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Texture, Microstructure and Mechanical Properties of Asymmetrically Rolled AA6082 Aluminum Alloy

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Ultrafine grained materials (UFGm) are gaining nowadays large importance because of higher mechanical properties compared to the conventionally processed materials. One of the most promising techniques for the production of bulk UFGm is severe plastic deformation (SPD). it is possible for this technique to impose a high and complex state of strain that promotes the continuous recrystallization of the alloy at room or moderately high temperatures. In addition, several UFG metals seem to be much more effective for high strain-rate superplastic forming.

In this work, asymmetric rolling has been exploited to impart SPD on a solution treated aluminium alloy, up to about 500% equivalent strain. In particular, this process has been compared with a conventional rolling procedure to evaluate differences in terms of resulting microstructure, mechanical properties and texture. To avoid or limit any phenomenon of recovery, the rolling processes have been conducted at room temperature.

Samples obtained have been analyzed by scanning and transmission electron microscopy to evaluate the evolution of microstructure, microhardness test and XRD measurement to determine the texture

The experimental investigations demonstrated that asymmetric rolling in the SPD regime could readily promote the achievement of an ultrafine grain structure and a different texture compared to conventional rolling.

Keywords: *aluminium alloys, SPD, asymmetric rolling, texture*

1. Introduction

It is well known that a reduction in grain size corresponds to enhanced mechanical properties of metallic alloys [1]. The production of Ultrafine Grained (UFG) materials, with a grain size in the submicrometer scale, thus leads to materials with higher strength and improved ductility at room temperature compared to coarse grained materials, as well as better formability at high temperature (under appropriate condition of strain rate and temperature superplastic behavior can occur) [2]. One of the exploitable mechanisms that allows strong refining of the grain structure is continuous dynamic recrystallization (cDRX) [3, 4]. According to this process, the material experiences the creation of deformation/microshear bands for low and medium amount of equivalent strain, while at higher level of strain, in the Severe Plastic Deformation (SPD) regime, grain subdivision can occur due to the increase in boundary misorientation, leading to high-angle grain boundaries [5].

Many thermo-mechanical processes are giving the possibility to refine the grain structure by discontinuous recrystallization. However, due to its high stacking faults energy the attempts to reduce grain size in commercial aluminum alloys exploiting this phenomenon have encountered many difficulties [6]. This characteristic strongly facilitates the phenomenon of recovery instead of recrystallization. In order to impart high amounts of equivalent strain to materials several SPD techniques have been developed in last decades, either at a lab or at the industrial scale, by exploiting cDRX mechanism. In the former group, it is possible to cite Equal Channel Angular Extrusion (ECAE) [6] and High Pressure Torsion (HPT). In the latter group it is possible to mention Asymmetric Rolling (ASR) and Accumulative Roll Bonding (ARB) [7]. Since they can be industrially exploited with modest modifications of the rolling mill, rolling processes are among the most attractive processes for SPD [8, 9].

The major texture in a fully annealed aluminum alloy sheet is the cube {0 0 1}<1 0 0> component with a relatively low r-value [4]. Through strong shear deformation the γ-fiber texture could be generated in aluminum alloy sheet [5–9]. Asymmetric rolling (ASR), a rolling process that allows rolls to rotate with different circumferential velocities, is a processing method that stimulates the generation of shear strain throughout the sheet thickness [10]. It has been demonstrated that ASR in pure aluminum forces the deformation texture to rotate about the transverse direction (TD) from the plane strain compression texture (β- fibre), which consists of Bs {0 1 1}<2 1 1>, S {1 2 3}<6 3 4> and Cu {1 1 2}<1 1 1>, towards the ideal shear texture, consisting of the γ-fibre and a rotated cube H {0 0 1}<1 1 0> [12]. It is known that an ideal shear texture in aluminum alloy sheet can increase sheet formability and reduce planar anisotropy [13]. In symmetric rolling the shear texture can be generated by the shear strain due to the roll–metal friction and rolling gap geometry, but only the volume from the sheet surface to one fourth thickness is really interested [12, 14]. Asymmetric rolling adds a shear strain component throughout the sheet thickness.

The aim of this work is to characterize the evolution of grain structure, mechanical properties and texture of a 6082-type asymmetrically rolled aluminum alloy deformed in the SPD regime by asymmetric rolling in order to highlight differences from conventionally (symmetrically) rolled sheets.

2. Materials and experimental procedures

Commercial bars of a type 6082 Al alloy having a thickness of 10 mm and width of 40 mm were annealed at 450°C for 30 minutes and cold rolled down to a thickness of 0,23 mm. This overall reduction was achieved by a multipass procedure with no intermediate annealing treatments. A laboratory rolling mill (roll diameter 150 mm, width 200 mm) featuring the possibility of independently modifying the rotational speed of its two rolls was adopted for this purpose. The rolling schedule imposed a reduction of thickness of about 20% at each step and the rotation of the billet along its longitudinal axis before each pass. The asymmetry ratio adopted was 1.4 on the basis of previous studies [14].

Microhardness measurements with a load on the indenter of 1 N were performed to evaluate mechanical properties. Microstructure analyses were carried out by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). SEM and TEM samples were prepared by mechanically grinding the materials down to about 85 micrometer thickness. Final twin jet thinning was performed at 18V with a solution of 30% HNO_3 in methyl alcohol at -30°C. Results have been analyzed as a function of equivalent strain calculated according to the equation (1) [15]:

$$\overline{\varepsilon} = 1{,}155 \cdot \ln\left(\frac{h_0}{h_f}\right) \qquad (1)$$

3. Results and discussion

In Figure 1 the evolution of microhardness is plotted as a function of equivalent strain calculated according to equation (1).

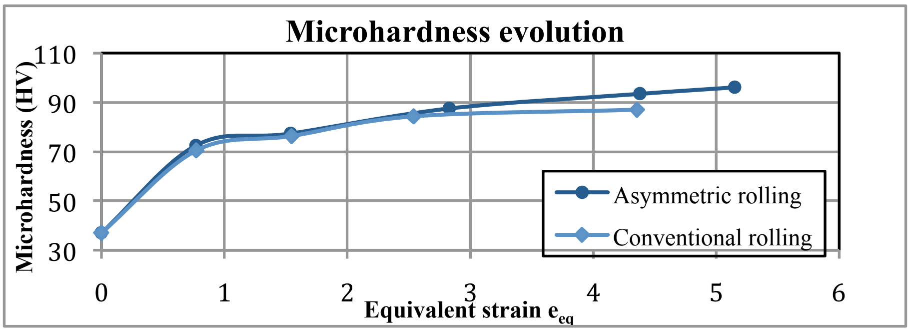


Figure 1 Evolution of microhardness as a function of equivalent strain

It is possible to see that the major growth in microhardness is concentrated at the beginning of the process. Indeed, while the value of microhardness doubles from the beginning to 0,77 of equivalent strain, there is a small increase from that point until the end of the rolling procedure. The effect of asymmetric rolling over conventional rolling becomes evident only at strain values exceeding 3, when the asymmetrically rolled samples increase in hardness more rapidly than the symmetrically rolled samples.

The microstructure characterization through transmission electron microscopy well reflects the rapid evolution of the hardness. In Figure 2 the as received microstructure is showed. It is possible to appreciate a well-defined grain structure, with a modest amount of dislocations inside the grains. The SADP in figure shows a well-defined coarse crystalline structure.

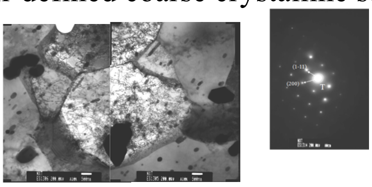


Figure 2 TEM micrograph and correspondent SADP of the starting material after annealing.

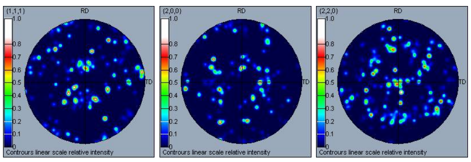


Figure 3 Pole figures of the annealed starting material

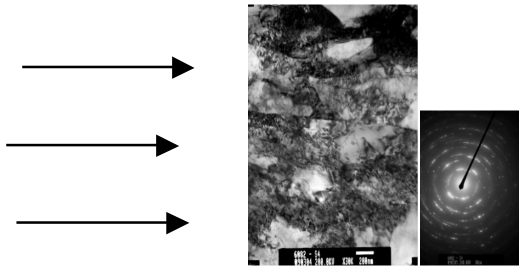
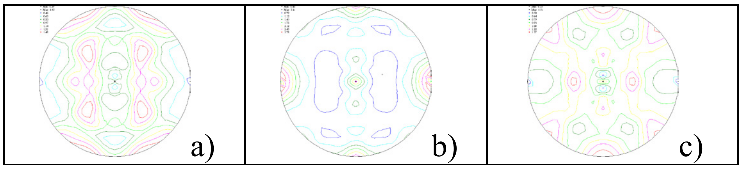


Figure 4 TEM Micrograph of ASRed sample subjected to equivalent strain of 77% and correspondent SADP

Figure 4 shows the microstructure of an asymmetrically rolled sample deformed to an equivalent strain of 0,77. The picture shows a completely different microstructure, with the presence of microshear bands (indicated by arrows) along the rolling direction. The SADP, as well, shows a clear rotation of the diffraction domains suggesting that the size of the grains and subgrains is reducing strongly. This fact is well underlined by the microhardness curve, which presents a clear increase.

Table 1 Pole figures of asymmetrically rolled sample to equivalent strain of 0,77 and maximum contour level 3; a) (111), b) (200), c) (220)



With respect to the starting material, featuring a fully annealed texture (Figure 3), after the first four rolling steps, a very weak brass texture is still present, even if the values of relative intensity are very low as shown in Table 1.

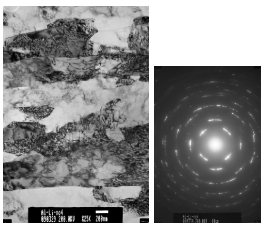


Figure 5 TEM micrographs of ASRed sample at equivalent strain of 154%

By increasing the rolling strain, the material experiences a reduction in thickness of the microshear bands (Figure 5) that is reflected by the relative SADP. In this phase of the process, the morphology of the microstructure remains the same, except for a rapid refining of grain size. This evidence is also supported by the modest increase in microhardness (Figure 1). In fact, from 77% to 154% the increase in microhardness is, about, 5 HV. Figure 6 shows a representative micrograph of the final step of the process, the one corresponding to an equivalent strain of 515%, which is very severe. In this case, the modification of microstructure is evident, especially because it is impossible to clearly distinguish any structure as grains, subgrains and even dislocation cells. It is possible to assert that the dislocation density has reached a maximum value and this fact leads to a homogeneous structure through the thickness. Furthermore, it is strongly linked to the fragmentation process of the microshear bands started at lower strains. The mechanical properties cannot grow so much since phenomena of recovery occurred during the last part of the process, as underlined by the microhardness curve.

Finally, this important aspect is witnessed by Figure 7, in which scanning electron micrographs are reported. By backscattered electrons channelling, it is possible to visualize the local orientation of crystalline domains. Table 2 shows a collection of pole figures relative to the beginning and the end of the complete rolling process. In particular, pole figures of conventionally and asymmetrically rolled samples are present. Looking at the values of the scales, it is possible to see that asymmetric rolling, at the beginning of the process tends to destroy the previously formed texture more rapidly than conventional rolling does. In fact, while the textures start to be different, the intensity of the conventionally rolled one is about 2 to 4 times with respect to the asymmetrically rolled samples. At the end of the process, instead, the development of a completely different texture is complete. From Table 2 it is clear that the conventionally rolled sheet has a β-fiber texture, and the asymmetrically rolled sheet has a shear texture

It is important to underline that the rolling texture developed in the process strongly depends on the rolling technique.

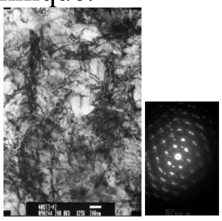
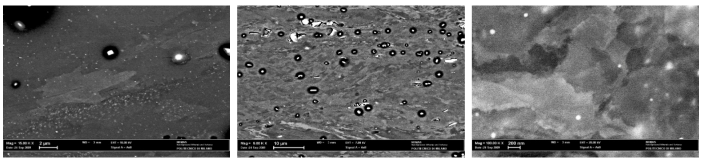


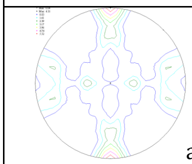
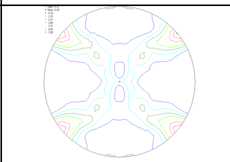
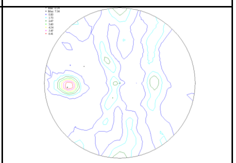
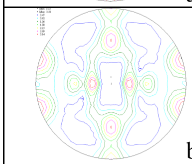
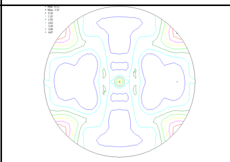
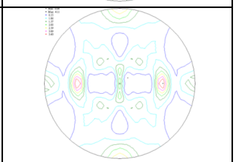
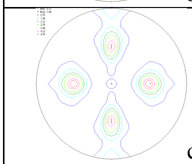
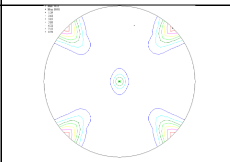
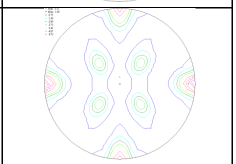
Figure 6 TEM Micrograph of ASRed sample at equivalent strain of 515%



a) **b)** **c)**

Figure 7 SEM BSE micrographs of asymmetrically rolled samples with equivalent strain of a) 77%, b) 154% and c) 515%

Table 2 Pole figures for rolled samples; a) conventionally rolled to ε =0,77, max contour level 6,3 b) conventionally rolled to ε=5,15, max contour level 5,3 c) asymmetrically rolled to ε =5,15, max contour level 10

111	200	220
 a)		
 b)		
 c)		

4. Conclusions

The investigations on symmetrically and asymmetrically rolled 6082-type alloy deformed at room temperature in the SPD regime, allowed to draw the following conclusions:

1 The texture developed are different with different intensities;

2 Asymmetric rolling develops more rapidly a rotated cube texture and it is indicated as the best texture to obtain high value of Lankford parameter: ASR has a strong influence over the texture development, stronger than conventional rolling due to an increased shear component through the thickness of the sample;

3 Mechanical properties increase dramatically at the beginning of the process, while the microstructure firstly forms bands and then, by recovery, refine them;

4 At the end of the process the material is highly homogeneous due to recovery phenomena occurring during the process and the dislocation density reaches a maximum;

5 SEM micrographs show that crystalline domains can be considered ultrafine.

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