CRYSTALLIZATION OF ULTRA-LIGHT ALLOYS ON BASE OF MAGNESIUM AND LITHIUM

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S u m m a r y

The paper presents the results of research relating to the registration of crystallization process of lightweight magnesium alloys based of ATND method. Investigated magnesium alloys containing about 8% Li have been produced in the Foundry Research Institute. Melting and crystallization curves for two selected alloys (MgLi8Al4 and MgLi8Ca5) are included in graphical form. Moreover, microstructures for the investigated alloys poured into metallic mould are presented.

Keywords: crystallization, magnesium alloys, ATND

Krystalizacja ultralekkich stopów magnezu i litu

S t r e s z c z e n i e

W artykule przedstawiono badania procesu krystalizacji stopów magnezu metody Analizy Termiczno-Napięciowo-Derywacyjnej (ATND). Stosowano stopy magnezu o zawartości Li ok. 8% oraz Al 4% lub 5%. Przeprowadzono analizę krzywych topienia i krystalizacji oraz badania mikrostruktury stopów MGLi8Al4 i MgLi8Ca5 odlewanych do formy metalowej.

Słowa kluczowe: krystalizacja, stopy magnezu, ATND

1. Introduction

Magnesium alloys feature very advantageous properties, which predispose them to manufacturing of products having wide applications in technology. Magnesium alloys with lithium belong to so called ultra-light alloys. Their density with maximal contents of the lithium (14-16% mass) met today, which amounts to 1,35-1,45 g/cm^3, is not too much higher than density of water (~1,0 g/cm^3). Castings from magnesium alloys are about 20-30% lighter than castings from aluminum alloys, and 50-75% lighter than castings from iron alloys. Magnesium alloys can be characterized by advantageous ratio of strength and/or modulus of elasticity to density, i.e. are able to transmit static and dynamic loads similar to iron and aluminum alloys, they feature good vibration damping, are corrosion resistant (provided that iron, nickel and copper

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impurities are restricted), and moreover, are resistant to changeable mechanical loads, also in conditions of elevated temperature.

Components from magnesium alloy are usually produced in various casting processes. The most applicable methods are high-pressure die casting (90% cast) and gravity casting, particularly sand and permanent mould casting. Other implemented production technologies are: Squeeze Casting, Thixocasting and Thixomolding [1-2].

Standards and other environmental legislation concerning environment protection cause that majority of car producers are going to use in future models 40-100 kg of magnesium alloys [3-5]. For instance, usage of 72 kg of magnesium alloys for components like engine block, four road wheel rims, gearbox housing, engine cradle and oil pan can reduce 48,5 kg in case of substituting for aluminum. In terms of CO_2 emission, it means that replacement of steel in this example will result in fuel saving of 0,25 l per 100 km, and in case of substituting for aluminum fuel saving will be about 0,1 l per 100 km [5].

The Mg-Li alloys were first produced in 1960s by NASA for utilization in aerospace fields. Several parts on Apollo aerospace plane are also made from LA141 alloy LA141 [6].

In the recent years an enormous growth of interest in magnesium and lithium alloys with Al, Cd, Zn and Ag alloying additives can be observed. Solubility of lithium in magnesium with hexagonal structure is low and amounts to about 5%, whereas magnesium forms a wide range of β solid solution, dissolving in lithium with regular structure, spatially centered up to 90% [7].

Adding Al to Mg-Li alloys effects in occurrence of ductile λ phase (constituting solid solution of Al in Li and having regular spatially centered lattice) and hard, enabling precipitation hardening, inter-crystalline AlLi compound of η phase with B2 structure, within hexagonal structure of δ phase (constituting solid solution of Al in Mg with limited formability). Ductility of such alloys increases with growth of portion of $\delta + \lambda$ eutectic mixture. Sometimes, in the alloys unstable Li_2MgAl phase is present [8].

Obtaining the best material structure for specific requirements becomes possible with making use of theories on crystallization to control technological processes [9, 10]. Registration of phenomena arisen in result of solidification process of alloys in order to determine their properties is enabled by 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) [11-13].

Registration of heating (melting) and crystallization processes of alloys on base of magnesium and lithium with use of the ATND method was the objective of performed investigations.

2. Research methodology

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 [14]. In the Fig. 1 is shown a scheme of the ATND method measuring stand.

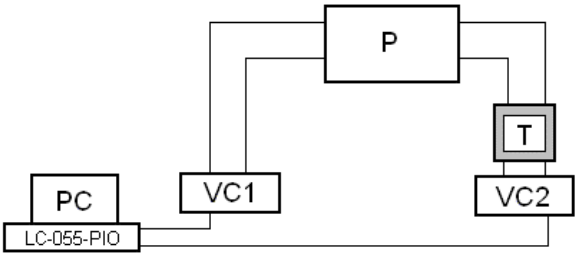

Fig. 1. Scheme of the ATND method stand: PC computer with measuring block, VC1 – digital voltmeter (voltage drop), VC2 – digital voltmeter (drop of SEM on thermocouple), T – vacuum bottle (about. 0^oC), P – silit furnace

The following alloys were used in course of crystallization process tests: MgLi8Al4 (7.57% Li, 4.4% Al) and MgLi8Ca5 (8.2% Li, 4.7% Ca). Investigated alloys were obtained from pure constituents and were cast in Krakow Foundry Institute on experimental stand for melting and pouring of ultra lightweight alloys [15]. Microstructural examination was performed on NEOPHOT 32 microscope.

Suitably prepared specimens of the alloy were melted in tubular silit furnace with CO_2 protective atmosphere. In course of melting and crystallization of the alloys there occurred permanent, simultaneous registration of specimen's temperature and potential's difference on measuring probes.

In the Fig. 2 is presented a view of the test stand used to registration of crystallization process with use of the ATND method.

3. Research results and their analysis

3.1. MgLi8Al4 alloy

MgLi8Al4 alloy belongs to diphase alloys, consisting of α phase (solid solution of magnesium with lithium and aluminum) and β phase (solid solution of lithium with magnesium and aluminum). In the Fig. 3 is shown a micro-

structure of the MgLi8Al4 alloy cast into metallic mould. Run of heating (melting) and crystallization process of the MgLi8Al4 alloy is shown in the Fig. 4.

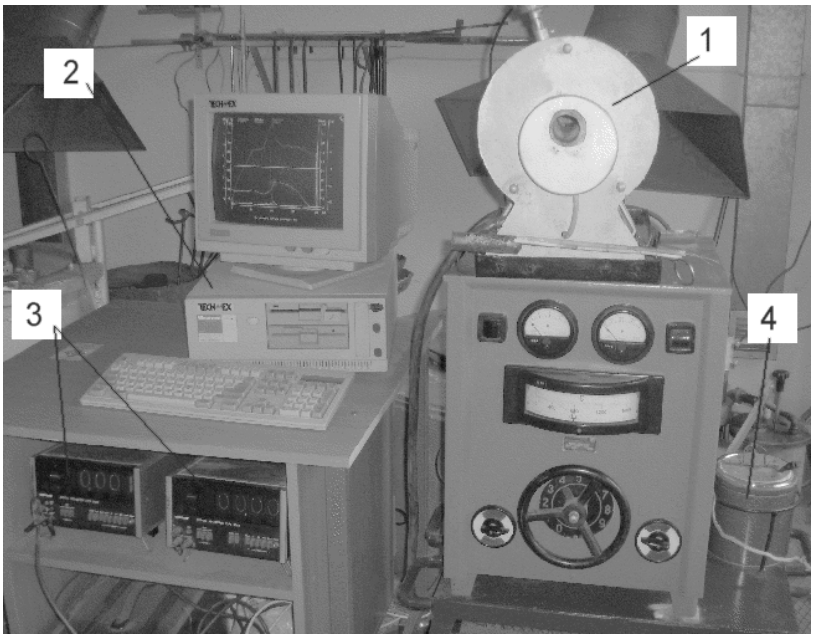

Fig. 2. Test stand: 1 – silit-type tubular furnace, 2 – computer with measuring block, 3 – micro-voltmeters, 4 – thermo bottle

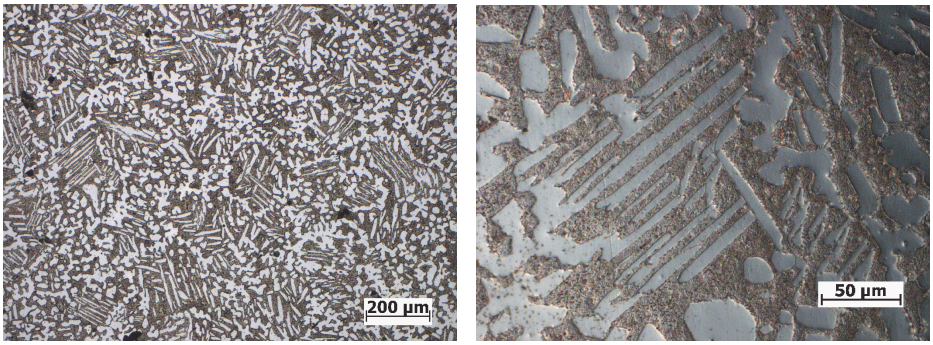

Fig. 3. Microstructure of MgLi8Al4 alloy

In the Fig. 5 is presented run of the MgLi8Al4 alloy melting process with marked characteristic points corresponding to melting temperatures. Fig. 6

concerns registered run of the crystallization process and temperatures related to this process.

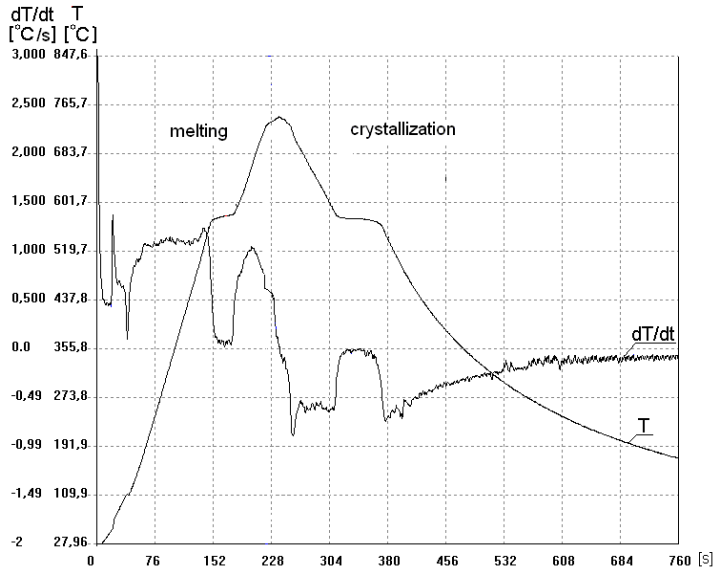

Fig. 4. Curves of ATND melting and crystallization of the MgLi8Al4 alloy

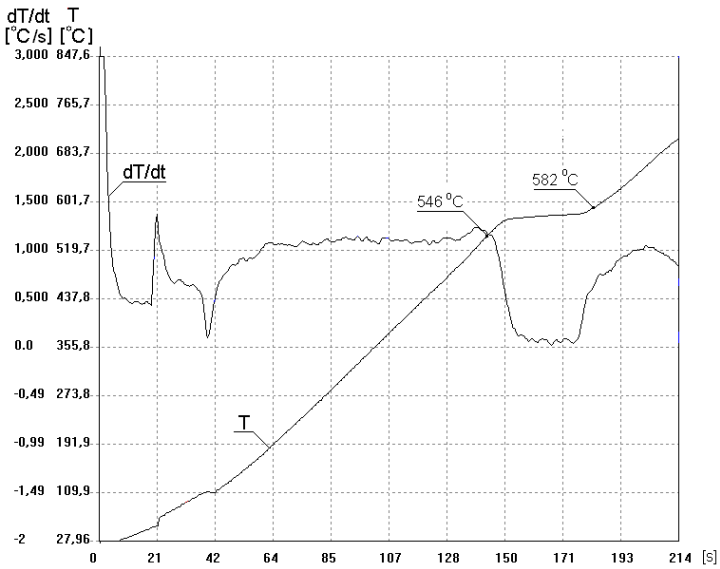

Fig. 5. Curves of the ATND method showing heating (melting) of the MgLi8Al4 alloy

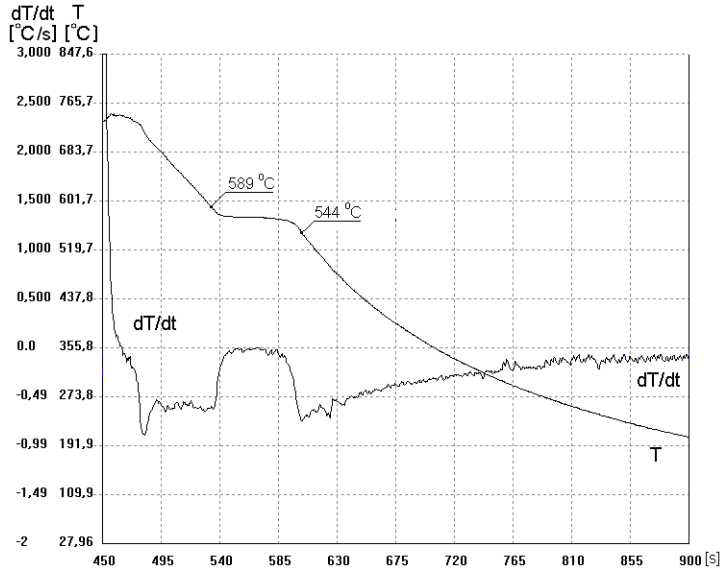

Fig. 6. Curves of the ATND method showing crystallization of the MgLi8Al4 alloy

Analysis of curves obtained from the ATND method enabled for the MgLi8Al4 alloy determination of temperatures (Fig. 5, Fig. 6):

- beginning of melting of the alloy: 546°C,
- completion of melting of the alloy: 582°C,
- beginning of crystallization of the alloy: 589°C,
- completion of crystallization of the alloy: 544°C.

3.2. MgLi8Ca5 alloy

In microstructure of the MgLi8Ca5 alloy 2 phases are present: solid solution and eutectic mixture. Solid solution of magnesium with lithium is the β phase. Eutectic mixture is composed from plates of hexagonal $CaMg_2$ phase and plates of magnesium, probably with hexagonal structure. In the Fig. 7 is shown a microstructure of the MgLi8Ca5 alloy cast into metallic mould.

Run of heating (melting) and crystallization of the MgLi8Ca5 alloy, registered with the ATND method is shown in the Fig. 8.

In the Fig. 9 is presented run of the MgLi8Ca5 alloy melting process with marked characteristic points corresponding to melting temperatures. The Fig. 10 concerns registered run of the crystallization process and temperatures related to this process.

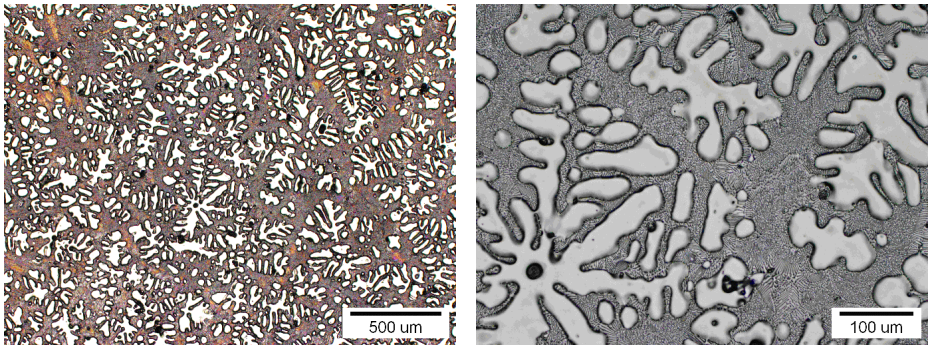

Fig. 7. Microstructure of MgLi8Ca5 alloy

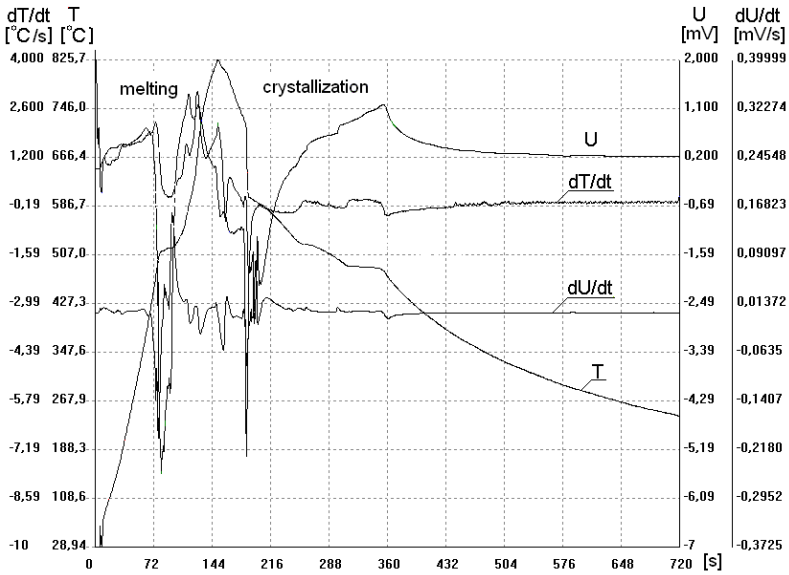

Fig. 8. Curves of ATND melting and crystallization of the MgLi8Ca5 alloy

Analysis of the obtained diagrams (Fig. 9, Fig. 10) has enabled to specify temperatures of:

- beginning of melting of the alloy: 492°C,
- completion of melting of the alloy: 570°C,
- beginning of crystallization of the alloy: 523°C,
- completion of crystallization of the alloy: 473°C.

Differences seen in run of registered curves of the ATND method and in specified temperatures of melting and crystallization of the investigated alloys are related directly to their microstructure and their phase constituents.

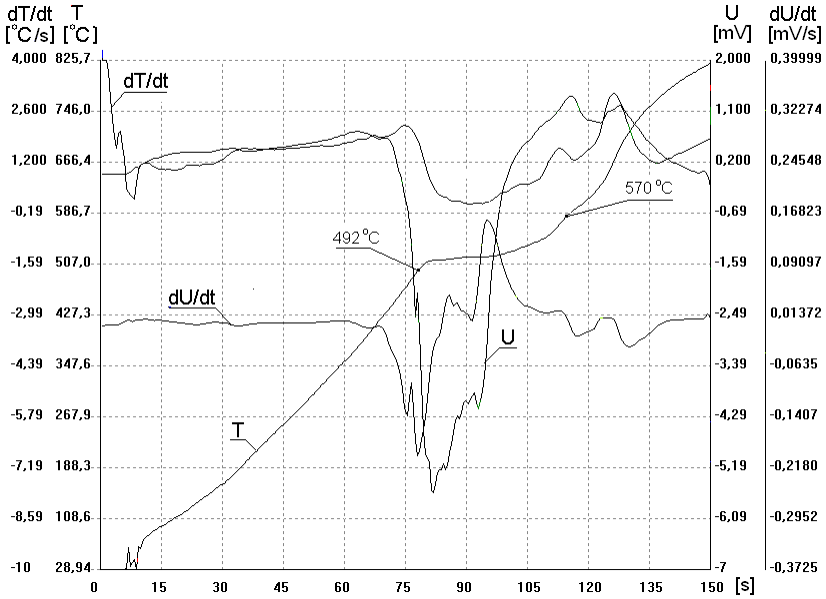

Fig. 9. Curves of the ATND method showing heating (melting) of the MgLi8Ca5 alloy

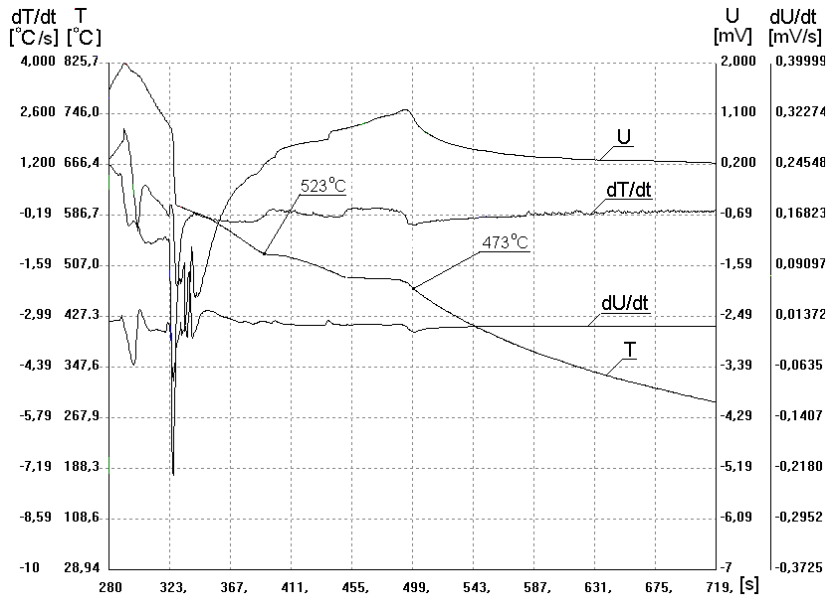

Fig. 10. Curves of the ATND method showing crystallization of the MgLi8Ca5 alloy

4. Conclusions

On base of obtained preliminary test results it has been stated that the ATND method:

- can be implemented to registration of heating, melting and cooling processes (crystallization) of Mg-Li alloys,
- represents, in form of thermal and voltage curves, a physical-chemical phenomena occurring in course of melting and crystallization processes of alloys.

In the ATND method, thermal and voltage curves show at physical-chemical phenomena occurring during melting and crystallization of the alloy. Performed tests has enabled determination of melting and crystallization temperatures of the investigated alloys.

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