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2014 IOP Conf. Ser.: Mater. Sci. Eng. 63 012152

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The texture development of ECAP processed AA1050 aluminum, before and after a final anneal: effect of the initial texture

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Abstract. Equal Channel Angular Pressing (ECAP) can be used to control deformation and annealing textures. The initial texture has a significant role on texture development and intensity after deformation and anneal. In this work AA 1050 Al samples with different initial textures and initial strain of 0.3 were deformed in a 120° ECAP die. Deformation followed route A, yielding equivalent strains of 1 and 3 above the initial. After ECAP one of the samples was rolled to a thickness reduction of 70%. Texture evaluation was performed by x-ray analysis in the as deformed state and after annealing at 350°C for 1 h, by calculating orientation distribution functions. The microstructure was observed by optical and scanning electron microscopy.

Keywords: ECAP, AA1050 aluminum, texture

1. Introduction

Equal channel angular processing (ECAP) is a novel technique whose main advantage is the production of fine-grained materials with outstanding tensile strength. The technique uses two square or circular die channels intersecting at a given angle Φ , usually equal to 90 or 120°. At the intersection the material undergoes simple shear deformation to an extent that depends on Φ . Since the sample section is kept constant the process can be repeated as intended [1-5].

It has been observed that shear deformation by ECAP can produce strong $\langle 111 \rangle$ // Normal Direction (ND) texture, an essential feature for good formability of fcc materials. This phenomenon is useful in the context of Al alloys, in which conventional deformation techniques do not produce said orientation. Thus processes in which shear is the main deformation mode, such as ECAP [6,7]; also a variation known as differential equal-channel pressing (DECAP) [8,9] and asymmetric rolling [10], have been recently applied to Al alloys in order to study the influence of shear deformation on their formability. The present knowledge on the relationships between ECAP processing, annealing heat treatments and texture can be summarized as follows: (i) texture development by ECAP is related to the original texture, deformation route (A, B_C or C) and number of passes [11]; (ii) deep drawing processes call for high ductility, hence annealing heat treatments are mandatory, but



the effect on the previous deformation texture has not been extensively studied [7,12]; (iii) there is no strong evidence that the $\langle 111 \rangle // ND$ orientation achieved by shear deformation will be retained after grain growth.

In the ECAP process the billet deforms by simple shear within a small area at the intersection of the two channels. After the first pass the slip plane tends to rotate towards the shear direction, which is $\Phi/2$. For fcc materials, the preferential textures are the $\{h k l\} \langle 110 \rangle$ fibre when the $\langle 110 \rangle$ direction in the crystal is oriented in the shear direction and the $\{111\} \langle uvw \rangle$ fibre when the $\{111\}$ plane of the crystal is parallel to the shear plane representing a rotation of the original texture around the transverse axis. The resultant textures are: A $\{111\} \langle 110 \rangle$; A* $\{111\} \langle 211 \rangle$; B $\{112\} \langle 110 \rangle$ and C $\{100\} \langle 011 \rangle$ [13]. The ECAP deformation displays monoclinic symmetry for the A and C routes (no rotation of the sample around its extrusion axis) and no deformation symmetry after routes B_A and B_C (rotation of the sample around its extrusion axis of $\pm 90^\circ$ or $+90^\circ$, respectively). Additionally, the deformation and the texture development are strongly influenced by die design (angle, curvature radii at the channels intersection), friction conditions, eventual application of back-pressure, and also by the work-hardening capacity of the material. The theoretical distribution of strain within the central section of the billet is uniform and can be described as simple shear. This applies when the deformation zone is as narrow as possible, a condition achieved with sharp corners, high friction and /or back pressure [14]. When this is not the case other strain-stress combinations intervene. Considering a cross section of the billet, it was observed that the zone where shear occurs is as wide as the die external corner angle, assuming a fan like shape, and that close to the outer channel wall the material is subjected to a combination of bending and tensile-compressive stresses. Therefore, the shear plane is not unambiguously defined and cannot be taken as reference. The observed textures shift across the sample thickness because the material is subjected to different amounts of rotations around the transverse axis [7,15,16]. Taking the billet surface as reference, the A, B, A* and C orientations can be seen as having the $\{112\}$, $\{111\}$ and $\{110\}$ planes parallel to the surface and thus as part of $\langle 112 \rangle // ND$, $\langle 111 \rangle // ND$ and $\langle 110 \rangle // ND$ fibres whose positions lie in the $\phi_2 = 45^\circ$ section of conventional ODF plots. This reference system will be used in the present paper.

In the present work an AA1050 alloy with three different initial textures was deformed by ECAP and by conventional rolling. The texture thus resulting and the recrystallization texture were analyzed and compared.

2. Experimental Procedure

A commercial AA1050 alloy was processed in the plant according to three different routes, from which three different initial textures were obtained: (i) Sample 1 (S1) - roll casting followed by a slow cooling rate and exhibiting a strong brass texture; (ii) Sample 2 (S2) - hot rolled, giving a mixture of copper, Goss and brass textures; (iii) Sample 3 (S3) - roll casting subjected to a high cooling rate and characterized by a mixture of near cube, copper Goss and brass textures.

ECAP processing took place in a 120° die with the angle subtending the outer curvature radius equal to 20° and $14 \times 14 \text{ mm}^2$ cross section channels (a schematic representation of the sample reference axes is shown in Fig. 1). Samples S1, S2 and S3 were cut as strips having $7 \times 14 \text{ mm}^2$ and 70 mm length, with the length parallel to the rolling direction. ECAP processing was performed at room temperature, stacking strips as pairs and following route A. Sample S3 was conventionally rolled to a thickness reduction of 70%, after ECAP deformation.

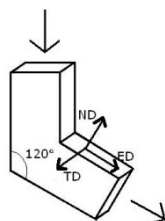


Figure 1. Sample orientation reference system to which the crystallographic texture will be referred.

After the above processes, S₁, S₂ and S₃ were heat treated at 350° C for 1 h and water quenched. The microstructure was revealed by conventional polishing techniques followed by anodizing (2.5 % HBF solution, 20V / 3 - 5 min) and observed under polarized light. The deformed billets were also observed in a FEI Quanta scanning electron microscope (SEM) equipped with automatic orientation imaging mapping (OIM) and EDAX/TSL software. The scans were performed in the ND x ED plane of the metallographic prepared samples. The ECAP processed samples are identified by the letter X, preceded by a number indicating the pass number: 1X, 2X, etc. Rolled samples were identified by adding the letter R to the previously described designation and the annealed condition by adding the letter a.

Texture was evaluated by x-ray analysis using CuK α lines in a Philips X-pert Pro MPD equipment. The (111), (200) and (220) pole figures, together with background and defocusing curves for further correction, were measured in the middle plane of the central third of the sample. On the ODF calculations triclinic sample symmetry was considered for the processed samples because shear deformation destroys the orthorhombic sample symmetry that is usually assumed for conventional rolling processes.

3. Results and Discussion

In ECAP processing, when route A is applied the crystal orientations are generated by rotation of the original texture around the transverse axis; in the present work such rotation was about 30°. This is shown in Fig.2, which contains the {111} pole figures and the ODF sections at $\phi_2=45^\circ$ of the as received and deformed samples. The ECAP die here employed had rounded edges at the channels intersection, thus it is expected that the amount of lattice rotation would vary across the sample thickness due to the imposed shear stress gradient. That is, the observed texture will change from that predicted for sharp inner angles [13] to the prevalent texture when simple shear is dominant [15].

In the present study the ODF sections show that in the middle plane of the plates the applied stress was close to simple shear. In sample S₁, after the first pass the original brass texture changed by rotating towards the {112} <110> orientation, that increased in intensity after four passes. In these samples the original copper orientation is first rotated into <111> // ND orientations (after the first pass) and after four passes only a small amount of the <110> // ND orientation was formed.

For samples S₂ and S₃, the <112> // ND orientations were observed after one pass, together with the <111> // ND orientations. Geometrically, the latter can be generated from S, Goss or copper textures (which were present in the initial S₂ and S₃), but not from brass (major texture component in S₁). Texture simulations by Han et al. [11] concluded that the {001}<110> texture developed from simple shear originated from the {12 3}<634> S texture, while both {112}<111> Cu and {110}<100> Goss textures yielded the <111> // ND textures. When rotated around the transverse axis the cube orientations will originate the {110}<110> rotated Goss orientation. For S₃, which contained the cube texture, originated from the original plant processing, a fiber with <110> direction parallel to the extrusion direction (or rolling direction) was formed as a result of the above described rotations. From these observations it is clear that the ECAP – induced orientation is influenced by the original

texture; conversely, deformation of S3 by rolling produced a typical rolling texture, unrelated to the previous orientation.

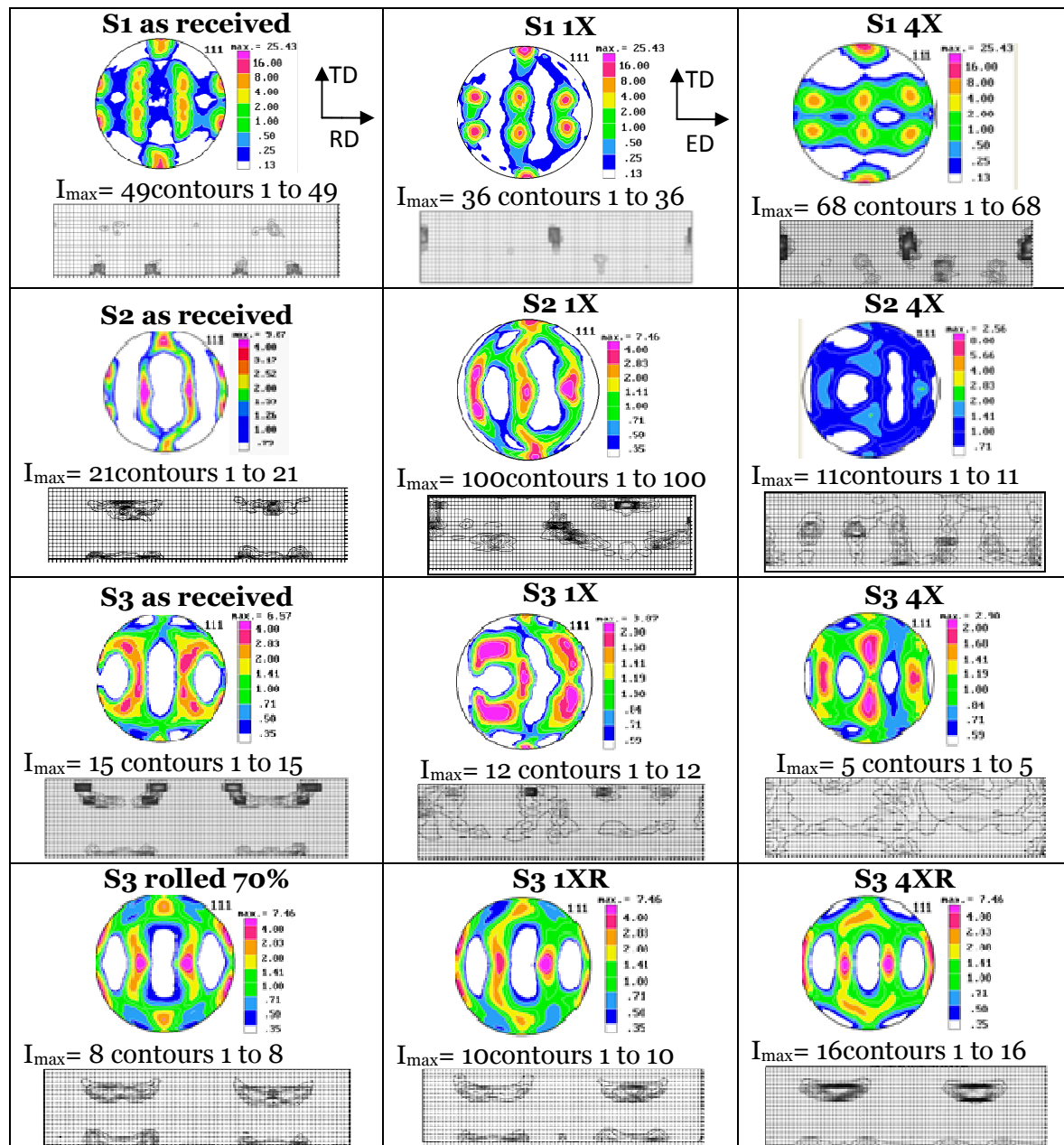


Figure 2. Textures of as received S1, S2 and S3 samples, and after one and four ECAP passes. S3 was also rolled 70% in the as received condition and after ECAP deformation.

It is consensual that grain refinement during the ECAP process is produced by accumulative strain and by the interaction of shearing planes with the crystal structure and the deformation texture. Partition and refinement of the microstructure are mechanically induced by dynamic recrystallization, which is believed to involve mechanisms such as grain/subgrain rotation plus flow localization in shear bands and their intersections. In pure Al, dynamic recrystallization has been observed even after the first ECAP pass [16], but in commercial alloys the process equivalent deformation necessary to achieve a high fraction of

high angle grain boundaries [6,17, 18] is only achieved after four passes in 90° ECAP dies and five to six when $\Phi = 120^\circ$.

In the present work the equivalent strain is below this threshold. Fig. 3 shows the results of the EBSD analysis giving the location of high angle grain boundaries in sample S3 after one and four ECAP passes and after ECAP plus rolling. It is clear that after ECAP no extensive formation of fine-grained structure has taken place, whilst after ECAP plus rolling a band-like structure is formed, with regions of fine grains within some of these bands (see Fig. 3c). These features are more developed in the sample deformed by four ECAP passes plus rolling, as shown in Fig. 3d.

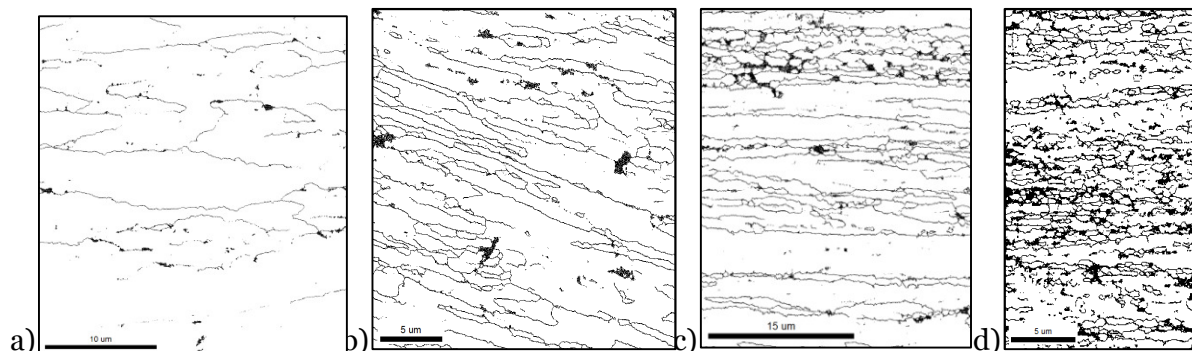


Figure 3. High angle grain boundaries maps of sample S3 after ECAP processing: (a) 1X; (b) 4X, and after ECAP plus rolling: (c) 1XR; (d) 4XR.

The formation of recrystallized grains in the ECAP samples should therefore start on deformation heterogeneities, such as shear bands, or close to distorted grain boundaries. On this respect, Fig.4 shows sample S2 deformed by four ECAP passes at the beginning of the annealing process and after full recrystallization.

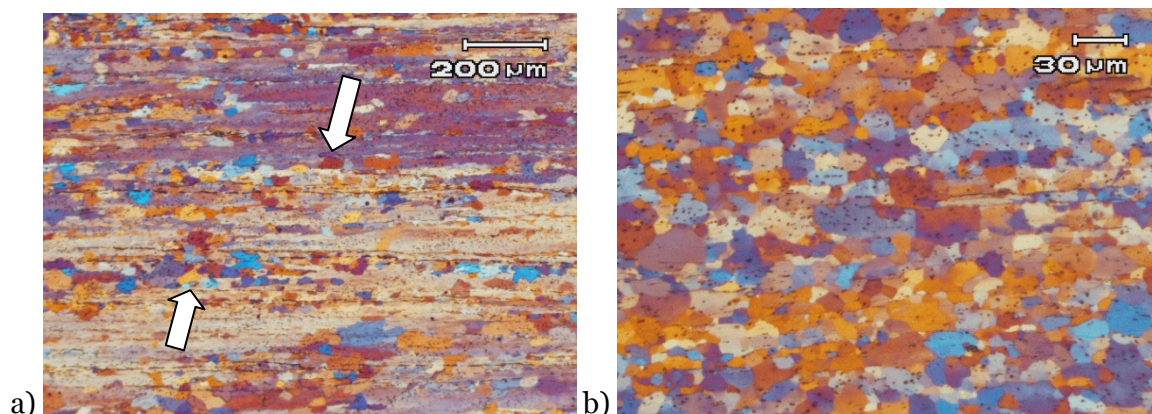


Figure 4. Sample S1, ECAP processed by four passes and heat treated at 350°C: (a) early stages of recrystallization; (b) after 1 hour, showing a fully recrystallized microstructure. The arrows mark the location of new grains formed at shear band and grain boundaries.

The recrystallization textures are shown in Fig. 5. Sample S1 retained the initial texture, and the $\{112\}\langle 110 \rangle$ orientations were reinforced after the heat treatment. Strengthening of the $\{110\}\langle 112 \rangle$ orientations was observed in sample S3 after four ECAP passes while the texture intensity decreased in S2 after the first pass. After annealing, samples S2 4X, S3 1X and S3 4X exhibited texture intensities identical to those of the deformed state. A spread of

texture orientations was observed in S2 and S3 after annealing. The $\langle 111 \rangle // \text{ND}$ fiber was observed in the annealed S2 but was less evident in sample S3, in which the texture is close to random for 4X, while the rotated Goss orientation was substituted by simple Goss in the annealed state.

In order to compare the evolution of texture from the deformed to the annealed condition, the sum of the intensities in the $\langle 100 \rangle$, $\langle 112 \rangle$, $\langle 111 \rangle$ and $\langle 110 \rangle // \text{ND}$ fibers in the $\varphi_2 = 45^\circ$ ODF section were summarized in Fig. 6. It can be seen that the deformation texture is strongly dependent on the initial texture; both cube and $\langle 111 \rangle$ fibers are absent after annealing when the initial texture was the brass texture (see Figs. 6a and 6b).

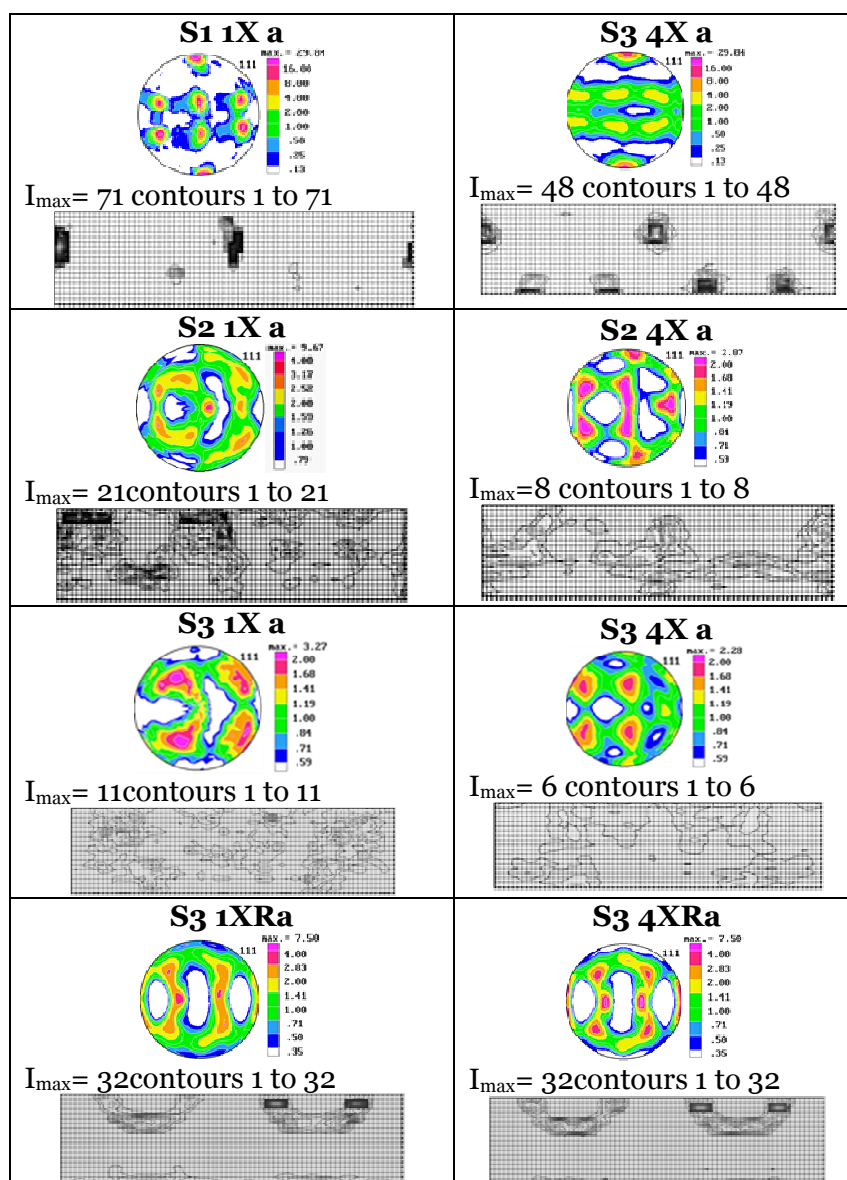


Figure 5. Recrystallization textures after a 350°C/ 1 h anneal of ECAP processed S1, S2 and S3 samples, and of S3 deformed by ECAP plus rolling,.

Although cube fiber textures exist in the deformed samples S2 and S3 (figures 6c and 6e), they do not grow preferentially during annealing (Figs. 6d and 6f). Also, when annealing samples deformed four ECAP passes these orientations tend to decrease. The same is

observed for the $\langle 111 \rangle$ fiber: its formation depends on whether the original copper or Goss textures were present, and is more intense after the first ECAP pass than after the fourth; also, no preferential growth during annealing was observed. Thus, the texture decreases with increasing deformation because during ECAP the shear plane position changes at each pass [19] and is not constant along the sample thickness. This yields to the prevalence of an isotropic distribution of deformation.

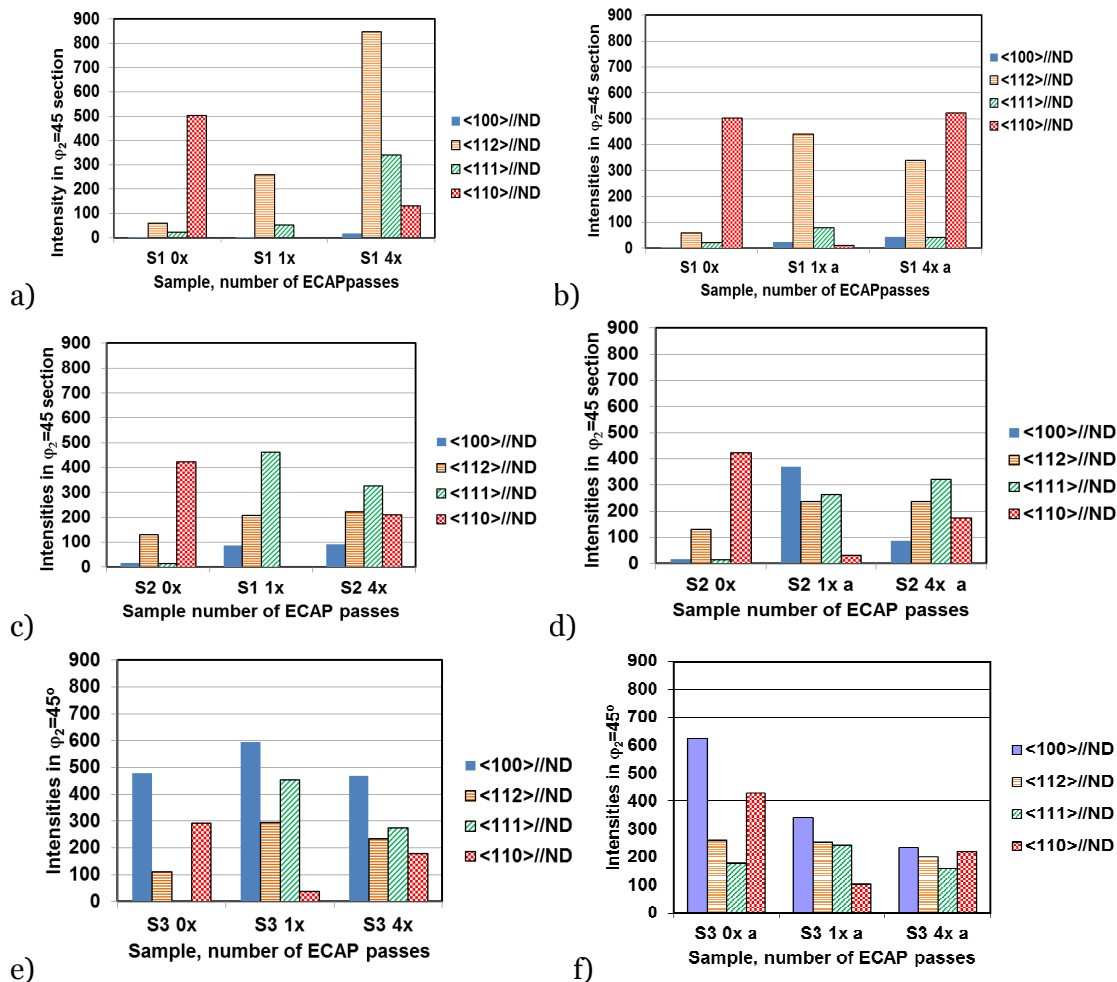


Figure 6. Intensities of deformation and recrystallization textures for different process conditions: (a) S1 ECAP deformed; (b) S1 ECAP deformed and annealed; (c) S2 ECAP deformed; (d) S3 ECAP deformed and annealed; (e) S3 ECAP deformed; (f) S3 ECAP deformed and annealed

Finally, Fig. 7 shows that irrespective the amount of deformation imposed before rolling, the cube texture always prevails in the annealed material.

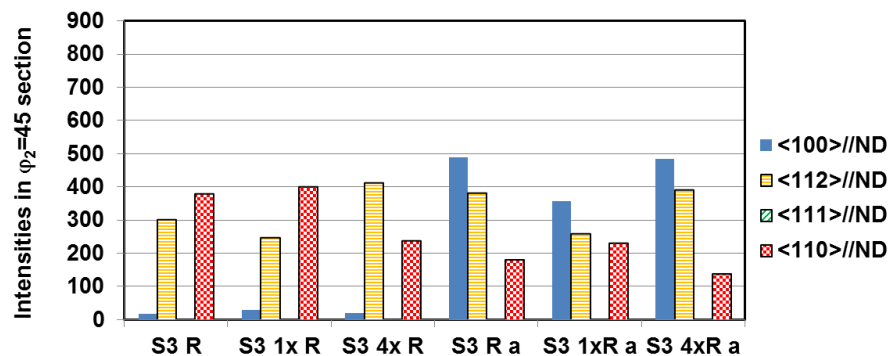


Figure 7. Correlation between the intensity of deformation by rolling and the recrystallization textures.

The figure also shows that in the present work the amount of deformation preceding rolling and the amount of grains of submicron size before annealing have no influence on the annealing texture, in which the cube texture always grows preferentially.

In Al alloys processed by rolling, submicron sized grains are known to act as nuclei for the recrystallization texture, and those grains with preferential growth are formed on persistent cube bands. Usually the volume fraction of the material with cube orientation increases with thickness reduction by cold rolling before heat treatment, but for high strain ($\epsilon_{eq} > 3$) retention of the rolling texture was also observed [20,21]. Rolling promotes a constant deformation path and concentration of deformation is easily induced, with some orientations storing more strain energy than others. An indication of the heterogeneity of stored deformation is, as said above, the presence of cube orientations in rolled and annealed Al.

4. Conclusions

ECAP orientation is influenced by the original texture; conversely, deformation by rolling produces a typical rolling texture, unrelated to the previous orientation.

The hot rolled initial texture containing Goss and Copper orientations yields the <111>//ND fiber texture.

The ECAP process yields to an isotropic distribution of deformation, with no preferential growth during recrystallization, but the deformation orientation is almost completely retained after annealing. Conversely, irrespective the amount of deformation imposed by ECAP processing, deformation by rolling always produced the cube texture in the annealed material

Acknowledgements

The authors would like to thank the financial support of São Paulo State Research Foundation (FAPESP -2011/02009-0). The material was donated by the Brazilian Aluminum Company (CBA).

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