

Registration of Melting and Crystallization Process of Ultra-light Weight MgLi12,5 Alloy with Use of ATND Method

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Abstract

To the main advantages of magnesium alloys belongs their low density, and just because of such property the alloys are used in aviation and rocket structures, and in all other applications, where mass of products have significant importance for conditions of their operation. To additional advantages of the magnesium alloys belongs good corrosion resistance, par with or even surpassing aluminum alloys. Magnesium is the lightest of all the engineering metals, having a density of 1.74 g/cm³. It is 35% lighter than aluminum (2.7 g/cm³) and over four times lighter than steel (7.86 g/cm³). The Mg-Li alloys belong to a light-weight metallic structural materials having mass density of 1.35-1.65 g/cm³, what means they are two times lighter than aluminum alloys. Such value of mass density means that density of these alloys is comparable with density of plastics used as structural materials, and therefore Mg-Li alloys belong to the lightest of all metal alloys. In the present paper are discussed melting and crystallization processes of ultra-light weight MgLi12,5 alloys recorded with use of ATND methods. Investigated magnesium alloy was produced in Krakow Foundry Research Institute on experimental stand to melting and casting of ultra-light weight alloys. Obtained test results in form of recorded curves from ATND methods have enabled determination of characteristic temperatures of phase transitions of the investigated alloy.

Keywords: Magnesium Alloys, Crystallization, Mg-Li Alloy, ATD, ATND

1. Introduction

Magnesium alloys constitute excellent alternative to aluminum and its alloys, as a material to implementation in light-weight structures.

The structures, depending of their function, should fulfill fundamental criteria, such as: productibility, strength, ductility, energy absorbability and corrosion, or combination of them. Magnesium alloys offer very good properties: the lowest density of all technically relevant structural materials, the highest specific strength, good mechanical damping properties, good radiation absorption of electromagnetic waves, good castability, good

machining properties even at high cutting speeds, good inert gas weldability, corrosion resistance through high purity alloys, and nearly unexplainable resources (e.g. 1 m³ sea water contains approximately 1.3 kg magnesium, depending on a location) [1].

Based on these advantages, magnesium alloys have comprehensive and huge potential application in aviation, spaceflight, automobile, 3D product, and military regions[1, 2-3].

The most powerful branch of industry in the present use of magnesium products is automotive industry, other industries working with the acceleration of masses, however, also discover magnesium alloys as constructional materials. Additionally, the reduction in mass of moved parts can optimize energy consumption, and therefore treats the environment with care [1].

But the usage of magnesium alloys in more complex applications is limited by insufficient properties regarding the ductility, corrosion and creep resistance. Additionally, the high reactivity of magnesium alloys leads to an increased tendency of contamination [1].

Auto manufacturing companies have made the most of research and development on Mg and its alloys. Volkswagen was the first to apply magnesium in the automotive industry on its Beetle model, which used 22 kg magnesium in each car of this model [4,5]. Magnesium average usage and projected usage growth per car are given as 3 kg, 20 kg, and 50 kg for 2005, 2010 and 2015, respectively [4,5].

Components from magnesium alloys are usually produced in various foundry processes. Among them are pressure die casting, permanent-mould casting, and sand casting, among others. To other implemented manufacturing technologies belong: casting with extrusion, tikso casting and tikso moulding [6-8].

Lithium with a relative density of 0.53 is the lightest of all metals and has extensive solid solubility in magnesium [9]. Furthermore, addition of nearly 11 wt% Li converts the hexagonal close-packed structure of pure magnesium to a body centered cubic lattice; markedly improving the formability of the alloy [9].

In the Fig. 1 is shown Mg-Li phase diagram

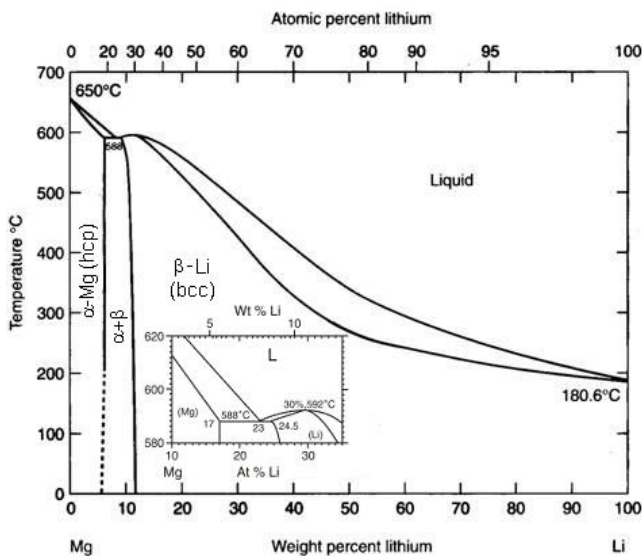


Fig. 1. Mg-Li phase diagram [10]

Small addition of Li can decrease the c/a ratio of the hexagonal Mg lattice. When Li addition is higher than 5,3%wt. [11], it introduces body-centered-cubic (BCC, β phase) β -Li solid solutions to hexagonal closed-packed (HCP, α phase) Mg-based alloys, which results in the (α + β) duplex alloys [12]. The phases exhibit a moderate strength and low formability, the phase has better ductility, but lower creep resistance. The two phase structure exhibits an interesting compromise of their properties because the both phases combine the moderate strength of the first phase and excellent ductility of the second phase [13]. When Li composition surpasses 10,7%wt. in Mg alloys [11], the structure of Mg alloy can be completely converted from HCP to BCC (Fig. 1).

Mg-Li binary alloys have some inherent disadvantages (low strength, poor anti-corrosion, poor stability). In order to avoid these disadvantages, some alloying elements should be added into the alloys.

Therefore, to obtain high-performance Mg-Li alloys, alloying is always used to improve performance of alloys. Commonly used alloying elements are Al, Zn, Ca, RE, etc. Many researchers have studied Mg-Al, Mg-Zn, Mg-Ca alloys [14-18]. Research results show that, RE in these alloys has many favorable effects, such as melt purification, improving microstructure, grain refinement, and dispersion strengthen. And the strength and high-temperature stability of magnesium alloys are accordingly improved. However, the reports about the effects of RE on Mg-Li alloys are very deficient [19].

Due to its strengthening effect, Al is the most commonly used alloy-forming element [20-21]. Addition of aluminum to Mg-Li alloys leads to appearing in hexagonal structure of phase δ , constituting solid solution Al in Mg having limited formability, of ductile phase λ being solid solution Al in Li having crystal body centered lattice and hard – enabling precipitation hardening – intercrystalline Al-Li compound of phase η with structure B2. Ductility of such alloys grows together with increase of portion of eutectic mixture δ + λ . Sometimes, in the alloys is present metastable phase Li_2MgAl [22].

Together with increase of Al content in Mg-Li alloys, the strength increases accordingly. While when the Al content is too high, elongation of the alloys decreases seriously. Suitable Al content in Mg-Li alloys is 3% (mass fraction) [23].

To refine grain size of alloys, Ce is often added in magnesium alloys. The suitable Ce content in Mg-Li alloys is 1% (mass fraction) [23].

Obtaining the best material structure for a specific requirements becomes possible with making use of theories on crystallization processes to control technological processes [24, 25]. Registration of a phenomena arisen in result of solidification process of alloys in order to determine their properties is enabled by a methods based on analysis of temperature changes run (thermal methods - ATD), of electric conductivity (electric methods - AED) and the method of the Thermal-Voltage Derivative Analysis (ATND) [26].

2. Methodology of the research

Investigated alloy (MgLi12,5) was obtained from pure constituents and was cast in Krakow Foundry Institute on experimental stand used to melting and pouring of ultra lightweight alloys.

The stand for melting and casting of Mg – Li alloys has a modular structure including:

- melting module, which consists of a chamber standing on the casting chamber, measuring 210x210x 300 mm (width x length x height)
- casting chamber forms lower part of the stand and measures 420x420x200 mm (width x length x height),
- gas mixing facility makes an integral part of the stand and is used for feeding to the crucible and casting chamber a mixture of

protective gas composed of argon (Ar) and sulphur hexafluoride (SF₆) [27].

A control system used in the crucible should allow the temperature stabilisation with an accuracy of + / -10C. It was also necessary to allow for the possible mechanical mixing of alloys in a crucible.

Suitably prepared specimens of the alloy were melted in tubular silit furnace with CO₂ protective atmosphere. In course of melting and crystallization of the alloy there occurred permanent, simultaneous registration of specimen's temperature and potential's difference on measuring probes. The testing stand comprised, except the silit furnace, two millivoltmeters and PC computer with software.

The ATND (thermal-voltage- derivative analysis) used in course of the testing consists in permanent measurement of the temperature and electric voltage generated on probes during crystallization and phase transformations of solidified alloy. In course of the measurement there were measured generated voltage and temperature of the specimen. Run of the crystallization is shown in form of diagram created during solidification of the alloy. In the ATND method, thermal curves (t and dt/dτ) are supplemented with voltage curves (U and dU/dτ) [8,26].

3. Description of obtained results

In the Fig. 2-4 is presented run of heating (melting) and cooling (crystallization) process of MgLi12,5 alloy, recorded with use of ATND method. Read values of temperatures concern the following points: A - beginning of melting of the alloy, B - end of melting of the alloy, C - processes in liquid state.

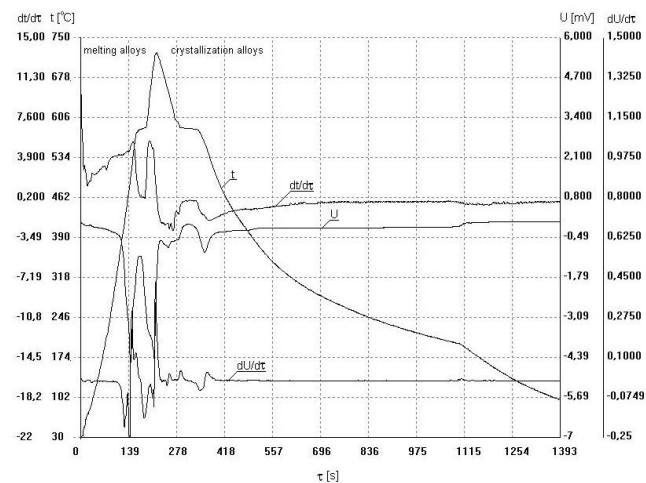


Fig. 2. Curves of ATND method for MgLi12,5 alloy

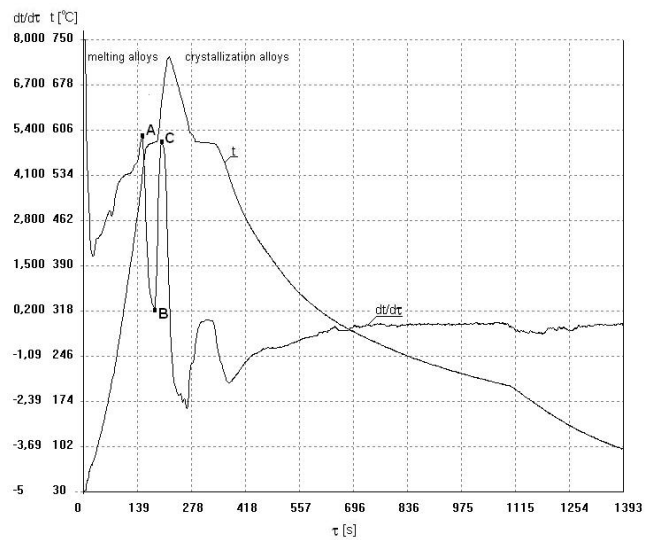


Fig. 3. Curves of ATND method for MgLi12,5 alloy with marked characteristic points for thermal curve: A - 539°C, B - 585°C, C - 662°C

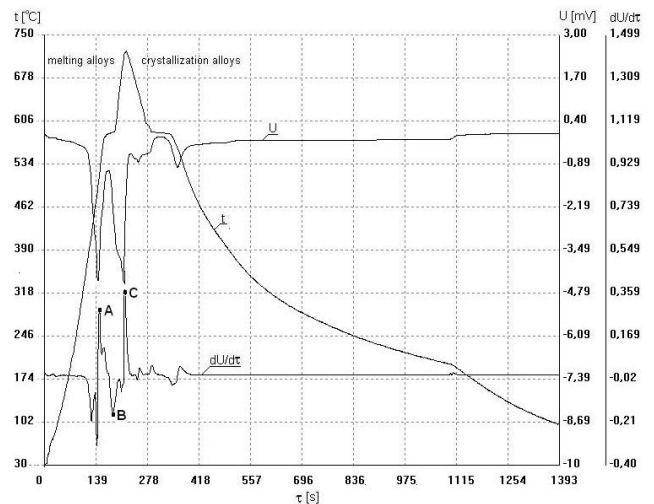


Fig. 4. Thermal and voltage curve for MgLi12,5 alloy with marked characteristic points for voltage curve: A - 496°C, B - 584°C, C - 663°C

4. Conclusions

ATND method can be implemented to registration of heating (melting) and cooling (crystallization) processes of MgLi12,5 alloy, representing physical-chemical phenomena occurring during run of melting and crystallization process of the alloy in form of thermal and voltage curves.

On thermal and voltage curve are present characteristic points, which correspond to temperatures connected with phase transitions of investigated alloy.

Performed investigations have enabled registration of heating (melting) process in aspect of determination of melting temperature of investigated alloy and phase transitions in solid state.

References

- [1] Haferkamp H., Boehm R., Holzkamp U., Jaschik Ch., Kaese V., Niemeyer M. (2001). Alloy Development, Processing and Applications in Magnesium Lithium Alloys. *Materials Transactions*. 42 (7), 1160-1166.
- [2] Wang J. Y., Chen Y. H., Yang Y. L., Lee S. (2005). Microstructures and mechanical behavior of processed Mg-Li-Zn alloy. *Material Science Forum*. 488-489, 465.
- [3] Haibin Ji, Guangchun Yao., Hongbin Li. (2008). Microstructure, cold rolling, heat treatment, and mechanical properties of Mg-Li alloys, *Journal of University of Science and Technology Beijing, Mineral, Metallurgy, Material*. 15 (4), 440-443. DOI: 10.1016/S1005-8850(08)60083-3.
- [4] Kulecki M. K. (2008). Magnesium and its alloys applications in automotive industry. *The International Journal of Advanced Manufacturing Technology*. 39 (9-10), 851-865. DOI: 10.1007/s00170-007-1279-2.
- [5] Friedrich H., Schumann S. (2001). Research for a „new age of magnesium“ in the automotive industry. *Journal of Materials Processing Technology*. 117 (3), 276–281. DOI: 10.1016/S0924-0136(01)00780-4.
- [6] Aghion E., Bronfin B. (2000). Magnesium Alloys Development towards the 21st Century, *Material Science Forum*, 350-351, 19-20. DOI: 10.4028/www.scientific.net/MSF.350-351.19.
- [7] Kainer K., U., Benzler T., U. (2004). Squeeze-Casting and Thixo-Casting of magnesium Alloys. *Magnesium - Alloys and technology*. 56-71. DOI:10.1002/3527602046.ch4.
- [8] Białobrzeski A., Pezda J. (2011). Registration of melting and crystallization process of synthetic MgLi_{3,5} alloy with use of ATND method. *Archives of Foundry Engineering*. 7 (3), 17-20.
- [9] Singh R. K. (1994). Ductility troughs in Mg-Li alloys. *Journal of Materials Science Letters*. 13 (10), 744-745. DOI: 10.1007/BF00461390.
- [10] Massalski T. B., Murray J. L., Benett L. H., Baker H. (1990). *Binary Alloy Phase Diagrams*. American Society for Metals.
- [11] Gasior W.; Moser Z.; Zakulski W.; Schwitzgebel G. (1996). Thermodynamic studies and the phase diagram of the Li-Mg system. *Metallurgical and Materials Transactions A*. 27 (9), 2419-2428. DOI: 10.1007/BF02652335.
- [12] Dong H., Wang L., Wu Y., Wang L. (2011). Preparation and characterization of Mg-6Li and Mg-6Li-1Y alloys. *Journal of Rare Earths*. 29 (7), 645–649. DOI: 10.1016/S1002-0721(10)60514-5.
- [13] Rudajevová A., Lukáč P., Kúdela S. (2005). Thermal Properties of Mg-Li and Mg-Li-Al Alloys. *Magnesium: Proceedings of the 6th International Conference Magnesium Alloys and Their Applications*. 106-109. DOI: 10.1002/3527603565.ch15.
- [14] Żydek A., Kamiński J., K.N. Braszczyńska-Malik K. N. (2011). Evolution of Mg-5Al-0.4Mn microstructure after rare earth elements addition. *Archives of Foundry Engineering*. 11 (2), 157-160.
- [15] Oniszczyk A., Rządkosz S., Wójcik A., Cieślak W. (2007). Iron presence in the technology of Mg-Al casting. *Archives of Foundry Engineering*. 7 (2), 19-24.
- [16] Rzychoń T., Kielbas A., Szala J. (2007). Microstructure and quantitative analysis of cast ZRE1 magnesium alloy. *Archives of Foundry Engineering*. 7 (1), 175-178.
- [17] Dobrzański L. A., Król M. (2010). Thermal and mechanical characteristics of cast Mg-Al-Zn alloy. *Archives of Foundry Engineering*. 10 (1), 27-30.
- [18] Gu X.N., Zheng W., Cheng Y., Zheng Y. F. (2009). A study on alkaline heat treated Mg-Ca alloy for the control of the biocorrosion rate. *Acta Biomaterialia*. 5 (7), 2790-2799. DOI: 10.1016/j.actbio.2009.01.048.
- [19] Liu B., Zhang M., Wu R. (2007). Influence of Ce on microstructure and mechanical properties of LA141 alloys. *Transaction of Nonferrous Metals Society of China*. 17, 376-380.
- [20] Drozd Z, Trojanova Z, Kudela S. (2004). Deformation behavior of Mg-Li-Al alloys. *Journal of Alloys and Compounds*. 378 (1-2), 192–195.
- [21] Sivakesavam O., Prasad Y. V. R. K. (2002). Characteristics of superplasticity domain in the processing map for working of as-cast Mg-11.5Li-1.5Al alloy. *Materials Science and Engineering: A*, 323 (1-2), 270–277. DOI: 10.1016/S0921-5093(01)01392-2.
- [22] Górný Z., Sobczak J.(2005). *Advanced cast materials based on non-ferrous metals*. Krakow: ZA-PIS.
- [23] Zhang M., Wu R., Wang T., Liu B., Niu Z. (2007). Microstructure and mechanical properties of Mg-xLi-3Al-1Ce alloys. *Transaction of Nonferrous Metals Society of China*. 17, 381-384.
- [24] Wasilewski P. (1993). *Silumins – Modification and its impact on structure and properties*. Katowice: PAN Solidification of metals and alloys, Zeszyt 21, Monografia.
- [25] Pietrowski S. (2001). *Silumins*. Łódź. Technical University Editorial. (in Polish).
- [26] Białobrzeski A., Pezda J., Ciucka T. (2007). Registration of crystallization process of ultra-lightweight Mg-Li alloys with use of ATND method. *Archives of Foundry Engineering*, 7 (3), 17-20.
- [27] Białobrzeski A., Saja K. (2011). Experimental stand for melting and casting of ultralight Mg-Li alloys. *Archives of Foundry Engineering*. 11 (3), 17-20.