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The Study of Plastic Deformation in the Crack Surrounding in AZ61 Alloy

This paper deals with the study of effect of microstructure on the development of plastic deformation around the propagating cracks of the magnesium alloy whose corrosion resistance is increased by the addition of 0.5 wt. % Ca. The crack was created during the three-point bending test with slow increase of load. Result of this analysis was that the slip bands and deformation twins were more significant in material after full polyhedrization of grains than in material in as-cast state.

Keywords: *magnesium alloy, dislocations, twining, transcrystalline fracture, intercrystalline decohesion.*

1. INTRODUCTION

Morphology of fracture surface and present fracture micro mechanisms depend on the stress state, strain rate, temperature as well as on the state of microstructure and substructure of mechanically loaded material. Formation of fracture surfaces and conditions of the development of propagating cracks are related to the internal structure of material. Fracture in metals occurs by deformation process and by the local fracture at the tip of slowly or rapidly propagating crack. In metals, synchronous fracture of interatomic bonds across the whole cross section is almost impossible. If the fracture occurred by creation and propagation of cracks, it is necessary to search for the mechanism of fracture in gradual loss of interatomic bonds of atomic pairs [1,2,3].

Different types of crack growth (e.g., fatigue, corrosion cracking, stress corrosion, hydrogen embrittlement or static overload) cause creation of characteristic marks on the fracture surface, which makes it possible to identify the mechanism which caused the fracture. Most frequently used methods for identification of crack initiation site is macro fractographic analysis. Technical application often requires analysis of the reasons of component fracture, damage of equipment and machines that occurred during the operation [4,5].

Currently, magnesium and its alloys are considered as a construction material, which can partially replace aluminum alloys, plastics and even steel, because of its higher ductility and higher rigidity [6]. The positive properties of magnesium include the good ratio between weight and strength, allowing significant decrease of the weight of a construction. For these reasons, this article focuses on the fracture micro mechanisms of magnesium alloys with 0.5 wt. % Ca content.

2. EXPERIMENTAL MATERIAL

Magnesium alloy AZ61 with addition of 0.5 wt. % Ca, manufactured by squeeze - casting in the shape of a square plate was used as experimental material. Chemical composition of this alloy is given in Tab. 1.

Specimens with square cross-section 8 x 8 mm with length of 55 mm were machined from as-cast state of experimental material. In the specimens the V shaped notches (stress concentrators) were machined which served as initiation sites for cracks formation. Surface perpendicular to the notch was previously metallographically prepared and etched by a standard metallographic procedure so it was possible to identify all structural components of the studied alloy [2].

Table 1. Chemical composition of AZ61

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

Microstructure of as-cast state was dendritic, formed by solid solution of aluminum and zinc in magnesium (δ phase), electron compound $Mg_{17}Al_{12}$ (γ phase) and other phases based on Mg and Al with combination of present elements (Ca, Zn, Mn). In some locations eutectics and discontinuous precipitates (Fig. 1 a) [7,8] appeared.

Heat treatment consisted of dissolution annealing at temperature of 490 °C for 32 h and fast cooling to 60 °C in water. After cooling, the specimens were annealed for 5 h at 200 °C and this resulted in full polyhedrization of grains with perfect dissolution of interdendritic inhomogeneities in dendritic microstructure. The result is a solid solution of Al and Zn elements in magnesium and phases based on Al-Ca, Al-Mn. The polyhedral grains eliminated the fine γ phase precipitates (Fig. 1 b).

3. RESULTS AND DISCUSSION

Changes of the intensity of plastic deformation, which depend on the microstructure, can be evaluated on the metallographically prepared surfaces. Geometry of test specimens, temperature and strain rate was the same during all the experiments, so it was possible to analyze the effect of the microstructure on plastic deformation and fracture micromechanisms.

During the three-point bending test the plastic deformation was gradually increasing and at the same time the nearby grains were slewing and strengthening, what is documented in Fig. 2 and Fig. 3.

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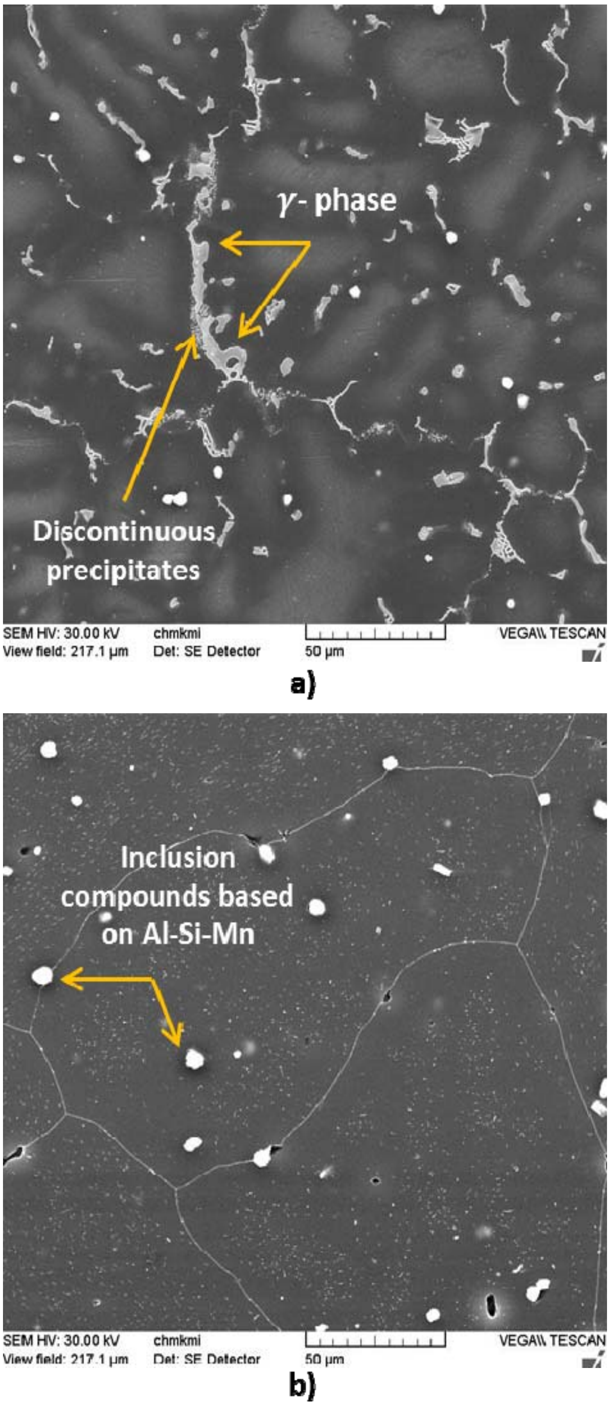


Figure 1. Microstructure of AZ61 alloy with addition of 0.5 wt. % Ca a) as – cast state, b) after heat treatment; (SEM)

With increase of the material resistance to deformation, the stress was gradually increasing and at the place of its highest concentration a crack was created, which depleted the accumulated energy. Increase of the crack length was continuously monitored during the loading and when the crack tip reached half of the cross-section, the test was terminated.

The mechanisms of plastic deformation could be observed on the surface by presence of slip bands and twins, while firstly were deformed grains with proper crystallographic orientation to the direction of loading stress. The change of orientation of slip bands depended on presence of hard and non-deformable intermetallic inclusions and the change of maximal stress vector orientation.

During the slip deformation the dislocation sources were active, which generated edge and screw dislocations (Fig. 4) and they formed a typical broken relief on the surface.

Plastic deformation created similar surface relief in both structural states with difference that plastic deformation of specimens in as-cast state was mainly done by twinning and higher number of cracks was formed by fracture of inclusions. Slip lines were slightly curved by interaction effect between the external mechanical stress and internal stress around inclusions. In places with high stress the plastic deformation caused fracture of the □ - phase particles. In Fig. 5 can be seen, that the plastic deformation was performed by slip of screw dislocations and also the formation of secondary micro-cracks.

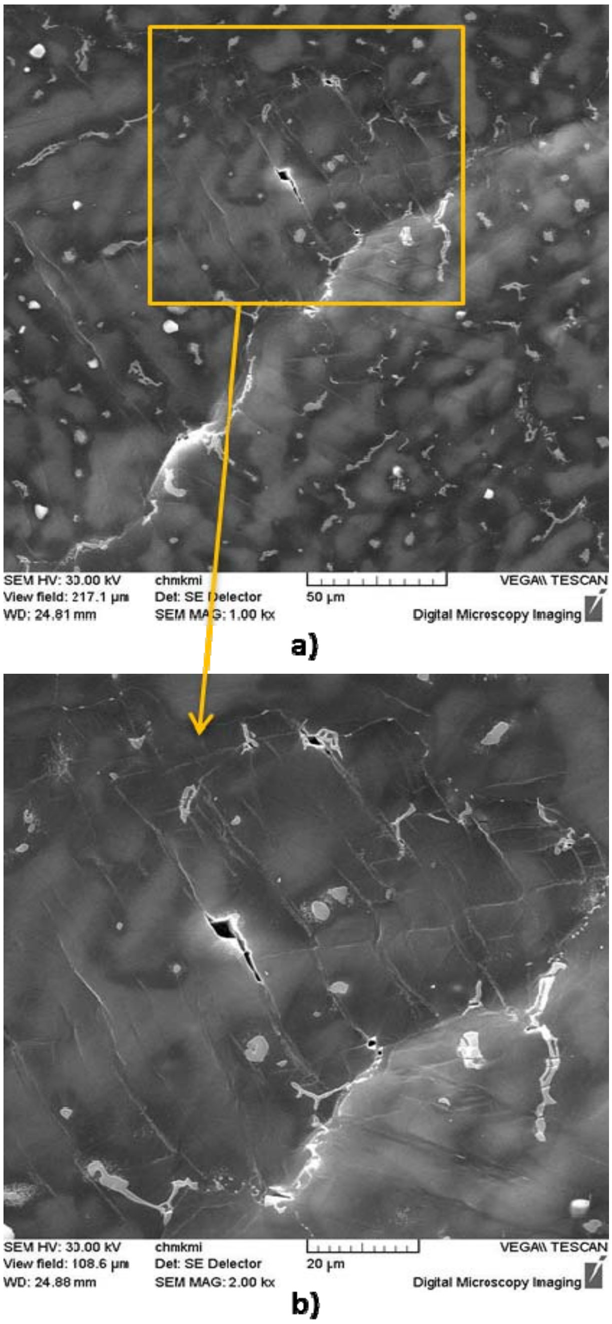


Figure 2. Plastic deformation on the surface of the experimental alloy a) intensity of plastic deformation – as-cast state, b) detail of plastic deformation on grain boundary – as-cast state; (SEM)

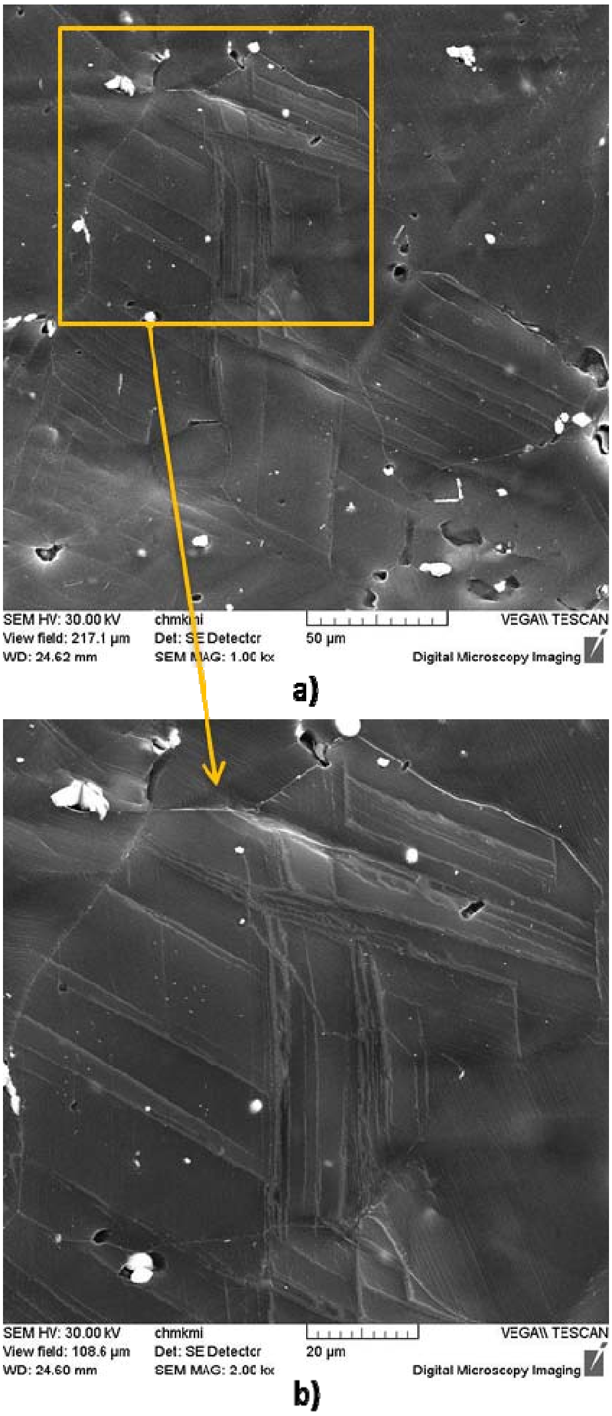


Figure 3. Plastic deformation on the surface of the experimental alloy a) intensity of plastic deformation – after heat treatment, b) detail of plastic deformation on grain boundary – after heat treatment; (SEM)

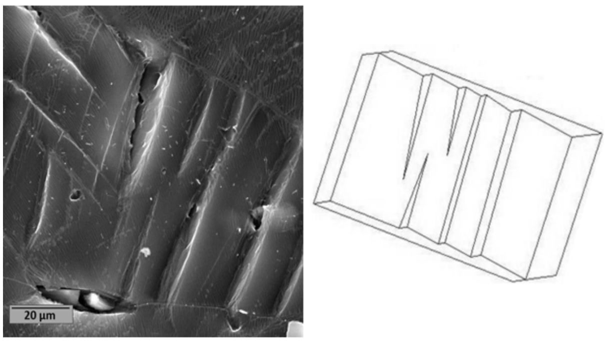


Figure 4. Model of plastic deformation by slip and screw dislocations – as-cast state; (SEM)

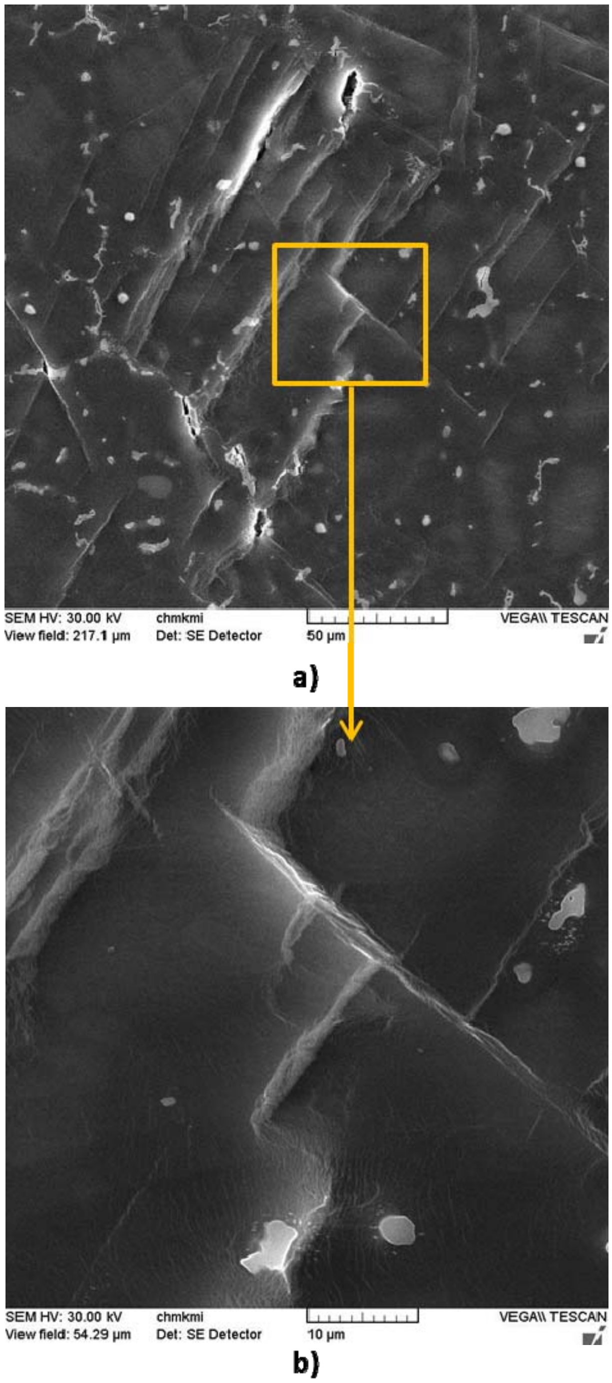


Figure 5. Plastic deformation realized by screw dislocations in the two perpendicular crystallographic directions in – as-cast state a) fracture of inclusions and secondary micro-crack formation, b) detail of deformation by slip of screw dislocations; (SEM)

Structural state after the heat treatment show straight and broken slip systems, with smaller representation of deformation by twinning. At the location distant from the crack only properly oriented grains were deformed and the deformation was restricted by grain boundaries (Fig. 6a). Fig. 6b shows how fine slip lines draw the shape of the barriers located below the surface.

After evaluating the plastic deformation on the surface, the test specimens were broken and the fracture micromechanisms were analyzed on fracture surfaces. From a macroscopic point of view specimens were broken with a ductile fracture. From the microscopic point of view, the transcrystalline ductile fracture was present on the fracture surfaces, with dimple morphology typical for casted magnesium alloys and the dimples were shallow. The shape and size of those dimples was influenced by the presence of dendritic microstructure and particles of the □ phase or phases based on Al-Ca-Mg and Al-Mg-Mn (Fig. 7a). Test specimens in the state after the heat treatment were fractured by transcrystalline ductile fracture with dimple morphology with deep and non-symmetric dimples (Fig. 7b).

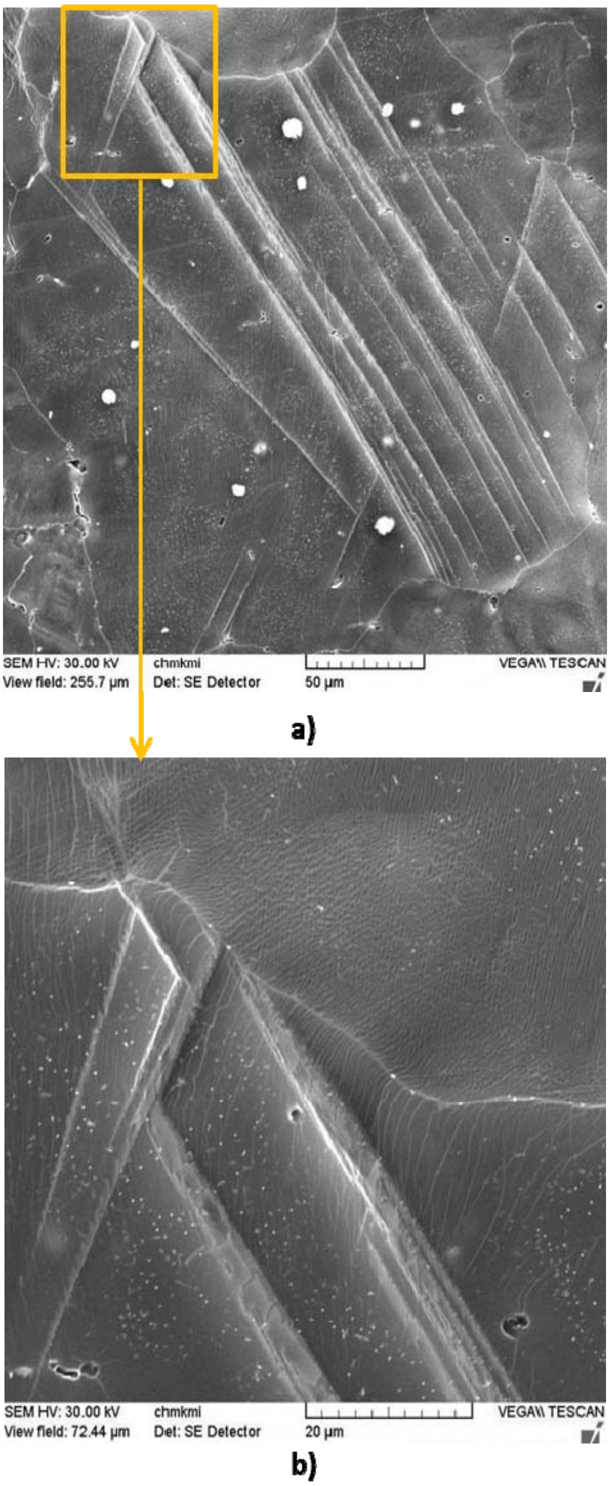


Figure 6. Plastic deformation of grains distant from the crack (alloy after heat treatment) a) limitation of plastic deformation by grain boundaries, b) fine slip lines deformed by barrier under the surface; (SEM)

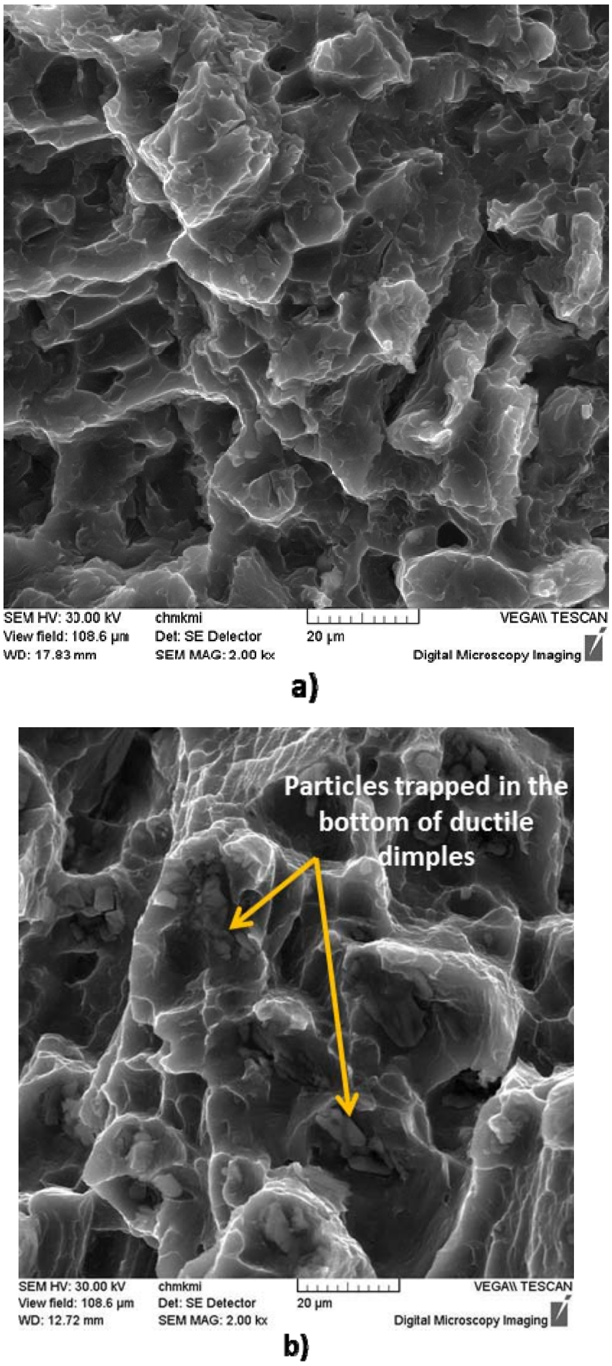


Figure 7. Transcrystalline ductile fracture with dimple morphology a) shallow equiaxed dimples – as – cast state, b) deep and non-symmetric dimples with higher density of trapped particles at the dimple bottom; (SEM)

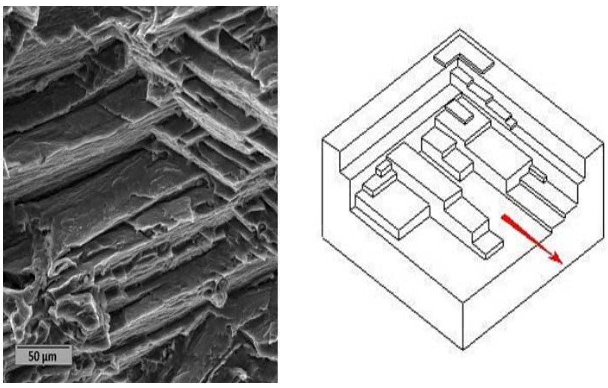


Figure 8. Fracture model of a crack where applied load was parallel to basal planes; (SEM)

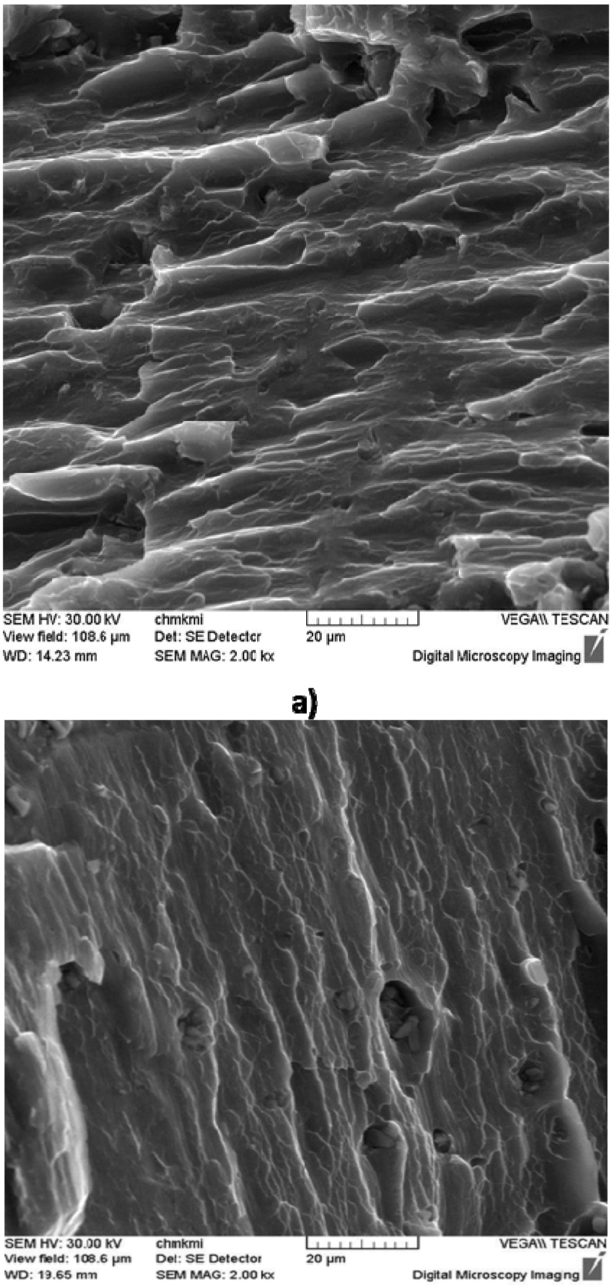


Figure 9. Morphology of intercrystalline facets a) bands formed by twinning deformation – as – cast state, b) bands with sections similar to tongue morphology – state after heat treatment; (SEM)

Besides the shape of dimples, the fracture surfaces differed in the density of particles, or more precisely, the remaining particles of intermetallic phases at the bottom of the dimples trapped in the matrix. Higher density of these particles was in the alloy after heat treatment.

In the minor part of the fracture surfaces the intercrystalline decohesion was present, where almost exclusively the shear fracture micromechanisms took part (Fig. 8).

Morphology of intercrystalline facets in as-cast state is characterized by formation of deformation twinning bands in the basal planes, Fig. 9a. Morphology of intercrystalline facets in state after the heat treatment is characterized by formation of bands with sections similar to tongue morphology, Fig. 9b.

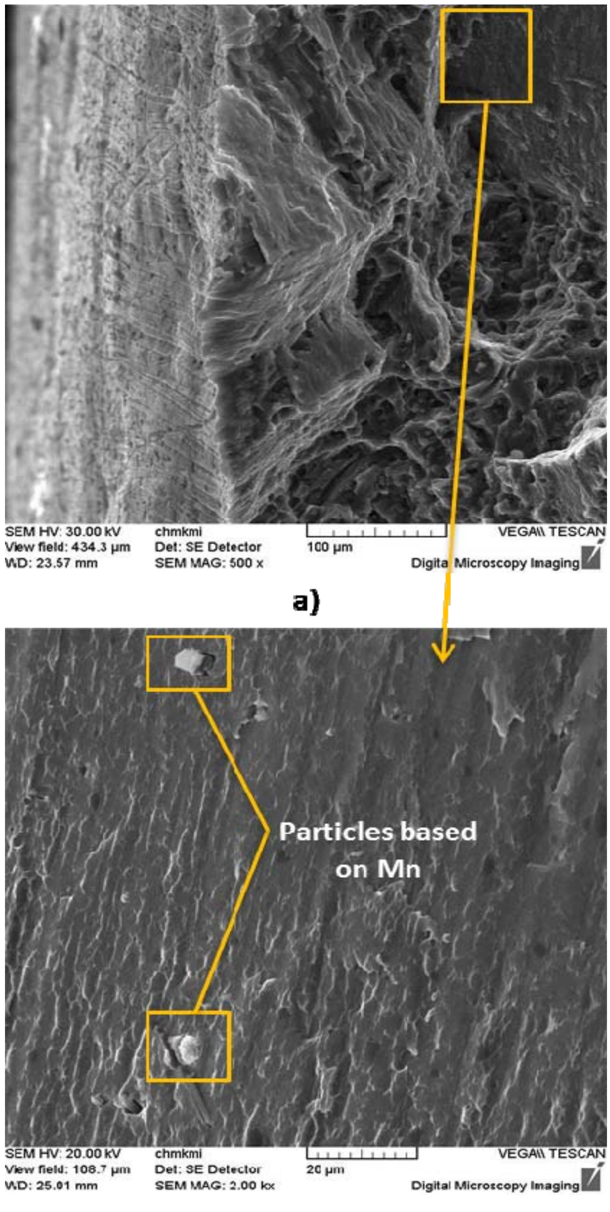
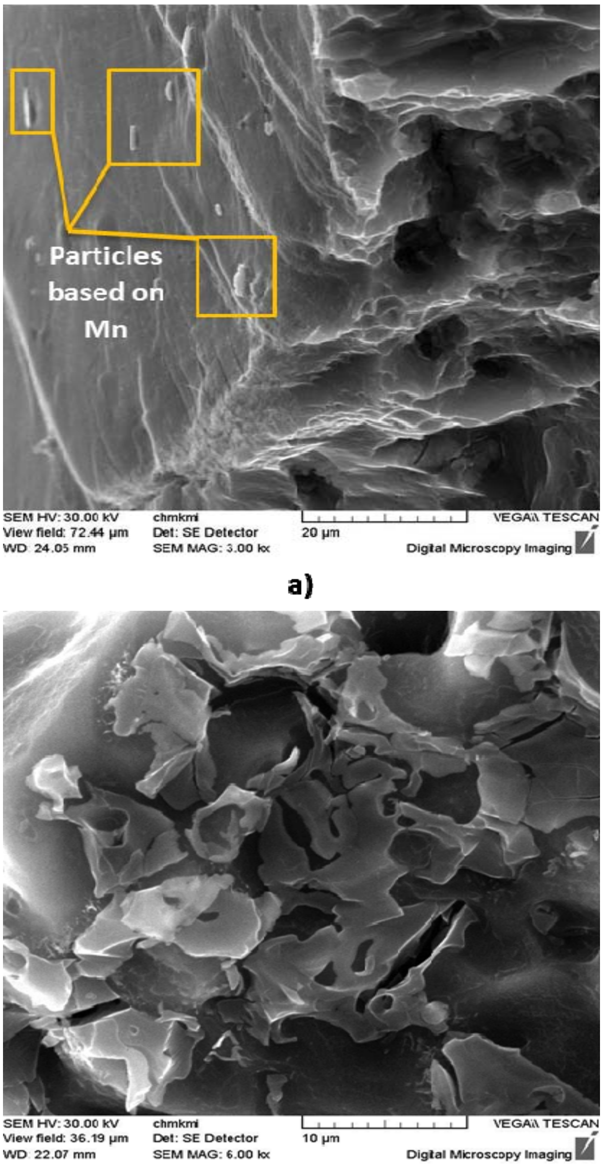


Figure 10. Particles based on Mn a) present on the fracture surface, b) detail of Mn particles on the surface – as- cast state; (SEM)

Facets of the intercrystalline fracture were characterized by planar surfaces, which copy the shape of the grains. On the fracture surfaces, in the area of intercrystalline decohesion, as well as on deformed surfaces of test specimen were observed particles based on Mn (Fig. 10 and Fig. 11a). The heat treatment had no influence on the character and distribution of those particles in the matrix. Fracture of intermetallic phases (Fig. 11b) occurred by accumulation of energy at the point of stress concentration during the plastic deformation of the material, and this can be explained by high hardness and brittleness of those particles.

4. CONCLUSION

The article deals with evaluation of the AZ61 magnesium alloy (with 0.5 wt. % Ca content) microstructure and the heat treatment influence on fracture mechanisms under static loading of the experimental material using fractographic methods.



a) b)

Figure 11. Particles based on Mn a) present on the deformed surface of test specimens - state after heat treatment, b) fracture of intermetallic phases on the fracture surfaces - state after heat treatment; (SEM)

Based on results of experimental measurements the following can be concluded:

- Test specimens were plastically deformed by dislocation slip and twinning during their static loading. Deformation slip bands and twins were more expressive on specimens after heat treatment. In the areas in the vicinity of the crack appeared secondary micro-cracks and cracking occurred of the intermetallic phases.
- Fracture surfaces had the character of transcrystalline ductile fracture with dimple morphology and intercrystalline decohesion, which formed only a small part the fracture surface.
- Ductile dimples on the fracture surfaces of specimens in as-cast state were shallow with insignificant plastic deformation on the ridge.
- At the bottom of dimples the particles of intermetallic phases were observed.
- After the heat treatment, the morphology and size of ductile dimples changed, and those were more deformed and residual particulates at the bottom of dimples appeared more often than in as-cast state.

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АНАЛИЗА ПЛАСТИЧНЕ ДЕФОРМАЦИЈЕ ЛЕГУРЕ AZ61 У ОКОЛИНИ ПРСЛИНЕ

П. Палчек, И. Хлавачова, М. Шалупова

Анализиран је утицај микроструктуре на развој пластичне деформације у околини пропагирајуће прслине у легури Mg код које је отпорност на корозију повећана додатком 0.5 wt. % Ca. Прслина је иницирана савијањем у 3 тачке са постепеним додавањем оптерећења. Резултати ове анализе указују на значајније присуство трага клизања и деформације двојниковањем после потпуне полиедризације зрна у поређењу са материјалом у стању ливења.