Evolution of microstructure and texture during annealing of Al-2.5%Mg-0.2%Sc severely deformed by a combination of accumulative roll bonding (ARB) and conventional rolling

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Evolution of microstructure and texture during annealing of Al-2.5%Mg-0.2%Sc severely deformed by a combination of accumulative roll bonding (ARB) and conventional rolling

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Abstract. Evolution of microstructure and texture during heavy cold-rolling and annealing of Al-2.5%Mg-0.2%Sc alloy was investigated. For this purpose recrystallized sheets of 1mm thickness having finely dispersed precipitates were processed to 3 cycles of ARB (equivalent strain, ε_{eq}=2.4) followed by conventional rolling to a final thickness of 200μm resulting in total equivalent strain of 4.0. Evolution of ultrafine microstructure and strong copper or pure metal type texture were observed during deformation. During annealing very stable microstructure was observed up to 400°C but further annealing resulted in formation of a layered microstructure with deformed layer sandwiched between recrystallized layers. Formation of strong cube texture is not observed in the recrystallized layers. Isothermal annealing for longer time at 500°C leads to abnormal growth of Q orientation ({013}<213>) within the deformed layer.

1. Introduction

Automobile industries are in real need of lightweight materials with superior mechanical properties. Aluminum alloys are widely used for this purpose. The development of annealing texture in aluminum alloys for automobile applications remains a subject of great importance as texture can greatly affect the mechanical properties of the processed materials [1, 2].
In the present work we investigate the development of deformation and annealing textures Al-2.5%Mg-0.2%Sc severely deformed by Accumulative roll bonding (ARB) [3]. Deformation of high stacking fault energy face centered cubic (FCC) materials leads to a strong copper or pure metal type texture consisting of copper (Cu) ((112)<111>), S ((123)<634>) and brass (Bs) ((110)<112>) orientations [4]. Annealing of this material leads to strong cube ((001)<100>) texture but the presence of second phase as fine precipitates changes the texture due to strong pinning effect as is observed in this work.

2. Materials and methods

The chemical composition of the alloy is given in Table 1. The as received blocks having dimensions of 150 mm^l x 60 mm^w x 10 mm^t were processed through various thermomechanical processing routes resulting in a final thickness of 1 mm. In Al-Mg-Sc alloy, very fine Al_3Sc precipitates are evolved during thermomechanical processing. These sheets are used as the starting materials for further processing. These 1 mm thick sheets are first processed through Accumulative Roll Bonding (ARB) to 3 cycles (equivalent strain of 2.4). A typical ARB processing cycle involves cutting of sheet to two halves, surface treatment including degreasing and wire brushing, stacking and roll-bonding of the sheets to 50% reduction in thickness in a single pass. The ARB was followed by conventional rolling to a final thickness of 200 μm (equivalent strain of ~4 corresponding to 97% reduction in thickness). The 97% deformed materials were isochronally annealed for 1hr at different temperatures to study the recrystallization behavior.

Table 1: Chemical composition of the Al-Mg-Sc alloy

Fe	Si	Ca	Cu	Mg	Sc	Al
20 ppm	10 ppm	5 ppm	22 ppm	2.5 wt%	0.2 wt%	Bal

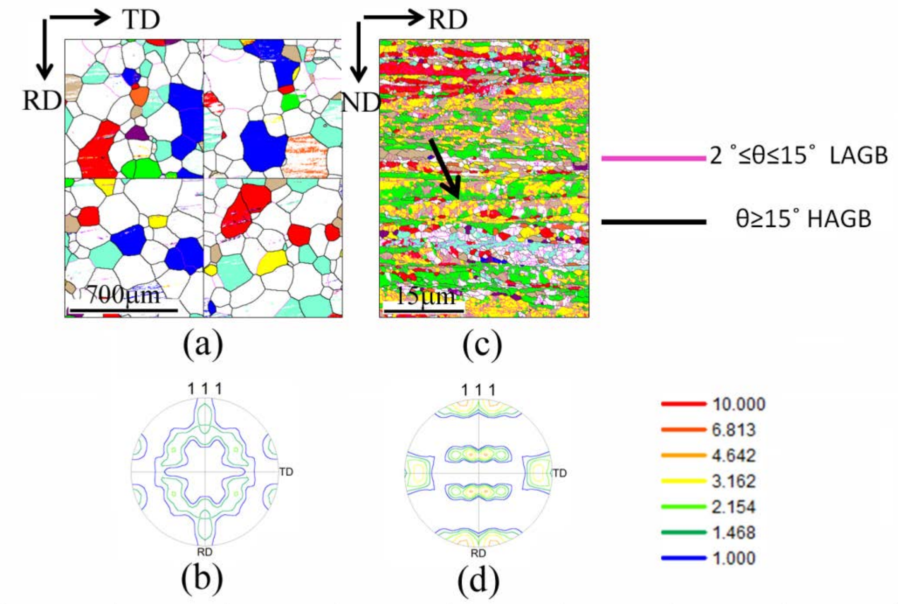
The microstructures were observed using electron back scatter diffraction (EBSD) attached to scanning electron microscope (SEM) in order to characterize microstructural changes. The post processing of the data was done using TSL-OIM™ software. The specimen along the longitudinal section including the normal direction (ND) and rolling direction (RD) were mechanically grinded and electropolished using 10% perchloric acid + 90% methanol at -30^{0}C and at a voltage of 20V. The volume fractions of texture components were calculated by taking a cut-off angle of 15° and assuming orthotropic sample symmetry.

3. Results and discussion

Figure 1 shows the orientation maps of starting and 97% cold rolled material. The merged orientation map of starting material shows recrystallized grains (average grain size ~ 115 µm) (Fig. 1(a)). The texture of the starting material is found to be weak (consisting mainly of cube and rotated cube grains denoted by Q as seen from Fig.1(a)) which is evident from the corresponding (111) pole figure (PF) (Fig. 1(b)). Deformation to 97% cold rolling (Fig. 1(c)) leads to the development of ultrafine lamellar structure extended parallel to the rolling direction (RD) with an average high angle grain boundary (HAGB) spacing of 980nm. The development of strong pure metal (copper) type texture characterized by the presence of Cu (red), S (yellow) and Bs (green) is observed in the orientation map in Fig. 1(c) which is also corroborated by the corresponding (111) PF (Fig. 1(d)).

When the heavily deformed material is isochronally annealed, the recrystallization behavior is found to be quite interesting. The material after annealing at 200°C (Fig.2(a)) and 350°C (Fig. 2(b)) shows the presence of deformation texture components. The stabilization of microstructure against discontinuous recrystallization is achieved by the addition of Sc through grain boundary pinning [5].

Discontinuous recrystallization is observed upon annealing at 400°C (Fig. 3(c)). When the material is annealed at higher temperature at 500°C (Fig. 3(d)), interestingly, a layered microstructure with two recrystallized regions separated by a deformed region is evolved. There is no grain growth into the deformed layer from either side and the grain growth is inhibited at the ARB interfaces on either sides.



Cube	Cu	S	Bs	Goss	C_{RD}	Q	R
(001)<100>	(112)<111>	(123)<634>	(110)<112>	(110)<001>	(013)<100>	(013)<213>	(214)<112>

Fig. 1: Orientation maps along with corresponding (111) pole figures of (a) starting and (b) 97% ARB+CR processed AlMgSc alloy.

When the two layers are analyzed separately, the deformed layer has very fine grain structure and the deformation texture components are strongly present. In the recrystallized regions, strong cube texture is not observed. This is in contrast with the single phase Al-Mg alloy processed by ARB+CR where the dominating recrystallization texture component is cube [6].

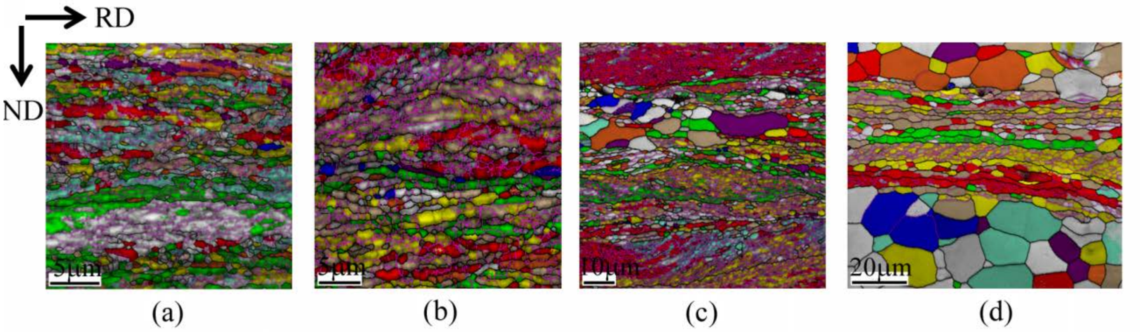


Fig. 2: Orientation maps of isochronally annealed 97% deformed AlMgSc alloy at (a) 200°C, (b) 350°C, (c) 400°C and (d) 500°C for one hour

In Al-Mg-Sc alloy the presence of precipitates plays an important role. Strong pinning due to the fine precipitates hinders strong recovery. The cube regions which undergoes preferential recovery during deformation results in early nucleation during recrystallization. However, absence of preferential recovery results in absence of preferential nucleation of cube grains and consequent absence of strong cube texture. Also the reason for the layered microstructure can be obtained from the processing route. Since in the ARB+CR processing route conventional rolling replaces the ARB, the contamination at the bonding interfaces are not distributed but concentrated at the center of the sheet which impart strong pinning leading to delayed recrystallization.

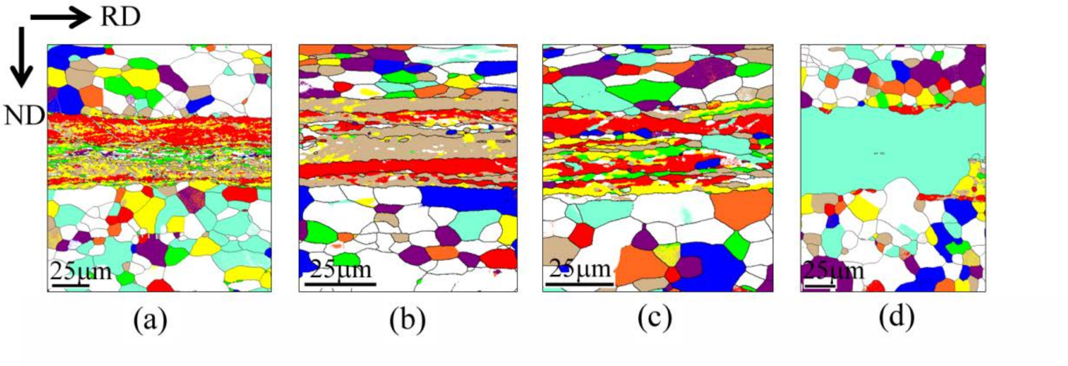


Fig. 3: Orientation maps of isothermal annealing at 500°C for (a) 2 seconds, (b) 30 min, (c) 90 min and (d) 180 min

To understand the stability of the layered microstructure isothermal annealing is carried out at 500°C for varying times. Figure 3 shows the orientation maps of material isothermally annealed at 500°C. It is very interesting to see that the layered structure developed at very short annealing time of 2 seconds (Fig. 3(a)). The recrystallization on either side of the deformed layer is very rapid. The orientations present in the recrystallized regions in all the cases seem to be similar. But within the deformed layer nucleation is observed after annealing for 90 minutes. It appears that preferential nucleation of ND rotated cube (designated as Q, (013)<213>)) grains (Fig. 3(c)). After 180 minutes the Q oriented grain consumes the entire deformed layer due to abnormal growth (Fig. 3(d)).

4. Conclusions

The severe deformation of Al-2.5%Mg-0.2%Sc alloy leads to very fine lamellar microstructure with pure metal type texture. Annealing at higher temperature results in an unusual layered microstructure with deformed layer sandwiched by recrystallized layers. Isothermal annealing for longer time leads to abnormal growth of Q orientation within the deformed layer.

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