ANNEALING EFFECT AT LOW TEMPERATURE ON THE EVOLUTION OF THE MICROSTRUCTURE, MECHANICAL AND ELECTRICAL PROPERTIES OF A DRAWN ALUMINUM WIRE

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Abstract

The purpose of this work is to study the evolution of the microstructure, mechanical and electrical properties of an aluminum alloy, depending on the deformation level and annealing treatment. The study was conducted on an AGS type aluminum wire used by the international company ENICAB of Biskra for electrical cabling. These wires were obtained by the cold drawing process undergo annealing treatment at the temperature 170 °C for different holding times (10 minutes, 4 hours and 20 hours). Various analysis techniques were used in this study to monitor the microstructural evolution, mechanical and electrical properties. The optical and electron microscopy, micro-hardness, tensile test and electrical resistivity measurement were used. It was noted that the drawn aluminum wire causes an increase in the micro-hardness. On the other hand, the annealing at 170 °C does not cause significant changes on the evolution of the mechanical strength and electrical resistivity compared to the deformed state. Furthermore there has been a remarkable decrease in elongation after 4 hours at 170 °C annealing compared to the deformed state.

Keywords: Annealing, aluminum alloy, cold drawing

1. INTRODUCTION

Aluminum alloys are the most used just after the cast iron and steels. Their excellent mechanical and electrical properties have allowed their use in various sectors such as aerospace, automotive, electric transport [1]. Mechanical and electrical properties of these heat treated alloys after deformation play a very important role in improving its properties. The research was focused on the Al-Mg-Si alloys (6000 series), which have advantageous mechanical and electrical properties. These alloys are used by the national electric cables company of Biskra (ENICAB).

The aim of our research work is the study of heat treatment effect (low temperature aging) on the development of mechanical and electrical properties of cold drawn Al-Mg-Si aluminum wire. This work is in collaboration with international company ENICAB (Biskra Algeria) that produces electrical wires.

2. MICROSTRUCTURAL CHARACTERIZATION

2.1. As received and drawn wire state

The microstructure in the initial state (as received wire) is shown in **Figure 1a)**. The microstructure shows the existence of certain phases in the grains. This structure is altogether regular, which means that the crystallites are substantially isotropic. As provided from literature sources [2, 3], the wire drawn shows a microstructure of elongated grains along the axis of drawing, and according to the rate of deformation increases, the thread acquires a textured fibrous microstructure (**Figure 1b**).

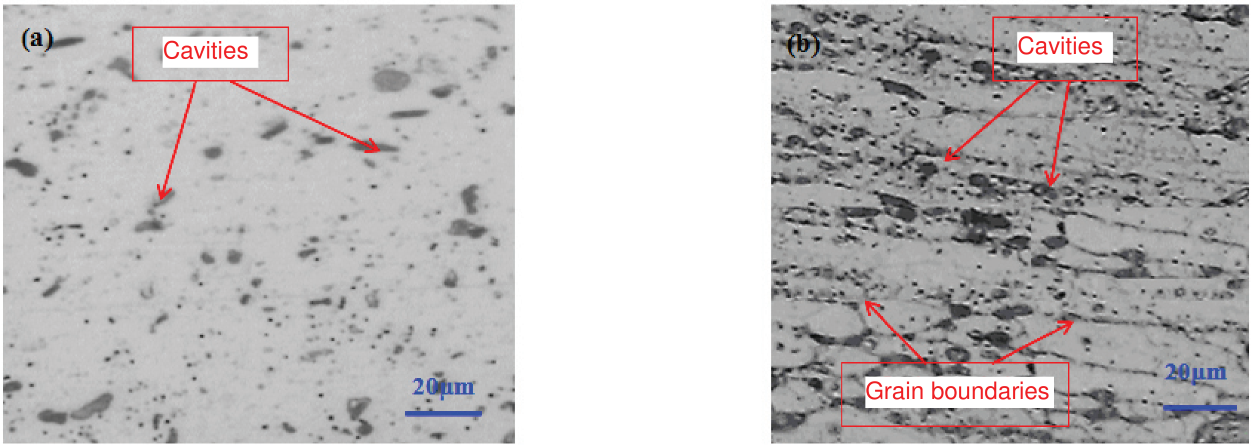
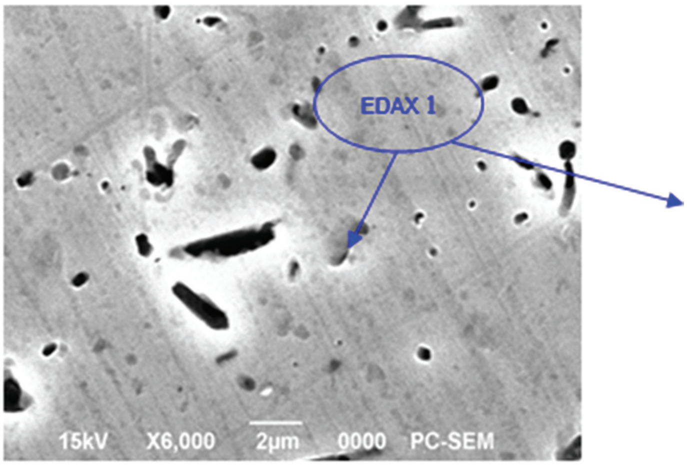


Figure 1 Optical microstructures of the aluminum alloy (a) received wire and (b) cold drawn wire (ε_2 = 69 %)

2.2. Aging state

To understand the deformation level effect on the structure evolution of the drawn and aged aluminum alloy wires, we took three different level deformations of the same alloy. The first level deformation was (ε_1 = 22 %), the second was (ε_2 = 69 %) and the third was (ε_3 = 87 %). The **Figure 2** shows the microstructure characterized by electron microscopy of deformed wire at 87 % and aged at 170 °C for 4 hours. This strongly deformed wire causes the formation of precipitates after aging. These precipitates are many, larger sizes and different shapes with the extension of the time [4]. The analysis by EDAX (Energy dispersive X-ray analysis) has been used to determine the chemical composition of these precipitates, According to the chemical microanalysis precipitates performed on these samples, the precipitates were of Mg_2Si type [3].



Element	At.%
Mg*K*	66.37
Si*K*	33.63

Figure 2 Electron microscopy of the cold drawn wire (ε_3 = 87 %) and aged at 170 °C for 4 hours showing the precipitate Mg_2Si (analysed by EDAX)

3. MECHANICAL AND ELECTRICAL PROPERTIES

The results of the mechanical and electrical properties are shown in **Table 1**. The measurements of the breaking strength showed an increase therefrom as a function of the deformation, caused by structural strain hardening [6]. Its value was equal to 362 MPa in deformation of 87 %, after it was 235 MPa in the undeformed state (as received wire) (**Figure 3**). The hardening of a metal or alloy had the effect of increasing its hardness and mechanical strength (breaking strength and yield strength) but, in return, to reduce its plasticity, that is to say its elongation at break and its deformability. Also there was an increase in electrical resistivity with deformation and a decrease in aging after the latter (**Figure 4**).

Table 1 Results of mechanical and electrical properties of the Al wire drawing and aging at 170 °C

Wire state	**Deformation level** *ε* (%)	**Mechanical properties**			**Electrical properties**
		Microhardness ***HV***	**Mechanical resistance** (MPa)	**Elongation** ***A*** (%)	**Resistivity** *ρ* (μΩ m)
Drawn Wires	ε_3 (87 %)	121.7	363	9	0.03671
	ε_2 (69 %)	97.1	310	6	0.03593
	ε_1 (22 %)	89.8	305	6.5	0.03508
	0	72.1	236	15	0.03362
Aging at 10 min	ε_3 (87 %)	109.3	365	10.5	0.03597
	ε_2 (69 %)	82.2	305	4.5	0.03510
	ε_1 (22 %)	78.1	279	1	0.03480
	0	69.2	239	14	0.03380
Aging at 4 hours	ε_3 (87 %)	119.0	359	4.5	0.03580
	ε_2 (69 %)	101.6	317	7	0.03494
	ε_1 (22 %)	111.4	305	8	0.03497
	0	77.9	256	6	0.03352

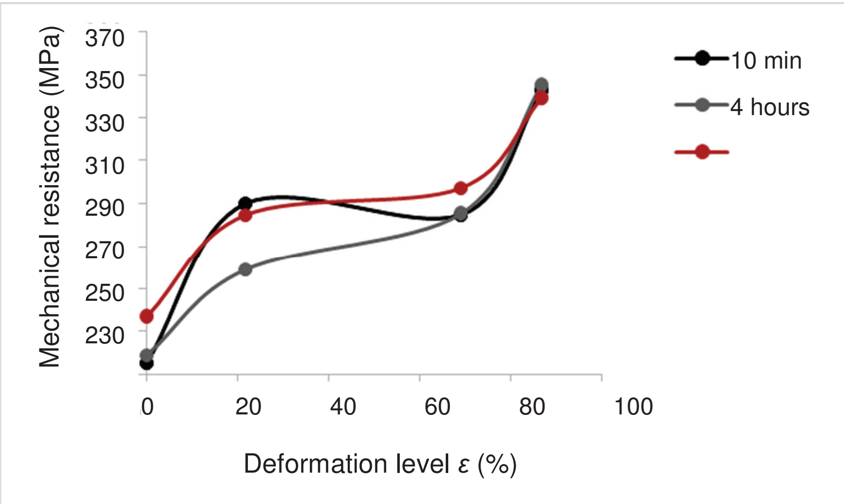


Figure 3 Evolution of mechanical resistance a function of deformation level

The **Figures 3** and **4** show that aging to 170 °C does not cause a significant change on the evolution of the mechanical strength and the electrical resistivity as a function of the deformation. By against there has been a noticeable decrease in elongation after 10 minutes returned to 170 °C after a deformation of 22 % and an increase of the latter with the holding time. The cold plastic deformation leads to the hardening of the material, thus curing. This hardening depends upon the chemical composition of the material, the applied strain level and deformation conditions (temperature, speed and mode of deformation) [7]. Indeed, the cold deformation causes a substantial increase of the dislocation density (i.e. stored elastic energy) in the material. It follows heterogeneity of the microstructure and crystallographic texture of the inside of the grains [8]. In a simplified way admitting that the electrical conductivity is due to the movement of electrons in the metal, it is therefore in direct relation to the number of "free electrons" and with their freedom of movement in the mass of metal. The electrons are slowed by their collisions with the atoms and it is conceivable that the electrical resistivity is affected by everything that destroys the "continuity" of the material, it at all scales: atomic, microscopic or macroscopic. In our case, the alloy had undergone a strong cold deformation, so it is affected by the effect of hardening, which deeply disturbs the order of the crystal lattice and influences the electrical resistivity which explains its gradual increase after each pass [9].

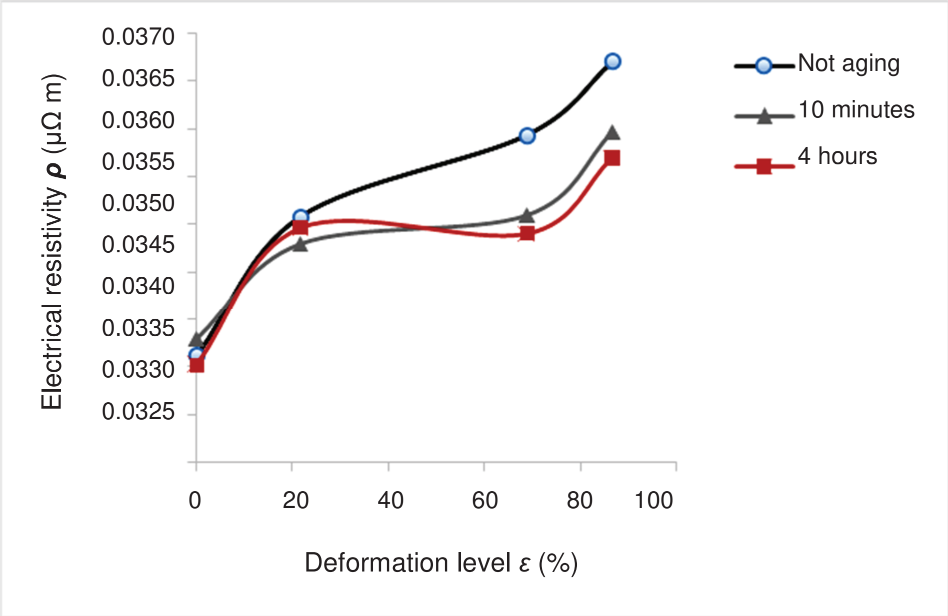


Figure 4 Evolution of electrical resistivity a function of deformation level

CONCLUSION

The study of aluminum alloy drawn and aged, has allowed us to draw the following conclusions: The microstructure in the initial state (as received wire) shows the existence of certain phases in the grains. This structure is quite regular, which leads us to say that the crystallites are substantially isotropic.

The drawing of aluminum wires causes an increase in the micro hardness, which produces a high hardening of the material accompanied by a development of a fibrous structure.

A decrease in microhardness for the wire sets drawn with respect to the initial state after 10 minutes of aging against an increase of the issue with the holding extension including the deformed wire of 22 % after 4 hours of aging. An increase in the mechanical strength with the rate level of reduction by drawing, on the other hand, the elongation will drop as a function thereof. Similarly there was an increase in electrical resistivity with increasing deformation. Aging at 170 °C causes a small change on the evolution of the mechanical strength and electrical resistivity as a function of the deformation. However there has been a remarkable decrease in elongation after 4 hours of aging at 170 °C.

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