PLASTICITY AND MICROSTRUCTURE OF MAGNESIUM - LITHIUM ALLOYS

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Abstract

The increase of susceptibility to plastic forming of magnesium alloys may be achieved by lithium addition in the amount of up to 15% of alloy mass. At the same time by introduction of lithium which has density of 535 kg/m3 a significant weight decrease of the alloy is achieved. A limitation here is significant decrease of resistance of the alloy. Also, smelting magnesium alloys with lithium is more difficult than other magnesium alloys due to intensive oxidation. It is only possible to conduct smelting in vacuum furnaces with application of overpressure of argon. Therefore, it is necessary to conduct tests which aim at exploration of phenomena which occur in microstructure of Mg-Li alloys during primary forming in conditions of vacuum metallurgy and under the influence of plastic deformation in room temperature and in elevated temperature.

The article presents the results of tests connected with influence of strain parameters on the susceptibility to plastic shaping of magnesium lithium alloys with lithium content of 4.0, 7.5% and 15% of mass. Plasticity tests were conducted in compression test from room temperature up to 400°C with strain speed of 0.1s-1. Conducted tests allowed for determination of susceptibility of magnesium alloys with different lithium content to plastic shaping. The results were compared with typical alloy AZ31. The results of influence of deformation temperature on the microstructure of tested alloys are also presented in this paper.

Keywords: Magnesium-lithium alloys, hot deformation, plastometric test, microstructure.

1. INTRODUCTION

Beneficial properties of magnesium caused that processes of manufacturing intermediate products from magnesium alloys shaped with the use of plastic working methods are currently in the phase of intensive development [1-4]. Chemical compositions of alloys were elaborated for plastic working with diversified composition containing mainly Al, Mn, Zn, Zr as well as rare-earth elements which form stable thermodynamic phases on grain boundaries. Further improvement of mechanical properties is possible through improvement of processes of heat-plastic working and with the use of unconventional processes of shaping structure and properties. Those processes mainly aim at grain refining in alloys, which lead to yield point increase. At the same time no significant decrease of plastic properties occurs. For magnesium alloys, the process faces a lot of difficulties due to small plasticity in ambient temperature and in elevated temperature [5, 6]. Particularly promising in terms of improvement of susceptibility to plastic forming are the new ultra-light magnesium alloys containing lithium [7]. In papers [9-12] it is shown that the addition of lithium influences the deformability of magnesium alloy positively but decreases its strength.

In balance system of Mg-Li the following appear: solid solution of hexagonal structure to 5.5 % mas. lithium (17 % at. Li), solid solution of spatially regular structure above 11% mas. lithium (30 % at. Li) and from 5.5 to 11 % mas. lithium the alloy is diphase and contains both types of solid solutions.

Lithium addition to magnesium has an effect on the crystal structure, i.e. the lattice parameters. With increasing lithium content the c/a axial ratio decreases in hexagonal magnesium cell. The c/a relation is decreased from the value of 1.624 for pure magnesium and up to 1.607, with the content of 17% at. Li [10]. It enables the decrease of critical stress to slip activation in prismatic system. Contrary to classic alloys they can be formed with the use of lower temperature. The design of the technology of plastic forming of constructional elements from the magnesium alloys requires a precise determination of the impact of the process parameters on the microstructure, and consequently on the mechanical properties of the executed elements. The aim of the paper was to compare the plasticity of magnesium alloy AZ31 with alloy content from 4 to 15 % lithium.

2. METHODOLOGY

Alloys were smelted in vacuum induction furnace VSG 02 by Balzers Company. The melting pot made of Al_2O_3 was used for smelting. The charging ingredients here were metals with technical purity by placing them directly in the melting pot. The melting was conducted in argon atmosphere and the pressure of it in workspace chamber of furnace equalled about 650 Torr. After melting the charging ingredients the metal was kept in liquid state for about 6 minutes and after that it was poured from temperature of 650-700 degrees Celsius (depending on lithium content) to a graphite mould. The alloys content 4%, 7.5% and 15% (wt) lithium and cast elements (Al, Zn, Mn) which improve mechanical properties of the alloys. Chemical composition of investigated alloys is presented in **Table 1**.

Table 1 Chemical composition of investigated magnesium alloys, [wt %]

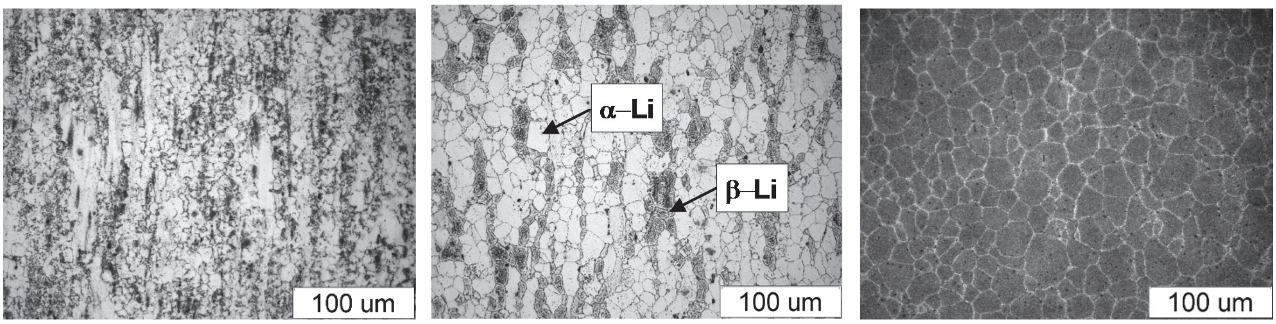
Alloy	Li	Al	Zn	Mn
Mg-4%Li	4.0	3.1	0.71	0.2
Mg-7.5%Li	7.5	2.8	0.61	0.4
Mg -15%Li	15.0	2.9	0.45	0.2

Ingots size 40 mm diameter and the length of 60 mm were were hot extruded on the press after soaking in temperature of 400°C to diameter of 12 mm with degree of plastic working of 10. From extruded rods samples for compression were prepared with diameter of 10 mm and height of 12 mm. Then alloys specimens were subjected to axial-symmetric compression on the Gleeble 3800 simulator. After extrusion, alloy specimens were subjected to axial-symmetric compression on the Gleeble 3800 simulator at temperatures ranging from room temperature to 400°C at 0.1 s^{-1} strain rates. Structural examination was performed on a cross-section parallel to the axis of a sample. The samples were included in a conducting material and etched in a solution intended for etching magnesium alloys, containing: 4.2g $(NO_2)_3C_6H_2OH$ - picric acid, 70ml C_2H_5OH - ethyl alcohol, 10ml H_2O - water10ml CH_3COOH - glacial acetic acid. Structural evaluation was performed using an Olympus GX51 light microscope, in bright field.

3. RESULTS

Microstructures of samples of tested alloys, in initial condition, after extrusion are shown in **Fig. 1**. Before deformation the tested alloy Mg-4%Li was characterised with phase microstructure of solution Li in Mg (α–Mg) and intermetallic phase AlLi was found and which was confirmed by prior X-ray tests. Alloy containing 7.5%Li is characterized with two-phase microstructure built of solid solution of lithium in magnesium with hexagonal structure (hcp) and magnesium in lithium with regular body-centred structure (bcc) and intermetallic phase AlLi. Alloy with 15% of Li characterised by single phase microstructure of solution β-Li.

Hot compression tests were conducted on heat-mechanical simulator Gleeble 3800 from room temperature (RT) to 400 °C. 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. The strain rate applied was 0.1 s^{-1} with given true strain value of 1.0. Registered value of load force and displacement in time function was calculated on the basis of redundancy of flow stress σ_p from strain ε. Redundancy curves of flow stress from strain, achieved in compression tests, show differentiated character of the test run depending on strain temperature and lithium content in the alloy. Example flow curves which show the influence of temperature on flow stress of tested alloys are presented in **Fig. 2, 3**. In room temperature the flow stress increases with the increase of strain but the intensity of the strengthening decreases the bigger the content of lithium.



a) b) c)

Fig. 1 Microstructure of Mg-Li alloys in initial state after casting and hot extrusion: a - Mg-4%Li, b - Mg-7.5%Li and c - Mg-15%Li alloy (dark field)

At room temperature in alloy AZ31 the failure occurs with strain value of 0.2. With lithium content of 4.0 % and 7.5 % the failure occurs with strain value of about 0.3 and 0.4 respectively (**Fig. 2, 3**). Increase of deformation temperature to 100°C leads to improvement of formability so not every alloy reaches the given deformation. Given strain is achieved by alloys AZ31 and Mg-4%Li in temperature of 200°C, and alloy containing 7.5 % lithium reaches it in 150°C. Together with the increase of lithium content regardless of strain temperature the value of maximum flow stress σ_{pp} decreases in comparison with alloy AZ31. In temperature of 300°C for Mg-4%Li alloy the maximum value of σ_p equals 90 MPa (**Fig.2**), and by 7.5 % Li it drops to value of 60 MPa (**Fig. 4**). Flow stress-strain curves of alloy AZ31 are characteristic for alloy in which during deformation a mechanism of plastic strain called twinning occurs [11]. As it can be observed, the decrease of deformation temperature, below 250°C changes the shape of flow curve for tested alloys with 4.0% and 7,5% lithium. A curve is achieved which initially has concave shape (**Fig. 3**), which is connected with intensive course of twinning in microstructure (**Fig. 5a**).

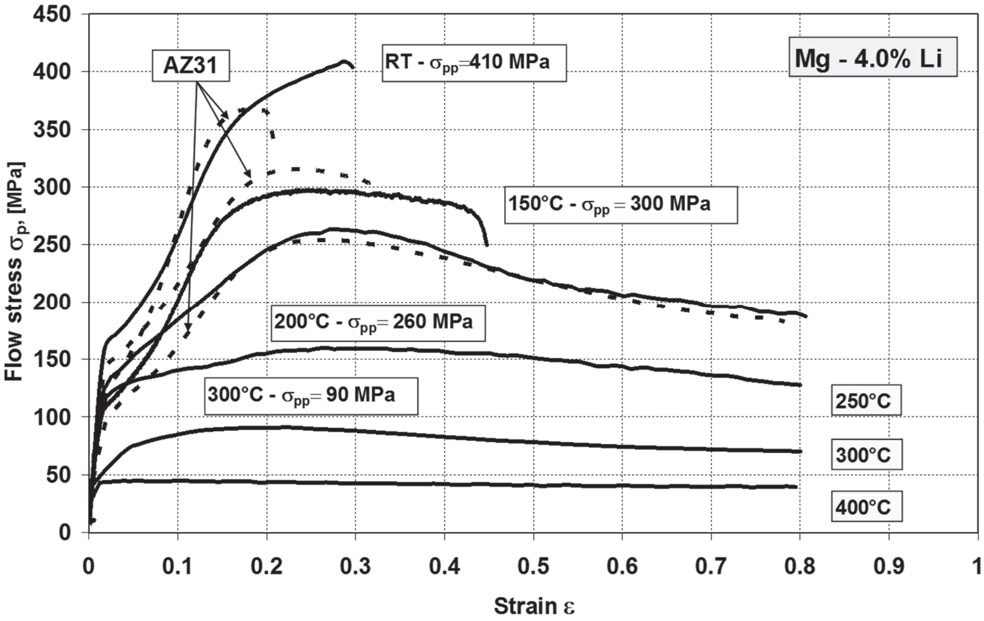


Fig. 2 Results of compression test of magnesium alloy AZ31 and Mg-4%Li at temperature range from room temperature (RT) to 400 °C

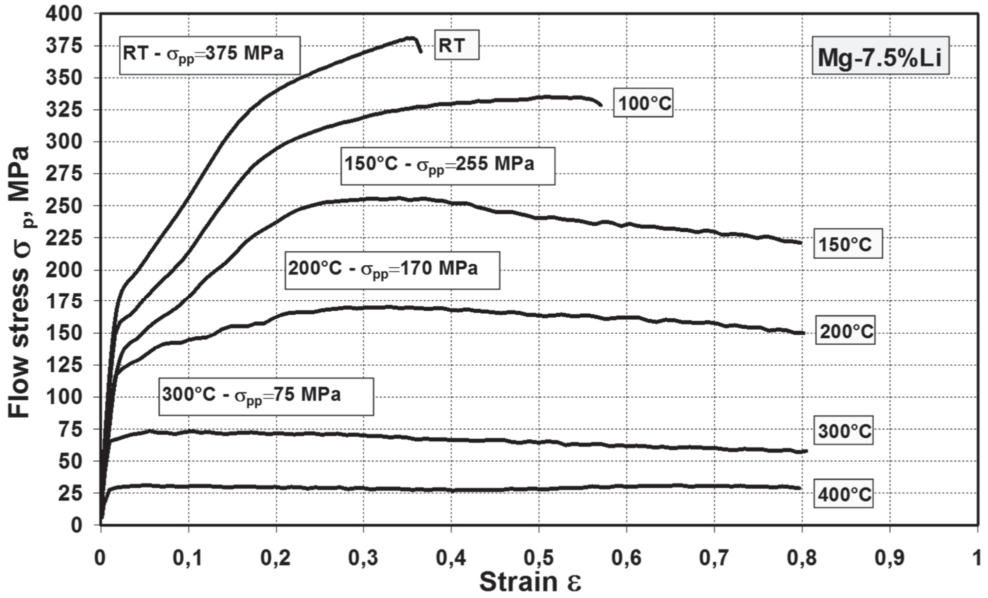


Fig. 3 Results of compression test of Mg-7.5%Li alloy at temperature range from room temperature (RT) to 400 °C

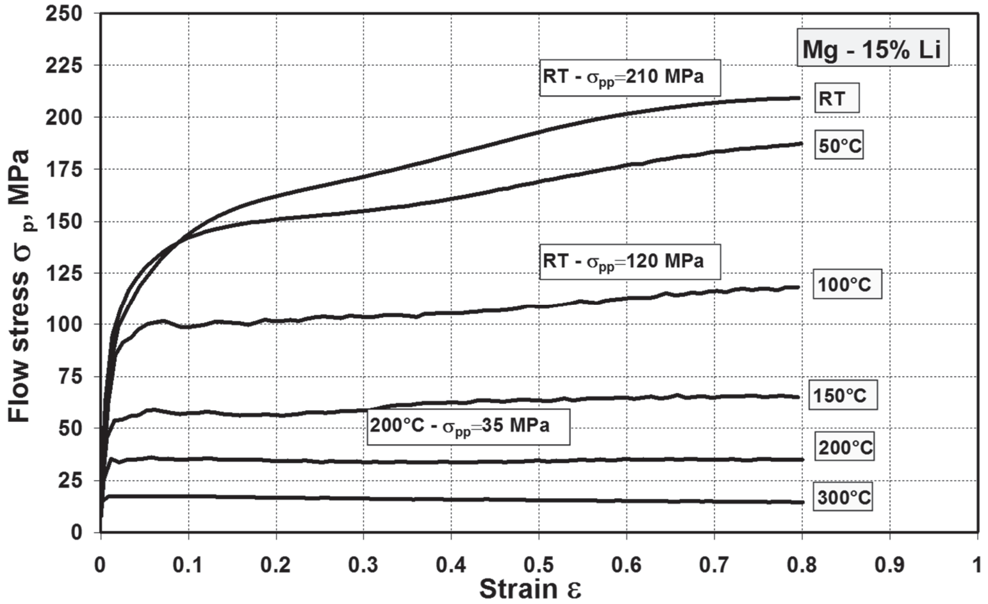
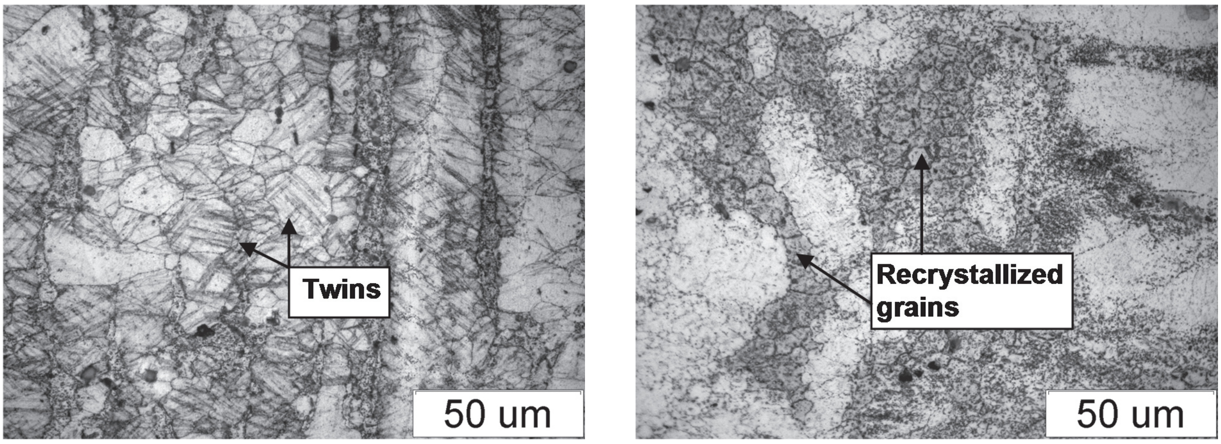


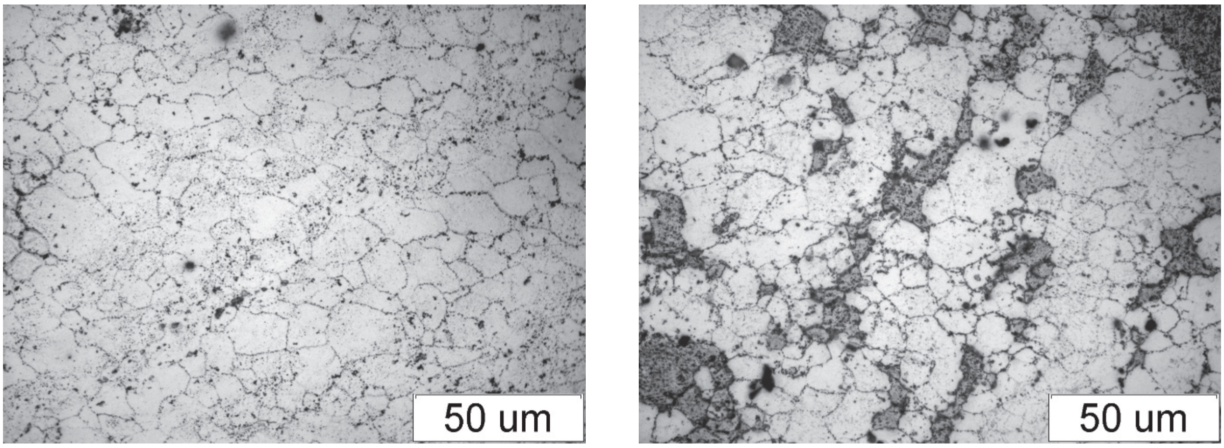
Fig. 4 Results of compression test of a Mg-15%Li alloy at temperature range from room temperature (RT) to 300°C

The presence of twinning mechanism in deformation of magnesium alloys decreases with the increase of lithium content and by big amounts of lithium (7.5 % Li) it is practically observed from room temperature to 150°C. It is visible in this range that the most beneficial susceptibility to deformation is alloy Mg -15%Li (**Fig. 4**). Compression of samples in low temperature lead to formation of a lot of mechanical twins of deformation in the microstructure (**Fig. 5a**). A rise in the compression temperature to 300°C leads to the occurrence of fine dynamically recrystallized grains on primary grain boundaries (**Fig. 5b**). Deformation at 400°C leads to intensive recrystallization of the structure. At deformation temperature of 400°C, a completely dynamically recrystallized structure becomes visible for both Mg-4.0%Li and Mg-7.5%Li (**Fig. 6a, b**). For comparison, the microstructure of Mg-15%Li alloy is fully recrystallized after compression in temperature of 300°C.



a) b)

Fig. 5 Microstructure of Mg-7,5%Li alloys after hot deformation at temperature 100°C to strain $\varepsilon = 0.58$ and Mg-4.0% Li after deformation at temperature 300°C to strain $\varepsilon = 0.8$.



a) b)

Fig. 6 Microstructure of Mg-4%Li alloy (a) and Mg-7.5%Li alloy (b) after hot deformation at temperature 400°C to strain $\varepsilon = 0.8$

CONCLUSION

The paper presents the results of plasticity and microstructure tests of Mg alloys with different lithium content. Achieved initial data shows the positive influence of Li on the course of plastic flow. The biggest stress in analysed deformation temperature range was determine for alloys AZ31 and Mg-4%Li and the smallest for alloy content of 15 % lithium (**Fig. 2, 3 and 4**). Decrease of process temperatures leads to a stoppage, an unusual course of flow stress changes and the curve has initially concave shape (**Fig. 2**). As a result of modification of the initial content of Mg alloy which included 4 % Li by addition of 3.0 % Al the improvement of resistance properties was achieved with only slight decrease of plasticity. It was proved that the formability of alloys improves with the increase of lithium concentration in microstructure of tested alloys. Alloys containing lithium show have better uniformity of plastic flow in comparison with conventional magnesium alloys, i.e. type AZ31 (**Fig. 2**) In deformed mono-phase alloys containing up to 4.0 % Li the twinning of deformation and the processes of dynamic recrystallization are observed. Behaviour of this alloy in conditions of deformation in room temperature and in elevated temperature is close to classical magnesium alloys. Alloys which contain more lithium, which is 7.5 % have good formability in temperature of 150°C (**Fig. 3**). The alloy content of 15 % lithium deformed in the temperature from room temperature to 300 °C demonstrates the most advantageous susceptibility to plastic forming from investigated alloy (**Fig. 4**). The shape of flow curves and microstructure of alloys after deformation in elevated temperatures show significant influence of dynamic recrystallization process. After compression of samples of the investigated alloy for full variability of the applied temperature three characteristic microstructure types can be singled out:

- a structure composed of primary grains with deformation twins (**Fig. 5a**);
- a structure composed of primary grains and dynamically recrystallized grains (**Fig. 5b**);
- a structure composed of dynamically recrystallized grains (**Fig. 6 a, b**).

It should be pointed out, however, that the drawback of alloys with lithium is decrease of resistance of magnesium alloys as well as decrease of corrosion resistance in case of big amount of lithium content. Test results will be useful in development of plastic working technology of construction elements which serve as light substitutes for currently used materials.

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