Materials Science and Engineering A 499 (2009) 126–129

Contents lists available at ScienceDirect

Materials Science and Engineering A

journal homepage: www.elsevier.com/locate/msea

The development of a new Al–Li alloy extrusion process

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ARTICLE INFO

Article history:
Received 12 April 2007
Received in revised form 14 August 2007
Accepted 12 November 2007

Keywords:
Al–Li alloy
Extrusion
Strength
Plasticity
Fiber texture

ABSTRACT

A new double extrusion Al–Li alloy production process is proposed by the authors, and influence of this process on the alloy's microstructures and properties is analyzed. The results show that double extrusion weakens ⟨1 1 1⟩ fiber texture and reduces the grain size of this alloy. This process provides an alloy write a certain remaining strength and improves its plasticity.

1. Introductions

Aluminum–lithium alloys may be widely used in aviation and aerospace industries. Because of its very poor plasticity or toughness, the usage of this alloy is limited [1]. So it is necessary to explore the mechanism for strengthening and to develop proper production processes. Extrusion is one of the major methods. Because of ⟨1 1 1⟩ plus ⟨1 0 0⟩ fiber texture after extrusion, there is usually higher strength but lower plasticity (so called extrusion effect). An Al–Li alloy with zirconium content of 0.1% and above will be difficult to re-crystallize in later heat treatment. In order to eliminate fiber texture and improve plasticity of Al–Li alloy, a new double extrusion processing technique is put forward in this paper.

2. Materials and experiments

Two industrial purity materials (IM, PM) analyzed are specified in Table 1, one is melted in a furnace with protective atmosphere (represented by IM) then heated to 510 °C, soaking 16 h for homogenizing, and the other is rapidly cooled powder (PM for short) that were vacuum thermal pressed at 450 °C.

In order to analyze the effect of the double extrusion on the alloy structure and performance, all the ingots and billets were double extruded at 400 °C, the first and second extrusion ratio are 44:1 and 5:1, respectively, between the first and second extrusions, all the billets were upsetting forged with a deformation of 70%. A solution treatment at 525 °C; for 40 min was followed by thermal aging at 170 °C 4 h + 190 °C 16 h.

All tensile specimens were short with a 25 mm gauge length, and tensile experiments were completed at an INSTRON tensile machine, at a tensile deformation speed of 2 mm/min. The planes for grain orientation distribution functions (ODF) fiber texture were the cross-section of the specimens, and tested with a SIEMENS D-500 automatic X-ray texture analyzer. The standard specimens for comparison were of the same composition and free of texture. Then ODF sectional diagrams, ⟨1 1 1⟩ whole fiber texture diagrams, and ⟨1 1 1⟩⟨1 0 0⟩ orientated density diagrams can be calculated.

The tensile fracture appearances were examined by use of a KYKY-Amway 1000B scanning electron microscope, and thin specimens (HITACHI H800) for transmission electron microscopy (TEM) were also obtained from the tensile specimens.

3. Results

3.1. Mechanical properties

Table 2 shows the mechanical properties of the two experimental materials. Compared write only normal extrusion, the specimens with double extrusions have higher ductility but lower strength; and the increase in ductility for IM alloy is higher than that for PM alloy.

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doi:10.1016/j.msea.2007.11.102

Table 1
The compositions of experimental alloys (wt.%)

Alloy	Li	Cu	Mg	Zr	Fe	Al
IM	2.40	1.63	1.08	0.20	0.22	Bal.
PM	2.54	1.64	1.23	≤0.12	≤0.14	Bal.

3.2. Microstructures

The maximum orientation densities for the tested alloys are shown in Table 3.

From Table 3, ODF sectional diagrams and whole fiber texture diagrams, it is obvious that there are strong ⟨1 1 1⟩ and weak ⟨1 0 0⟩ mixed fiber textures in the two materials. The double extrusions have decreased the degree of ⟨1 1 1⟩ texture, especially in IM alloy.

Figs. 1 and 2 are scanning electron microscopy (SEM) images for tensile appearances, Figs. 3 and 4 are TEM images. From them it can be seen that grain sizes for double extrusions IM alloy are much lower than those after normal extrusion.

4. Discussion

4.1. The strength of alloys

An Al–Li–Cu–Mg–Zr alloy can be strengthened by the following mechanisms (see, e.g. [2]) element solution strengthening, or fine second-phase particles such as δ′ (Al_3Li), S′ (Al_2CuMg), T1(Al_2CuLi), or Al_3Zr particle at grain boundaries as sub-boundaries. For extruded materials, there is also texture strengthening because of the so-called extrusion effect.

In an Al–Li alloy with certain composition, if the solution and aging process are the same, the strengthening effects are the same. So the strength difference shown in Table 1 between the one and double extrusions is only the effect of texture and grain size [3].

According to metal plastic mechanics:

$$\sigma_s = M(\tau_0 + kd^{-1/2})$$

Table 3
The maximum orientation densities for the tested alloys

Materials	Process	⟨1 1 1⟩	⟨1 0 0⟩
IM	Normal extrusion	20.71	4.0
	Double extrusion	8.32	2.9
PM	Normal extrusion	9.93	4.0
	Double extrusion	8.05	3.7

where, σ_s is the yield strength, τ_0 is friction stress of the crystal to dislocation movement, d is average grain size, k is a constant and M is the average orientation factor.

Here, the average orientation factors can be calculated as follows: M_{111} = 3.67 for ⟨1 1 1⟩ texture, M_{100} = 2.45 for ⟨1 0 0⟩ texture, and M_{other} = 3.06 for all other textures. It since M_{111} is the greatest of them, the yield strength is highest in this direction. Because of the highest elastic modulus in the ⟨1 1 1⟩ direction, Al and its alloys have the largest elastic strength in this direction too [4].

Generally speaking, after double extruding, on one hand, strength deceases as the ⟨1 1 1⟩ orientated density decreases. But on the other hand, double extrusion makes smaller grain sizes that will increase the alloy strength. In the present work, the final result is that the two counteracting factors can decrease the alloy strength, and their illustrates that the texture strength is the main factor.

4.2. The alloys' plasticity

The plasticity of an Al–Li alloy depends upon the grain size, dimension of δ′ phase, distribution of S′ and T1, and the characteristics of grain boundaries which include elements segregation, the amount of δ′ (Al_3Li), or δ (AlLi), and then the size of participation-free zone (PFZ) [5]. The extrusion effect must also be taken into account for extruded alloy. The grain size and ⟨1 1 1⟩ direction deformation texture are two key influential factors of the material plasticity to a certain composition alloy with proper heat treatment.

One of the deformation mechanisms for an Al–Li alloy is the shearing of δ′ (Al_3Li) particles by dislocations, and localisation

Table 2
The mechanical properties of the alloys

Materials	Processing technique	In solution condition			In aging condition		
		$\sigma_{0.2}$ (MPa)	σ_b (MPa)	δ (%)	$\sigma_{0.2}$ (MPa)	σ_b (MPa)	δ (%)
IM	Normal extrusion	225	342	13.6	433	521	8.7
	Double extrusions	212	313	15.1	418	568	12.5
PM	Normal extrusion	277	432	10.7	466	535	6.9
	Double extrusions	258	408	12.3	431	558	9.7

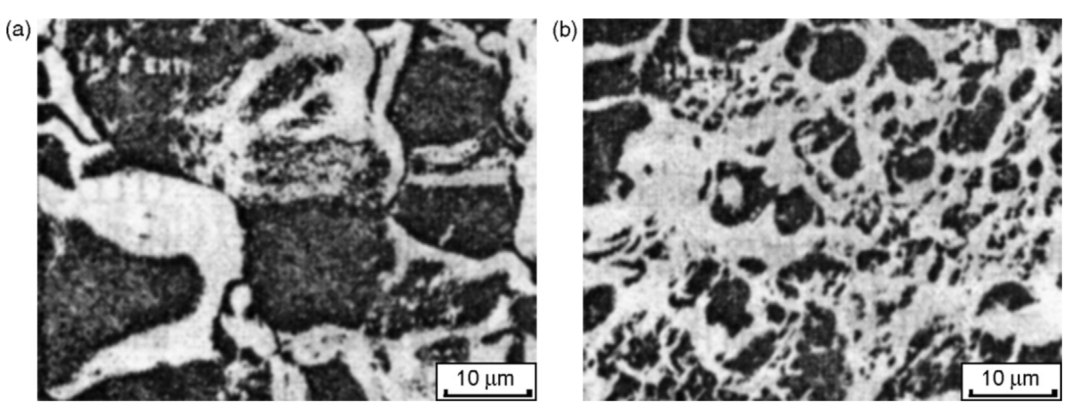

Fig. 1. SEM images for IM materials tensile samples (a) normal extrusion and (b) double extrusion.