THE INFLUENCE OF Li, Ca CONTENT ON THE MICROSTRUCTURE AND PROPERTIES OF Mg-Li-Ca ALLOYS AFTER EXTRUSION PROCESS

Iwona BEDNARCZYK

Silesian University of Technology, Faculty of Materials Engineering and Metallurgy, 40-019 Katowice, Poland, EU, iwona.bednarczyk@polsl.pl

Abstract

The article presents tests results of the influence of Li and Ca content on the microstructure and properties of Mg-4Li-1Ca (LX41) and Mg-8Li-2Ca (LX82) alloys after extrusion process. Achieved microstructures of magnesium alloys after extrusion were compared with microstructure after casting and homogenisation. An analysis was conducted of the microstructure in initial condition and in condition after plastic deformation with the use of techniques of light and scanning microscopy. Presented results show the mechanical properties marked in static extrusion test in room temperature. It was stated that alloy Mg-4Li-1Ca (LX41) is characterised with better plasticity than the alloy Mg-8Li-2Ca (LX82).

Keywords: Mg-Li-Ca alloys, microstructure, extrusion process, electron microscopy, static compression test

1. INTRODUCTION

Magnesium alloys are commonly applied as construction materials in automotive and aviation industries due to their low specific weight and high strength. Considering the technology of their production, magnesium alloys can be divided into casting magnesium alloys and alloys for plastic working. In the group for plastic working there is a generation of ultra-light alloys which is especially worth mentioning and it is a group of alloys containing lithium in their chemical composition [1,2]. Alloys Mg-Li-Ca are more commonly used in construction of modern, ultra-light metal constructions. An important aspect of application for magnesium alloys is medicine. Implants, surgical clips for joining bones as well as surgical threads are prepared from magnesium alloys. The advantage of the application of those alloys is mainly the ability to dissolve in the human body. Such application of magnesium alloys prevents from conducting a second operation just to remove the implant from the patient's body. The presence of lithium beneficially influences the plasticity, decreases the density of the alloy but deteriorates the strength properties [3-5]. The Institute of Materials Science of the Silesian University of Technology conducts research works devoted to elaboration of shaping technology for magnesium alloys. Besides the conventional magnesium alloys such as AZ61, WE43 and AZ31 the attention was also turned to the new generation of the ultra-light alloys which include lithium in their chemical composition [6,7]. It is assumed that 1% of lithium weight content in the magnesium alloy reduces its density by about 3%. Additionally, it reduces the resistance to corrosion, due to high reactivity of lithium [6], which results in the limitation for technical application of those alloys. Due to their phase composition connected with the lithium content, alloys Mg-Li can be divided into three main groups: mono-phase with structure α, two-phase α+β, and mono-phase with structure β [2]. New, ultra-light Mg-Li-Ca alloys may become promising materials of the future, due to their low density, good resistance, ductility and bio-compatibility to be applied in medicine in biodegradable implants and surgical suture [8-10]. They can also become an alternative to the currently applied conventional magnesium alloys. The paper presents the results of tests which analyse the microstructure and properties of Mg-4Li-1Ca (LX41), Mg-8Li-2Ca (LX82) alloys in initial state and after extrusion process.

2. EXPERIMENTAL PROCEDURE

Materials for extrusion process were ingots with a height of 90 mm and diameter of ϕ 40 mm from magnesium alloys Mg-4Li-1Ca (LX41), Mg-8Li-2Ca (LX82) (wt.%). In accordance with phase equilibrium system and due to the presence of lithium in chemical composition it is possible to achieve the following alloys: single-phase α (Mg-4Li-1Ca) or two-phase alloy α+β (Mg-8Li-2Ca) [2]. The alloys Mg-4Li-1Ca and Mg-8Li-2Ca were smelted in single-compartment, laboratory induction vacuum furnace VSG 02 by Balzers Company [6]. **Figure 1** shows an example primary structure and the appearance of the achieved ingot from magnesium alloy Mg-4Li-1Ca, Mg-8Li-2Ca after casting process. Macrostructure of the achieved ingots consists only of equiaxial grains (**Figure 1**). The lack of presence of areas with columnar grains - despite the fact of casting into graphite moulds which quickly absorb heat - indicates that the tested alloy has a strong tendency to volume crystallisation. It is a very beneficial phenomenon because the fine-grained, complex structure consisting of equiaxial grains usually has a better technological plasticity than the structures in which columnar grains dominate. There was a heat treatment conducted for tested alloys Mg-4Li-1Ca in temperature of 400 °C and Mg-8Li-2Ca in temperature of 300 °C with annealing for 3h and cooling in furnace all performed after casting process. For alloy Mg-8Li-2Ca there was lower temperature applied for heat treatment due to bigger content of lithium 8 wt.% in chemical composition and the risk of ignition during conduction of the process.

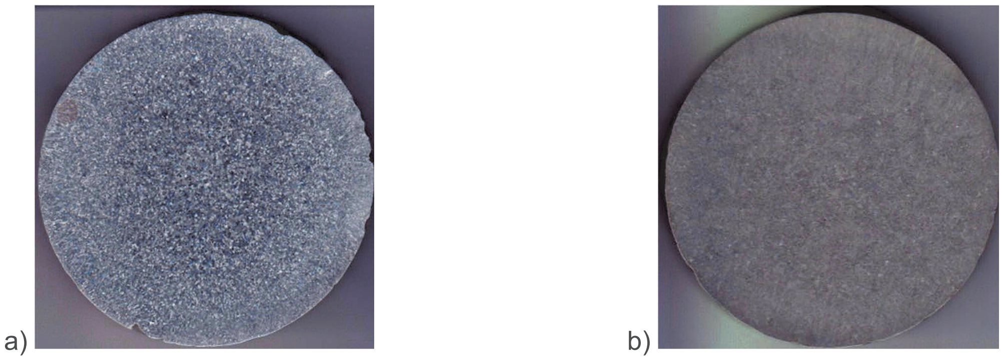


Figure 1 Magnesium alloys after casting process, macrostructure: a) Mg-4Li-1Ca, b) Mg-8Li-2Ca

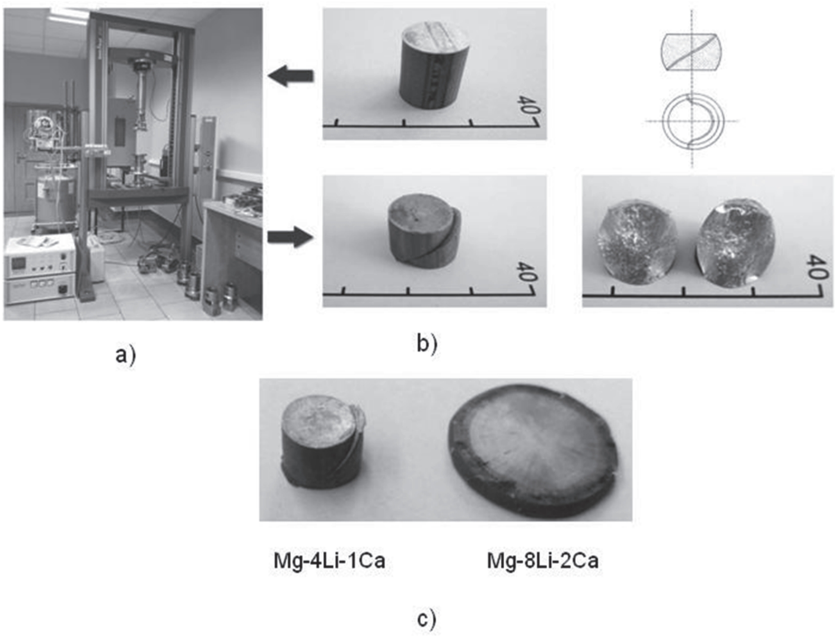
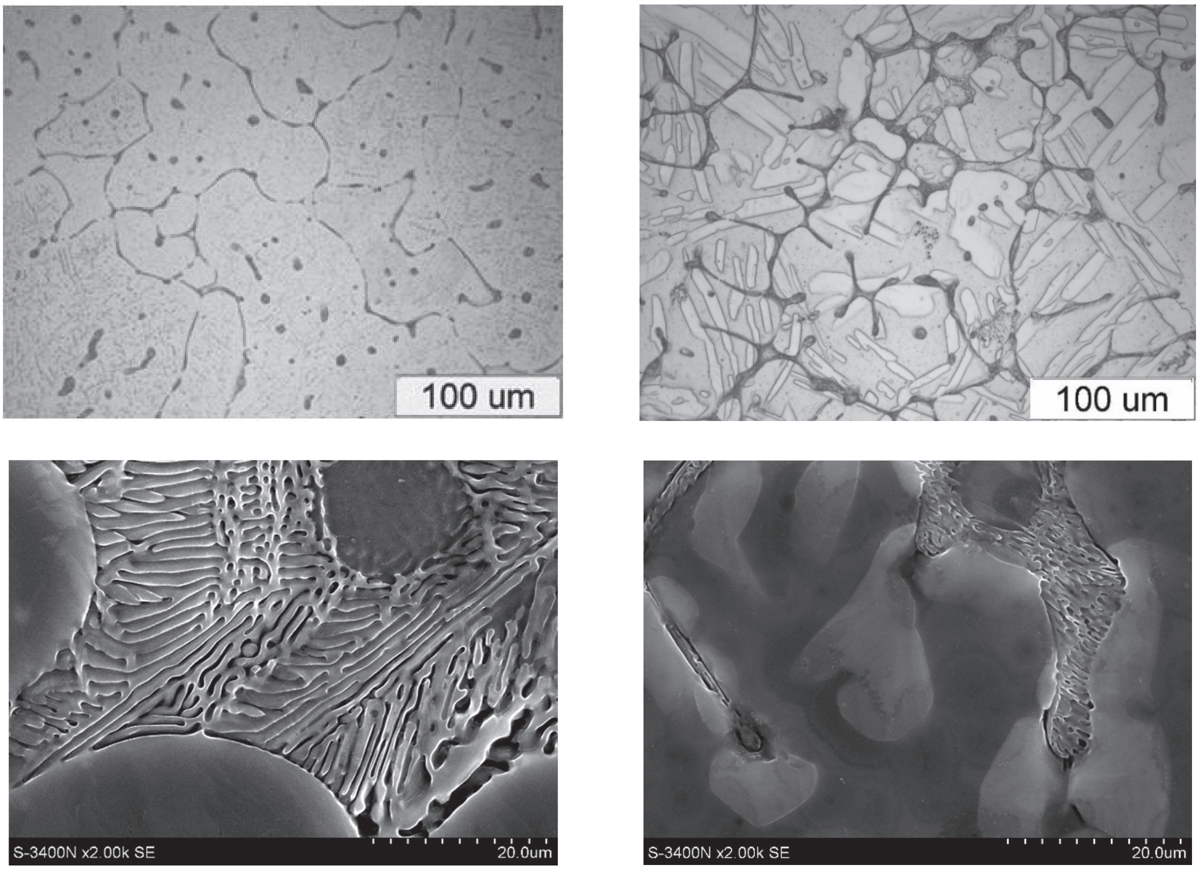


Figure 2 Static compression test: a) machine Zwick/Roell Z100, b-c) view of the samples for tests, view of samples after conduction of static compression test

After casting process and homogenisation the alloys Mg-4Li-1Ca and Mg-8Li-2Ca underwent extrusion process. The process was conducted in the Institute of Materials Science of Silesian University of Technology on hydraulic press with the use of hydraulic press Hydromet. The temperature applied for extrusion was 400 °C and capacity force of the press of 420 kN. The effect of conduction of extrusion process was achievement of rods with diameter of 10 mm. The surface of the achieved rods was correct and did not include any defects. The analysis of microstructure was conducted after each conducted stage of tests with the use of light and scanning microscopy techniques. Tests of mechanical properties of the achieved rods were conducted with the use of testing machine Zwick/Roell Z100, in room temperature. Measurements of micro-hardness were done with the use of Vickers method with load of 0.2 kg ($HV_{0.2}$) on samples in initial condition and after extrusion process.

3. RESULTS AND DISCUSSION

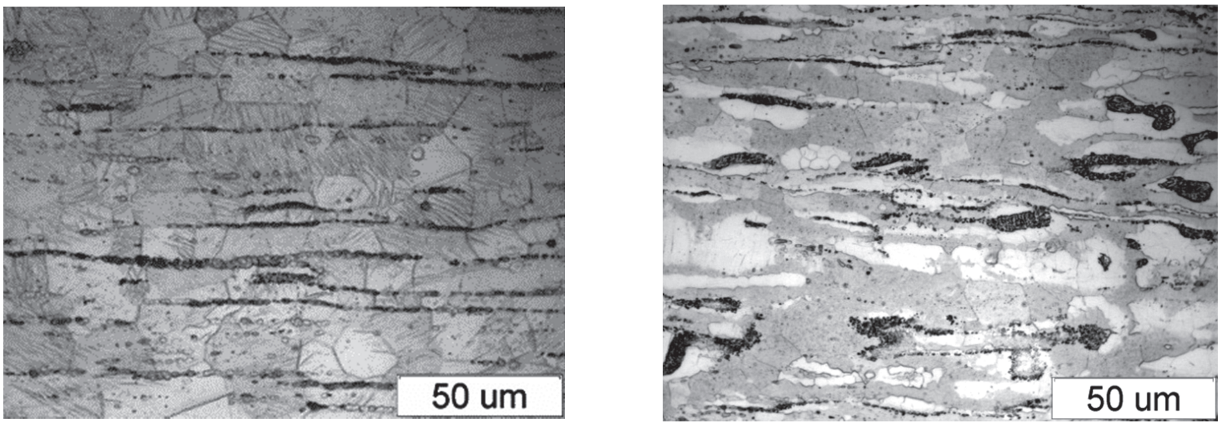
Figure 2 presents example microstructure of alloys Mg-4Li-1Ca, Mg-8Li-2Ca after casting and homogenisation. The homogenisation has been conducted in temperature of 400 °C Mg-4Li-1Ca, 300 °C Mg-8Li-2Ca for 3 hours. Samples were cooled in furnace. In the microstructure in the initial state there were traces of dendritic structure with clearly marked grain boundaries observed (**Figures 3a, b**). In the microstructure of alloy Mg-8Li-2Ca there was presence of phases observed with lamellar shapes located inside and on the boundaries of grain present in the whole analysed surface (**Figure 3b**).The eutectic is a mixture of phases α-Mg and Mg_2Ca [2]. There was also found the eutectic with lamellar structure situated in inter-dendritic areas of phase α-Mg (**Figures 3a, b**).



a) b)

Figure 3 Microstructure of alloys after casting and homogenisation: a) Mg-4Li-1Ca (LX41), b) Mg-8Li-2Ca(LX82);visible eutectics with lamellar structure in inter- dendritic areas

The microstructures of alloy Mg-4Li-1Ca, Mg-8Li-2Ca after extrusion process are presented in **Figure 4.** Microstructure of the tested alloy after extrusion process was characterised with the presence of equiaxial, recrystallized grains inside of which there were deformation twins. After extrusion process the observed eutectics are present mainly on grain boundaries and form a band arrangement (**Figures 4 a, b**). **Figure 5** presents an example diagram of dependencies of stress from relative draft to shortening in tested alloys. Alloy Mg-8Li-2Ca is characterised with 4 times bigger deformability where the relative draft achieved to cracking equalled 80%. However, for the alloy Mg-4Li-1Ca the value of draft to cracking was 18% (**Figure 5**). **Figure 6** presents the measurements of micro-hardness $HV_{0.2}$ after applied processes of: heat treatment, extrusion and static compression test. It was stated that the alloy Mg-8Li-2Ca is characterised with higher hardness value in comparison with alloy Mg-4Li-1Ca. It probably results from bigger lithium and calcium content in the chemical composition of Mg-8Li-2Ca. Alloys Mg-4Li-1Ca and Mg-8Li-2Ca are characterised with higher hardness values after extrusion process in comparison with their condition after heat treatment. It is caused by significant refinement of the microstructure and bigger amount of grain boundaries. Micro-hardness $HV_{0.2}$ after static compression tests of alloys Mg-4Li-1Ca and Mg-8Li-2Ca significantly increases which is caused by strain-hardening caused by the presence of deformation twins (**Figure 6**).



a) b)

Figure 4 Microstructure of alloys after extrusion process : a) Mg-4Li-1Ca (LX41), b) Mg-8Li-2Ca (LX82); eutectics, deformation of twins

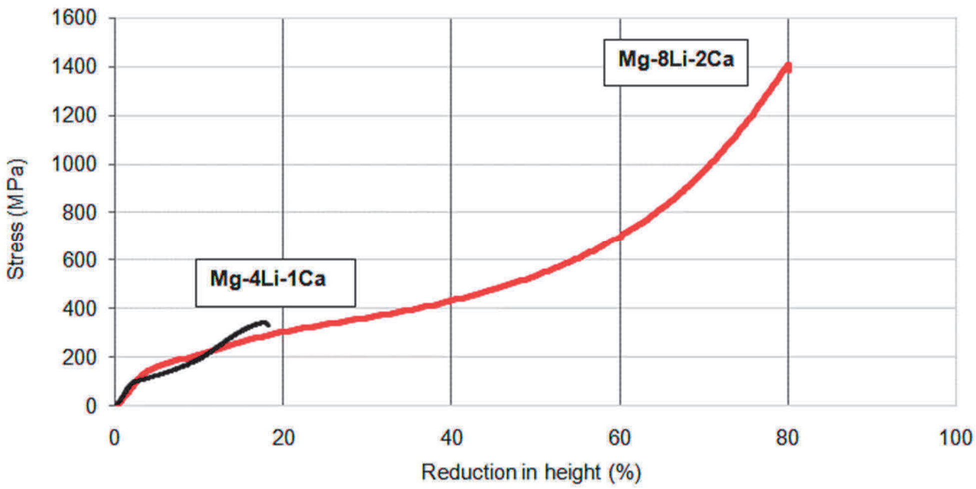


Figure 5 Diagram of dependencies of stress from relative draft to cracking for alloys Mg-4Li-1Ca (LX41) and Mg-8Li-2Ca (LX82)

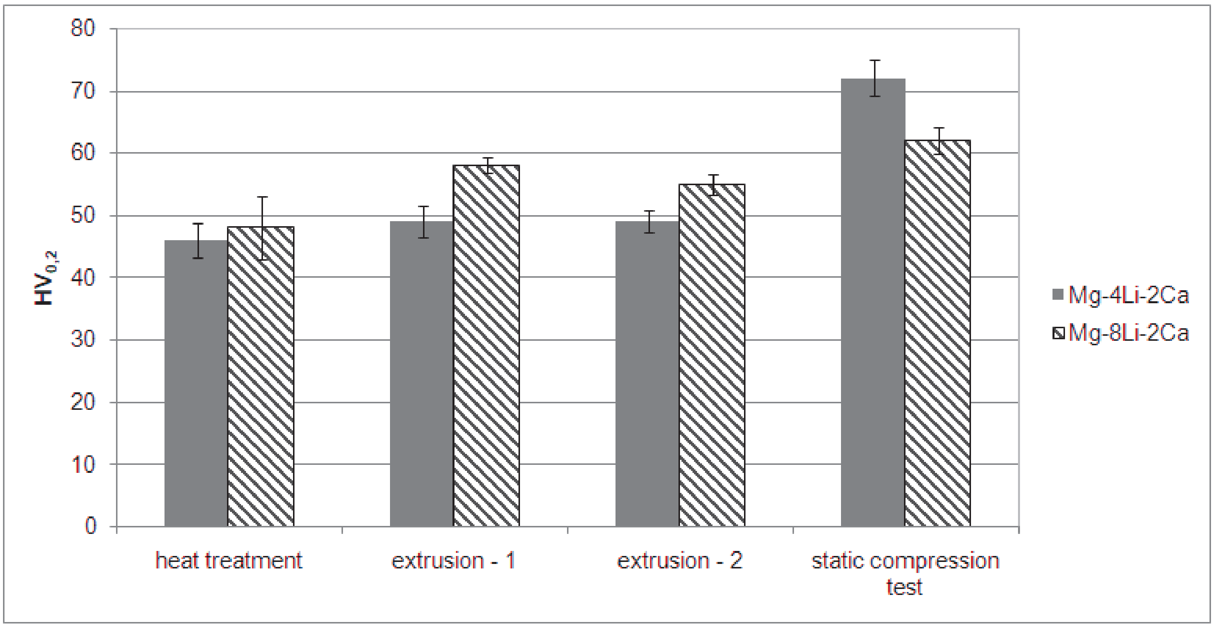


Figure 6 Results of measurements of micro-hardness of alloys Mg-4Li-1Ca (LX41) and Mg-8Li-2Ca (LX82) after processes of: heat treatment, extrusion (1- cross- section, 2- longitudind micro-section) and static compression test

4. CONCLUSION

Presented tests results show beneficial influence of addition of lithium and calcium on the microstructure and properties of the alloy Mg-4Li-1Ca, and even more beneficial influence in case of alloy Mg-8Li-2Ca. Magnesium alloys with lithium are a new generation of ultra-light construction materials. Introduction of lithium to the chemical composition was aimed at the decrease in the density of the alloy and at the same time increase of their deformability. The introduction of calcium, however, works deoxidising during the processes of heat treatment and casting. It also influences beneficially on the resistance to corrosion and resistance to creep in elevated temperature. Extrusion processing results in grain refinement of microstructure. The results of dynamic recrystallization processes are evident in the microstructure of Mg-4Li-1Ca and Mg-8Li-2Ca alloys. The biggest deformability was found for alloy Mg-8Li-2Ca - value of draft to cracking - 80% in comparison with alloy Mg-4Li-1Ca - 18%. For alloy Mg-8Li-2Ca after processes of: heat treatment and extrusion the values of micro-hardness $HV_{0.2}$ were higher in comparison with those for alloy Mg-4Li-1Ca.

ACKNOWLEDGEMENTS

The work was supported by the Ministry of Science and Higher Education within the framework of the BK-221/RM0/2018

REFERENCES

[1] BIAŁOBRZESKI, A., SAJA, K. and HUBNER, K. Ultra-light magnesium-lithium alloys. *Archives of Foundry Engineering.* 2007. vol. 7, pp. 11-16.

[2] BIAŁOBRZESKI, A., LECH-GREGA M., ŻELECHOWSKI J. Scanning examinations of magnesium- and lithium- based alloys of two-phase α-β and monophase β structure. *Works of the Foundry Institute.* 2010. vol. 50, no. 1, pp. 17-28.

[3] SANJAY, N. *Development of ultralight and ultrafine grained Mg-Li-Ca alloy by compositional optimisation and severe plastic deformation*. Doctor thesis. 2016. Monash University. Faculty of Engineering. Department of Materials Science and Engineering and Indian Institute of Technology, Bombay.

[4] AL-SAMMAN and GOTTSTEIN, G. Dynamic recrystallization during high temperature deformation of magnesium. *Materials Science and Engineering*. 2008. A490, pp. 411-420.

[5] SONG, G.S. and KRAL, M.V. Characterization of cast Mg-Li-Ca alloys. *Materials Characterization*. 2005. no. 54, pp. 279-286.

[6] BEDNARCZYK, I. MRUGALA, A. and TOMASZEWSKA, A. Influence of plastic deformation process on the structure and properties of alloy WE43. *Archives of Metallurgy and Materials*. 2016. vol. 161, pp. 389-392.

[7] MIKUSZEWSKI, T. Melting and casting of ingots from made of Mg-Li type alloys. *Metalurgija*. 2014. vol. 53, pp. 588-590.

[8] MIKUSZEWSKI, T. Manufacture, cast structure and plastic properties of selected multicomponent Mg-Li alloys. *Materials Engineering*. 2014. no. 3, pp. 258-262.

[9] KUC, D., HADASIK, E., MIZERA, J. and MIKUSZEWSKI J. Plasticity and microstructure of magnesium - lithium alloys. *Solid State Phenomena*. 2014. vol. 212, pp. 11-14.

[10] BEDNARCZYK, I. Characterization of magnesium LAE442 alloy microstructure after deformation process with the use of KoBo method. *Materials Engineering*. 2018. no. 2, pp. 56-60.