MULTI-SCALE ANALYSIS BY EBSD, X-RAY DIFFRACTION AND NEUTRON DIFFRACTION OF MICROSTRUCTURE AND TEXTURE OF Al-Mg-Si ALUMINUM ALLOY WIRES DRAWN AND ANNEALED

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Abstract

The ENICAB company in Biskra uses the cold drawing process on several types of wires rod of different materials and grades. Our study was carried out on an Al-Mg-Si (AA6101) aluminum alloy wire rod, the most used by the ENICAB company in the manufacture of electrical energy transmission cables. The purpose of this work is to understand the evolution of the deformation texture and the stored energy in the grains during cold drawing of wire, as well as the combined influence of deformation and annealing at 400 °C during different holding time on recrystallization kinetics and evolution of local and global crystallographic texture. Characterization methods used in this work is: Optical Microscopy (OM), Scanning Electron Microscopy (SEM), Back Scatter Electron Diffraction (EBSD), X-ray diffraction, Neutron diffraction, Vickers microhardness and Chemical analysis by EDS.

Keywords: Texture, annealing recrystallization, wire drawing deformation, AlMgSi alloy

1. INTRODUCTION

The cold drawing is a very common technique used for producing electrical wires of different diameters. During this process, the shaping of the material is achieved by the mechanism of a plastic deformation.

Cold plastic deformation is mainly by plastic shear or slip where one plane of atoms slides on the adjacent plane by defect motion (dislocations). Indeed, the cold plastic deformation causes an important increase of the dislocation density of dislocation (i.e. stored elastic energy) in the material. This type of deformation leads to a change of the mechanical properties and microstructural. When the deformations are important, they product a preferential crystallographic orientation of the grains in the material. To restore the wire mechanical and electrical properties, it is necessary to perform an annealing. Recrystallization annealing results in the transformation of the fibrous microstructure to an equiaxe microstructure, this explains the decrease in total number of crystal defects in the material. The present study was conducted on an Al-Mg-Si aluminum wire rod which is the most used by ENICAB company [1].

2. RESULTS

2.1. Evolution of the microstructure and deformation texture

In our case, the fiber <111> // DN was majority and the fiber <100>//DN was minority throughout the peripheral zone of more deformed wire (Total fraction: 52.4 % <111> and 18 % <100> with a dispersion of 15°)

(**Figure 1**). Hargue et al. [2] observed in a drawn aluminum wire a mixture of texture <001> (minority) and <111> (majority) at the center of the wire, whatever the reduction level. For against in the peripheral area, for section reductions of 50.5 % and 71.8 %, the texture varies between the two components <111> and <112> and for highest reduction levels (> 93.0 %) there is a full fiber development of <111> [3].

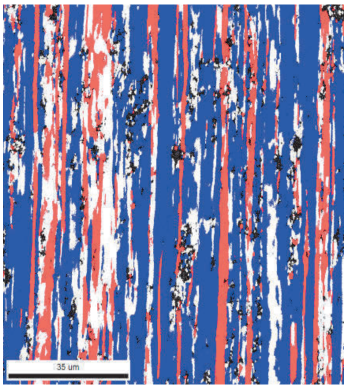
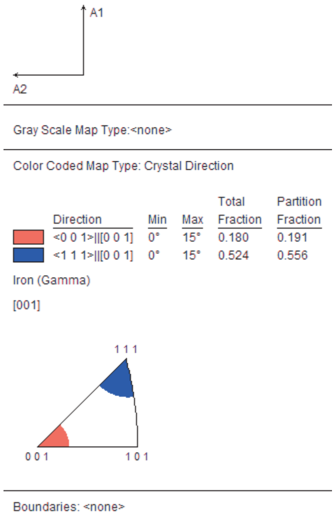
	EBSD map	**Volume fraction and inverse pole figure**
Wire drawn to 86.8 %		

Figure 1 EBSD map for the wire drawn to 86.8 % measured in the periphery zone

2.2. Volume fraction

The evolution of the volume fraction of <111> and <100> is presented on **Figure 2**. We notice the decrease of the fractions of the two fibers <111> and <100> and the increase of the fraction of the random fibers when the deformation level increases. Xiao-guang Mo et al. [4] have found in their study on cold-drawn aluminum wire that the texture components (fiber textures) gradually changes to <111> and <100>, and its volume fraction decreases with the increasing of the deformation level. This is due to the fact that <100> and <111> parallel to the drawing direction are stable orientations in metals and alloys (c.f.c) [4].

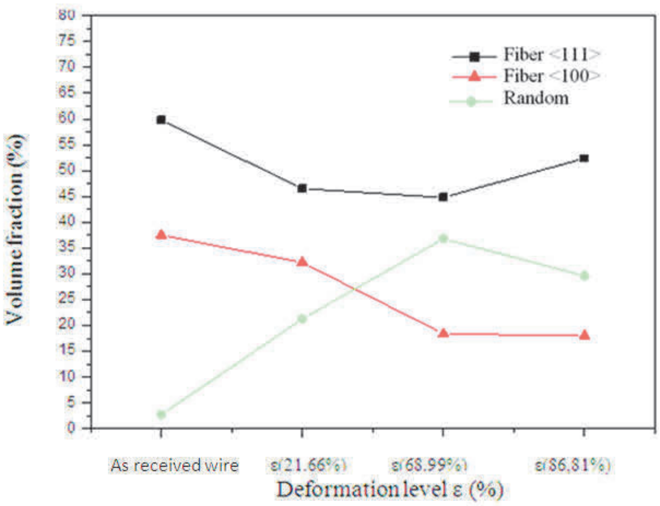


Figure 2 Variation of the volume fraction of deformation texture components as a function of the deformation level

3. DISTRIBUTION OF THE GOS PARAMETER

The distributions of the GOS (Grain Orientation Spread) calculated by OIMTM are also shown in **Figure 3**. The grains which have a GOS value less than 1° are often considered to be recrystallized [5,6]. We notice the GOS value was found to be greater than 1° for the the differents deformation levels, hence none is recrystallized.

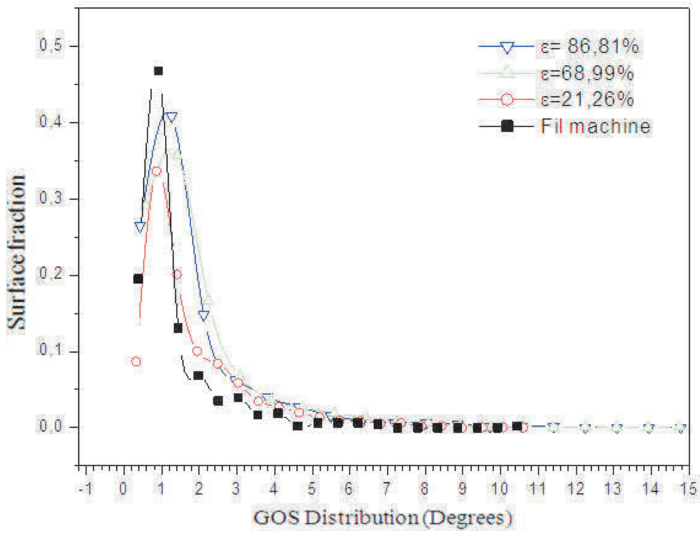


Figure 3 Distribution of the GOS parameter of the aluminum wire at different deformation levels

4. STORED ENERGY MEASUREMENTS BY NEUTRON DIFFRACTION AS A FUNCTION OF ORIENTATION

Figure 4 shows the evolution of the average values of the stored energy (E). For the deformations up to 69 %, that is the fiber <100> which stores the most energy, but beyond 86 %, it is the fiber <111> which takes over. The reduction of the section of the wire leads an increase in the energy stored in the <111> grains.

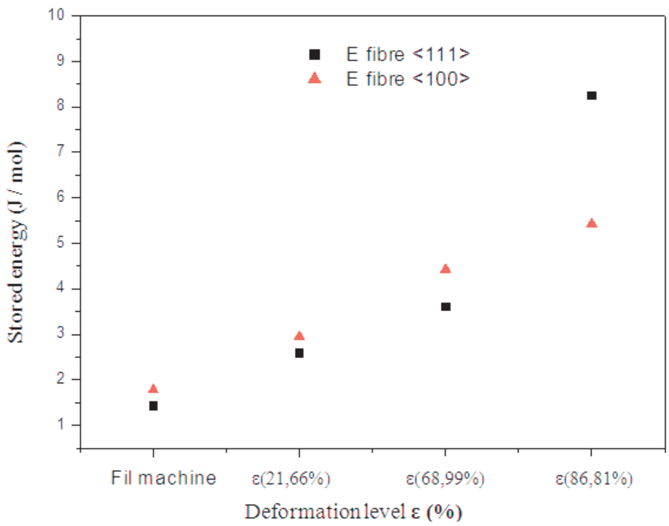


Figure 4 Evolution of the stored energy in deformed grains

5. EVOLUTION OF THE RECRYSTALLIZATION ANNEALING MICROSTRUCTURE AND TEXTURE

Figure 5 shows the microstructure of the wire drawn to 69 % after 400 °C annealing for 10 minutes, characterized by EBSD at the periphery and the center. For the strongly deformed wire, the EBSD maps of the center and periphery show two microstructures of recrystallized grains of similar size between 7.20 µm and 10.8 µm.

For the deformation level at 69 %, the map illustrates two distinct microstructures; the recrystallization appears more advanced than the periphery heart. Similarly, the grain size measurements show a difference between the periphery and the center. The average grain sizes are 6.30 - 11.30 µm for the periphery zone and 14.8 - 19 µm for the center, respectively.

According to Jin et al. [5], the strain hardening can reduce the inhomogeneity of the deformation along the radial direction of the wires [5], which leads to the disappearance of the subdivision difference of the grain along the radial direction wires with the deformation ε> 0.58 [4].

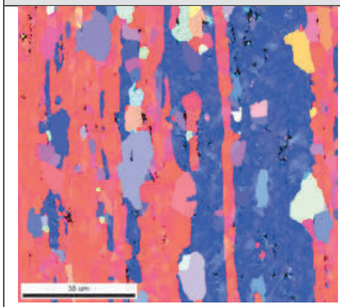
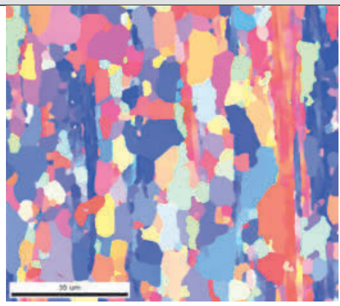
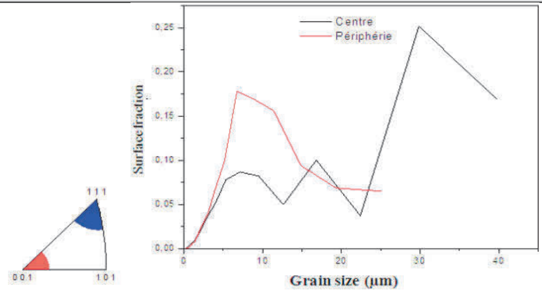
CENTER	PERIPHERY	Grain size (diameter)
		

Figure 5 Microstructures characterized by EBSD at the periphery and at the center of wire drawn to 69 % and annealed at 400 °C for 10 min

6. EVOLUTION OF THE VOLUME FRACTIONS

Figure 6 shows the variation of recrystallized volume fraction of the fibers according to the deformation levels. As it can be seen, the evolution of the volume fraction adopts variable and incoherent behaviors, the fraction of the fiber <100> increases between the deformation levels 21 % and 69 % and then falls between 69 % and 86 % at the wire center. At the periphery, the opposite occurs. This attitude, for all fibers (<111>, <100> and random fibers), cannot allow a coherent and complete interpretation of the obtained results [7,8].

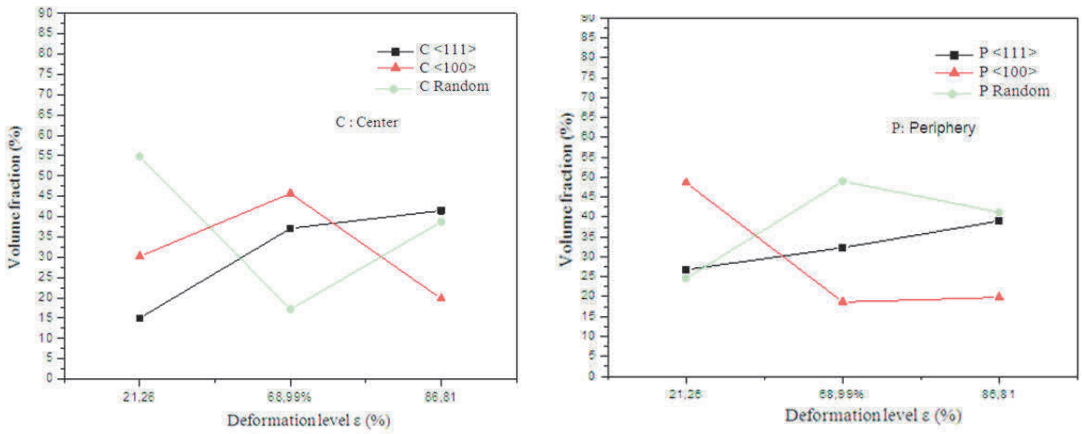


Figure 6 Evolution of the volume fractions of the wires annealed at 400 °C for 10 min.

7. RECRYSTALLIZATION KINETICS AT 400 °C

The grain Orientation Spread (GOS) represents the average of the disorientations of each pixel of the same grain compared to the average orientation of this grain. A low GOS value means that we are dealing with a grain with low internal disorientation, which corresponds exactly to the definition of a recrystallized grain. On the contrary, a grain with a restored area will have a higher GOS [9]. In **Figure 7**, it is clearly observed that a recrystallized grain having low internal disorientations corresponds to a low value of GOS. These recrystallized grains are located at the grain boundaries of the deformed structure [9,10].

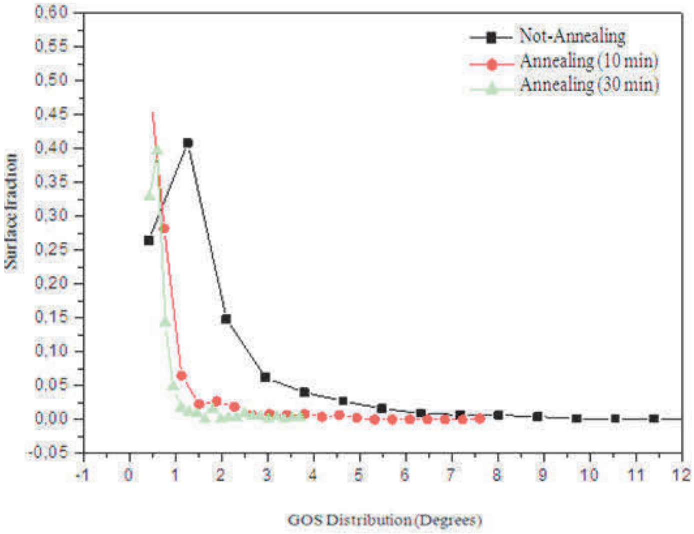


Figure 7 Distribution of the GOS parameter of the aluminum wire deformed at a 86.8 % at different deformation levels annealed at 400 °C (10 minutes and 30 minutes).

8. CONCLUSION

The aim of this thesis was to understand the texture of deformation and recrystallization of AGS-6101 aluminum alloy wires, industrially drawn to the ENICAB company of Biskra-Algeria. In this work, we also tried to understand the combined influence of the deformation level and the annealing temperature at 400 °C on the recrystallization kinetics. The results obtained previously allow us to conclude the following points:

- The microstructure of the initial state of the alloy 6101 (the wire rod) is not isotropic, it already contains a texture composed of two main fibers <111> and <100>
- The wire drawing does not modify the main texture of the wire rod, it only modifies the volume fraction of the fibers present by lowering the quantity of the majority fibers according to the level of deformation applied.
- Deformation induced in grains increases the quantity of energy stored in the grains with the level of deformation.
- Heat treatment at 400 °C causes a heterogeneous recrystallization according to the section of the wire.
- Recrystallization, too, does not modify the initial texture but influences the volume fractions of its components and their distribution in the radial section of the wires.
- Recrystallization modifies the mesh parameter of crystallites formed.

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