle$ poles which means that grains are oriented in such a way that prismatic planes are perpendicular to the extrusion direction. It also means that basal planes are parallel to the extrusion direction. However, the texture is seen to be distributed up to 50° from extrusion direction and the maximum texture intensity is 1.5 times the random intensity. This shows that M1 extruded at this temperature does not show strong texture. M1.1.6Sr extruded at 300°C (Figure 4b) still shows relatively weaker texture with texture distribution up to 60° and some additional peaks developing in the pole figure. The maximum intensity in this case is 1.4 times the random intensity.

M1 alloy extruded at 350°C (Figure 5a) develops the texture which is closer to the typical fiber texture developed in magnesium alloys after extrusion. The texture is mainly concentrated near $\langle 10\bar{1}0\rangle$ and $\langle 11\bar{2}0\rangle$ poles and the distribution is within 30°C from the extrusion direction. The maximum texture intensity is 2.4 times the random intensity which is higher than that for M1 at 300°C. This probably means that the typical fiber texture in M1 alloy is more pronounced at higher extrusion temperature. M1-1.6Sr alloy extruded at 350°C (Figure 5b) produces relatively weaker textures than that of M1 with lower value of maximum intensity (2 times random intensity) and wider texture distribution (up to 50°). This shows that the texture weakening with Sr addition occurs more prominently at higher temperatures. As observed in Figure 3b, PSN grains are associated with stringers and extensive recrystallization occurs in M1-16.6Sr alloy extruded at 350°C. The important characteristic of PSN is that it produces new grains with different orientations than that of parent grains. As higher extrusion temperatures create

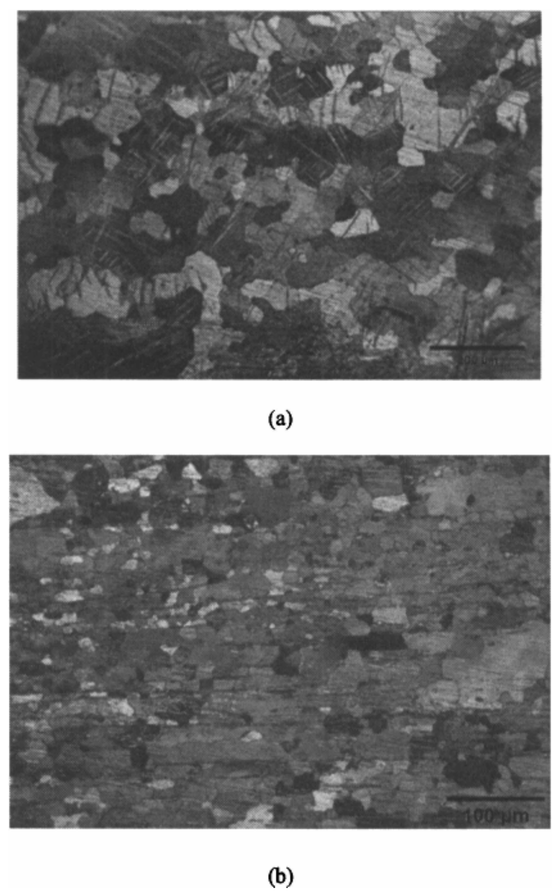
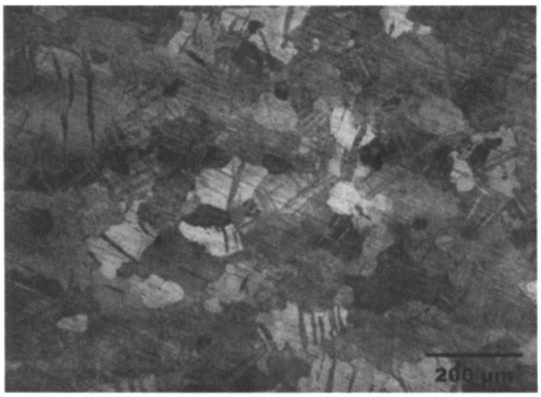
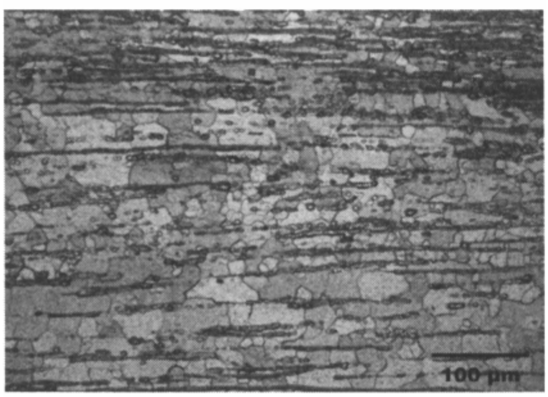


Figure 2. Microstructure of extruded samples at 350 °C and 4 mm/s ram speed (a) M1 (b) M1-1.6Sr

higher driving force for the recrystallization, large numbers of PSN grains with different orientations are available in the microstructure which can reduce the overall texture.



(a)

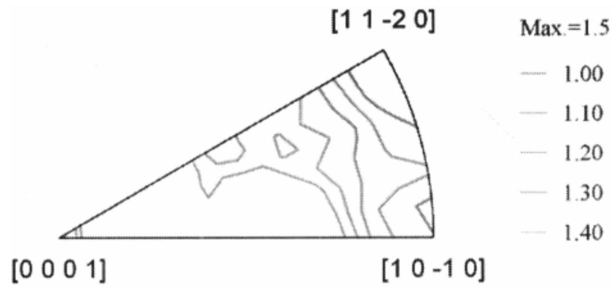


(b)

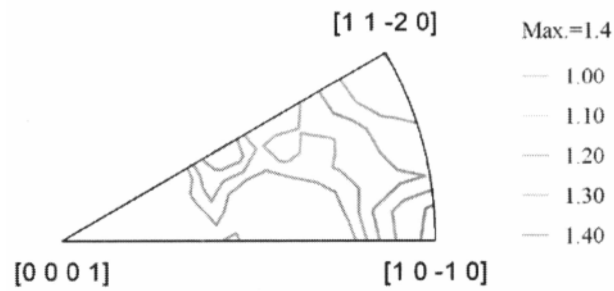
Figure 3. Microstructure of extruded samples at 350°C and 8 mm/s ram speed (a) M1 (b) M1-1.6Sr

Figure 6 shows the inverse pole figures of M1 and M1-1.6Sr extruded at 350°C and at ram speed of 4mm/s. Comparison of Figure 5a and 6a shows that M1 develops stronger texture at higher ram speed. However, higher ram speed produces higher strain which helps promoting PSN in M1-1.6Sr and hence the overall extruded texture is weaker in this alloy at higher ram speed than that at lower ram speed (Figure 5b and 6b). It can also be concluded that the effect of PSN is more pronounced at higher ram speed.

In the past, texture weakening of wrought Mg alloys with rare earth elements has been reported [5-7] in which rare earth addition produces a distinct peak in the inverse pole figure. However, with Sr addition, texture weakening occurs with random distribution and without typical distinct peak in the inverse pole figure.

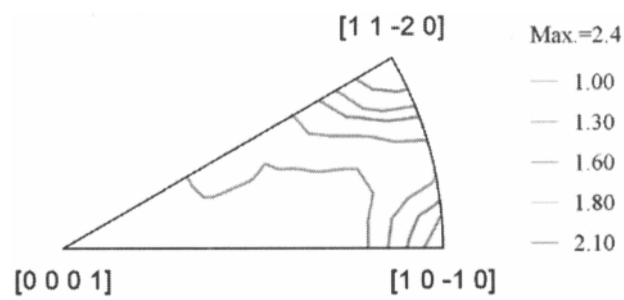


(a)

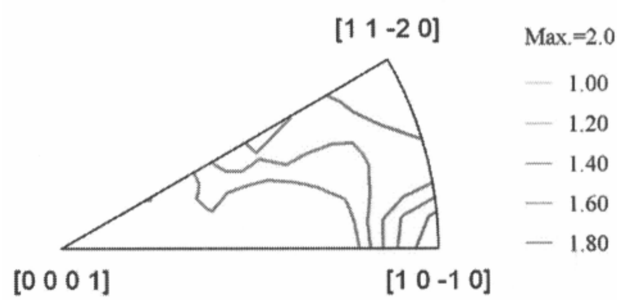


(b)

Figure 4. Inverse pole figures of samples extruded at 300°C and 8 mm/s ram speed (a) M1 and (b) M1-1.6Sr



(a)



(b)

Figure 5. Inverse pole figures of samples extruded at 350°C and 8 mm/s ram speed (a) M1 and (b) M1-1.6Sr

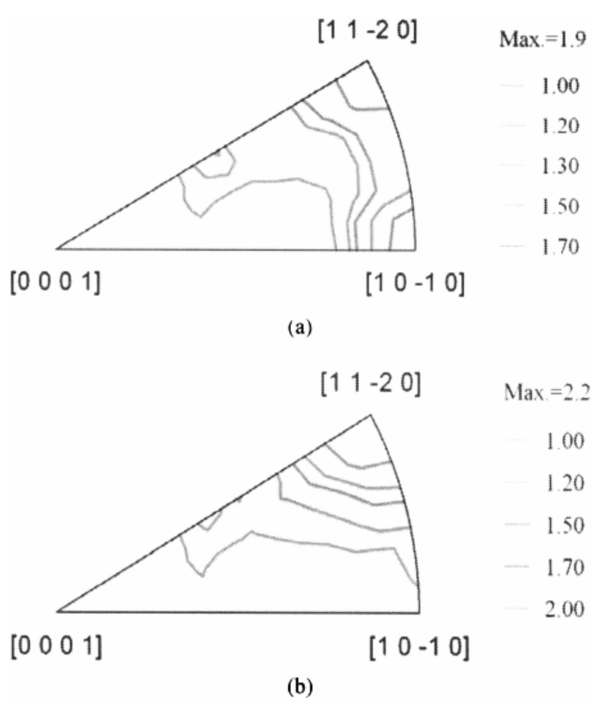


Figure 6. Inverse pole figures of samples extruded at 350°C and 4 mm/s ram speed (a) M1 and (b) M1-1.6Sr

Conclusions

Microstructure of M1 extruded at 350°C and at lower and higher ram speeds shows presence of twins and recrystallized grains around parent grains. M1-1.6Sr extruded at these conditions shows refined microstructure in which recrystallized grains are associated with Mg-Sr stringers elongated in extrusion direction. The extent of recrystallization increases with increasing ram speed owing to higher amount of strain. The texture of extruded M1 weakens with Sr addition and this effect is more pronounced at higher extrusion temperatures and higher ram speeds. The mechanism of texture weakening is suggested to be PSN in which new grains are formed with orientations different than that of parent grains.

Acknowledgements

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References

[1] B.L. Mordike, T. Ebert, Mater. Sci. Eng. A 302 (2001) 37-45.

[2] N. Stanford, Mater. Sci. Eng. A, 527(2010), 2669-2677.

[3] M.R. Barnett, Z. Keshavarz , A.G.Beer, D.Atwell, Acta Mater 52 (2004) 5093-5103.

[4] S.R Agnew, J.W.Senn, JOM 58 (May 2006), 62-69.

[5] J. Bohlen, M.R. Nurnberg, J.W. Senn, D. Letzig, S.R.Agnew, Acta Mater. 55 (2007) 2101.

[6] S.R.Agnew, O.Duygulu, Int.J.Plasticity 21(2005), 1161-1193.

[7] M. Masoumi, M. Hoseini, M. Pekguleryuz, Mater. Sci. Eng. A 528 (2011) 3122-3129.

[8] J.E.Gruzleski and C.A.Aliravci,U.S.Patent No 5,143,564,1992.

[9] M. Yang, F. Pan, R. Cheng, A. Tang, Mater. Sci. Eng. A, 491(2008) 440-445.

[10] X.Q. Zeng, Y.X.Wang,W.J. Ding, A. Luo, A.K. Sachdev, Metall. Mater. Trans. A 37 (2006) 1333.

[11] Z. Li, J. Dong, X.Q. Zeng, C. Lu, W.J. Ding, Mater. Sci. Eng. A, 466 (2007) 134-139.

[12] I.J. Polmear, Light Alloys: Metallurgy of the Light Metals, Arnold Publications, 1995.

[13] A. Sadeghi, M. Pekguleryuz, Mater. Sci. Eng. A 528 (2011) 1678-1685.

[14] Govind, K. S. Nair, M. C. Mittal, R. Sikand, A. K. Gupta, Materials Science and Technology, 2008, Vol 24,NO 4,399-405