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# Structure and properties of Mg-Zr and Mg-Si alloys

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**Materials**

## ABSTRACT

**Purpose:** of this paper is to extend a complex evaluation of magnesium alloys which requires very often knowledge of structure and mechanical properties. These properties are connected with microstructure that is influenced by metallurgical and technological factors and conditions of exploitation. Presented knowledge expresses very important information for design and exploitation of these alloys.
**Design/methodology/approach:** The methods of the light microscopy for metallographic and analyses of alloys were used.
**Findings:** Objective of this work consisted in determination of structure and mechanical properties progressive magnesium alloys.
**Research limitations/implications:** Knowledge of alloys structure characteristics will be determined new research direction of scope.
**Practical implications:** The results may be utilized for a relation between structure and properties of the investigated material in process of manufacturing.
**Originality/value:** These results contribute to complex evaluation of properties magnesium alloys namely for explanation of structure developed new magnesium alloys. The results of this paper are determined for research workers deal by development new exploitations of magnesium alloys.
**Keywords:** Metallic alloys; Magnesium alloys; Structure; Light metallographic microscopy

## 1. Introduction

Increasing the share of light structural materials in structures of airplanes or vehicles leads to reduction of environmental load. Magnesium alloys also play an important role among these materials (Fig.1) [1-5].

The interest in application of magnesium alloys in wide spectrum of industries rises from traditional used alloys, such as alloys with admixture of aluminium [6-15] as the main alloying component which is continuously improving and still new types are being developed [1,2]. The increasing use of magnesium alloys is caused by the progress in the manufacturing of new reliable alloys with the addition of Zr, Ce, Cd and very light alloys are made from Li [1,2].

Mg-Al-Si alloys improve resistance to creep at temperatures up to 150 ºC, they have good plasticity, ultimate strength and yield strength. They are used in crank cases of air-cooled automobile engines, for production of clutch pistons and blade stators.
Alloys containing silicon are approximately of eutectic character with silicon contents of approx. 1 – 1.5 weight %. If the silicon contents are higher than the limit corresponding to eutectic concentration, the phase $Mg_2Si$ crystallises in the form of needles and the alloy becomes brittle. Advantage of these alloys consists in their good cast- ability and resistance to corrosion.

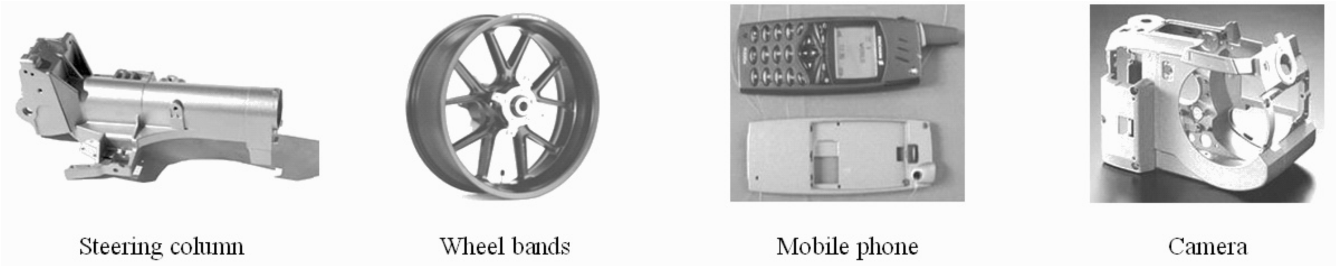


Fig. 1. Examples of elements from magnesium alloys [1-3].

## 2. Materials and experimental methods

The model alloys AS31 (three sheets of the alloy AS31 with modified silicon contents), as well as Mg-Zr alloy made of high-purity magnesium with contents of added zirconium 0.7%, AZ91 and pure magnesium – for reason of comparison hardness measurement were used for investigation of structure and properties in experimental part of the work. Chemical composition of alloys is given in the Tab.1.

The samples for metallographic evaluation were prepared in usual manner: there were wet-ground on disc sanders with use of emery papers with roughness: 600, 800, 1000 and 1200. Special care was paid during grinding to prevention of possible deformation of the surface layer. That's why the samples were cooled with water.

Polishing of samples was made in two stages. In the first stage the samples were polished on cloth with use of the $Al_2O_3$ based polishing suspension. Discs of the polishing machines rotated by speed of 200 rev./min.

In the second stage the polishing was made on very fine velvet cloth with short fibres. Diamond powder with grain size of 1 µm was used as polishing material. Diamond was applied by spraying and cloth was regularly wetted by alcohol-based liquid. Speed of disc rotation was reduced to 150 rev./min. The samples were moved against the direction of disc rotation with application of slight thrust. The samples were finally flushed with water and spirit and dried by stream of hot air.

The samples were then etched by Nital. Duration of etching varied from 5 to 10 seconds.

Light microscope NEOPHOT 2 was used for evaluation of microstructure of alloys.

Investigation of microstructure was completed also by determination of hardness or micro-hardness by Vickers on HPO250 or LECO.

## 3. Description and discussion of achieved results

Microstructures of samples of the alloy AS31 are shown in the Fig.2-4. It follows from these figures that microstructure of all the samples of alloys with silicon show dendritic character. They are formed by coarse-grained basic solid solution α with partly segregated phase $Mg_{17}Al_{12}$ along the grain boundaries and together with areas of „Chinese characters" which is $Mg_2Si$ based compound. It is also possible to assume from these figures that areas with "Chinese characters" are distributed mostly in inter-dendritic spaces in the scope corresponding to composition of the alloy. In case of the alloy AS31-2 the Fig.2 shows a smaller extent of the area with segregated $Mg_{17}Al_{12}$ due to more distinct change of chemical composition.

Examples of microstructure of the alloy containing zirconium are shown in Figs. 5-6.

Microstructure of the alloy with zirconium is formed mostly by equi-axed grains of various sizes, which contain oblong particles. Due to the fact that the alloy with this composition has been developed recently and its structure is not described in available literature, it can be assumed that these can be grains of magnesium based solid solution, in which a precipitation of fine minority phases could have occurred during solidification due to influence of positive solubility coefficient [11]. However, due to orientation of these etch patterns it is impossible to completely exclude the possibility that these are so called artefacts caused by imperfect removal of the deformed surface layer on the cut. It is also possible to take into consideration forming of a relief at surface deformation during preparation of the sample, or decoration of possible twins or glide bands enriched by dissolved zirconium. It was verified by thorough repeated preparation of the sample surface realised with maximum care, whether this effect disappears, but this phenomenon repeatedly re-appeared even in these cases of extra-careful preparation. Detailed explanation of this will require application of chemical or electrolytic methods of polishing or possibly even etching of the sample surface (provided that etching effect is achieved), or by methods of electron microscopy.

Fig.7 shows microstructure of the sample of pure magnesium. Under the given conditions area etching of grains occurred. Structure is formed predominantly by equi-axed grains of various sizes, similarly as in case of the alloy with zirconium.

The above mentioned alloys were then subjected to determination of hardness according to Vickers HV30 or HV5 with use of HPO 250 hardness tester.

Determination of hardness for the Mg-Si was done without any problem and the values HV30 and HV5 practically did not differ. These results are given in the Tab. 2.

Nevertheless, it was impossible to read the values of diagonals at determination of the hardness HV30 of the alloy Mg-Zr due to heavy deformation of these diagonals. Hardness HV5 was determined for Mg-Zr without any problem, average hardness was 27.77 HV5 and standard deviation was 2.55 HV5. Under heavier load it became impossible to determine the size of diagonals, since the indentation was strongly deformed due to large grains and high anisotropy.

Table 1.
Chemical composition of used alloys (weight %)

| Alloy | Al | Zn | Mn | Si | Fe | Be | Zr | Sn |
|---|---|---|---|---|---|---|---|---|
| AS31-1 | 3.43 | 0.13 | 0.289 | 0.852 | 0.000 | 0.001 | 0.002 | 0.002 |
| AS31-2 | 3.76 | 0.17 | 0.363 | 0.883 | 0.002 | 0.000 | 0.001 | 0.002 |
| AS31-3 | 3.60 | 0.16 | 0.352 | 0.996 | 0.002 | 0.000 | 0.001 | 0.003 |
| Mg-Zr | 0.07 | 0.01 | 0.02 | - | - | - | 0.07 | - |

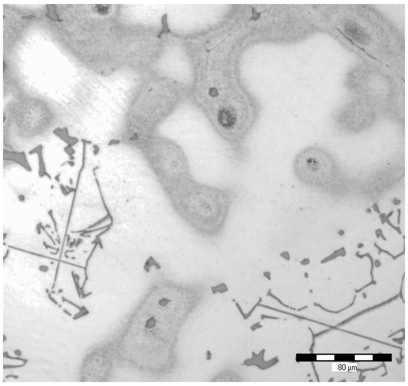

Fig. 2. Microstructure of the alloy AS31-1

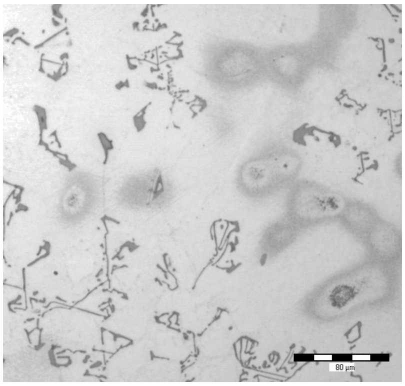

Fig. 3. Microstructure of the alloy AS31-2

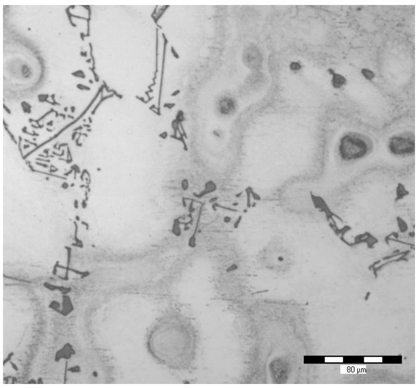

Fig. 4. Microstructure of the alloy AS31-3

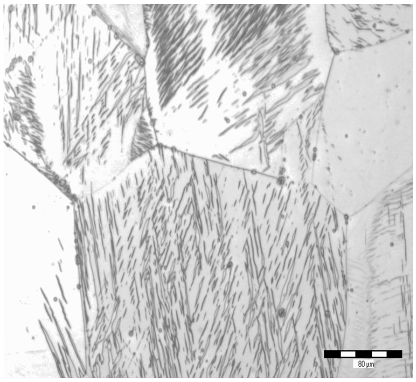

Fig. 5. Microstructure of the alloy Mg-Zr

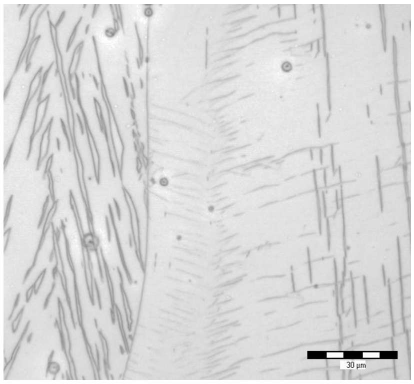

Fig. 6. Microstructure of the alloy Mg-Zr

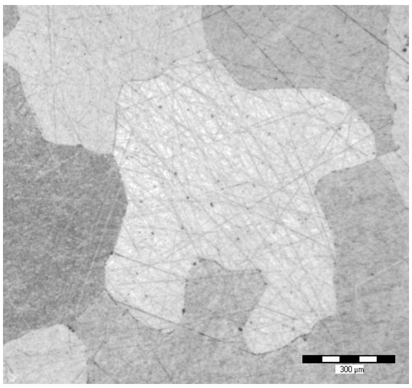

Fig. 7. Structure of pure magnesium

Table 2.
Values of hardness for individual samples of the alloys AS31 and Mg-Zr

| Alloy | HV30 | HV5 |
|---|---|---|
| AS31-1 | 47.48 | 45.65 |
| AS31-2 | 45.82 | 44.94 |
| AS31-3 | 47.14 | 46.84 |

In the case of pure magnesium it was impossible to determine the both hardness value of HV30 and HV5. In proximity of indentation distinctive slip lines were observed caused by plastic deformation on slip planes.

For this reason a possibility of determination of micro-hardness of pure magnesium was verified at lower loads. In this case it was possible to determine these values of micro-hardness without any problem.

## 4. Conclusions

On the basis of obtained results it is possible to draw the following conclusions:

- Microstructure of the alloys Mg-Zr is formed by polyedric grains of Mg based solid solution with dimensions 100 – 500 μm. It is characterised by occurrence of numerous etching artefacts, the origin of which cannot be determined unequivocally.
- Microstructure of pure magnesium is similar. Etching artefacts were not observed.
- Microstructure of the alloy Mg-Al-Si is of dendritic character, it is formed by comparatively coarse-grained basic solid solution α with partly dendritically segregated phase $Mg_{17}Al_{12}$ and „Chinese characters”, which is $Mg_2Si$ based compound
- Determination of hardness in the samples of the alloy Mg-Si was done without any problem and the values HV30 and HV5 practically did not differ.
- In case of pure magnesium a dependence of the micro-hardness values on magnitude of the load was observed. It was found that the micro-hardness value slightly decreases with increasing load.

## Acknowledgements

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## 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. Friedrich, S. Schumann, Research for a New age of magnesium in the automotive industry, Journal of Materials Processing Technology 117 (2001) 276-281.

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

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

[6] A. Kiełbus, Structure and mechanical properties of casting MSR-B magnesium alloy, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 131-134.

[7] B.L. Mordike, T. Ebert, Magnesium. Properties-applications-potential, Journal of Materials Processing Technology 117 (2001) 37-45.

[8] 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.

[9] 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.

[10] T. Rzychoń, A. Kiełbus, The influence of wall thickness on the microstructure of HPDC AE44 alloy, Archives of Materials Science and Engineering 28/8 (2007) 471-474.

[11] 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.

[12] A. Kiełbus, T. Rzychoń, R. Cibis, Microstructure of AM50 die casting magnesium alloy, Journal of Achievements in Materials and Manufacturing Engineering 18 (2006) 135-138.

[13] T. Rzychoń, A. Kiełbus, Microstructure of WE43 casting magnesium alloys, Journal of Achievements in Materials and Manufacturing Engineering 21/2 (2007) 31-34.

[14] L. Čížek, M. Greger, L Pavlica, 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.

[15] J. Drápala, L. Kuchař, K. Tomášek, Z. Trojanová: Hořčík, jeho slitiny a binární systémy hořčík – příměs [Magnesium, its alloys and binary systems magnesium–admixture], VŠB-TU, Ostrava 2004.