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Light alloys for application as engine parts – comparison of properties of three materials

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Abstract

This paper discusses the mechanical properties, microstructure and crystallographic texture of light alloys made on the base of aluminium, magnesium and lithium. An acoustic emission (AE) technique was applied to detect the moment of twinning or slip activation during compression and channel – die tests to extend the comprehension on the nature of the plastic deformation processes occurring in the investigated alloys.

Introduction

Contemporary trends in vehicle and airplane designing place great emphasis on the reduction of the weight. This contributes to energy saving and to reduction of their negative environmental impact. One of the methods of weight reduction is use of aluminium and magnesium alloys. The diversity of these materials are currently in use. The alloys of the Mg–Li–Al system are foreseen for application. Short comparison of the properties of the light alloys is presented below.

The properties of aluminium alloys

Aluminium alloys are widely used in manufacturing aircraft and Diesel engines. They are used either to produce pistons and engine blocks. They have high ductility and corrosion resistance. At subzero temperatures, their strength can be increased. However, their strength can be reduced at high temperatures of about 200–250°C. Wide application in the industry have two members of the aforementioned material – 2618 alloy and A226 alloy. The chemical composition of the alloys are presented in table 1.

Table 1. The chemical composition of Aluminium 2618 and A226 alloys (percent by weight)

Element	2618 alloy, content [%]	A226 alloy, content [%]
Aluminium	93.7	ca. 84
Copper	2.3	2.0–3.5
Magnesium	1.6	0.1–0.5
Iron	1.1	0.4–1.2
Nickel	1.0	–
Silicon	0.18	8.0–11.0
Titanium	0.07	–
Manganium	–	0.15–0.55
Zinc	–	0.3–1.2

Both materials have good castability and can be machined in heat treated conditions. Tensile strength of 2618 alloy is 440 MPa, while yield strength is 370 MPa. This alloy can be additionally cold worked in the heat treated or annealed conditions. It can be applied to produce such engine parts as pistons or gearbox elements. Variations of the chemical compositions within the tolerance limits according to EN AB-4600 of A226 alloy cause pronounced changes in the mechanical properties.

The yield strength of permanent mold casts samples produced of the A226 alloy ranges from 100 to 300 MPa what pretends this material for production cost-effective high pressure castings of minor responsibility as: transmissions, crankcases or oil pans.

In the literature there are some information about the impact of the alloys on chemical composition on their mechanical properties [1]. Magnesium and copper increase the material strength due to solid solution hardening. Iron decrease the desired ductility. However, as for ductility the whole system has to be considered. Cu and Mg decrease the ductility due to their hardening effect and the higher level of intermetallic phases. The influence of increasing Mn contents is reflected in a partial compensation of the ductility – reducing the effect of iron. This can be explained by the transformation of the plate – shaped β – phase with high aspect ratio to the α – $Al_{15}(Fe\ Mn)_3Si_2$ which is less harmless to micro -cracking. The example microstructure of A226 alloy, containing pores taken from casting is presented in figure 1.

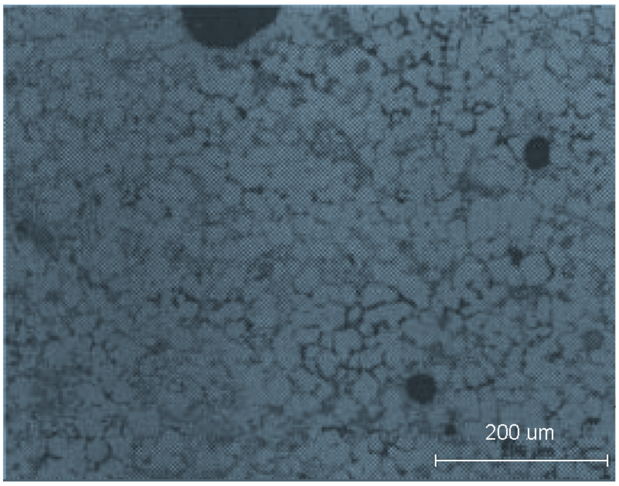

Fig. 1. A226 alloy microstructure comprising pores (black spots) made of cast, follow by [1]

The properties of aluminium alloy AZ31

Magnesium is the lightest structural element with desirable mechanical properties and its use is environment-friendly. However, due to hexagonal close-packed crystal structure, resulting in insufficient independent number of slip systems, magnesium alloys exhibit poor formability at ambient temperature.

Conventional methods of hot extrusion of Mg-AZ31 alloy results in the formation of inhomogeneous microstructure consisting of α–Mg matrixes and fine particles identified as Al–Mn phase with presence of inclusions and pores. The chemical composition (in mass%) of the alloy is the following: 3% Al, 1% Zn, 0.3% Mn and Mg (balance). Yield strength of AZ31 alloy is about 30% lower than that measured in 2618 alloy.

The distribution of grain size is characterized by large spread. Typically elongated coarse grains are surrounded by much smaller equiaxed recrystallized grains (Fig. 2, top). Such microstructure is not beneficial for plastic properties of magnesium alloys. The elongated coarse grains have basal planes mostly parallel to the direction of extrusion so their rotation due to basal slip at room temperature is very limited. These grains undergo contraction or tensile twinning depending on applied strain tensor. In result many twinning boundaries are formed inside elongated grains and they are recognized as spots of crack initiation during cold deformation [2].

Hot extruded rods typically have strong fiber texture (Fig. 2, bottom) with basal planes and ⟨01–10⟩ direction lying parallel to the extrusion direction. Such texture formation is ascribed to preference of basal slip even at high temperatures due to large difference in critical resolved shear stress (CRSS) between the basal slip and non-basal slips [3]. Strong texture decreases the ability of

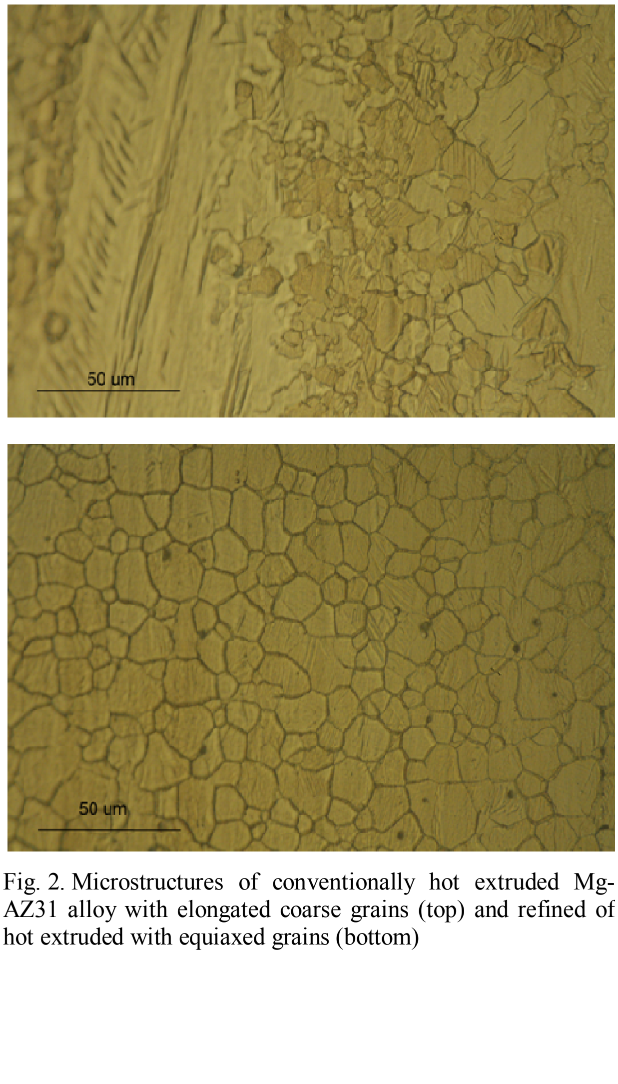

Fig. 2. Microstructures of conventionally hot extruded Mg-AZ31 alloy with elongated coarse grains (top) and refined of hot extruded with equiaxed grains (bottom)

Mg–AZ31 alloy extrusions to deform at room temperature, because again basal slip is the main deformation mode. However, the effect of deformation twinning in coarse grains enables some strain until twin saturation. It has been observed that almost whole initial grains can be consumed by following generations of twins [3].

We discuss the possibility of enhancing plasticity of magnesium alloys by proper modification of microstructure. The application of new method of hot extrusion prevents formation of coarse elongated grains having a detrimental effect on the Mg–AZ31 alloy plasticity. Grain refinement can also support activation of additional prismatic slip, which has relatively low CRSS, due to stress concentration at grain boundary [4].

In the paper, the results of investigations of ductile Mg–AZ31 alloy are presented. The rod extrusions, favorably oriented for {10–12} ⟨10–11⟩ twinning were tested in compression to various extent. Analysis of grain orientation, twinning saturation and crystallographic texture supports description of the microstructure changes. An acoustic emission (AE) technique was also used in this approach to detect the moment of twinning or slip activation during compression tests (Fig. 3). Acoustic emission activity of light alloys was described in detail in [5, 6] and the details of the application of the AE method has been already presented earlier in this Journal [7]. The comparison of AE diagrams with orientation image maps shows correlation between microstructure changes and AE peak occurrence.

The investigation of novel alloys of Mg–Li–Al system

The Mg–Li alloys have been still attractive candidates for light and tough construction materials for the application in automobile (e.g. car engine housings), aviation and space industries. The alloys can occur in three different phase areas. The alloys containing up to 4 wt. % Li consist of α phase of hexagonal lattice A3 (*hcp* – hexagonal close-packed cell), while these with above 12 wt. % Li are in the form of β phase, which is cubic A2 (*bcc* – body centered cubic cell). The alloys of Li content from 4 up to 12 wt. % are two-phase and occur as the mixture of $\alpha + \beta$ phases. The mechanical properties of the α phase are worse than these of the β phase, which reveals very good plasticity. The methods of intensive deformation have recently been more frequently applied [8] in order to obtain ultra fine-grained refinement which ensures high strength and plasticity as well as prospects for the superplastic flow of the material in conditions of relatively low temperatures. The AE technique has been helpful in the examinations of deformation mechanisms in alloys of described system, particularly regarding the mentioned materials of ultra fine-grained (nonocrystalline) morphology obtained after processing with intensive strain methods. These methods are applied to increase the relatively low level of strength of the alloys of Mg–Li–Al system. The aim of the research made by the authors of the paper was to describe and explain the correlations between the proceeding of the

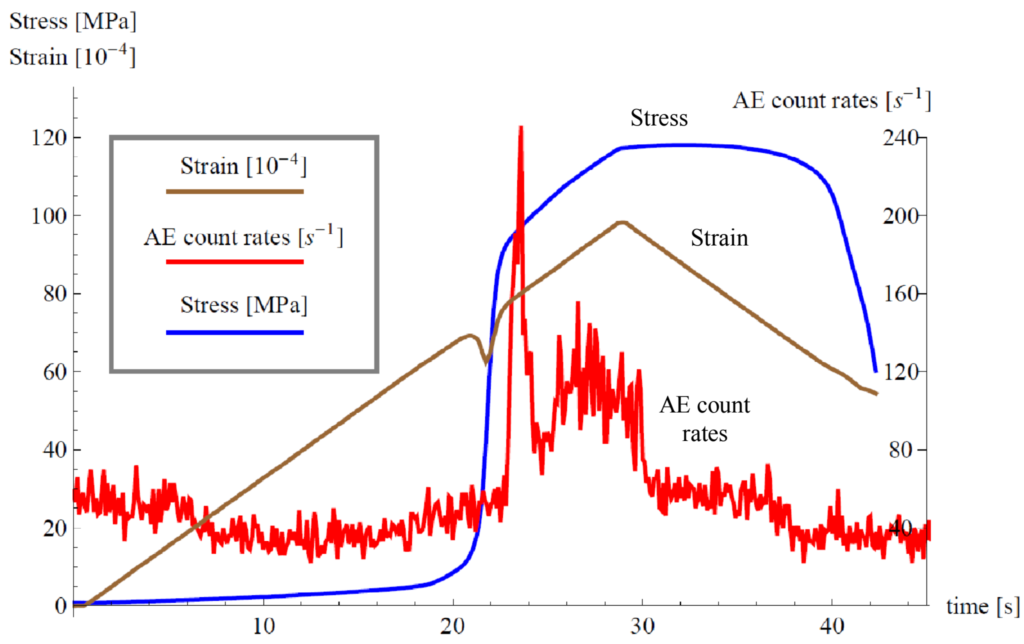

Fig. 3. Stress-strain curve, AE count rates and strain in interrupted compression test for Mg–AZ31 alloy at room temperature and strain rate of 0.00035 1/s

generated AE signals and the mechanisms of plastic (or possible superplastic) deformation in the Mg–Li alloys subjected to compression tests in the channel-die before and after the application of High Pressure Technique (HPT). The Scheme of HPT method is presented in figure 4. The sample is in the form of cylinder of base radius R and height L. Non-dilatational deformation γ after N rotations is $\gamma = 2\pi RN)/L$, while the equivalent deformation is $\varepsilon_N = \gamma/1.73$.

The samples destined for the torsion and HPT tests were in the form of discs of diameter 10 mm and thickness 2÷5 mm. The compression tests in the channel-die were performed in the INSTRON–3382 testing machine before and after the HPT processing. The traverse speed of the machine was 0.05 mm/min. Simultaneously with the registration of external force F the parameter of AE events rate of $\Delta N/\Delta t$ [1/s], was recorded.

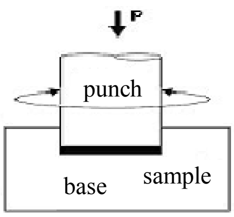

Fig. 4. The Scheme of HPT method

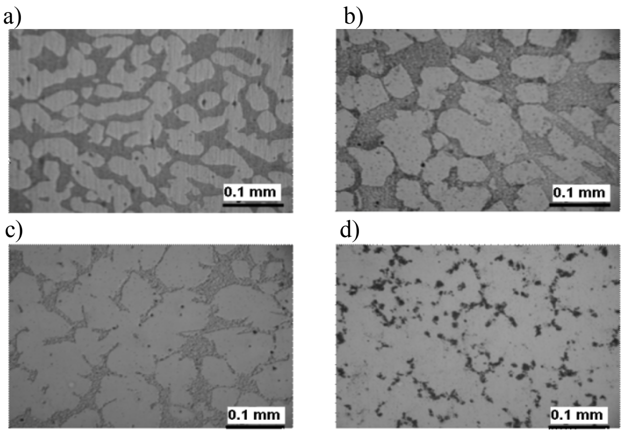

Fig. 5. The light microphotographs of alloys Mg9Li (a), Mg9li1Al (b), Mg9Li3Al (c) and Mg9Li5Al (d) before the HPT operation

A broad-band piezoelectric detector registered acoustic impulses in the frequency range from 5 up to 200 kHz. The contact of the sensor with the sample was maintained with the aid of steel rail which was a washer in the channel die. The total amplification of acoustic signals was 70 dB, while the discriminator threshold voltage – 0.5 V. To minimize the effects of friction, each sample was covered with a Teflon foil. The examinations were carried out on the alloys Mg9Li, Mg9li1Al, Mg9Li3Al and Mg9Li5Al. The compression tests were performed on samples after one-, two-, four- and six-fold HPT operations. The optical microstructres of these three alloys before the HPT operation are presented in figure 5. Figure 6 presents the TEM microphotograph of Mg9Li alloy before and after 6-fold HPT operation.

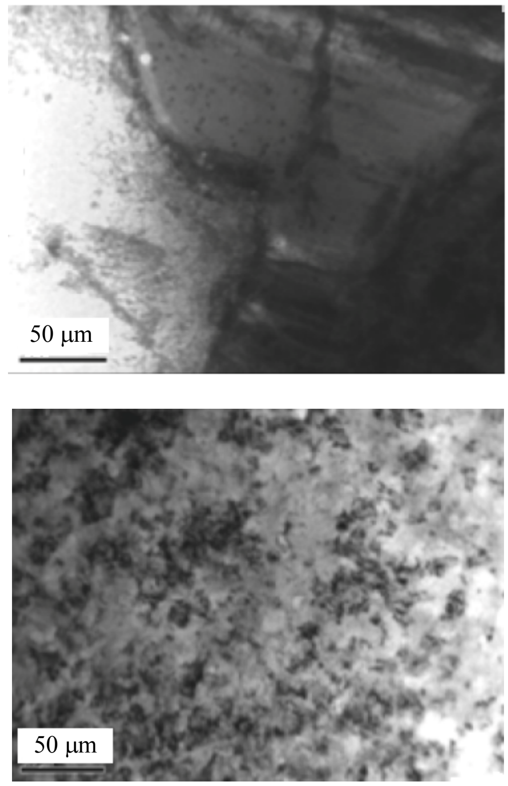

Fig. 6. TEM microphotographs of Mg9Li alloy before and after 6-fold HPT operation

Analysing the AE behaviour in samples compressed before and after processing with the HPT method (Figs. 7–9), it can be stated that the level of AE intensity significantly decreases in the compressed material HPT processed with respect to the unprocessed ones. Moreover, AE practically decays in specimens six times processed by HPT (Fig. 9). The phenomenon of the decrease of AE intensity and activity observed in the materials subjected to the HPT processing results generally from the increase of the grain refinement and can be explained based on the consideration of two important processes. It is assumed first, that the mechanism of generation of AE impulses is connected with collective and highly synchronized accelerated motion of groups of many dislocations as well as internal and surface annihilation of them [7]. The first process effects from the mechanism of strengthening during intensive deformation, which consists in the increase of dislocation density compared with the state before the HPT. In this way, the tendency to the collective, synchronized motion of dislocations generated during the plastic deformation is highly restricted by the immobile forest of dislocations.

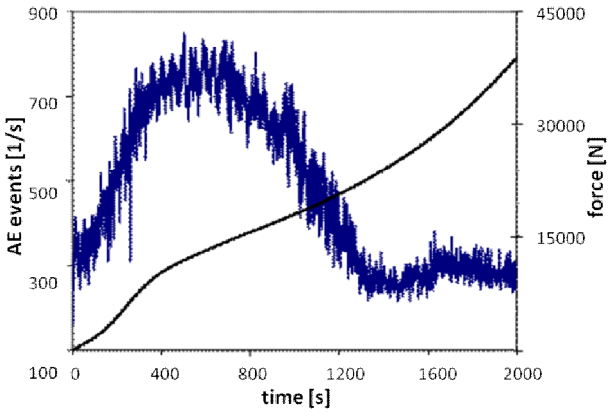

Fig. 7. AE events rate and external force in Mg9Li alloy compressed before HPT process

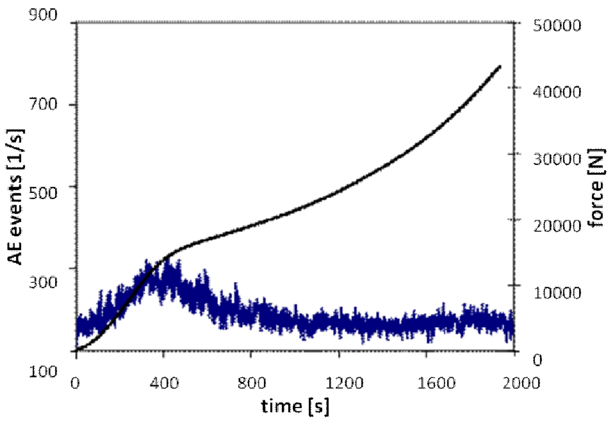

Fig. 8. AE events rate and external force in Mg9Li alloy compressed after 4-fold HPT process

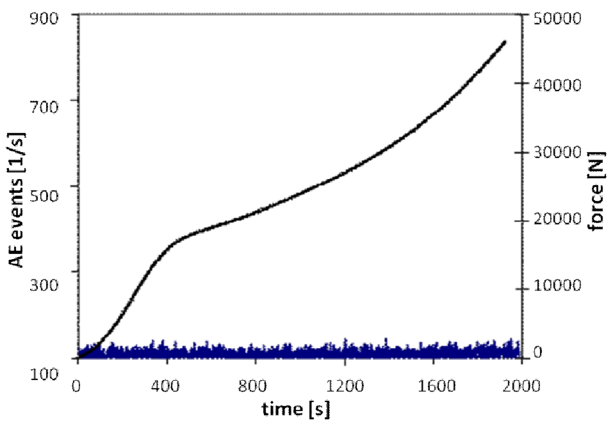

Fig. 9. AE events rate and external force in Mg9Li alloy compressed after 6-fold HPT process

Conclusions

The obtained results allowed drawing the following conclusions:

- Intensity and activity of acoustic emission in Mg–Li–Al alloys subjected to compression tests after processing with the HPT method distinctly decreases in comparison to unprocessed alloys.
- The AE decrease in alloys processed with the HPT technique is related with the increase of the degree of grain refinement and the tendency to the increase of plasticity.
- The increase of AE accompanying the increase of Al content in the Mg–Li–Al alloys results from the growth of volume contribution of more efficient acoustically hexagonal α phase.
- The correlations between the AE and the strain mechanisms may be interpreted based on collective and highly synchronized processes of accelerated motion and annihilation of great amount of dislocations.
- The hypothesis, that the decrease of AE in the Mg–Li–Al alloys compressed after intensive strain HPT processing is connected with the work-hardening processes and the appearance of slip along the grain boundaries was put forward.

Acknowledgements

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