Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 24 ISSUE 2 October 2007

# Fracture analysis of selected magnesium alloys after different testing methods

**L. Čížek [a,*], M. Greger [a], L.A. Dobrzański [b], R. Kocich [a], T. Tański [b], M. Praźmowski [c]**
[a] VŠB-Technical University of Ostrava, 17.listopadu 15, 708 33 Ostrava, Czech Republic
[b] 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
[c] Opole University of Technology, ul. S.Mikolajczyka 5, 45-271 Opole, Poland
* Corresponding author: E-mail address: lubomir.cizek@vsb.cz

Received 20.03.2007; published in revised form 01.10.2007

Methodology of research

## ABSTRACT

**Purpose:** of this paper is to extend a complex evaluation of magnesium alloys which requires very often knowledge mechanical properties. These properties are connected with microstructure that is influenced by metallurgical and technological factors and conditions of exploitation. Very important information for design and exploitation of these alloys is knowledge of fracture characteristics.

**Design/methodology/approach:** Testing methods used magnesium alloys were based on tensile test and torsion test. The methods of the light microscopy and SEM for metallographic and fracture analyses of alloys after testing were used.

**Findings:** Objective of this work consisted in determination of changes of mechanical properties and fracture characteristics of magnesium alloy in dependence on testing methods. Mg-Al alloy with graduate aluminium content as cast state and after heat treatment was used. It was confirmed that during heating at chosen temperatures there occurs partial dissolution of minority phases.

**Research limitations/implications:** According to the alloys characteristic, the applied cooling rate and alloy additions seems to be a good compromise for mechanical properties and microstructures, 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:** The results may be utilized for a relation between plastic and strength properties of the investigated material in process of research and manufacturing

**Originality/value:** These results contribute to complex evaluation of properties magnesium alloys namely for explanation of fracture mechanism in changing condition of testing and exploitation. The results of this paper are determined for research workers deal by development new exploitations of magnesium alloys.

**Keywords:** Mechanical properties; Magnesium alloys; Tensile and torsion tests; Fracture characteristics

## 1. Introduction

Magnesium alloys and their derivatives, alike materials from the lightweight and ultra-lightweight family, characterize of low density 1.5-1.8 g/cm$^3$) and high strength in relation to their weight [1–4]. Apart from the commonly used Mg binary alloys, ternary alloys (eg. Mg-Al-Zn, Mg-Al-Si) are very widely used, as well as their more complex ones [1–11]. Magnesium alloys, which are produced, often are fill in them, especially in fewer reliable construction.

The properties of magnesium alloys are connected with microstructure that is influenced by metallurgical and

Table 1.
Chemical composition of alloys

| Alloy | weight [%] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Al | Zn | Mn | Si | Cu | Fe | Be | Zr | Sn | Ni | Pb |
| A-AZ91 | 8,95 | 0,76 | 0,21 | 0,041 | 0,003 | 0,008 | 0,0005 | 0,003 | 0,01 | 0,003 | 0,059 |
| B-AZ61 | 5,92 | 0,49 | 0,15 | 0,037 | 0,003 | 0,007 | 0,0003 | 0,003 | 0,01 | 0,003 | 0,034 |
| C-AZ31 | 2,96 | 0,23 | 0,09 | 0,029 | 0,002 | 0,006 | 0,0001 | 0,003 | 0,01 | 0,002 | 0,013 |

technological aspects. Recently, however, increases also utilisation of formed magnesium alloys [11-16].

The experimental part study fracture characteristics of magnesium alloys with graduated aluminum content in dependence of used testing methods.

## 2. Materials and experimental methods

Experimental investigation was made with use of cast plates (size 10x20x150 mm) of magnesium alloy AZ91 - Samples A, AZ61 - Samples B and AZ31 - Samples C (after ASTM Standard) in initial state as cast. Chemical composition of alloys is given in Table 1.

Samples A were heat treated (T4-signed after ASTM Standard): pre-heating 375°C/3h → heating 415°C/18h, cooling in air (A1), water (A2) and furnace (A3) [11].

Testing of mechanical properties was made on tensile testing machine INOVA- TSM 50 [12].

Samples A, A1, B and C were next investigated by torsion test on torsion plastometer SETARAM at 360°C.

The observation of microstructure of alloys was performed with Neophot 2 light microscope. Fracture observation after testing was performed with Jeol 50A scanning microscope.

## 3. Description and discussion of achieved results

Microstructure in initial as cast state and after heat treatment of Mg-Al alloys is showed in Fig.1.

As a result of the microscopic examination performed, it was found out that the casting AZ91 alloy is characterised by a solid solution structure α with α+β eutectic and β phase ($Mg_{17}Al_{12}$) at grain boundaries (Fig.1a). In the case of AZ61 alloy (Fig.1b) the portion of eutectic structure is decreased and in the case of AZ31 alloy the eutectic structure is missed (Fig.1c). In these cases a more etched place instead before eutectic regions are occurred. After heat treatment in the case of cooling in air and water α+β eutectic ανδ β phase ($Mg_{17}Al_{12}$) at grain boundaries dissolve and misses, while in the case cooling in furnace β phase is dispersed again in the shape of fine lamellas.

Pictures of fracture areas after tensile test are showed in Fig.2. and Fig.3 and after torsion test in Fig.4 - Fig.7.

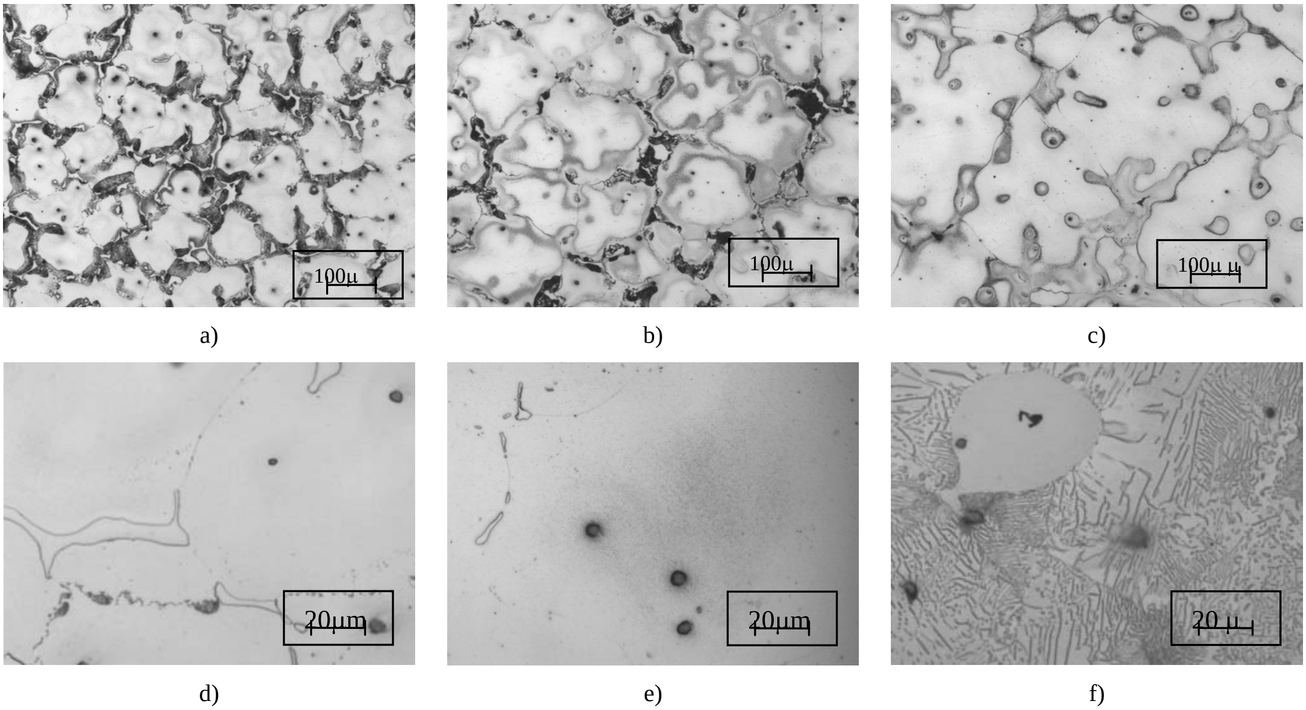
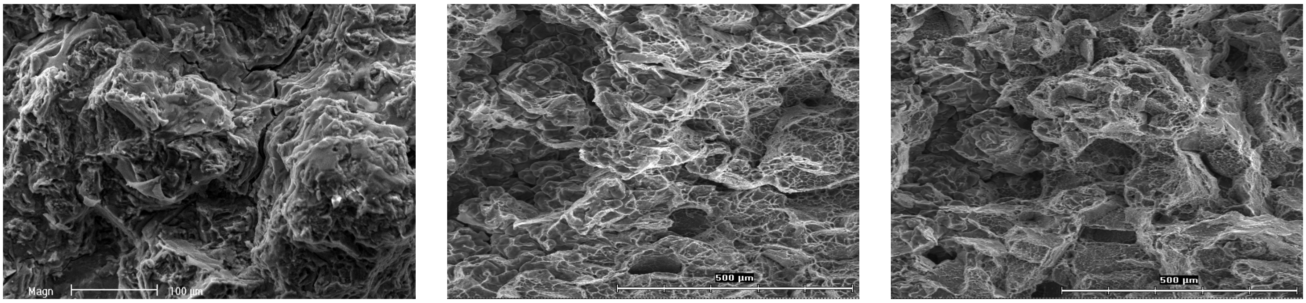
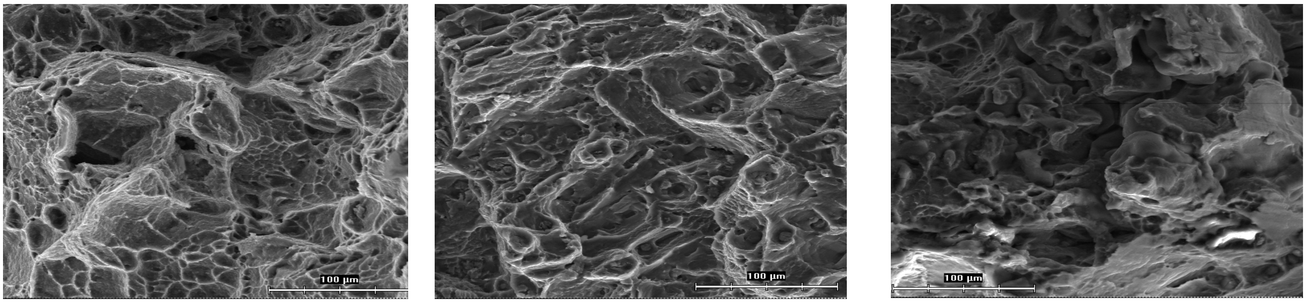



Fig. 1. Microstructure of magnesium alloys: a) Sample A, b) Sample B, c) Sample C, d) Sample A1, e) Sample A2, e) Sample A3




a) b) c)

Fig. 2. Fracture area of the as-cast magnesium alloys: a) Sample A, b) Sample B, c) Sample C




a) b) c)

Fig. 3. Fracture area of magnesium alloys after heat treatment: a) Sample A1, b) Sample A2, c) Sample A3

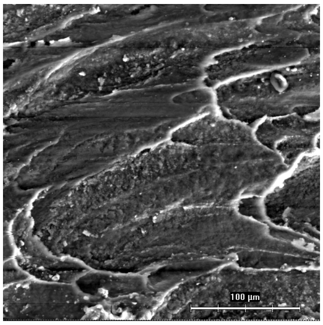



Fig. 4. Fracture area of the as-cast magnesium alloys after torsion test at 360°C (Sample A)

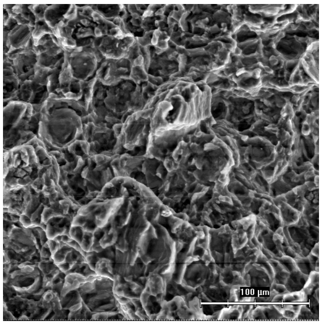



Fig. 5a. Fracture area of magnesium alloys after heat treatment and torsion test at 360°C (Sample A1)- plastic part

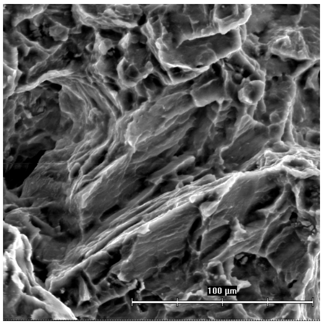



Fig. 5b. Fracture area of magnesium alloys after heat treatment and torsion test at 360°C (Sample A1)- brittle part

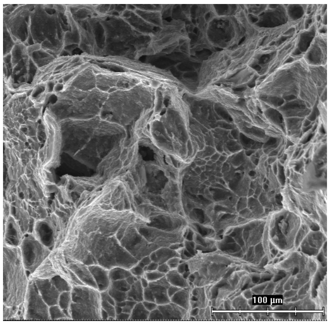



Fig. 6a. Fracture area of magnesium alloys after heat treatment and torsion test at 360°C (Sample B)- plastic part

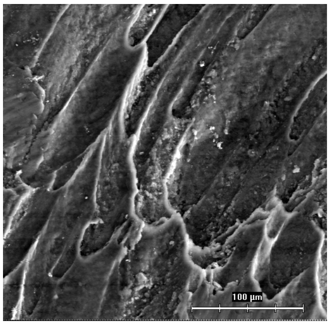



Fig. 6a. Fracture area of magnesium alloys after heat treatment and torsion test at 360°C (Sample B)- brittle part

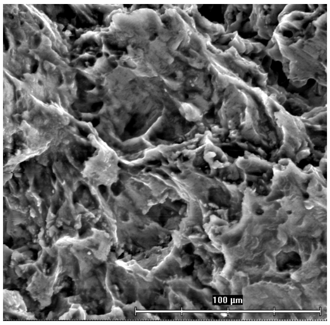



Fig. 7. Fracture area of magnesium alloys after heat treatment and torsion test at 360°C (Sample C)- plastic part

As it is seen from Fig.2 in the case of fracture in sample A has almost brittle intercrystalline character but at the sample B and C is changed on plastic transcrystalline thats.

After heat treatment alloy A in the case of cooling of samples in air and water the fracture has mostly plastic transcrystalline character and after cooling in furnace the fracture was changed on brittle fine intercrystalline character.

Fracture areas at samples after torsion tests at elevated temperature have not so different character as in the case of samples after tensile test namely from the reason elevate temperature. As shows Fig.4 the fracture of sample A has almost brittle character and after heat treatment (sample A1) we can see brittle (Fig.5a) and plastic (Fig.5b) parts.

## 4. Conclusions

The following conclusions can be drawn from results of evaluation of structural characteristics of used magnesium alloy:

- Microstructure of the Mg-Al alloys in initial state as cast at used cooling conditions do not reached an equilibrium state.
- Microstructure has dendritic character, minority phases are comparatively continuously distributed in interdendritic areas, which represent suitable places for initiation and propagation of cracks under load.
- During heating AZ91 alloy at chosen temperatures there occurs partial dissolution of minority phases. Homogenisation of microstructure is, however, accompanied by simultaneous forming of inter-granular non-integrities, which is unfavourable from the viewpoint of strength and plastic properties.
- Examine fracture characteristics on samples after tensile test correspond with above mentioned microstructures.
- Results of measurements on torsion plastometer extended knowledge about plastic behaviour at elevated temperatures a showed changing fracture characteristic of magnesium alloys with graduated Aluminium content.

## Acknowledgements

The work was co- financed by aim of INTERREG IIIa, by Project MSM 6198910015 and MSM 6198910013. Moreover 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] J.R Davis, Metals Handbook, Desk. Edition, Second Edition, ASM International, The Materials Information Society, USA, 1998, 560- 564.

[2] ASM Specialty Handbook. Magnesium and Magnesium Alloys, ed. Avedesian, ASM International, The Materials Information Society, USA, 1999.

[3] H. Baker, Physical properties of magnesium and magnesium alloys, The Dow Chemical Company, Midland, 1997.

[4] K.U. Kainer, Magnesium – Alloys and Technology, Wiley-VH, Weinheim, Germany, 2003.

[5] L. Ptáček, Magnesium alloys- present state of development and exploitation, Proceedings of conference "METAL 2001", Ostrava-Hradec n. Moravicí, 2001, 1-12 (in Czech).

[6] K.A. Dahle, Z.C. Lee, M.D. Nave, P.L. Schaffer, D.H. Johnson, Development of the as-cast microstructure in magnesium-aluminium alloys, Journal of Light Metals 1 (2001) 61-73.

[7] P. Palček, P. Lukáč, M. Chalupová, Z. Trojanová, Influence of temperature on fracture characteristics selected magnesium alloys, Proceedings of Conference "Degradation of structural materials ´2005", Těrchová - Biely Potok, 2005, Publication in Materiálove Inžinierstvo (Materials Engineering) 3 (2005) 7-10 (in Slovak).

[8] L.A. Dobrzański, T. Tański, L. Čížek, Influence of modification with chemical elements on structure of magnesium casting alloys, Proceedings of 13th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2005, Gliwice–Wisla, 2005, 199-202.

[9] L.A. Dobrzański, T. Tański, L. Čížek: Influence of Al addition on microstructure of die casting magnesium alloys, Journal of Achievements in Materials and Manufacturing Engineering 19 (2006) 49-55

[10] L. Čížek, R. Kořený, I. Juřička, J. Maisner, M. Greger, s. Lasek, P. Beťáková, A. Hernas, Structure and Properties of the Selected magnesium Alloys, Proceedings of 10th Jubilee International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2001, Gliwice- Zakopane, 2001, 75-78.

[11] L. Čížek, L. Pawlica, M. Greger, J. Pavelcová, T. Tański, Mechanical properties of the model casting magnesium alloy AZ 91, Proceedings of 11th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2002, Gliwice - Zakopane, 2002, 47-50

[12] J.C. Tan, M.J. Tan, Dynamic continuous recrystallization characteristic in two stage deformation of Mg3Al1Zn alloy sheet, Materials Science and Engineering A339 (2003) 124-132.

[13] T. Rzychoń, A. Kiełbus: Microstructure of WE43 casting magnesium alloys, Journal of Achievements in Materials and Manufacturing Engineering 21 (2007) 31-34.

[14] T. Rzychoń,, J. Michalska, A. Kiełbus: Corrosion resistance of Mg-RE-Zr, Journal of Achievements in Materials and Manufacturing Engineering 21 (2007) 51-54.

[15] 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.