Structural Changes in Volume of Deformed Alloy 1441 (Al–Li–Cu–Mg–Zr–Mn) under Ion Bombardment

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Abstract – The paper presents metallographic investigation of the effect of Ar^+ ions irradiation (E = 40 keV) on granular structure of initially deformed (ε = 72%) alloy 1441 of the system Al–Li–Cu–Mg–Zr–Mn. It was established that, under irradiation to a dose of ~ $4.6 \cdot 10^{16}$ cm^{-2} (irradiation time 37 s, T < 320 ºC), there is observed formation of recrystallized grains 12–20 µm long and 7–12 µm wide, and in some sections, of very small equiaxial grains ~2–5 µm in size. The structure formed under irradiation is similar to that formed in the course of annealing (T = 370 °C, 2 h). At a higher irradiation dose of ~$2.5 \cdot 10^{17}$ cm^{-2}, significant, up to 25–30 µm, growth of equiaxial grains is observed. The noted changes in microstructure take place over the entire sample thickness (1 mm), which is almost 10^5 times larger than the Ar^+ ions mean projected ranges in Al of ~40 nm.

1. Introduction

At present, deformed aluminum-lithium alloys are successfully employed in different spheres of modern engineering, aircraft engineering including. Acquisition of new data on these alloys structural state and its evolution under different exposures is quite topical for evaluating reliability of these materials in service, and for development of new non-traditional methods of their treatment, which allow physical and mechanical properties to be improved.

The object under investigation was commercial aluminum alloy 1441 of the system Al–Li–Cu–Mg–Zr–Mn. A characteristic feature of this alloy is high temperature of the beginning of recrystallization, which is due to the presence of anti-recrystallizing elements in the alloy composition, including zirconium which is considered to be the strongest of them.

In this work, metallographic investigation of the structure of 1 mm thick alloy 1441 samples after cold rolling (deformation degree 72%), intermediate annealing (T = 370 °C, 2 h) used to in the rolling technique to remove cold-work, and irradiation with 40-keV Ar^+ ions of the cold-worked alloy to varying doses was carried out.

2. Main part

The samples under investigation were cut from clad cold-worked 1 mm thick sheets of alloy 1441 manufactured at the Kamensk-Uralsky Metallurgical Plant.

Samples irradiation was carried out in the PULSAR ion implanter with an Ar^+ ion glow-discharge source with a cold hollow cathode [1]. The irradiation parameters and the maximum temperature to which the sample was continuously heated under the ion beam in the indicated period of time (without exposure under such temperature) are given in Table 1.

Table 1. Parameters of irradiation of alloy 1441 samples with accelerated Ar^+ ions

Ions energy, keV	Ion current density, µA/cm^2	Irradiation dose, cm^{-2}	Irradiation time, s	Sample temperature, °C
40	200	$2.5 \cdot 10^{15}$	2	< 80
		$4.6 \cdot 10^{16}$	37	< 320
		$2.5 \cdot 10^{17}$	200	< 400

Metallographic analysis of a section square with the irradiated surface was performed with the use of the Neophot-30 optical microscope. Etching of alloy 1441 microsections was done in different etchants: 9-% water solution of H_3PO_4 (up to 15 min), Keller reagent (30 ml of 5-% water solution of HF + 30 ml of 5-% solution of HNO_3 + 90 ml of 5-% solution of HCl + 50 ml of distilled water), or 2-% solution of NaOH at 60-80 °C.

The microstructure of aluminum alloy 1441 observed in sample section, in the initial cold-worked state and after annealing at 370 °C during 2 h, is shown in Fig. 1.

The microstructure of alloy 1441 in the initial cold-worked state is characterized by linear structure pointing to the presence of elongated thin grains, with the distance between them being 2.2 µm (Fig. 1, *a*).

After annealing at T = 370 °C during 2 h, both equiaxial and elongated grains are observed in the alloy, they form chains parallel to the sheet surface. Grain average size is 7–10 µm (Fig. 1, *b*).

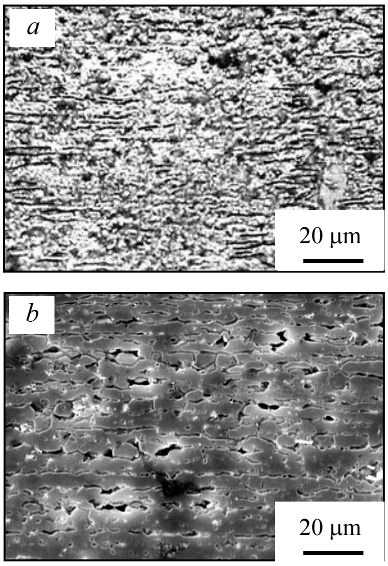

Fig. 1. Microstructure of alloy 1441 in initial cold-worked state (*a*) and after annealing at 370 °C during 2 h (*b*)

Irradiation of cold-worked alloy 1441 with Ar^+ ions to a dose of $2.5 \cdot 10^{15}$ cm^{-2} does not result in any noticeable changes in the structure (Fig. 2, *a*).

After irradiation to a higher dose of $4.6 \cdot 10^{16}$ cm^{-2}, grains 12 to 20 μm long and 7–12 μm wide forming chains are present in the alloy structure. Regions with very fine equiaxial grains ~2–5 μm in size (Fig. 2, *b*) are found near them. Morphological changes in the initial grain, and appearance of a fraction of new fine equiaxial grains points to the development of rest and recrystallization processes.

It may be seen that the structure formed under irradiation to the named dose is similar to that formed under annealing (T = 370 °C, 2 hours).

With further irradiation dose increase to $2.5 \cdot 10^{17}$ cm^{-2}, grains elongation practically disappears. Grains acquire equiaxial shape, and considerable grains growth is observed. Grain average size is 25–30 μm. According to data found in [2], similar grain growth in alloys of the system Al–Li–Cu–Mg–Zr–Mn is usually observed only during 1–2 h after annealing at a temperature of 460 °C corresponding to intensive dissolution of small and large intermetallics.

It should be noted that, with 3–6 times grain growth at dose increase from $4.6 \cdot 10^{16}$ to $2.5 \cdot 10^{17}$ cm^{-2}, the density of intermetallic inclusions 2–5 μm in size decreases abruptly.

The observed changes of microstructure take place over the sample entire thickness (~1 mm), which is more than 10^4 times greater than the Ar^+ ions mean projected range in Al, equal to ~40 nm according to estimate made by the TRIM method [3].

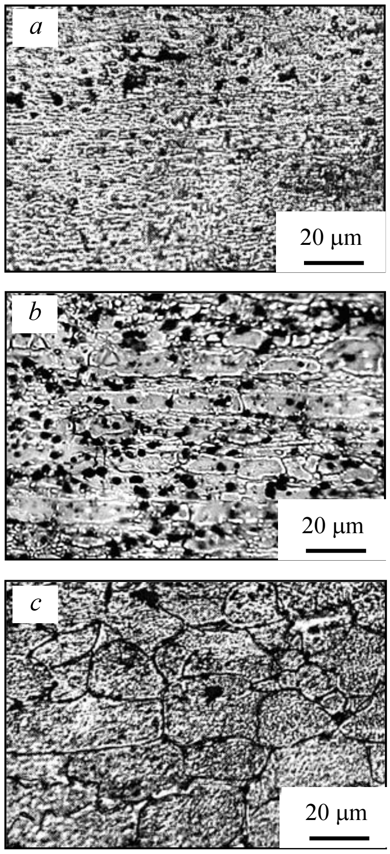

Fig. 2. Microstructure of alloy 1441 after irradiation with Ar^+ ions to doses of $2.5 \cdot 10^{15}$ (*a*), $4.6 \cdot 10^{16}$ (*b*), and $2.5 \cdot 10^{17}$ cm^{-2} (*c*)

3. Conclusion

It was established that irradiation of cold-worked alloy 1441 with 40-keV Ar^+ ions to doses beginning from ~$4.6 \cdot 10^{16}$ cm^{-2} (irradiation time 37 s, T < 320 ºC) and higher may cause the processes of recrystallization in the entire volume of the 1 mm thick sample under continuous heating to temperatures close to those of a normal annealing process in a furnace: 370 ºC, 2 h (without exposure at such temperatures). It is important that changes in granular structure take place in an exceedingly short time measured by seconds, not hours, as it normally happens in furnace annealing.

References

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