ANNALS OF FACULTY ENGINEERING HUNEDOARA
– International Journal of Engineering
Tome XI (Year 2013) – FASCICULE 4 (ISSN 1584 – 2673)

[1.]Peter PALČEK, [2.]Mária CHALUPOVÁ, [3.]Ivana HLAVÁČOVÁ

EVOLUTION OF PLASTIC DEFORMATION AND HARDNESS OF MAGNESIUM ALLOY AZ61 AFTER HEAT TREATMENTS

[1-3.] DEPT. OF MATERIALS ENGINEERING, FACULTY OF MECHANICAL ENGINEERING, UNIVERSITY OF ŽILINA, ŽILINA, SLOVAKIA

ABSTRACT: This paper deals with the study of effect of microstructure on the development of plastic deformation of the prospective magnesium alloy with addition of 0.5 wt. % Ca. Plastic deformation was created in the surrounding area of the indentation. A change in the intensity and distribution of plastic deformation was caused by deformation strengthening and shifting of grain boundaries.
KEYWORDS: microstructure, magnesium alloy, plastic deformation

INTRODUCTION

Due to their high specific strength and low density, magnesium alloys are widely used in many weight-saving applications. Most magnesium alloys are produced by casting techniques such as sand cast, low and high-pressure cast. Cast magnesium alloys are widely employed in powertrain applications, airbag supports, and seat frame in automobiles [1, 2].

The use of magnesium alloys has been limited because of low ductility, formability and corrosion resistance. The limited ductility of these alloys is caused by dislocation slip only in basal slip systems at room temperature [3, 4]. It was found that Ca reduces the oxidation of Mg alloys during melting and heat treatment, improves their strength and corrosion resistance. Ca addition has also been proven to be effective in grain refinement of magnesium castings and thermally stable phase such as Mg_2Ca or Al_2Ca is created. These brittle intermetallic phases, usually formed on grain boundaries can affect ductility and deformability. Deformation of Mg alloys at normal temperatures causes that each grain is deformed to the shape determined by nearby grains. The preferred plane of Mg alloys for the formation of twins is $\{1\ 0\ 1\ \bar{2}\}$ in the slip direction $[1\ 0\ 1\ \bar{1}\ ]$[5, 6]. Due to fact that the slip deformation tends to occur easily on the Mg basal plane at a low critical shear stress, crystal orientation with his basal plane on the surface negatively influences the wear-resistance [7, 8].

This research is aimed at investigating the plastic deformation and hardness of commercial AZ61 alloy.

EXPERIMENTAL

Experimental material AZ61 alloy with the addition of 0.5 wt. % Ca was manufactured by squeeze - casting in the form of a square plate. Chemical composition of these alloys is in Table 1. The experimental material was heat treated to achieve full polyhedrization of grains with almost complete phase dissolution of the dendritic structure. Heat treatment consisted of dissolution annealing at temperature 490°C for 32 h and fast cooling to 60°C water. After cooling, the specimens were annealed for 5 h at 200°C in order to obtain a stable microstructure.

The result is solid solution of Al and Zn elements in magnesium and phases based on Al-Ca, Al-Mn [5]. The polyhedral grains eliminate the fine γ phase precipitates (Figure 1). From experimental material after heat treatment were machined specimens with square cross-section 15 x 15 mm with length of 25 mm. Surface perpendicular was previously metallographically prepared and etched by a standard metallographic procedure so it was possible to identify all structural components of the studied alloy.

Table 1.Chemical composition of AZ61

Element [wt. %]	Al	Zn	Mn	Cu	Si	Fe	Ni	Ca	Mg
	5.8-7.2	0.4-1.5	0.15-0.5	≤0.05	≤0.1	≤0.005	≤0.005	0.5	balance

After microstructure evaluation a steel indentor was pressed perpendicular to the metallographically prepared surface, consequently on the surrounding area was created a network of slip bands, deformation twins and some grains were shifted due the plastic deformation. Steel roller had diameter of 1 mm and the used strength was 3800 and 7800 N (Figure 2). The stress in the

material is gradually increasing and when enough energy is accumulated and no plastic deformation is possible a crack is created in the place of maximal stress concentration. Creation of new surfaces consumes this accumulated energy and by rapid decreasing of the load is possible to stop the crack propagation. The amount of energy consumed by crack propagation depends on the surface stress and on the fracture micromechanisms.Character of plastic deformation is shown in Figure 3 (deformation zone had an oval shape with 6.5 mm in height and 6.0 mm in width).

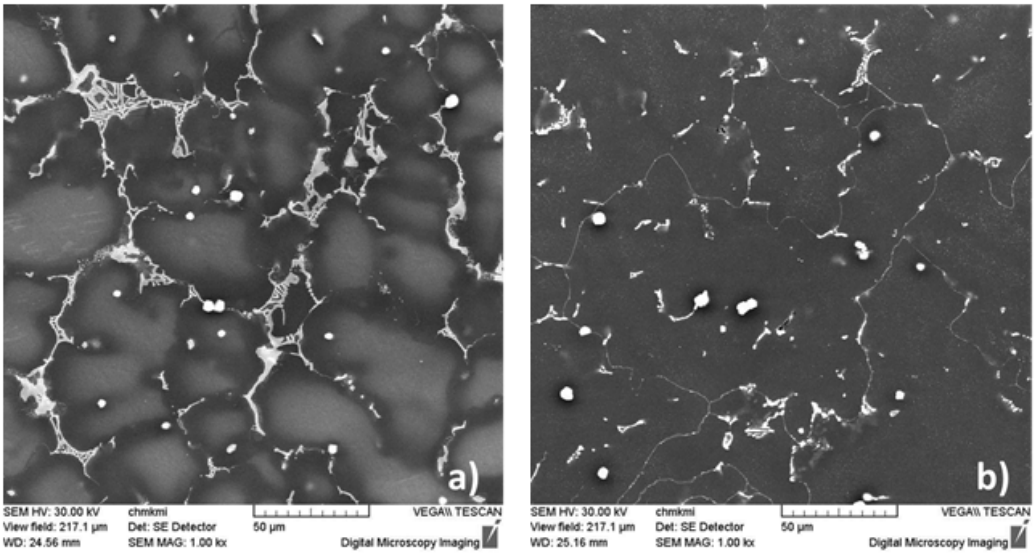

Figure 1. Microstructure of experimental material AZ61 with 0.5 weight % Ca
a) as-cast state, b) after heat treatment

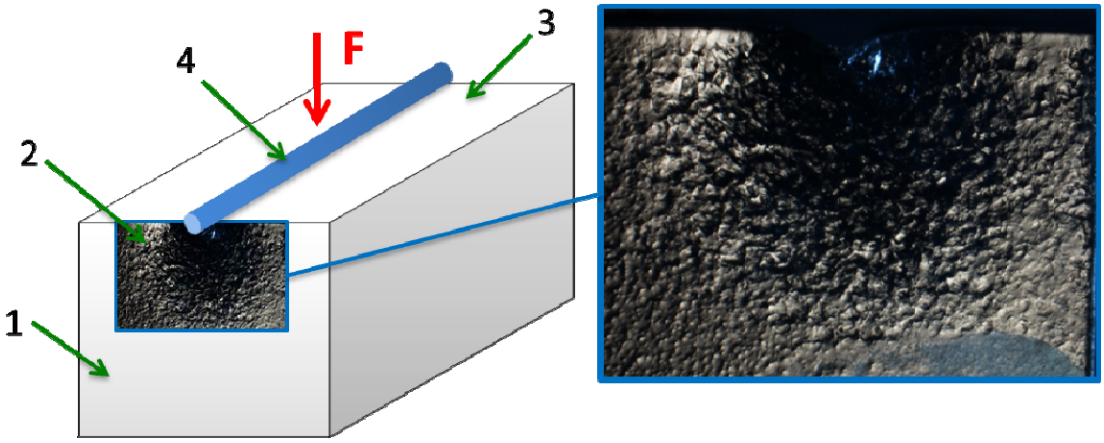

Figure 2. The scheme of loading, 1 - metallographically prepared surface, 2 -deformation field (macro view of the deformed surface), 3 -test specimen, 4 - indentor (steel rod)

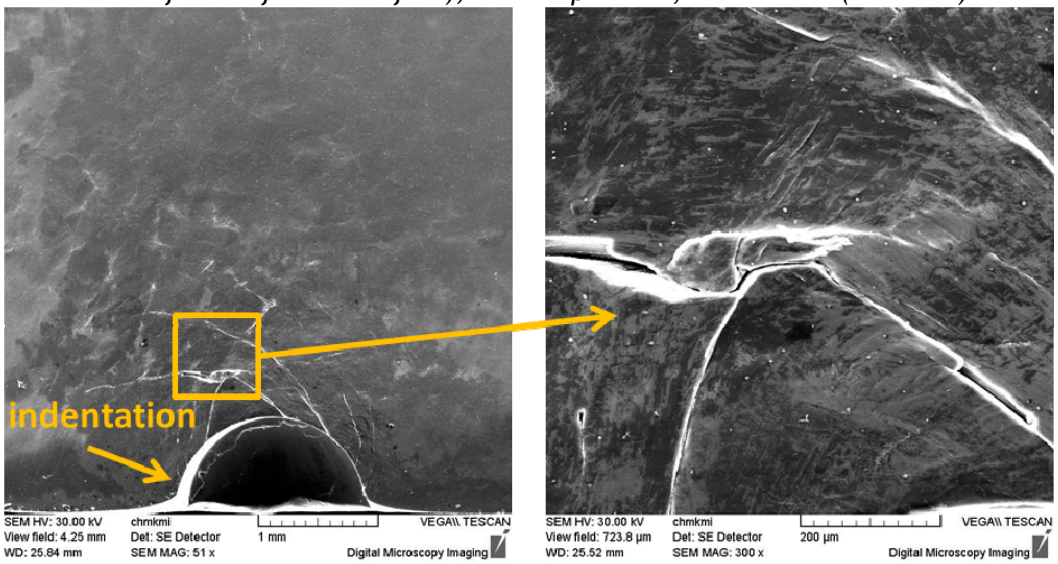

Figure 3. Plastic deformation in the nearby area of the indentor - cracks formation

Geometry of the test specimens, the temperature and strain rate were the same during experiments. By the stress release in the surrounding of the indentor there were formed small cracks in several directions and some of them, due their proper orientation, formed one or more magistral cracks.

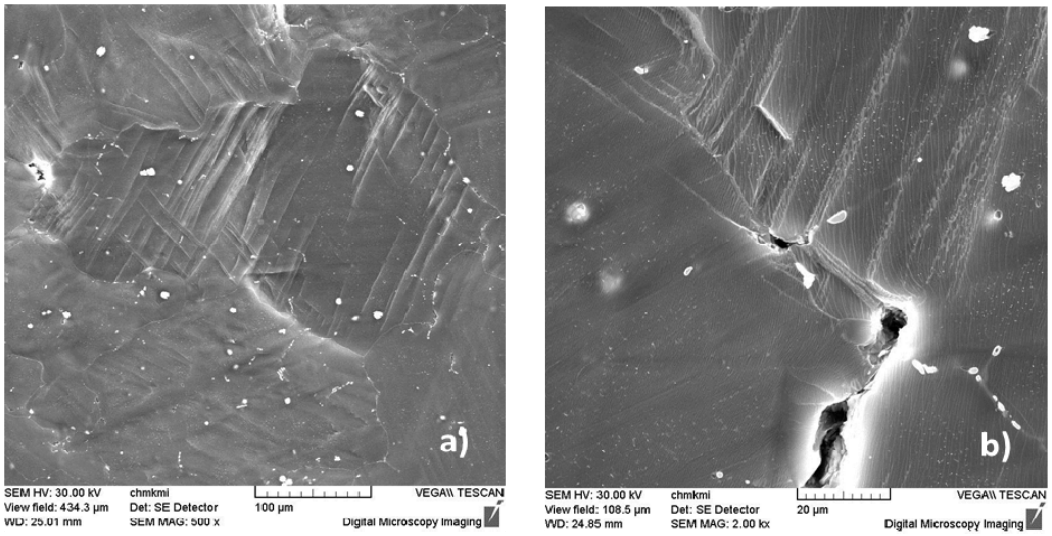

Figure 4. Plastic deformation on the surface of the experimental alloy with polyhedral structure after heat treatment a) intensity of plastic deformation, b) retardation of deformation on a grain boundary, fine deformation twins

During loading of the specimen with polyhedral microstructure, the plastic deformation was formed massive twinning and slip can be observed very fine deformation twins and slip bands on the surface (Figure 4a). Also the activation of slip systems in several crystallographic directions and plastic deformation realized by slip of screw dislocations can be clearly seen Figure 4b. The change of the direction of plastic deformation propagation occurred due to the presence of undissolved phases in grains and also on grain boundaries, which were present in the microstructure even after heat treatment (Figure 5).

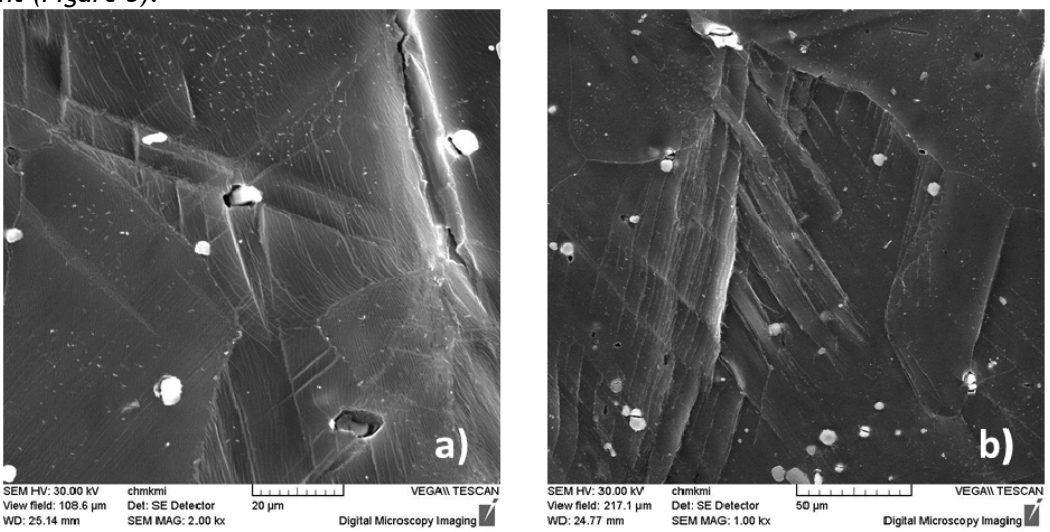

Figure 5. The change of the direction of plastic deformation due to the presence the undissolved phases a) in grains, b) on grain boundaries

Decreasing of the plastic deformation intensity caused by improper crystallographic orientation of grains. In these grains the process is not so intensive to cause significant plastic deformation of the grain surface. After polishing of the deformed surface was measured microhardness HV 0.1, so that the change of the plastic deformation intensity was documented in all influenced surface. The gradual change of hardness with increasing distance from the bottom of the indentation place is shown in Fig. 6. The highest measured hardness was 82HV and in the places with the highest plastic deformation in loading area. The lowest hardness (51 HV) was in the surrounding area of decreasing the intensity of plastic deformation.By comparing the hardness course and the surface deformation relief can be stated that there is good correlation between them and hardness measurement is a suitable method for evaluation of the plastic deformation range in Mg alloys.

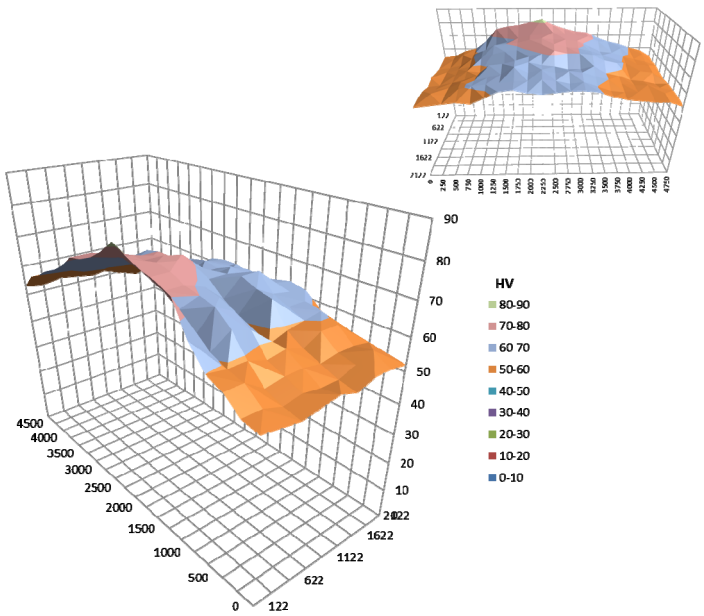

Figure 6. The gradual change of hardness with increasing distance from the bottom of the indentation

CONCLUSIONS

Based on experimental work it can be concluded:

- *The experimental specimens after heat treatment were loaded by compression loading.*
- *Plastic deformation was performed by twinning and slips plastic deformation and in the surrounding area of the indentation was created cracks.*
- *Deformation strengthening and shifting of grains boundaries were caused by changes the intensity and distribution of plastic deformation.*
- *Measuring of the microhardness showed increase of hardness in the places with the highest plastic deformation in loading area, the highest hardness was 82 HV.*

ACKNOWLEDGEMENT

The research was supported partially by SK VEGA grant No. 1/0797/12, No. 1/2594/12 and project SK-PL-0083-12. Authors gratefully acknowledge this support.

REFERENCES

[1] *JAFARI, H., IDRIS, M.H. et al.: Effect of thermomechanical treatment on microstructure and hardness behavior of AZ63 magnesium alloy, In ActaMetallurficaSinica, 2009, pp. 401-407*

[2] *KANG, H. T., OSTROM, T.: Mechanical behavior of cast and forget magnesium alloys and their microstructures, In Materials Science and Engineering: A, 2008, USA, pp. 52-56*

[3] *POLMEAR, I. J.: Light Alloy, 2006, Australia, pp. 237 - 296, ISBN 0-7506-6371-5*

[4] *WANG, Q., CHEN, J. et al.: Microstructure and Super High Strenght of Cast Mg-8.5Gd-2.3Y-1.8Ag-0.4Zr Alloy, In Material Science and Engineering, 2010, China, pp. 323-328*

[5] *BARNETT, MR.: Twinning and the Ductility of Magnesium Alloys: Part II.—Contraction Twins, Materials Science and Engineering A, 2007*

[6] *PALČEK, P., HLAVÁČOVÁ, I. et. al.:Influence of AZ61 Structure on the Plastic Deformation Around a Crack. In: 29th DANUBIA-ADRIA : Symposium on Advances in Experimental Mechanics : September 26 - 29, 2012, Planeta Print : Belgrade, Serbia - 2012. p. 134-135. - ISBN 978-86-7083-762-1*

[7] *RAUCH, M., LEGROS, M. et al.: Small Volume Investigation of Slip and Twinning in Magnesium Single Crystals, Universtitéde Grenoble, 2011*

[8] *TROJANOVÁ, Z., SZÁRAS, Z., et al. Magnesium Alloys Based Composites. In: Magnesium Alloys - Design, Processing and Properties. Publisher: In Tech, Rijeka, Croatia, 2011, p. 501-526. ISBN 978-953-307-520-4*

[9] *HE, S. M.: Study on the Microstructural Evolution , Properties and Fracture Behavior of Mg-Gd-Y-Zr(-Ca) Alloys, PhD Thesis, ShanghaiJiaoTongUniversity, 2007*

[10] *HE, S. M., ZENG, X. Q., PENG, L. M. et al. Microstructure and Strenghtheningmechanim of High Strenght Mg-10Gd-2Y-0.5Zr Alloy, In Journal of Alloys and Compounds, 2007, China, pp.316-323, ISSN 09258388*

[11] *HOSHIKAWA, H., MAKI, S., KAMADO, S. et al.: Realization on Excellent mechanical properties in Mg-Gd-Ag-Zr and Mg-Gd-Cu-Zn-Zr Casting Alloys Containning LPSO Structure, Proceedings of 2nd Asian Symposium on Magnesium Alloys, Fukuoka International Congress Center, 2007, Japan, pp. 136 -137*