Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 32
ISSUE 2
February
2009

# Selection of heat treatment condition of the Mg-Al-Zn alloys

**L.A. Dobrzański [a,*], T. Tański [a], L. Čížek [b], J. Madejski [a]**
[a] Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
[b] Faculty of Metallurgy and Materials Engineering, Technical University of Ostrava, Tř.17 Listopadu 15, 708 33 Ostrava, Czech Republic
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

Received 05.01.2009; published in revised form 01.02.2009

Manufacturing and processing

## ABSTRACT

**Purpose:** Main aim of this paper are results of the optimization of heat treatment conditions, which are temperature and heating time during solution heat treatment or ageing as well the cooling rate after solution treatment for MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 cast magnesium alloys.
**Design/methodology/approach:** The following results concern mechanical properties especially hardness.
**Findings:** The different heat treatment kinds employed contributed to the improvement of mechanical properties of the alloy.
**Research limitations/implications:** According to the alloys characteristic, the applied cooling rate and alloy additions seems to be a good compromise for mechanical properties, nevertheless further tests should be carried out in order to examine different cooling rates and parameters of solution treatment process and aging process.
**Practical implications:** Generally magnesium alloys are applied in motor industry and machine building, but they find application in a helicopter production, planes, disc scanners, a mobile telephony, computers, bicycle elements, household and office equipment, radio engineering and an air - navigation, in chemical, power, textile and nuclear industrial, etc.
**Originality/value:** Contemporary materials should possess high mechanical properties, physical and chemical, as well as technological ones, to ensure long and reliable use. The above mentioned requirements and expectations regarding the contemporary materials are met by the non-ferrous metals alloys used nowadays, including the magnesium alloys.
**Keywords:** Heat treatment; Magnesium alloys; Mechanical properties

**Reference to this paper should be given in the following way:**
L.A. Dobrzański, T. Tański, L. Čížek, J. Madejski, Selection of heat treatment condition of the Mg-Al-Zn alloys, Journal of Achievements in Materials and Manufacturing Engineering 32/2 (2009) 203-210.

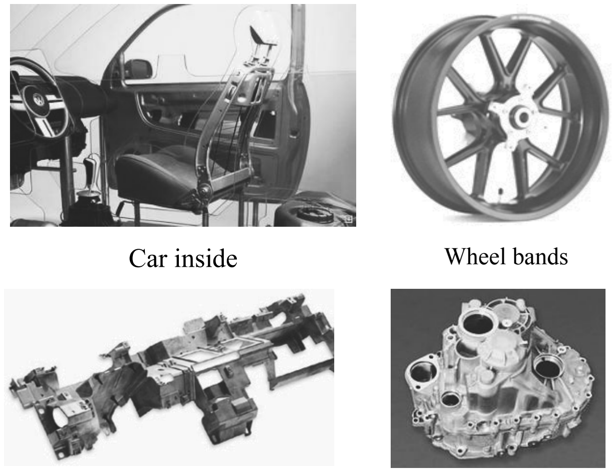
## 1. Introduction

A contemporary technological development makes it necessary to look for new constructional solutions that aim at the improvement of the effectiveness and quality of a product, at the minimization of dimension and mass as well as the increasing of reliability and dimension stability in the operation conditions. For a dozen or so years one can observe a rising interest in the non-ferrous metals alloys including magnesium alloys. The dynamic industrial development puts some higher and higher demands to the present elements and constructions. These demands belong production and research newer and newer materials for materials engineering materials with relation to predictable work conditions and arise needs. Magnesium alloys gets a huge importance with present demands for light and reliable construction [1-11].

Magnesium alloys have low density and other benefits such as: a good vibration damping and the best from among all construction materials: high dimension stability, small casting shrinkage, connection of low density and huge strength with reference to small mass, possibility to have application in machines and with ease to put recycling process, which makes possibility to logging derivative alloys a very similar quality to original material [12, 13, 16-18, 28-31].

A desire to create as light vehicle constructions as possible and connected with it low fuel consumption have made it possible to make use of magnesium alloys as a constructional material in car wheels, engine pistons, gear box and clutch housings, skeletons of sunroofs, framing of doors, pedals, suction channels, manifolds, housings of propeller shafts, differential gears, brackets, radiators and others (Table 1) [6-11].

A number of companies as well as the use of magnesium and its alloys are still growing. Products made of magnesium and its alloys are still relatively expensive, however customers get high quality products, advanced both in technology and functionality. Generally they are applied in motor industry and machine building, but they find application in a helicopter production, planes, disc scanners, a mobile telephony, computers, bicycle elements, household and office equipment, radio engineering and an air - navigation, in chemical, power, textile and nuclear industrial (Fig. 1) [14, 15, 19-27].



Car inside Wheel bands

Dashboards Housing of the gearbox

Fig. 1. Elements from magnesium alloys [1-11]

Table 1.
The examples of applications magnesium alloys [1-13, 28-31]

| Industry | Products | Required Properties | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lightness | Strength | Ductility | Vibration damping | Heat resistance | Heat dissipation | EMI shielding | Recyclable | Dimensional precision | Thin-wall molding |
| Auto-mobiles | Seat frames | • | • | • | • | | | | • | • | • |
| | Steering wheels | • | • | • | • | | | | • | • | |
| | Road wheel | • | • | • | | | | | • | • | |
| | Oil pumps | • | • | | | | | | • | | |
| | Key lock housing | • | • | | | | | | • | • | |
| | Transmission parts | • | • | | • | | | | • | • | • |
| | Navigation system parts | | • | | | • | | • | • | • | • |
| Electronic equipment<br>Office equipment<br>Communi-cations | Cameras | • | • | | | | | | • | • | • |
| | Video cameras | • | • | | | | • | • | • | • | • |
| | Digital cameras | • | • | | | | | • | • | • | • |
| | Minidisk players | • | • | | | | | • | • | • | • |
| | (Personal Data Assistant parts | • | • | | | | • | • | • | • | • |
| | Notebook type PC | • | • | | | | • | • | • | • | • |
| | Hard disk drives | • | • | | | | | • | • | • | |
| | CD-ROM drives | • | • | | | • | • | | • | • | |
| | Optical pickups | • | • | | | • | • | • | • | • | • |
| | TV monitors | • | • | | | | • | • | • | • | • |
| | Plasma displays | • | • | | | • | • | • | • | • | • |
| | LCD projectors | • | | | | • | • | | • | | |
| Others | Power tools | • | • | • | | | | | • | • | |
| | Bicycle wheels | • | • | | | | | | • | | |
| | Fishing gears | • | • | • | | | | | • | • | |

The rising tendencies of magnesium alloy production, show increased need of their application in world industry and what follows the magnesium alloys become one of the most often apply construction material our century. The goal of this paper is presentation of the investigation results of the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 casting magnesium alloy in its as-cast state and after heat treatment.

## 2. Experimental procedure

The investigations have been carried out on test pieces of MCMgAl12Zn1 (Table 2, No. 1), MCMgAl9Zn (Table 2, No.2), MCMgAl6Zn (Table 2, No. 3), MCMgAl3Zn (Table 2, No. 4) magnesium alloys in as-cast and after heat treatment states made in cooperation with the Faculty of Metallurgy and Materials Engineering of the Technical University of Ostrava and the CKD Motory plant, Hradec Kralove in the Czech Republic. The chemical composition of the investigated materials is given in Table 2. A casting cycle of alloys has been carried out in an induction crucible furnace using a protective salt bath *Flux 12* equipped with two ceramic filters at the melting temperature of 750±10ºC, suitable for the manufactured material. In order to maintain a metallurgical purity of the melting metal, a refining with a neutral gas with the industrial name of *Emgesalem Flux 12* has been carried out. To improve the quality of a metal surface a protective layer *Alkon M62* has been applied. The material has been cast in dies with betonite binder because of its excellent sorption properties and shaped into plates of 250x150x25 mm. The cast alloys have been heated in an electrical vacuum furnace *Classic 0816 Vak* in a protective argon atmosphere.

Table 2.
Chemical composition of investigation alloy

| The mass concentration of main elements, % | | | | | | | |
|---|---|---|---|---|---|---|---|
| No. | Al | Zn | Mn | Si | Fe | Mg | Rest |
| 1 | 12.1 | 0.62 | 0.17 | 0.047 | 0.013 | 86.96 | 0.0985 |
| 2 | 9.09 | 0.77 | 0.21 | 0.037 | 0.011 | 89.79 | 0.0915 |
| 3 | 5.92 | 0.49 | 0.15 | 0.037 | 0.007 | 93.33 | 0.0613 |
| 4 | 2.96 | 0.23 | 0.09 | 0.029 | 0.006 | 96.65 | 0.0361 |

The optimization of the heat treatment ie. the temperature and time of heating during the solution heat treatment and ageing and the cooling rate after the solutioning, has been carried out based on the hardness test including, in all, a few dozen of possible combinations. The optimization has been used to work out the methodology of material designing of the most favorable physical and mechanical properties of the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1 and MCMgAl3Zn1 alloys. The solution heat treatment (water, air, furnace) for the examined materials has been carried out in the temperatures of 400, 415 and 430°C in the time of 10, 20 and 30 hours. Whereas after solutioning in the water, the ageing has been made together with air cooling in the ranges of temperatures from 150 to 210 every 20°C and in times of 5, 10 and 15 hours. For each specimen, five tests have been done respectively and the arithmetic mean calculated, receiving 27 cases of the mean hardness for each of the alloys after the solution heat treatment and 108 cases after the ageing. The obtained matrix included altogether 540 cases of the mean values, gained from the hardness tests for the after solution heat treatment and ageing states (Figs. 2-6).

## 3. Discussion of experimental results

On the basis of the hardness tests one has stated that the changes of the temperature in ranges between 400 and 430°C, as well as the changes of the solution heat treatment time of between 10 and 30 hours, do not significantly influence the diversification of hardness of the particular alloys, as the revealed differences of measurements change in the range of the permissible error.

The increase of the aluminum concentration in the alloys from 3 to 12 % has caused the increase of the mean hardness of the specimen after the solution heat treatment with the furnace cooling up to 49.5 HRF, water cooling – to 32.6 HRF and air cooling – to 41.9 HRF. The highest hardness values, measured for the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1 alloys, have been obtained for the specimen after the solution heat treatment with furnace cooling, as well as the water-cooled specimen for the MCMgAl3Zn1 material.

The carried out ageing after the water solution heat treatment of the specimen of the MCMgAl12Zn1, MCMgAl9Zn1, MCMgAl6Zn1, MCMgAl3Zn1 magnesium cast alloys has influenced the increase of hardness, depending both on the temperature and time of the solutioning as well as the temperature and the ageing time.

The highest hardness values have been obtained for the specimen exposed to solutioning in the temperature of 430°C for 10hrs and ageing in 190°C for 15 hours. It has also been stated that the application of the precipitation hardening for the magnesium cast alloys with the aluminium concentration of 6% - MCMgAl6Zn1, MCMgAl3Zn1, causes a small increase of the mechanical properties. The highest difference of the mean hardness – 19.8 HRF in relation to the state after the water solution heat treatment has been obtained for the MCMgAl12Zn1 alloys.

The above obtained results, explicitly show that the most beneficial kind of the heat treatment both in terms of the optimum working conditions and the time and energy used for carrying out the solutiong and ageing, as well as getting the most advantageous mechanical properties, is the solution heat treatment in the temperature of 430°C for 10 hours and ageing in the temperature of 190°C for 15 hours (Tables 3, 4).

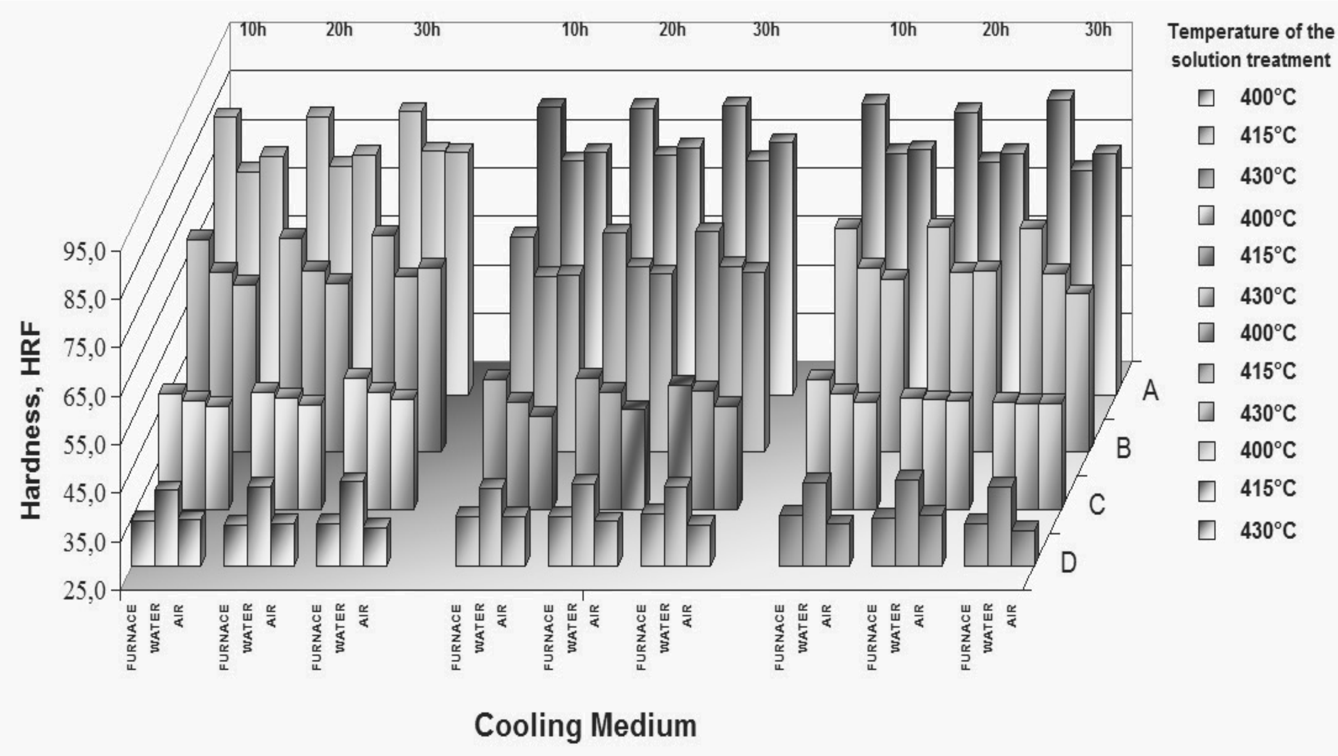



Fig. 2. Average hardness values for the cast magnesium alloys after solution treatment: A) MCMgAl12Zn1, B) MCMgAl9Zn1, C) MCMgAl6Zn1, D) MCMgAl3Zn1

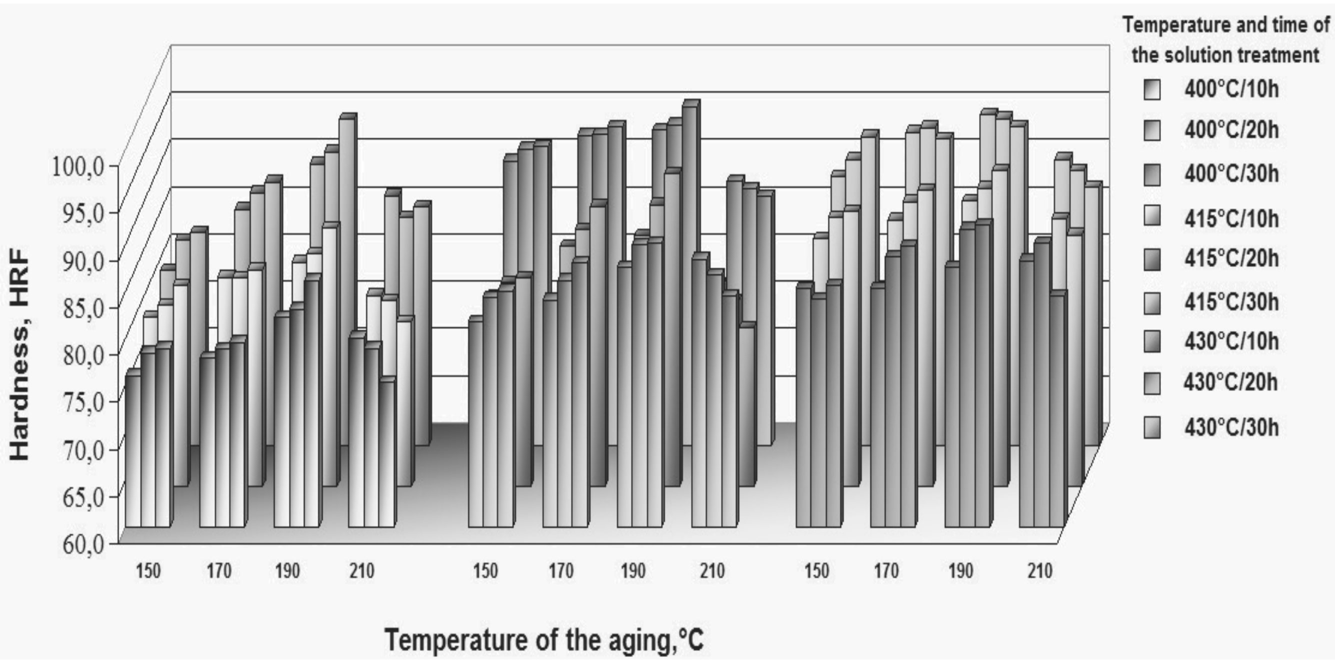



Fig. 3. Average hardness values for the cast magnesium alloys MCMgAl12Zn1 after ageing for 5, 10 and 15 hours at a temperature from 150 to 210°C, in steps of 20°C

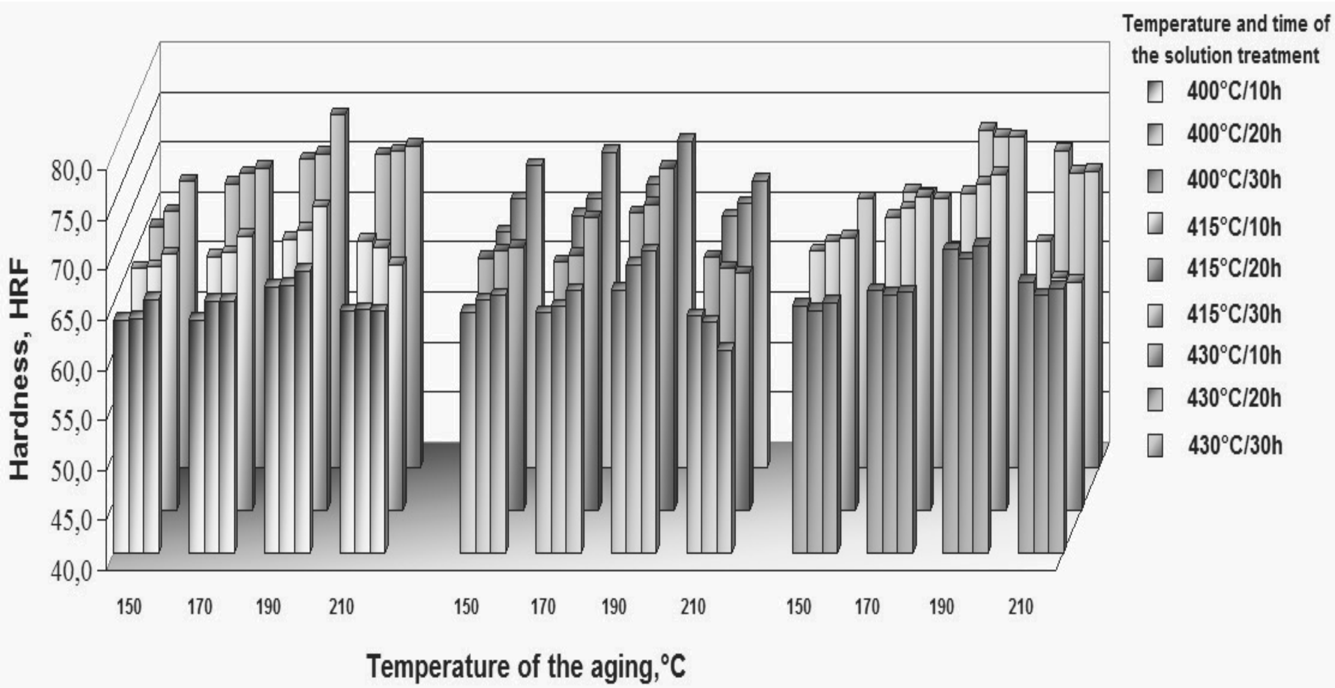



Fig. 4. Average hardness values for the cast magnesium alloys MCMgAl9Zn1 after ageing for 5, 10 and 15 hours at a temperature from 150 to 210°C, in steps of 20°C

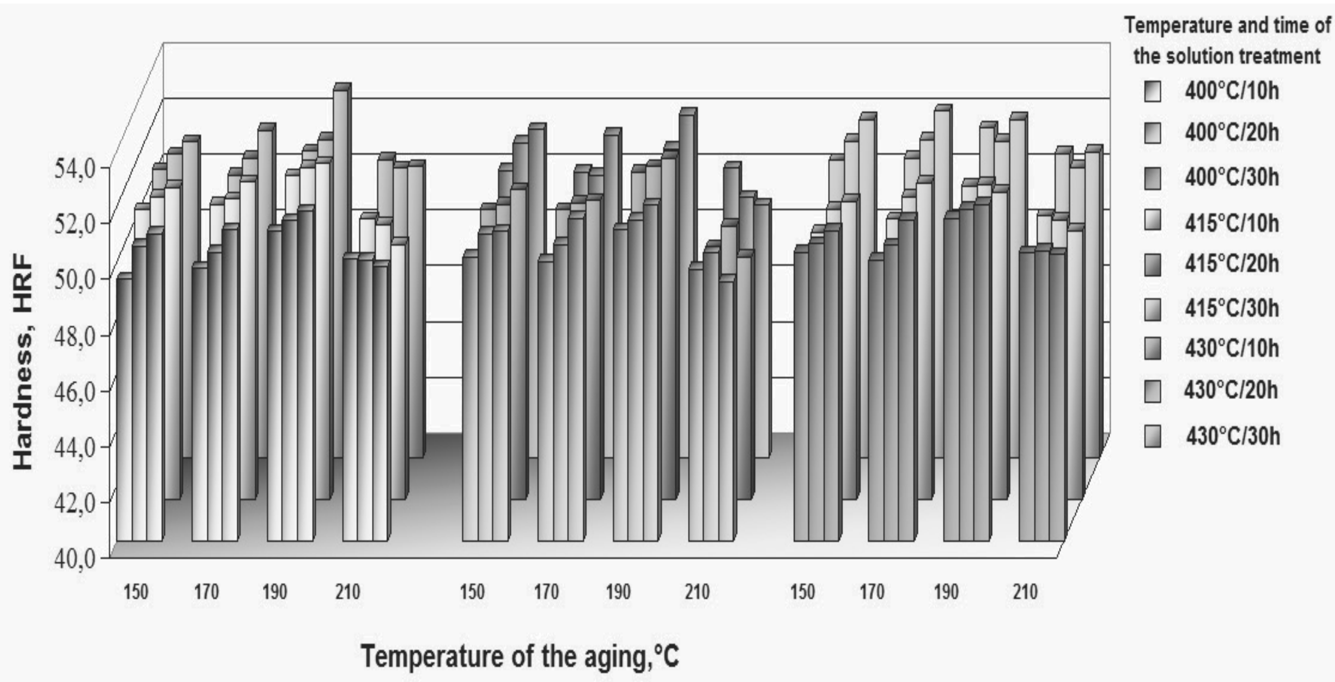



Fig. 5. Average hardness values for the cast magnesium alloys MCMgAl6Zn1 after ageing for 5, 10 and 15 hours at a temperature from 150 to 210°C, in steps of 20°C

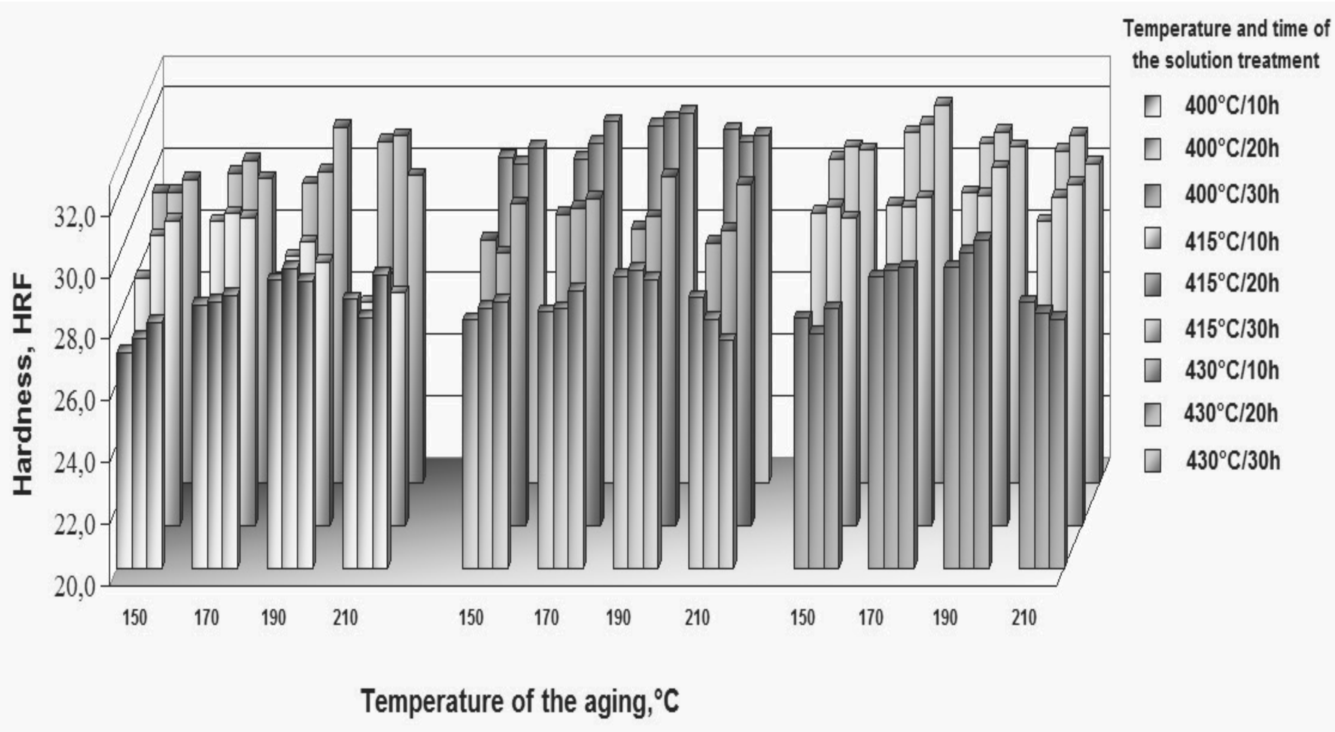



Fig. 6. Average hardness values for the cast magnesium alloys MCMgAl3Zn1 after ageing for 5, 10 and 15 hours at a temperature from 150 to 210°C, in steps of 20°C

Table 3.
Optimal heat treatment parameters of the investigated alloys

| Heat treatment process | Parameters of heat treatment | | |
|---|---|---|---|
| | Temperature, °C | Heating time, h | Cooling method |
| 0 | As-cast | | |
| 1 – solution heat treatment | 430 | 10 | water |
| 2 – solution heat treatment | 430 | 10 | air |
| 3 – solution heat treatment | 430 | 10 | furnace |
| 4 – aging | 190 | 15 | air |

Table 4.
Results of the hardness test

| Hardness. HRF | Heat treatment process | | | | |
|---|---|---|---|---|---|
| | As-cast | Solution heat treatment (water) | Solution heat treatment (air) | Solution heat treatment (furnace) | Aging |
| | | | Alloy MCMgAl12Zn1 | | |
| Arithmetic mean | 75.38 | 74.80 | 75.55 | 85.11 | 94.60 |
| | | | Alloy MCMgAl9Zn1 | | |
| Arithmetic mean | 65.68 | 63.04 | 60.74 | 71.18 | 75.14 |
| | | | Alloy MCMgAl6Zn1 | | |
| Arithmetic mean | 51.94 | 48.88 | 47.20 | 51.84 | 53.20 |
| | | | Alloy MCMgAl3Zn1 | | |
| Arithmetic mean | 30.64 | 40.68 | 33.70 | 35.66 | 31.50 |

## 4. Summary

The selection of optimal heat treatment conditions that is temperature and heating time during solution treatment and ageing as well the cooling rate after solution treatment, was performed using criterion of maximal hardness calculated after the whole heat treatment process – solution treatment and ageing. The above obtained results, explicitly show that the most beneficial kind of the heat treatment both in terms of the optimum working conditions and the time and energy used for carrying out the soluting and ageing, as well as getting the most advantageous mechanical properties, is the solution heat treatment in the temperature of 430°C for 10 hours and ageing in the temperature of 190°C for 15 hours (Figs. 2-6) (Tables 3, 4).

## Acknowledgements

This scientific work is fragmentary financed within the framework of scientific financial resources in the period 2007-2008 as a research and development project R15 0702 headed by Prof. L.A. Dobrzański.

## References

[1] K.U. Kainer, Magnesium – Alloys and Technology, Wiley-VH, Weinheim, Germany, 2003.
[2] E.F. Horst, B.L. Mordike, Magnesium Technology. Metallurgy, Design Data, Application, Springer-Verlag, Berlin-Heidelberg, 2006.
[3] H. Friedrich, S. Schumann, Research for a ”New age of magnesium in the automotive industry”, Journal of Materials Processing Technology 117 (2001) 276-281.
[4] A. Fajkiel, P. Dudek, G. Sęk-Sas, Foundry engineering XXI c. Directions of metallurgy development and light alloys casting, Publishers Institute of Foundry engineering, Cracow, 2002.
[5] X. Ming-Xu, Z. Hong-Xing, Y. Sen, L. Jian-Guo, Recrystallization of preformed AZ91D magnesium alloys in the semisolid state, Materials and Design 26 (2005) 343-349.
[6] L. Čížek, M. Greger, L. Pawlica, L.A. Dobrzański, T. Tański, Study of selected properties of magnesium alloy AZ91 after heat treatment and forming, Journal of Materials Processing Technology 157-158 (2004) 466-471.
[7] L.A. Dobrzański, T. Tański, L. Čížek, Z. Brytan, Structure and properties of the magnesium casting alloys, Journal of Materials Processing Technology 192-193 (2007) 567-574.
[8] L.A. Dobrzański, T. Tański, Influence of aluminium content on behaviour of magnesium cast alloys in bentonite sand mould, Solid State Phenomena 147-149 (2009) 764-769.
[9] L.A. Dobrzański, M. Król, T. Tański, R. Maniara, Thermal analysis of the MCMgAl9Zn1 magnesium alloy, Journal of Achievements in Materials and Manufacturing Engineering 34/2 (2008) 113-116.
[10] L.A. Dobrzański, T. Tański, J. Domagała, M. Król, Sz. Malara, A. Klimpel, Structure and properties of the Mg alloys in as-cast state and after heat and laser treatment, Journal of Achievements in Materials and Manufacturing Engineering 31/2 (2008) 123-147.
[11] L.A. Dobrzański, T. Tański, L. Čížek, J. Domagała, Mechanical properties and wear resistance of magnesium casting alloys, Journal of Achievements in Materials and Manufacturing Engineering 31/1 (2008) 83-90.
[12] C. Yan, L. Ye, Y.W. Mai, Effect of constraint on tensile behavior of an AZ91 magnesium alloy, Materials Letters 58 (2004) 3219-3221.
[13] W. Kasprzak, J.H. Sokołowski, M. Sahoo, L.A. Dobrzański, Thermal characteristic of the AM50 magnesium alloys, Journal of Achievements in Materials and Manufacturing Engineering 29/2 (2008) 179-182.
[14] D. Kuc, E. Hadasik, G. Niewielski, A. Płachta, Strcture and plasticity of the AZ31 magnesium alloy after hot deformation, Journal of Achievements in Materials and Manufacturing Engineering 27/1 (2008) 27-30.
[15] K. Bryła, J. Dutkiewicz, M. Faryna, T.V. Dobatkina, L.L. Rokhlin, The influence of Nd and Ho addition on the microstructure of Mg-7Al alloy, Journal of Archives of Materials Science and Engineering 29/1 (2008) 40-44.
[16] Z. Trojanová, Z. Drozd, P. Lukáč, A. Chatey, Mechanical properties of a squeeze cast Mg-Al.-Sr alloy, Journal of Archives of Materials Science and Engineering 29/2 (2008) 97-104.
[17] N.V. Ravi Kumar, J.J. Blandin, C. Desrayaud, F. Montheillet, M. Suéry, Grain refinement in AZ91 magnesium alloy during thermomechanical processing, Materials and Engineering A 359 (2003) 150-157.
[18] T. Rzychoń, A. Kiełbus, Microstructure of WE43 casting magnesium alloys, Journal of Achievements in Materials and Manufacturing Engineering 21/1 (2007) 31-34.
[19] H. Watanabe, H. Tsutsui, T. Mukai, M. Kohzu, PP. Tanabe, K. Higashi, Deformation mechanism in a coarse-grained Mg-Al-Zn alloy at elevated temperatures, International Journal of Plasticity 17 (2001) 387-397.
[20] W.J. Kim, C.W. An, Y.S Kim, S.I. Hong, Mechanical properties and microstructures of an AZ61 Mg Alloy produced by equal channel angular pressing, Scripta Materialia 47 (2002) 39-44.
[21] P. Venkateswarana, S. Ganesh Sundara Ramana, S.D. Pathaka, Y. Miyashitab, Y. Mutoh, Fatigue crack growth behaviour of a die-cast magnesium alloy AZ91D, Materials Letters 58 (2004) 2525-2529.
[22] Y. Guangyin, L. Manping, D.Wenjiang, A. Inoue, Microstructure and mechanical properties of Mg-Zn-Si based alloys, Materials Science and Engineering A 357 (2003) 314-320.
[23] Z. Koren, H. Rosenson, E.M. Gutman, Ya. Unigovski, A. Eliezer, Development of semisolid casting for AZ91 and AM50 magnesium alloys, Journal of Light Metals 2 (2002) 81-87.
[24] S. Lun Sin, D. Dubé, Influence of process parameters on fluidity of investment-cast AZ91D magnesium alloy, Materials Science and Engineering A 386 (2004) 34-42.
[25] K. Suseelan Nair, M.C. Mittal, K. Lal, R.K. Mahanti, C.S. Sivaramakrishnan, Development of rapidly solidified (RS) magnesium–aluminium–zinc alloy, Materials Science and Engineering A 304-306 (2001) 520-523.

[26] B. Bieri, P.J. Uggowitzer, M.O. Speidel, T. Imwinkelried, J. Lagemann, J.P. Gabathuler, Influence of process parameters on the microstructure and the mechanical properties of thixoformed plates, Proceedings of the Scientific International Conference "Semi-Solid Processing of Alloys and Composites", 1998, 530-537.
[27] K. Iwanaga, H. Tashiro, H. Okamoto, K. Shimizu, Improvement of formability from room temperature to warm temperature in AZ31 magnesium alloy, Journal of Materials Processing Technology 155-156 (2004) 1313-1316.
[28] M. Greger, R. Kocich, L. Čížek, L.A. Dobrzański, I. Juřička, Possibilities of mechanical properties and microstructure improvement of magnesium alloys, Archives of Materials Science and Engineering 28/2 (2007) 83-90.
[29] T. Tański, L.A. Dobrzański, L. Čížek, Influence of heat treatment on structure and properties of the cast magnesium alloys, Journal of Advanced Materials Research 15-17 (2007) 491-496.
[30] L. Jina, D. Lina, D. Maoa, X. Zenga, W. Dinga, Mechanical properties and microstructure of AZ31 Mg alloy processed by two-step equal channel angular extrusion, Materials Letters 59 (2005) 2267-2270.
[31] B.L. Mordike, T. Ebert, Magnesium. Properties-applications-potential, Materials Science and Engineering A 302/1 (2001) 37-45.