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EVOLUTION OF MICROSTRUCTURE AND TEXTURE DURING SEVERE COLD ROLLING AND ANNEALING OF Al-2.5%Mg AND Al-2.5%Mg-0.2%Sc ALLOYS

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Abstract

Evolution of microstructure and texture in Al-2.5%Mg and Al-2.5%Mg-0.2%Sc alloys during severe cold rolling and subsequent annealing was studied using electron back scatter diffraction (EBSD). These alloys were first thermo-mechanically processed to sheets of average thickness (~1mm) with well recrystallized microstructures. These sheets were subsequently severely cold-rolled up to an equivalent strain of 4.32 using a combination of Accumulative Roll Bonding and conventional cold-rolling. The deformed alloys were subjected to isochronal annealing treatment for one hour in a wide temperature range. Development of Ultrafine lamellar microstructure subdivided by high angle grain boundaries (HAGB) and pure metal or copper type texture was observed in both the alloys during deformation. Al-Mg-Sc consistently showed higher hardness as compared to the Al-Mg. Al-Mg recrystallized around ~ 2500C but in Al-Mg-Sc the recrystallization was greatly delayed up to 500°C and the deformation texture components were retained during annealing. The differences in the recrystallization behavior of two materials were discussed with regard to the deformation microstructure and presence of fine precipitates.

Introduction

Lightweight materials with superior mechanical properties are in great demand in automobile industries for reducing the weight of the vehicles in order to reduce fuel consumption. Aluminum alloys are widely used for this purpose due to the possibility of achieving high strength combined with good formability. Mechanical strength of the aluminum alloys can be further enhanced by achieving ultrafine grain size (average grain size less than 1µm known as ultrafine grained or UFG materials) [1, 2]. UFG materials can be successfully produced through severe plastic deformation (SPD) processes [3]. Out of several available SPD processes Accumulative Roll Bonding (ARB) is a promising method for the bulk production of ultrafine grained sheet materials [4]. In contrast to conventional rolling processes much higher plastic strain can be imparted during ARB processing without any concomitant change in the thickness of the rolled sheet. ARB processing has been applied on a range of materials and showed very intriguing properties [5, 6]. However, it is envisaged that a combination of ARB and conventional cold-rolling can be particularly interesting due to the possibility of achieving high plastic strain with greater easiness of fabrication but needs to be clarified. In the present work we investigate the evolution of microstructure, texture and hardness properties of Al-2.5%Mg and Al-2.5%Mg-0.2%Sc alloys severely deformed by a combination of conventional cold-rolling and ARB.

Materials and Methods

The chemical composition of the two alloys is listed in Table 1. The as-received materials having dimensions of 150mm^l x 60mm^w x 10mm^t were processed through controlled thermo-mechanical processing with final thickness of 1 mm with well recrystallized grain structure. In Al-Mg-Sc alloy very fine Al3Sc precipitates are evolved during the controlled thermo-mechanical processing. These sheets were used as the starting materials for further ARB processing. A typical ARB processing cycle consists of cutting, surface treatment, stacking and roll-bonding of the sheets. The ARB processing was carried out at room temperature up to 3 cycles of ARB followed by conventional cold-rolling of the ARB processed sheet to a final thickness of 200µm resulting in an equivalent strain of 4.32.

	Fe	Si	Ca	Cu	Mg	Sc	Al
Al-Mg	15.0 ppm	5.0 ppm	5.0 ppm	20.0 ppm	2.51 wt%	-	bal
Al-Mg-Sc	20.0 ppm	10.0 ppm	5.0 ppm	22.0 ppm	2.5 wt%	0.2wt %	bal

The heavily strained materials were isochronally annealed for 1 hour in a salt bath furnace over a wide temperature range (150°C-500°C) in order to study the recrystallization behavior. The microstructure and texture evolution was observed using electron back scatter diffraction (EBSD) attached to scanning electron microscope (SEM). The post processing of the data was done using TSL-OIMTM software. The specimen along the longitudinal section including the normal direction (ND) and rolling direction (RD) were mechanically polished followed by electro-polishing at -300C and at a voltage of 20V using 80%C2H5OH + 20% HClO4 as electrolyte. The hardness at every stage of deformation was taken using a Vickers hardness tester (Emcotest make and model Durascan).

Results and Discussions

Figure 1 shows the gradual evolution of microstructure and texture in Al-Mg alloy during deformation. Figures 1(a) through (d) show the grain boundary (GB) maps of the starting and deformed materials to strain levels of 1.6 (Fig.1(b)), 3.2 (Fig.1(c)) and 4.32 (Fig.1(d)), respectively. The high angle (HAGBs with misorientation angles>150) and low angle grain boundaries (LAGBs; misorientation angle <150) are shown in black and grey lines, respectively. The starting Al-Mg alloy shows recrystallized microstructure with average grain size of ~16µm (Fig.1(a)). Following two cycles of ARB processing (ε=1.6) development of an elongated microstructure along rolling direction could be observed (Fig.1(b)). On further deformation to strain of 3.2 (Fig.1(c)), lamellar microstructure starts to evolve with HAGBs running parallel to RD. Following severe straining to 4.32

(Fig.1(d)), ultrafine lamellar microstructures is observed. The average HAGB spacing measured perpendicular to the rolling direction in this condition is ~730nm. Appearance of the (111) pole figure after straining to 3.2 (Fig.1(c1)) indicates the development of pure metal or copper type rolling texture characterized by the presence of strong Cu, S and Bs orientations. The copper type deformation texture is gradually strengthened with increasing strain (Fig.1(c1)-(d1)).

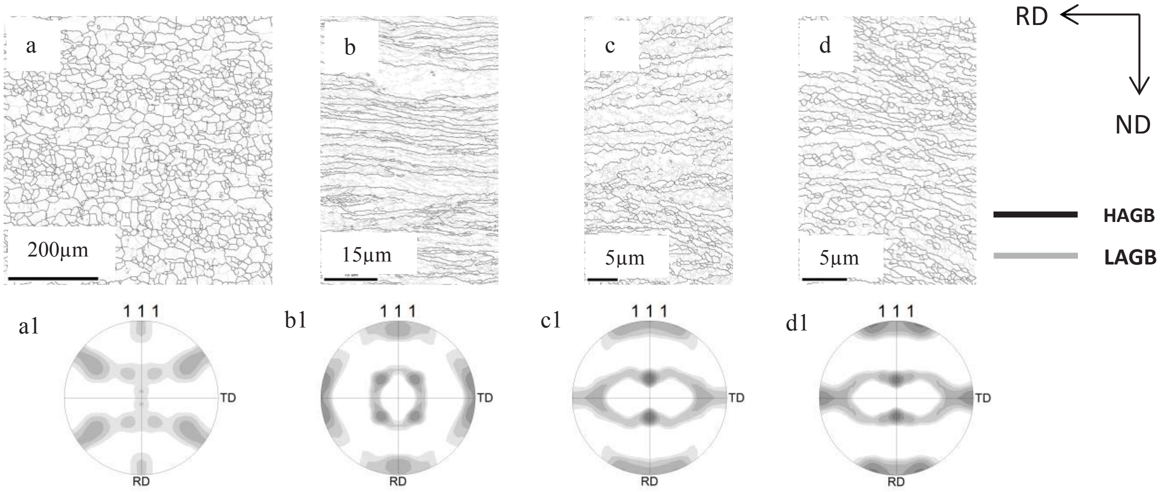

Fig.1: Grain boundary maps of (a) starting, (b) ε = 1.6, (c) ε = 3.2 and (d) ε = 4.32 strained Al-Mg alloy; (a1)-(d1) are corresponding (111) pole figures

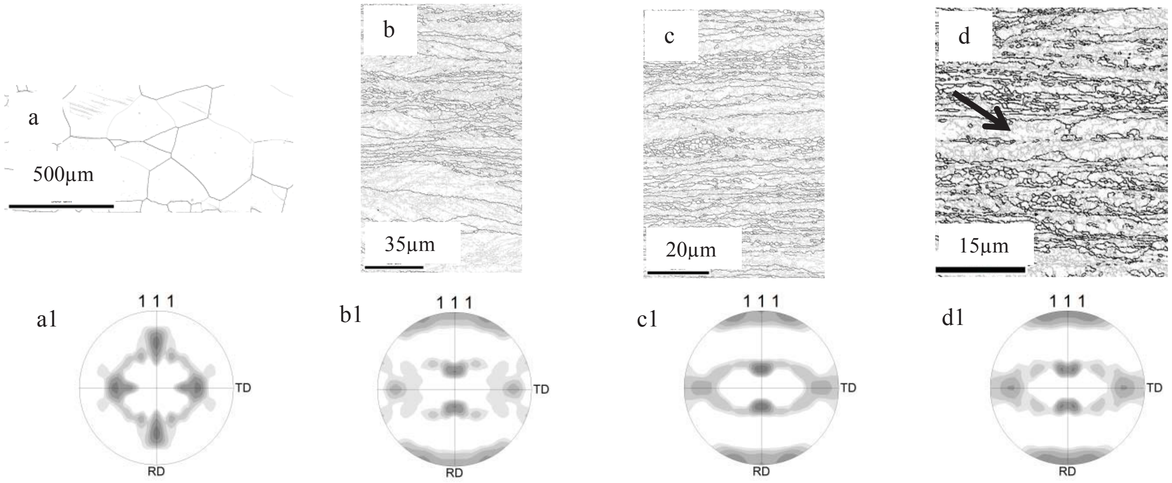

Fig.2: Grain boundary maps of (a) starting, (b) ε = 1.6, (c) ε = 3.2 and (d) ε = 4.32 strained Al-Mg-Sc alloy; (a1)-(d1) are corresponding (111) pole figures

The development of microstructure and texture in Al-Mg-Sc alloy is shown in Fig.2. The starting microstructure of the alloy shows coarse recrystallized grains with an average grain size of ~140μm (Fig.2(a)). The (111) pole figure of the starting material suggests the presence of recrystallization texture components which is due to the previous thermo-mechanical processing of the starting material (Fig.2(a1)). The microstructure after a strain of 1.6 has somewhat coarse appearance (Fig.2(b)) but continuous refinement in microstructure with imposed strain may be seen observed which is evident from the microstructure of alloy processed to equivalent strain levels of 3.2 (Fig.2(c) and 4.32 ((Fig.2(d)).

A lamellar structure finally subdivided by HAGBs is observed after severe cold rolling to strain of 4.32. The average HAGB spacing measured perpendicular to the rolling direction in this condition is ~980nm. The appearance of the (111) pole figure in 1.6 strained material (Fig.2(b1)) suggests the development of a pure metal or copper type texture which is gradually strengthened with increasing strain (Fig.2(c1)-(d1)).

Fig.3 shows the hardness profiles of both Al-Mg and Al-Mg-Sc alloys with deformation. The hardness of Al-Mg-Sc at every stage of deformation is higher than Al-Mg, which is attributed to the presence of very fine Al3Sc precipitates in the starting Al-Mg-Sc alloy.

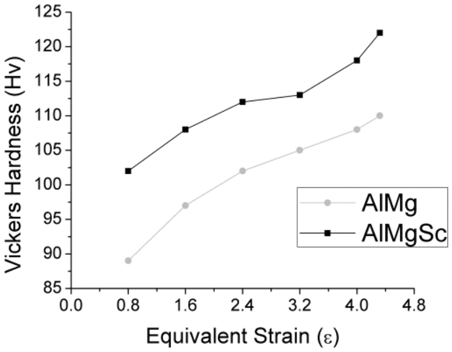

Fig.3: Hardness evolution in Al-Mg and Al-Mg-Sc alloys during deformation through ARB and cold rolling.

The recrystallization behavior of Al-Mg and Al-Mg-SC severely deformed to equivalent strain of 4.32 are shown in Fig.4 and Fig.5. The microstructural changes in Al-Mg are shown in fig.4((a)-(d)). At a lower temperature, 150°C, the microstructure is still in deformed condition (fig 4(a)) but at 200°C, evolution of a fine grain structure is observed (fig. 4(b)), where these fine grains are bounded mostly by medium angle boundaries (50<θ<150). At still elevated temperatures of about 2500C, a microstructure comprising of both recrystallized grains and recovered grains is observed (fig.4(c)). On further annealing to 3000C, a fully recrystallized microstructure is observed (fig.4(d)). (a1)-(d1) shows the corresponding (111) pole figures showing the presence of pure copper type texture till 200°C annealing and later strong presence of cube component along with strong S component is seen after recrystallization.

This sequence in change in texture i.e. a recrystallization texture different from the deformation texture in Al-Mg alloy indicates that conventional discontinuous recrystallization is the primary softening process in heavily deformed Al-Mg alloy during annealing.

However in Al-Mg-Sc alloy the recovery and recrystallization are greatly delayed to a large extent due to the presence of precipitates. Here, recovery started to occur at 325°C (fig. 5(b)) and is extended till 450°C (fig. 5(c)). Recrystallization occurred at 500°C (fig. 5(d)) and this recrystallization behavior in Al-Mg-Sc is quite intriguing. It is observed to form a layered microstructure consisting of alternate recrystallized regions separated by rather fine structured regions.

The evolution of such unusual but attractive microstructure appears to be due to the deformation structure where rather fine deformed regions coexist with thick banded regions (marked by arrow). It appears that recrystallization initiates and proceeds rapidly from the deformed regions due to the high stored energy of the region. This results in the attractive banded microstructure.

From the inset of Fig.5(d), it is observed that the fine grains within the band are surrounded by mostly medium angle boundaries having misorientation (5˚<θ<15˚, marked in green) rather than HAGB, marked in blue.

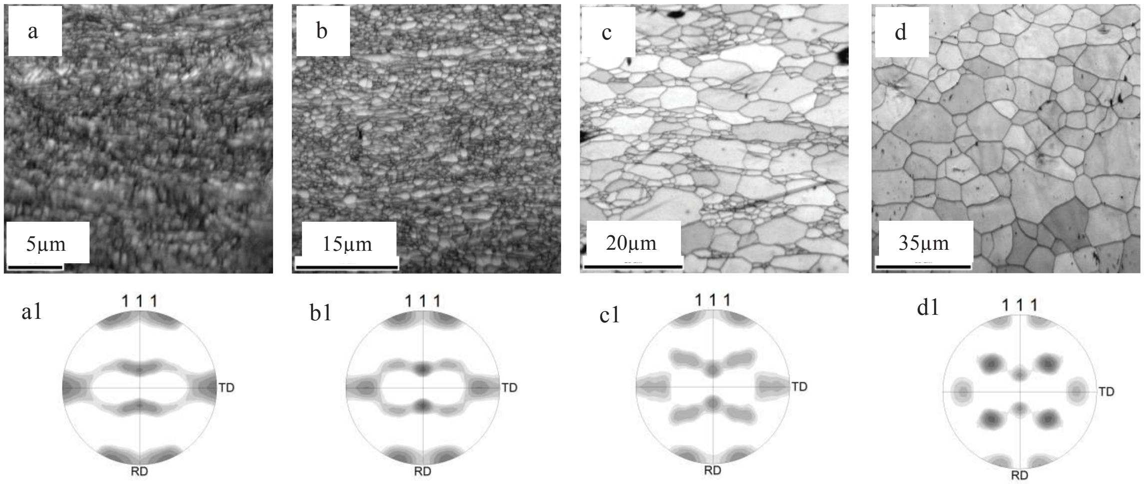

Fig.4: EBSD micrographs of 4.32 strained Al-Mg alloy isochronally annealed for one hour at (a) 150C, (b) 200C, (c) 250C and (d) 300C ; (a1)-(d1) are corresponding (111) pole figures.

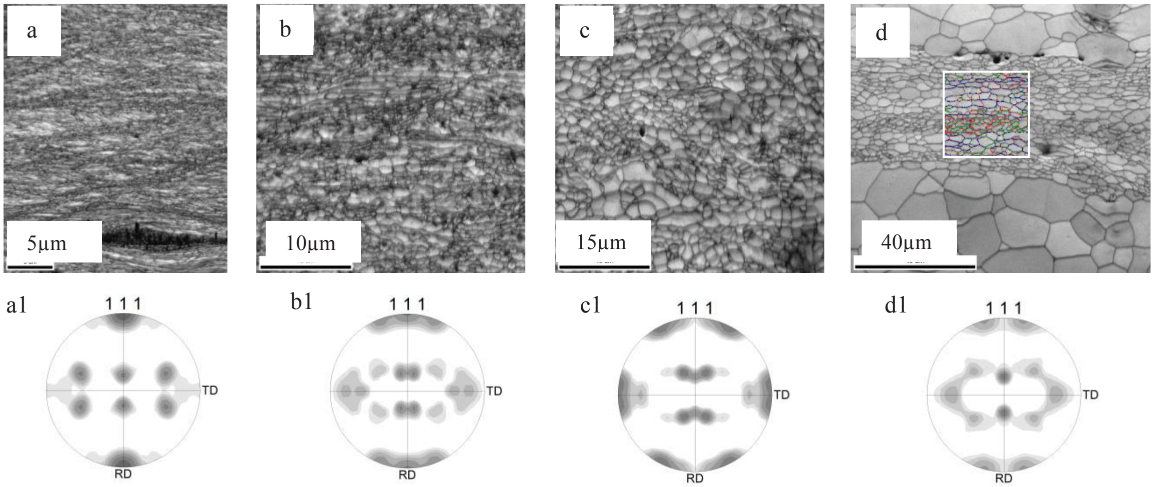

Fig.5: EBSD micrographs of 4.32 strained Al-Mg-Sc alloy isochronally annealed for one hour at (a) 150C, (b) 325C, (c) 450C and (d) 500C ; (a1)-(d1) are corresponding (111) pole figures

Conclusions

Severe deformation through ARB and cold rolling lead to the evolution of a lamellar type ultrafine deformation structure and copper type texture in the experimental Al-Mg and Al-Mg-Sc alloys. The consistently higher hardness values of Al-Mg-Sc alloy in comparison to Al-Mg during processing could be attributed to the presence of fine Al3Sc precipitates in the starting Al-Mg-Sc alloy. The discontinuous recrystallization process appears to be the primary softening mechanism in Al-Mg alloy during annealing. On the other hand a very novel banded microstructure consisting of alternate layers of relatively coarse recrystallized and fine grained regions evolves in Al-Mg-Sc alloy during annealing.

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