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Effect of Sr addition on texture evolution of Mg–3Al–1Zn (AZ31) alloy during extrusion

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ABSTRACT

An experimental investigation of texture evolution during the elevated temperature extrusion of AZ31 alloys containing strontium (Sr) additions is reported. The crystallographic texture of hot extruded alloys containing different levels of Sr has been examined. Hot compression tests have been carried out in order to investigate the hot deformation behavior of the as-cast alloys. It was seen that, at different extrusion temperatures and levels of Sr, different dynamic recrystallization (DRX) mechanisms become dominant which affect the final texture. At lower temperatures and at low levels of Sr, the bulging of grain boundaries was activated, resulting in a necklaced grain structure. Furthermore, a strong deformation texture of ⟨10.0⟩ parallel to extrusion direction was developed as a result of bulging at the grain boundaries. Twining which was activated in the early stages of deformation, acted as nucleation sites for DRX. In contrast, at high temperatures and high levels of Sr, particle stimulated nucleation (PSN) becomes significant resulting in the weakening of the overall texture with the recrystallization of new grains of random orientation. In order to prevent the surface cracking in the extruded sample, a limit for Sr concentration and deformation temperature was determined. A shoulder region was found in between the bulging and PSN-dominant areas where both mechanisms are active.

1. Introduction

Because of their restricted workability and complex deformation behavior, Mg wrought alloys have not reached their potential level where they could be widely used for weight-sensitive applications. This is due to the limited number of active slip systems in HCP (hexagonal close-packed) Mg, which necessitates the combination of different deformation modes to attain uniform deformation. In Mg alloys, the thermo-mechanical conditions play important roles in the activation of different deformation micro-mechanisms which influence the final texture [1–5]. Alloying elements could also affect the deformation modes and the final texture either by dissolving in the Mg matrix or forming various precipitates [6–17]. It has been shown in a number of works [6–10] that the addition of rare earth elements and their dissolution in Mg matrix can improve ductility. The effect of alkali earth elements such as Ca [10–12] and Sr [12,14] on the extrusion behavior and mechanical properties of Mg alloys have also been previously studied.

Strontium (Sr) is known to be an effective element for improving the high temperature mechanical properties of Mg alloys via the formation of thermally stable precipitates [13–17]. The $Mg_{17}Sr_2$ intermetallic (melting point: 624 °C [18]) precipitates in Mg–Sr alloys that do not contain aluminum. In Mg–Al–Sr alloys, Sr binds with Al to form the Al_4Sr precipitate (melting point: 740 °C [18]) and minimizes or eliminates the β-$Mg_{17}Al_{12}$ observed in Mg–Al alloys [19]; Sr also decreases the solid solubility of Al in primary Mg [20]. Recently, the authors have studied the effect of Sr addition on the precipitation, microstructure and extrusion texture of AZ31 (Mg–3Al–1Zn) [14,19,20]. It was reported that 1 wt%Sr in AZ31 weakens the ⟨10.0⟩ extrusion texture at high temperatures (350 °C) as a result of particle stimulated nucleation (PSN) of recrystallized grains at the Al_4Sr stringer boundaries. In contrast, at relatively lower temperatures (250 °C), Sr strengthens the texture by reducing the solute-drag effect due to the reduced Al solubility and by increasing dynamic recrystallization (DRX) via grain boundary bulging or twin induced mechanisms [20].

Even though Sr was seen to exert different effects depending on the Sr level and deformation temperature, it was noted that further experimental work across a range of temperatures and Sr levels would be necessary to elucidate the micro-mechanisms which affect the final texture under different thermo mechanical conditions. In the present paper, two-dimensional (2D) contours of recrystallization texture, peak stress of hot compression, and DRX critical strain have been plotted versus temperature and Sr concentration. The gradients and extrema between all three parameters have been compared and a comprehensive trend-view has been

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Table 1
Chemical composition of the alloys.

Hot compression samples					Hot extrusion samples				
Alloy	Chemical composition (wt%)				Alloy	Chemical composition (wt%)			
	Al	Zn	Mn	Sr		Al	Zn	Mn	Sr
AZ31	2.57	0.66	0.35	–	AZ31	3.15	0.89	0.52	–
AZ31 + 0.01%Sr	2.64	0.61	0.34	0.009	AZ31 + 0.05%Sr	3.19	0.82	0.51	0.05
AZ31 + 0.035%Sr	2.58	0.60	0.28	0.029	AZ31 + 0.4%Sr	2.76	0.79	0.35	0.34
AZ31 + 0.05%Sr	2.47	0.63	0.41	0.037	AZ31 + 0.8%Sr	2.83	0.79	0.33	0.81
AZ31 + 0.075%Sr	2.66	0.67	0.33	0.064					
AZ31 + 0.1%Sr	2.62	0.65	0.29	0.08					
AZ31 + 0.35%Sr	2.60	0.69	0.36	0.31					
AZ31 + 0.5%Sr	2.62	0.61	0.29	0.43					
AZ31 + 0.75%Sr	2.69	0.64	0.36	0.71					
AZ31 + 1%Sr	2.64	0.68	0.30	0.91					

derived. Finally, by adding the boundaries of twining, and surface cracking to the DRX contours, a general map for extruding AZ31 containing up to 1%Sr at 250 °C to 400°C has been plotted.

2. Experimental procedure

Alloys were synthesized by adding different levels of Sr in to Mg–3 wt%Al–1 wt%Zn (AZ31) alloy. Four (4) alloys were selected for extrusion and ten (10) were hot compressed. The chemical compositions of the alloys with different Sr contents were determined by inductively coupled plasma (ICP). The selected alloys for hot compression and hot extrusion deformation are listed in Table 1. All compositions are given in wt% unless otherwise specified. Molten alloys were all cast into a preheated steel die under the cover of a protective gas. Details of casting have been explained elsewhere [20].

Cylindrical bars were machined out of the castings to prepare the extrusion billets (30 mm in diameter, 50 mm in height) and hot compression samples (6 mm in diameter, 9 mm in height). Extrusion was performed at four temperatures (250, 300, 350, and 400 °C) for all the four selected compositions (16 extrusion trials) to 1/9 cross section using a 100 T hydraulic press, a steel die setup and a ceramic insulated band heater to maintain the desired deformation temperature. Strain rate was kept constant trough all the trials (0.3 s^{-1}). A high temperature anti-seize paste (Molycote P-37) was used as a lubricant during hot extrusion. All extruded samples were air cooled after deformation.

Hot compression tests were conducted using a 510 MTS servo-hydraulic mechanical testing machine. Straining was carried out to true strains of 0.8 at a strain rate of 0.01 s^{-1}. Samples were subjected to heat 15 min prior to deformation and were protected from oxidation at high temperatures by using an argon shield. Mica plates and boron nitride powder were used to minimize friction and enhance uniform deformation in the compressed samples. The critical strain for the start of dynamic recrystallization (DRX) (ε_c) and the maximum stress (σ_{max}) were obtained from the stress–strain curves which were plotted based on the hot compression data.

Microstructures were revealed using a picric acetic solution and studied using optical microscopy (OM) and scanning electron microscopy (SEM). In order to investigate the second phase morphologies and remove the effect of the Mg matrix during chemical analysis, precipitate extraction was performed using an acetic solution. Surface characterization of the extruded samples has been carried out using optical stereoscopic microscopy.

The crystallographic texture was measured by X-ray diffraction (XRD) using a Bruker D8 X-ray diffractometer. Pole figures and orientation distribution functions (ODF) were calculated using TexTools texture analysis software. The volume fraction of prismatic planes perpendicular to the extrusion direction (F_v) has been used as a measure of ⟨10.0⟩ texture development during extrusion

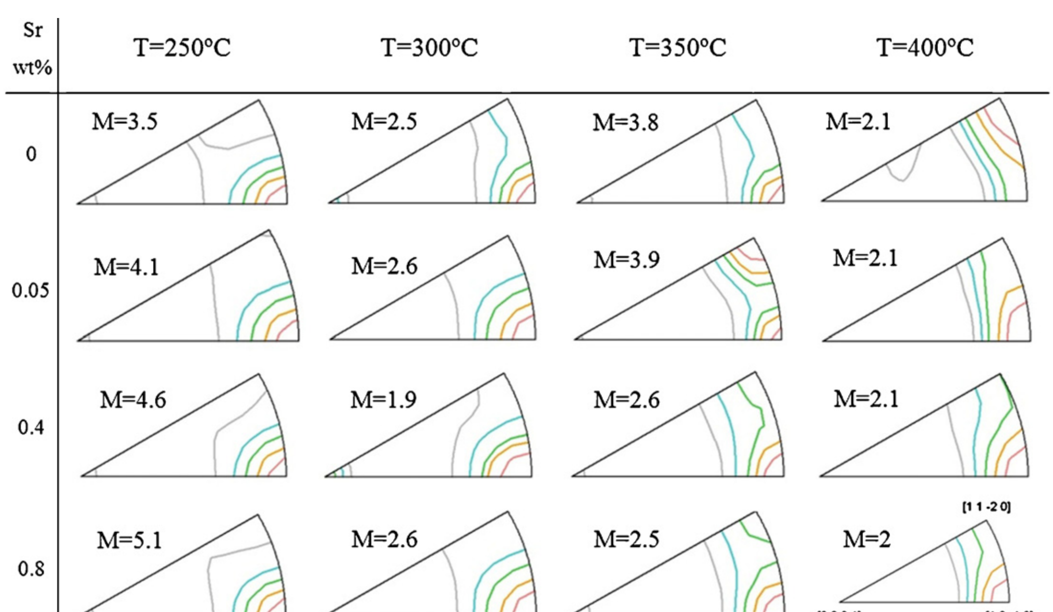

Fig. 1. Inverse pole figures (IPF) at extrusion direction of the samples extruded at different temperatures and levels of Sr.