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THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF MAGNESIUM ALLOYS Mg-Li-RE AFTER THE PROCESS OF CASTING AND EXTRUSION

The article presents tests results of the influence of extrusion process on the microstructure and mechanical properties of magnesium alloy with lithium and rare earth elements with symbols LAE442 and LAE842. Microstructures of magnesium alloys after extrusion were compared with microstructure after casting and homogenisation. Presented results show the mechanical properties marked in static compression test in room temperature. It was stated that alloy LAE842 is characterised with better plasticity than the alloy LAE442.

Keywords: ultra-light Mg-Li-RE alloys, extrusion process, microstructure, mechanical properties

1. Introduction

At present there is a growing demand of aviation industry on spare parts made of light alloys which show the adequate rigidity and strength. Application of magnesium alloys in aviation industry aims at decreasing the weight of vehicles in order to reduce the fuel consumption, in view of operating expenses reduction and protection of environment. Technology of plastic shaping of magnesium alloys is a demanding task. Due to that fact there are alternative methods of plastic shaping of magnesium alloys being tested. Up till now, testing magnesium alloys has been mainly limited to products achieved by means of casting which decreased their application range [1-2]. New, ultra-light magnesium alloys with lithium are especially promising in terms of improvement of susceptibility to plastic shaping. Lithium has a favourable effect on the deformability of magnesium alloys replacing the hardly deformable hexagonal α-Mg(hcp) lattice with a body-centred cubic β-Li lattice (bcc), which reduces mechanical properties due to the appearance of β phase. Ultra-light magnesium-lithium alloys, due to addition of lithium, which as the only one decreases the weight of magnesium, match the tendency to reduce the weight of products. Depending on the alloy additive content the properties of the charge meant for shaping change together with, first and foremost, the susceptibility to plastic deformation. Alloys Mg-Li, depending on the lithium content may have a single-phase structure α or β or two-phase structure α+β. The structure the alloys Mg-Li are then characterised with different properties. It is visible, in accordance with the phase equilibrium system of Mg-Li that a small addition of lithium (about 5%) does not cause the change of the hexagonal lattice of the magnesium (phase α). With such lithium content in chemical composition the alloys are characterised with sufficient strength but the susceptibility to plastic shaping is low. Two-phase alloys (phases α+β) occur in the range from 5 to 11% of lithium and combine within themselves the features of both phases which give them the good plasticity and strength properties on the satisfactory level [3-5]. They are characterised with good electrical and thermal conductivity but their disadvantages are small resistance to creep in temperature of more than 50°C and small resistance to corrosion. Literature data on magnesium alloys with lithium show that the tests conducted on this group of materials have been concentrated mainly on optimisation of their chemical composition through introduction of additional chemical elements such as: Al, Zn, Y, Ca or rare earth elements. These elements improve the strength of alloy, its temperature stability, and creep resistance. This group of magnesium alloys, which include alloying additions in their chemical composition: Ca, Al, Zn and rare-earth elements after plastic processing, has shown a huge potential in terms of possibilities to achieve the increase of strength and plastic properties. That is why the achieved information after conducted tests on alloys from Mg-Li-RE group can be applied in the production of parts which need to be the lightest possible and with high mechanical and plastic properties [6-12]. The paper presents the analysis of microstructure in initial condition and after extrusion process of alloys LAE442 and LAE842. Static compression test was conducted in room temperature in which the mechanical properties of the tested alloys were marked.

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2. Material and test methodology

Materials for tests were ingots from magnesium alloys with aluminium (4% mass) and content of rare earth elements (in the form of mischmetal) but with varied lithium 4% mass, 8% mass content. The mischmetal included lanthanum, cerium and neodymium. Chemical composition of ingots is presented in table 1.

TABLE 1

Chemical composition of magnesium alloys [mass%]

Alloys	Al	Li	RE	Mg
LAE442	4	4	2	rest
LAE842	4	8	2	rest

Alloys were gravity casted to cold graphite moulds to achieve the ingots sized ϕ 40 × 80 mm in laboratory furnace VSG 02 by Balzers Company. Casting was conducted in argon atmosphere under pressure of 650 Tor in order to limit to minimum the evaporation process of the charging elements. Temperature of smelting was in the range of 630÷660°C, depending on the lithium content [4]. In order to increase the susceptibility of alloys to plastic deformation they underwent the process of homogenisation in temperature of 350°C for alloy LAE442 and 300°C for alloy LAE842, with soaking time of 3h. Then alloy samples were subjected to axial-symmetric compression on the Gleeble 3800 simulator at temperatures ranging from 200°C to 300°C at 0.1 s^{-1} strain rates. Compression tests were conducted after heating the sample to strain temperature with heating rate of 3°C/s and holding in this temperature for 300 s. Classic extrusion of ingots to the form of rods with diameter of 10 mm was conducted in a special device fixed on hydraulic press. Extrusion process parameters are presented in table 2.

Microstructure analysis of tested magnesium alloys in initial condition and after extrusion process was conducted with the use of light and scanning microscopy. Mechanical properties of alloys LAE442 and LAE842 were determined in static compression test with strain rate of 0.01 s^{-1} with the use of testing machine ZWICK/Z100 in room temperature. Additionally, there was an identification of phase composition conducted with the use of X-ray method.

TABLE 2

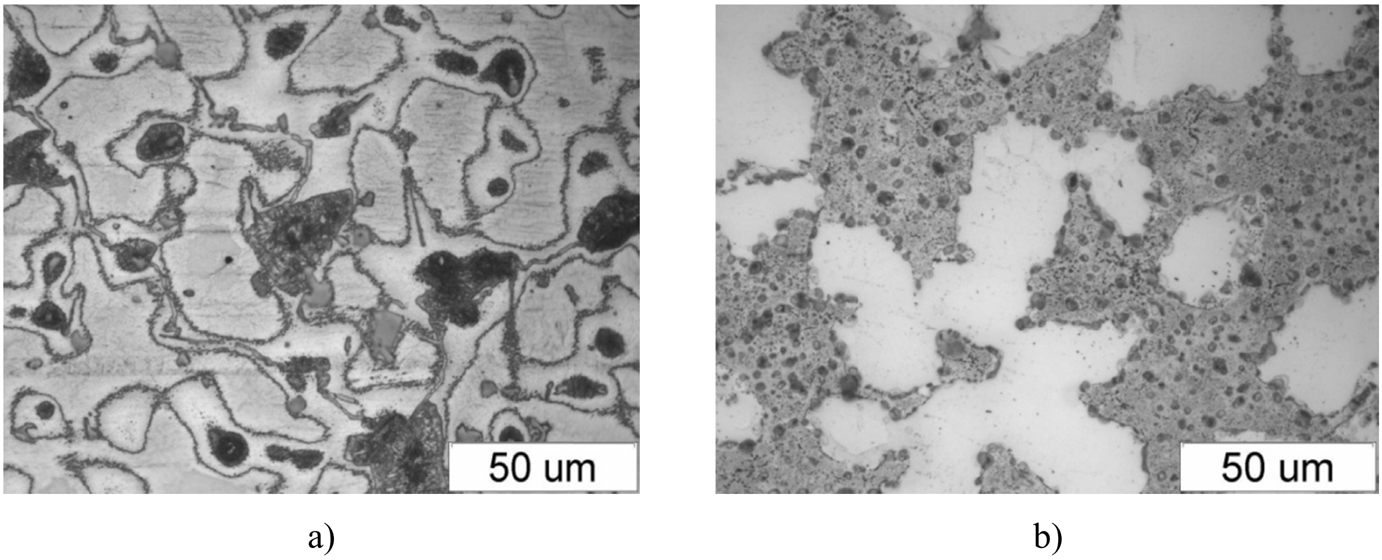
Parameters of the extrusion process of the ingots

Alloys	Temperature of heating, [°C]	Temperature of extrusion, [°C]
LAE442	370	350
LAE842	320	300

3. Results

The microstructures of alloys LAE442 and LAE842 after casting and homogenisation are presented in figure 1. Microstructure of alloys LAE442 and LAE842 is coarse-grained with the presence of precipitations with differentiated shape and morphology as well as with eutectics. Microstructure of alloy LAE842 is dual microstructure (Fig. 1b). For observed precipitations, both in alloys LAE442 and LAE842, there were chemical composition analyses conducted. Observed precipitations are rich in Mg, Al, La and Ce which are all included in the chemical composition of tested alloys. Lithium was not identified due to limitations of the method [12].

Identification of the phase composition after casting and homogenisation was conducted with the application of X-ray phase analysis. For LAE442 there was presence of phase α-Mg found (solid solution of lithium in magnesium) and phase composition content of 18.4% at. Li and 8.16% at. Mg. This phase has hexagonal structure. Intermetallic phase Al_2Ce_1 with regular structure was identified. For alloy with higher lithium content (LAE842) there was phase α-Mg identified (solid solution of



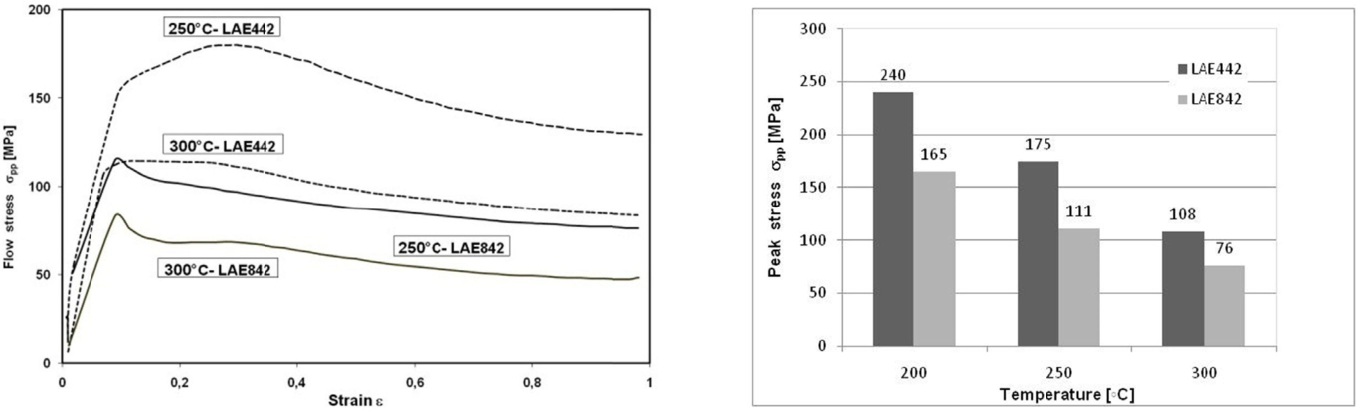
a) b)

Fig. 1. Microstructure of the alloys: a) LAE442, b) LAE842 after the process of casting and homogenization (LM)

magnesium in lithium) content of 18.4% at. Li and 8.16% at. Mg and phase β-Mg – content of 30% at. Li and 70% at. Mg [12]. The aim of conducted plastometric tests was to assess the influence of deformation parameters (temperature, deformation speed) on the plasticity and deformability of alloys LAE442 and LAE842. Results from conducted compression tests allowed for marking the curves in yield stress σ_{pp} – deformation ε (Fig. 2). Flow stress curves for both tested alloys are presented in figure 2a. The course and the shape of the flow curves for alloys LAE442, LAE842 is varied and dependent on the strain temperature. Influence of deformation temperature on the values of maximum yield stress for tested alloys LAE442 and LAE842 are presented in figure 2b. For both tested alloys in temperature of 300°C the decrease of maximum yield stress σ_{pp} occurs as well as decrease of the value of the corresponding strain ε_p which suggests that the strengthening is deleted by the phenomena of dynamic reconstruction of structure (Fig. 2a). Flow stress-strain curves of alloy LAE442, LAE842 are characteristic for alloys in which during deformation, a mechanism of plastic called twinning occurs. As it can be observed, the decrease of deformation temperature, below 300°C changes the shape of flow curve for tested alloys with LAE442 and LAE842. A curve is achieved which initially has concave shape, which is connected with intensive course of twinning (Fig. 2a). The alloy deformed in the temperature to 300°C demonstrates the most advantageous susceptibility to plastic forming from investigated alloy LAE842 (Fig. 2).

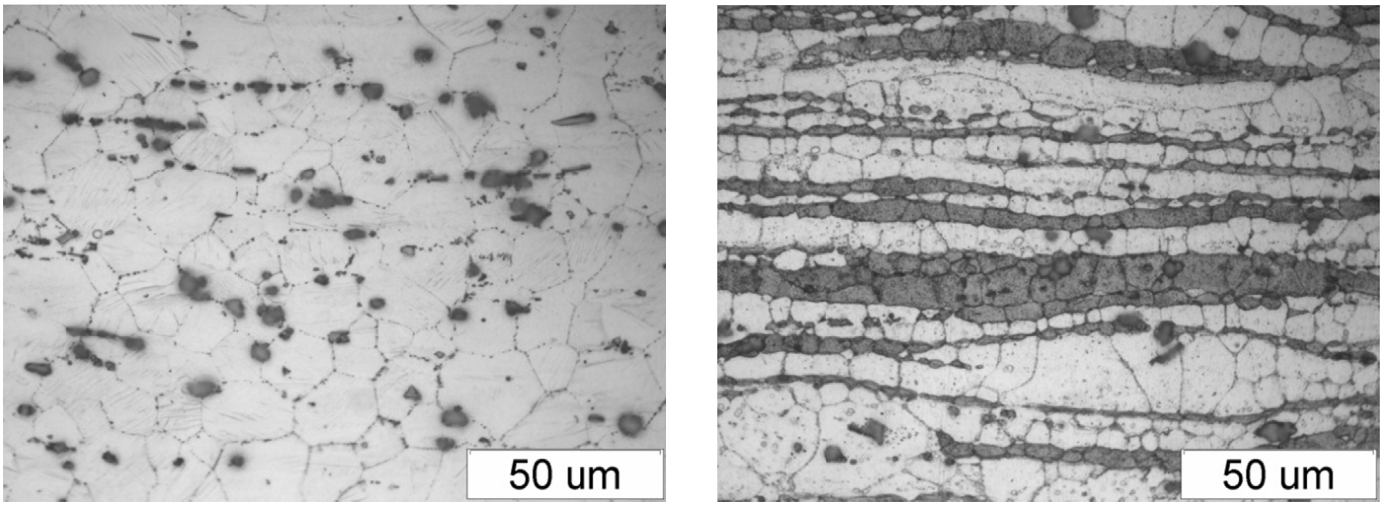
In tested temperature the flow curves for both tested alloys show characteristic maximum of yield stress σ_{pp} and decrease of the value after exceeding the maximum. For temperature of 250°C, 300°C alloy LAE842 shows lower values of yield stress in comparison with LAE442 (Fig. 2b). Microstructures of alloys LAE442, LAE842 after the process of extrusion are presented in figure 3. Microstructure of both alloys after the process of extrusion is fully recrystallised (Fig. 3).

Mechanical properties of alloys LAE442 and LAE842, marked in static compression test performed in room temperature, are shown in table 3. Results show bigger deformability of alloy LAE842 in comparison with classic alloy LAE442. Alloy



a) b)

Fig. 2. a) Example flow stress curves of the for alloys LA442, LA842 in compression at 250°C, 300°C and a strain rate of 0.1 s^{-1}, b) The effect of temperature (200°C, 250°C, 300°C) on the maximum deformation peak stress σ_{pp} of alloys LAE442, LAE842



a) b)

Fig. 3. Microstructure of the alloys: a) LAE442, b) LAE842 after the extrusion process (LM) longitudinal micro-section

LAE842 with lithium content of about 8% shows the biggest deformability visible in the relative draft to fracture which equalled 37%.

TABLE 3

Mechanical properties of magnesium LAE442, LAE842 alloys

Alloys	**Compressive strength [MPa]**	**Relative draft to fracture [%]**
LAE442	370	26
LAE842	371	37

4. Summary

The paper presents the results of tests which aim at determination of the influence of extrusion process on the microstructure and mechanical properties of magnesium alloys LAE442 and LAE842. Magnesium alloys with lithium are a new generation of ultra-light magnesium alloys [3]. Lithium addition which was introduced into chemical composition influences on the decrease of density of alloys but at the same time increases their deformability. The presence of rare earth elements influences the decrease of the porosity of the castings and increase of the resistance to corrosion in elevated temperature. In initial condition the microstructure of alloys LAE442 and LAE842 is coarse-grained, dendritic and with presence of many divisions and eutectics. Metallic matrix of alloy LAE442 is hexagonal phase α-Mg whereas the metallic matrix of LAE842 consists of two phases: hexagonal phase α-Mg and regular β-Mg (solution of magnesium in lithium). Conducted tests of axisymmetrical compression with Gleeble simulator allowed for marking the flow curves in flow stress σ_{pp} – deformation ε system. For the analysed temperature and deformation rate the curves have classic course of changes of the yield stress values. Achieved results of conducted plastometric tests have given the knowledge about plasticity and deformability of the tested alloys. After extrusion, as a result of recrystallisation, the achieved rods were characterised with fine-grained structure. The biggest deformability is present in alloy LAE842 which results from the presence of plastic phase β-Mg (solution of magnesium in lithium) in this alloy.

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