Archives of Materials Science and Engineering

Volume 68
Issue 2
August 2014
Pages 66-74

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Utilization of acoustic emission at study of mechanical properties and structure of magnesium-aluminium alloy AZ61 under elevated temperatures

L. Čížek [a], A. Hanus [a], P. Lichý [a], T. Tański [b,*], M. Kraus [a], S. Rusz [a], W. Borek [b]

[a] VŠB – Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava, Czech Republic

[b] Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland

* Corresponding e-mail address: tomasz.tanski@polsl.pl

Received 20.05.2014; published in revised form 01.08.2014

ABSTRACT

Purpose: This work present experimental determination of the elastic-plastic condition of the magnesium alloy depending on the temperature and pace of the sample tensile stress.

Design/methodology/approach: At the acoustic emission (next denoted the „AE”) use, tensile tests at high temperatures may, among other things, be used for analysis of the AE signal sources and set, in more detail, the temperature limit of elastic-plastic deformations existence in the material under examination. The AE is, during tensile tests at high temperatures, based on the scanning of released elastic waves generated by sharp tension changes in the body as a result of the subsequent physical-metallurgical processes such as plastic deformation, tension redistributing, creation of microcracks and their spreading in macroscopic scale.

Findings: The aim of the acoustic emission monitoring at tensile tests at higher temperatures is therefore the specification of the critical heat barrier of the elastic-plastic condition of materials and provision of information concerning the dynamics of deformation processes at tension including influences of surface layers for which acoustic emission, as confirmed by measurement results is a very suitable method.

Research limitations/implications: The results of testing above mentioned magnesium alloys will serve for evaluation of possibility those magnesium alloys for application of SPD methods. Presented work was further focused on determination of structure characteristics including investigation of fracture characteristics with use of light microscopy and SEM analysis.

Originality/value: Knowledge of the relaxation properties of metal materials at high temperatures is necessary for the verification of susceptibility of castings to the creation of defects during the production process. Generated tensions in the castings are the cause of creation and development of defects.

Keywords: Magnesium alloys; Mechanical properties under elevated temperatures; Structure; Acoustic emission

Reference to this paper should be given in the following way:

L. Čížek, A. Hanus, P. Lichý, T. Tański, M. Kraus, S. Rusz, W. Borek, Utilization of acoustic emission at study of mechanical properties and structure of magnesium-aluminium alloy AZ61 under elevated temperatures, Archives of Materials Science and Engineering 68/2 (2014) 66-74.

PROPERTIES

1. Introduction

At the contemporary stage of the development of the engineering thought, and of the product technology itself, material engineering entered the period of new possibilities of designing and manufacturing of elements, introducing new methods of melting, casting, forming, and heat treatment of the casting materials, finding wider and wider applications in many industry branches. Engineers whose employment calls for significant expenditure of labour and costs strive to reduce material consumption. Therefore the development of engineering aims at design optimizing, reducing dimensions, weight, and extending the life of devices as well as improving their reliability. Scope of utilisation of foundry magnesium alloys is continuously being extended, therefore, if we aim at becoming compe-itive producers, it is necessary to actively investigate properties of alloys, optimise their chemical composition and study metallurgy processes, including heat treatment [1-4]. In this research, complex evaluation of magnesium alloy AZ61 requires the acoustic emission monitoring at tensile tests at elevated temperatures and the study of structure and mechanical properties, including investigation of fracture characteristics using the SEM.

2. Problem analysis

The AE is, during tensile tests at high temperatures, based on the scanning of released elastic waves generated by sharp tension changes in the body as a result of the subsequent physical-metallurgical processes such as plastic deformation, tension redistributing, creation of microcracks and their spreading in macroscopic scale [5,6]. The level of emitted elastic waves is, among other things, substantially influenced by the nature of the voltage field in the body as it determines the level of dynamics of the given process and thus various level of its discontinuity. The elastic wave released during the given physical-metallurgical process is actually an energy surplus unexpended for the given process. E.g. part of energy unexpended during crack spreading is used for its motion and creation of new surfaces and is emitted in the form of elastic waves and heat to the surface [4-8]. The AE is thus an instrument for evaluation of mutual interaction between the supplied energy and actual process [9,10]. As far as tensile tests are concerned, the loading system has a substantial influence on the response of the stressed material and thus the AE signal at emitted frequencies id detected. It is therefore necessary to monitor the strength influence of the loading system and pace of deformation when the test body is stressed. The tensile test may be generally divided into three basic parts: a) elastic stress up to the yield limit; b) plastic deformation area; c) strengthening and break of the test. In each of the above-mentioned areas, there are elastic waves released by various mechanisms. The tension level increases and surface layers crack during the elastic stress. Most energy of the released waves is reached around the yield limit where there is a sharp change of the voltage field in the test body. On the contrary, the AE signal has a nature of the so-called "white noise" with low energy levels during the plastic deformation. The signal amplitude increases, material strengthens and microcracks are initiated until cohesion is torn up – sample breaking at the end of the tensile test. That is confirmed by the results of the experiment.

3. Material and experimental procedures

Experimental investigation was done with the use of cast plates (size 10x20x150 mm) of magnesium alloy AZ61 (after ASTM Standard) in the initial state as a cast. Chemical composition of alloy is given in Table 1.

Testing of mechanical properties under elevated temperatures was made on electrohydraulic tensile testing machine INOVA- TSM 20 with a loading force of 20 kN) with added acoustic emission monitoring device [10]. The test bar had a form of bar with the length of 115 mm and 6 mm in diameter, the diameter was reduced in the central part to 4 mm in the length of 30 mm and was warmed up in a graphite furnace in inert argon atmosphere. Its surface temperature was measured with a Pt/PtRh thermocouple placed in a hole of the furnace jacket. Spots of test bar fixing as well as spots of argon connection were cooled by water. The AE scanners were mechanically fixed on adjusted journals in the top and bottom part of the tensile test coming from the furnace. The manner of canners fixing was designed and implemented so that a perfect acoustic link between the scanner and test sample was ensured.

Table 1.
Chemical composition of alloy (weight %)

Al	Zn	Mn	Si	Cu	Fe	Be	Zr	Sn	Ni	Pb
5.92	0.49	0.15	0.037	0.003	0.007	0.0003	0.003	0.01	0.003	0.034

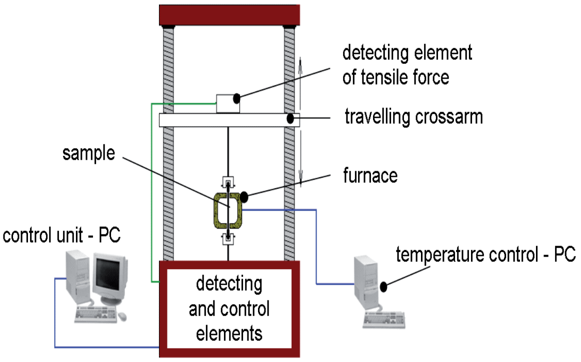

Fig. 1. Experimental set

The temperature on scanners did not exceed the value of 80°C during the testing. Details concerning the experimental equipment are mentioned in Fig. 1. The AE scanner records released elastic waves (overshoots) in a frequency band between 30 kHz and 400 kHz. The output from the scanner is carried to the AE preamplifier where it is amplified and impedance-adjusted so that it can be transferred to the further reaching places. After that, the signal is carried to the EMIS 01 system and then out with an RS 485 serial channel. The measured data are stored to the PC's hard disk and are processed in the EXCEL software after being converted into a text form. The purpose of the measurement was the study of deformation and tension at the tensile test with simultaneous acoustic emission measurement. These dependencies were also monitored at: a) various temperatures of sample heating from 15°C to 400°C and b) various paces of the crosshead shift of 6 mm/min and 0.6 mm/min.

4. Results of measurements AE and their evaluation

Dependency between the sample deformation course until its destruction and the AE response at various sample temperature at the crosshead shift pace of 6 mm/min was monitored in the first series of trials and 0,6 mm/min was monitored in the second series of trials. The measurement was performed at four temperature levels in the range from 15°C to 400°C. The curves of sample loading and AE course characterise at the initial stage of burdening the elastic condition of the material followed by the plastic condition, which corresponds with the reality. Figs. 2-6 show records of tensile strengths at various temperatures (black line) with appropriate records of the acoustic emission (colour lines – selected emitted frequencies) at a shift of separator jaws of 6 mm/min between 15°C and 400°C. Fig. 7 shows the comparison of tensile stress curves – 6 mm/min. Figs. 8-11 show records of tensile strengths at various temperatures with appropriate records of the acoustic emission at a shift of separator jaws of 0.6 mm/min between 15°C and 400°C.

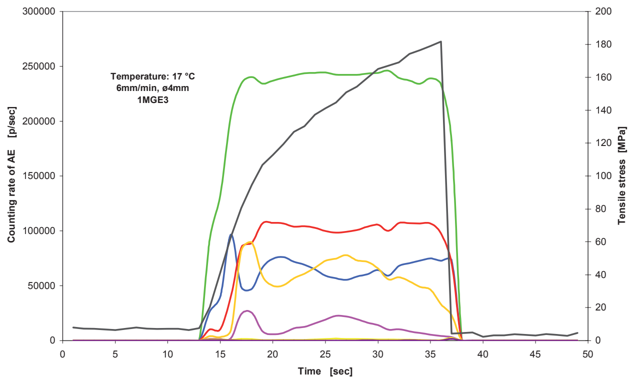

Fig. 2. Record of tensile stress curve with AE – 6 mm/min, 17°C

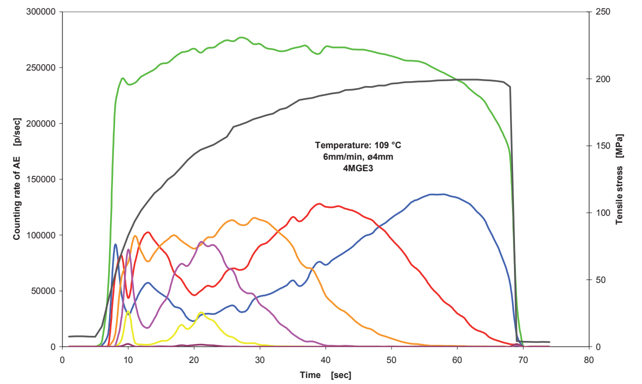

Fig. 3. Record of tensile stress curve with AE – 6 mm/min, 109°C

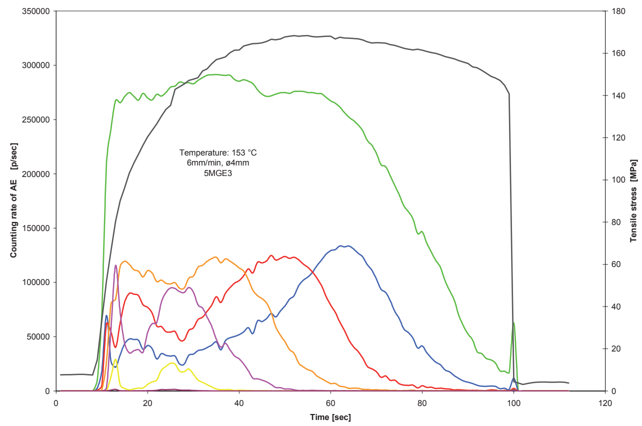

Fig. 4. Record of tensile stress curve with AE – 6 mm/min, 153°C

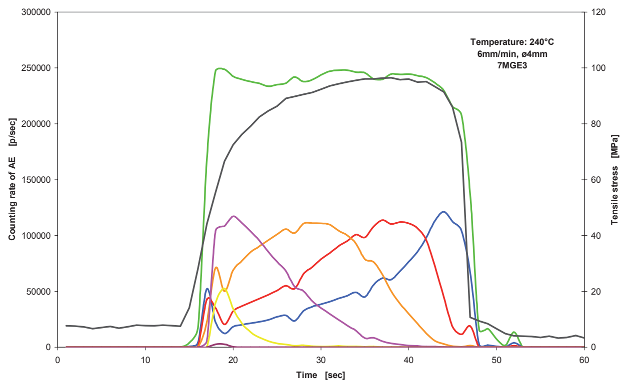

Fig. 5. Record of tensile stress curve with AE – 6 mm/min, 240°C

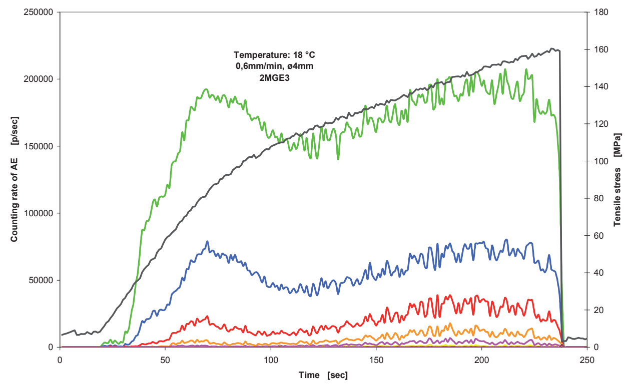

Fig. 8. Record of tensile stress curve with AE – 0.6 mm/min, 18°C

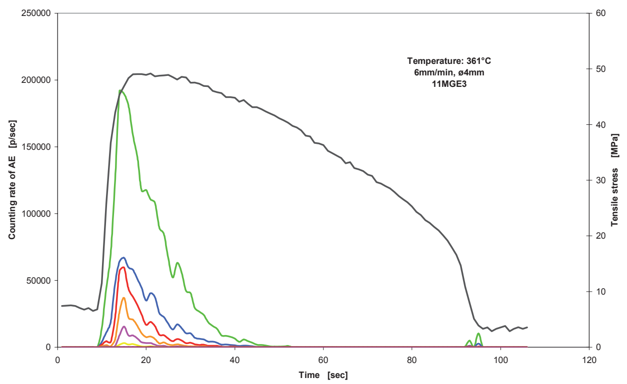

Fig. 6. Record of tensile stress with AE – 6 mm/min, 361°C

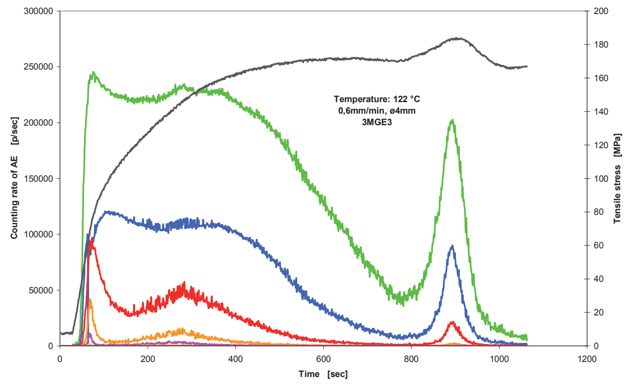

Fig. 9. Record of tensile stress curve with AE – 0.6 mm/min, 122°C

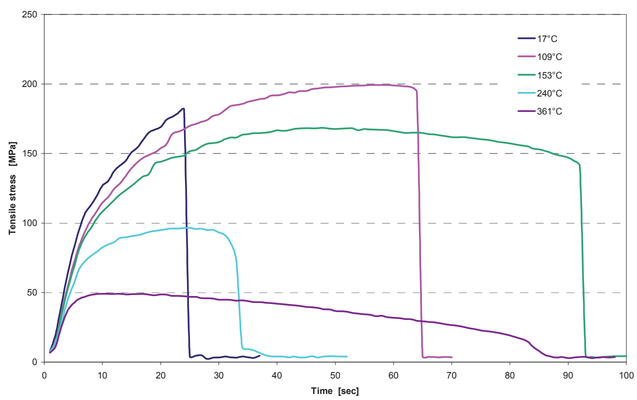

Fig. 7. Comparison of tensile stress curves – 6 mm/min

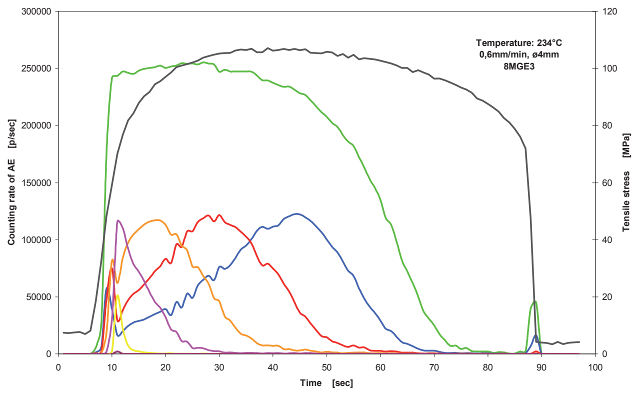

Fig. 10. Record of tensile stress curve with AE – 0.6 mm/min, 234°C

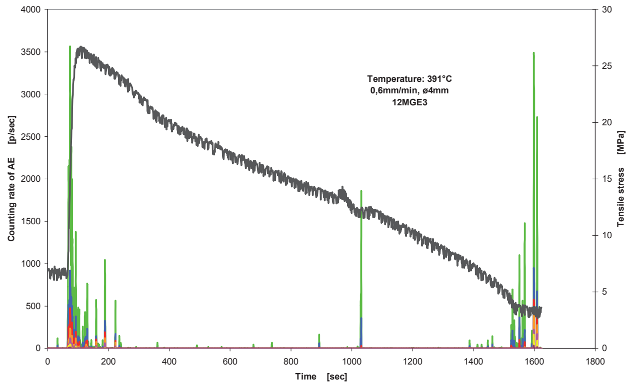

Fig. 11. Record of tensile stress curve with AE – 0.6 mm/min, 391°C

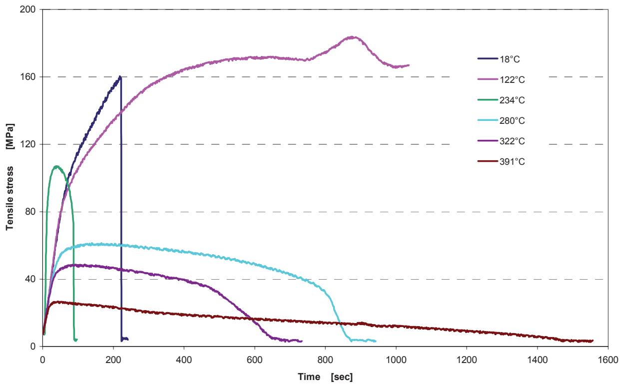

Fig. 12. Comparison of tensile stress curves – 0.6 mm/min

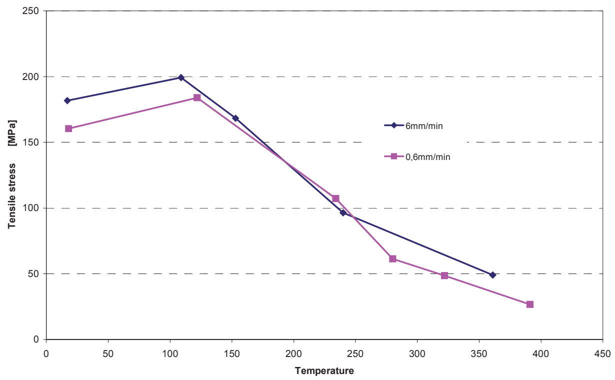

Fig.13. Comparison of tensile stress curves with crosshead rate 6 and 0.6 mm/min

Similarly as the temperature increases, also the lower pace of the crosshead of 0.6 mm/min at sample loading works upon material properties. It is shown by the decrease in the strength limit with a current increase in the entire deformation prior breaking. The plastic deformation mechanism is different compared to a higher loading pace. At a lower deformation pace, a more equal state of stress in the test sample is generated, which is finally reflected by lower levels of the emitted signal. The level of elastic stress and frequency of emitted elastic waves and their energy also decreases with a higher temperature. The plastic deformation share, by contrast, increases. The lower strength limit of the material at the current increase in the entire deformation and decrease in the emission activity at a higher loading pace is probably invoked by a different mechanism of the plastic deformation compared to actions at higher paces of sample loading. The results of the tensile strength depending on the temperature and pace of loading at the magnesium alloy are included in Fig. 12. The sudden strength decrease takes place at as low temperature as 110°C. The different pace of sample loading (6 mm/min and 0.6 mm/min) leads to a situation when the material is strengthened more intensively as far as deformation is concerned. The consequence includes reaching of higher strength values (see Fig. 13). At lower test temperatures, processes connected with the generation and release of dislocations and their subsequent interactions with eventual interstitials take apparently place).

5. The complex evaluation of mechanical properties

The evaluated results indicate that state of stress changes are accompanied with an emitted signal with higher amplitudes while the plastic deformation development leads to restricted AE overshoots. That is connected with the development of the plastic deformation of a basic die including the possible reorientation of prior defects in the die. The detailed measured values at tensile tests are included in Table 2.

6. Metallographic and fracture analysis

In order to complete the obtained results and to clarify the mechanical properties measured (Table 2), an evaluation of microstructure and character of fracture was performed in the relevant samples of the tensile tests at crosshead rate 6 mm/min. Light microscope NEOPHOT 2 was used to evaluate the microstructure of alloys. For fracture characteristics investigation SEM JEOL 50A was used. The sample microstructure in an initial state of the alloy before tensile tests is shown in the Figure 14. Microstructure in initial as cast state is formed by crystals of matrix on the basis of magnesium, surrounded by minority phases of the type $Mg_{17}Al_{12}$ in almost continuous formations in interdendritic areas, which may represent places of initiation and propagation of failure at tensile test [11,12]. At temperatures from 240°C to 361°C there occurs partial dissolution and coagulation of the massive phase (Figs. 15a-18a). These processes are accompanied by forming of micro-pores in interdendritic areas contributing also to initiation of crack propagation along the phase boundary [5]. The examples of fracture areas and microstructure near the fracture surface after testing in the cutting plane parallel with its axis of samples at selected temperatures are shown in the Figures 15b-18b. Predominant fragile interdendritic character of failure was demonstrated on fracture surfaces at all temperatures exception temperature 361°C, where ductile hollow fracture prevailed.

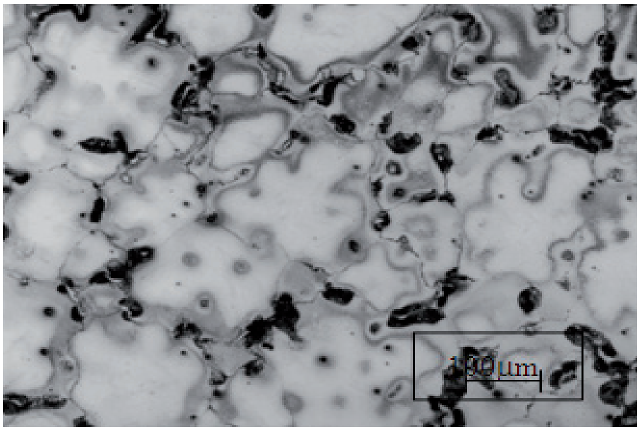

Fig. 14. Microstructure of sample in initial state of alloy

Table 2.
Mechanical properties of experimental material

Sample	Experimental temperature, °C	Tensile force, N	Tensile rate, MPa	Diameter of fracture surface, mm	Reduction of area, %	Deformation to fracture, mm	Deformation energy, J
Crosshead rate 6 mm/min							
1	17	2282	181.7	3.84	8	2.95	4.65
4	109	2505	199.5	3.58	20	6.88	13.94
5	153	2116	168.4	3.21	36	9.84	18.17
7	240	1212	96.5	3.70	14	4.13	3.80
11	361	618	49.2	2.21	69	8.58	3.81
Crosshead rate 0.6 mm/min							
2	18	2016	160.5	3.85	7	2.14	2.99
3	122	2311	184.0	3.28	33	10.15	19.53
8	234	1347	107.3	2.88	48	8.61	10.12
9	280	770	61.3	2.91	47	8.02	4.93
10	322	611	48.7	2.93	46	6.22	2.7
12	391	336	26.7	1.83	79	13.62	-

a) b)

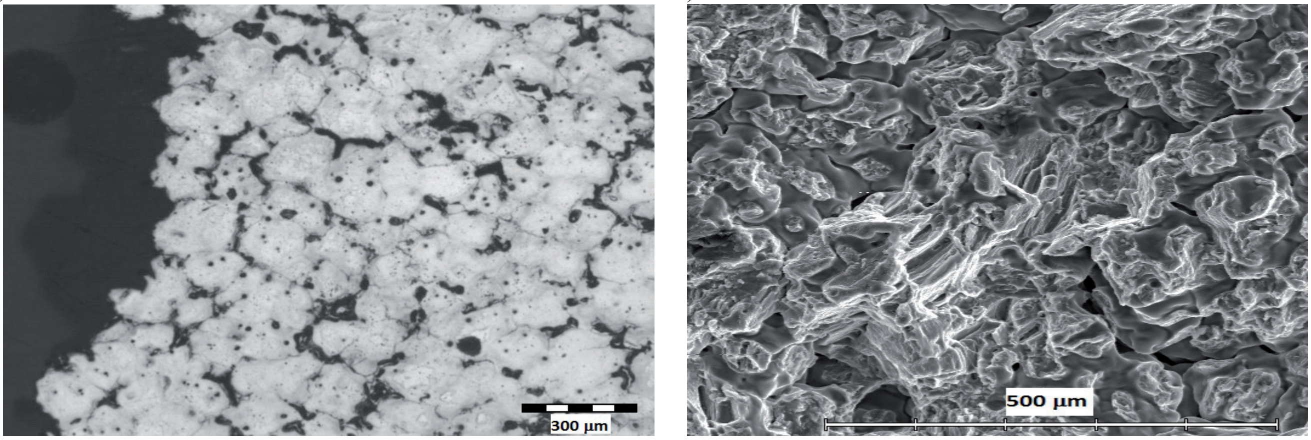

Fig. 15. Testing temperature – 17°C: a) microstructure of sample, b) fracture areas of sample

a) b)

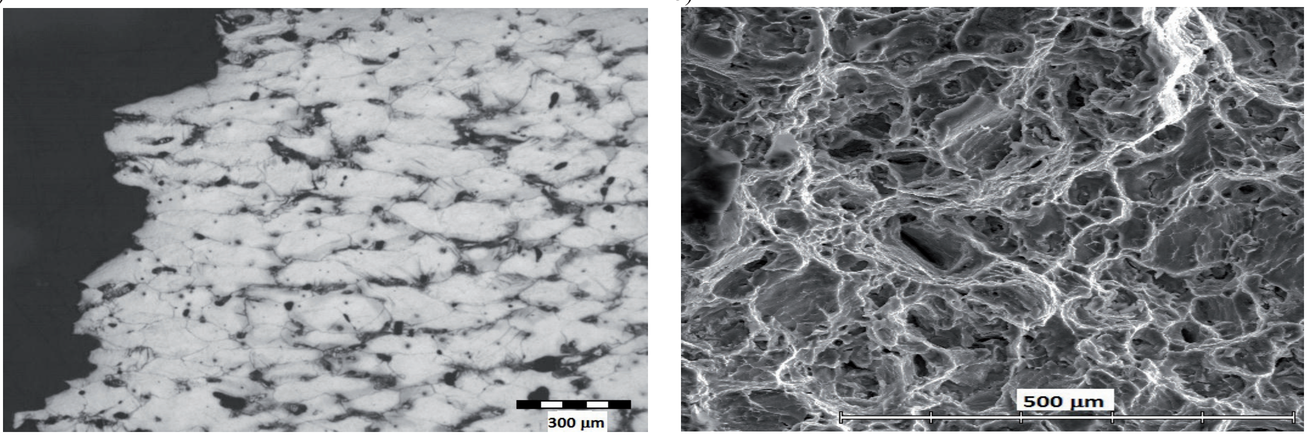

Fig. 16. Testing temperature – 153°C: a) microstructure of sample, b) fracture areas of sample

a) b)

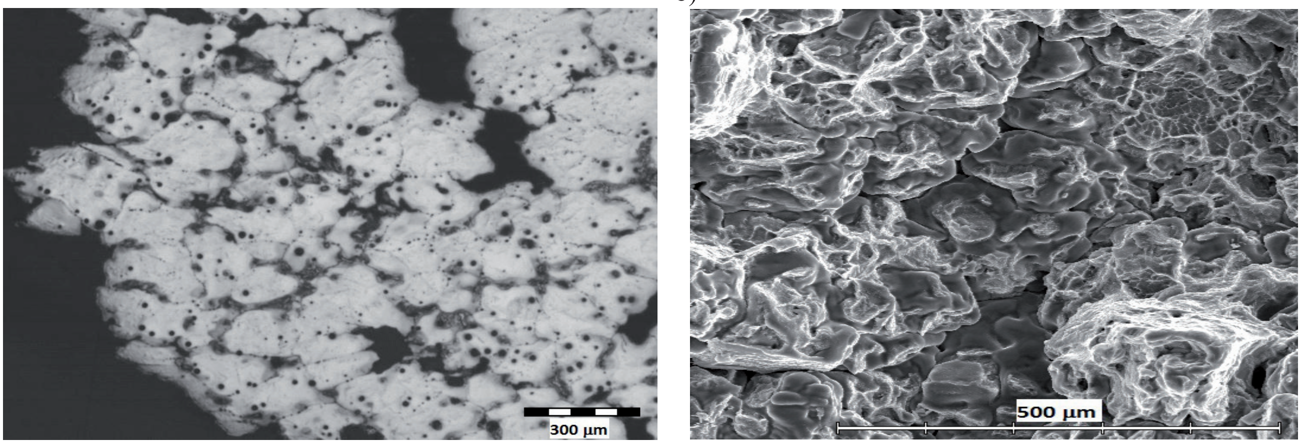

Fig. 17. Testing temperature – 240°C: a) microstructure of sample, b) fracture areas of sample

a) b)

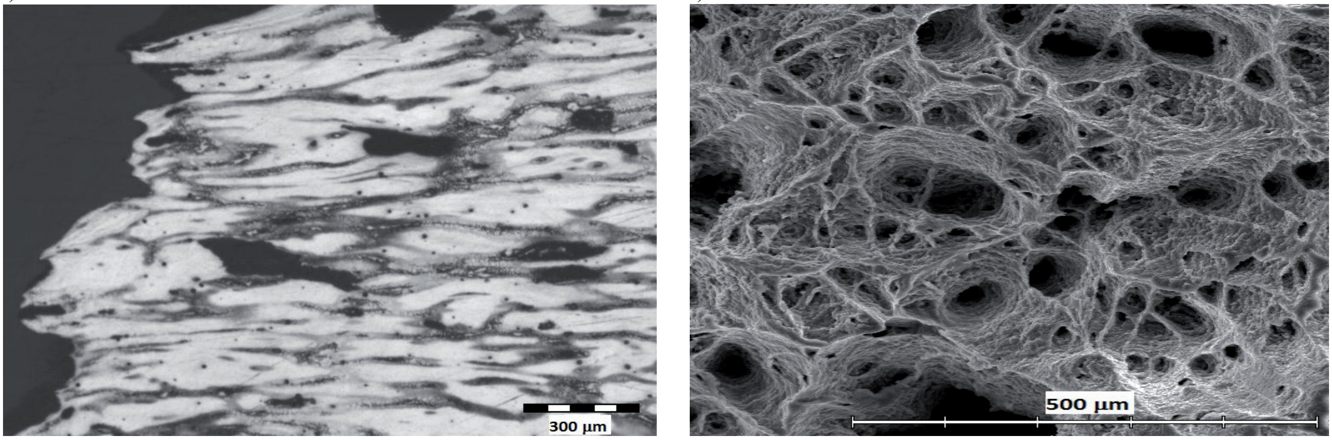

Fig. 18. Testing temperature – 361°C: a) microstructure of sample, b) fracture areas of sample

7. Conclusions

The authors of the presented work solve an experimental determination of the elastic-plastic condition of the magnesium alloy depending on the temperature and pace of the sample tensile stress. An acoustic emission method was used for a better analysis of the course of the deformation action at the tensile test. The AE method enables to study the dynamics of these processes at various temperatures and at various loading manners [5]. The different nature of the signal, whose source includes the plastic deformation, compared to a signal generated with an elastic condition of the state of stress, significantly contributes to the specification of temperature limits between both deformation processes at the magnesium alloy. The measurement results appeared to be very promising. It was found out that:

- within app. 110°C, the strength limit with the temperature and deformation pace increase and then decrease,
- the increased loading pace of a crosspiece shift of 6 mm/min generates higher strength than the pace of 0.6 mm/min,
- the opportunity to study deformation processes preceding initiation of cracks and monitoring the initiation and crack growth up to the macroscopic scale is a big advantage of the AE.
- the method is therefore used in technical diagnostics and to check technological operations in the production process.

The following conclusions can be drawn from results of evaluation of mechanical properties, structural and fracture characteristics of the used magnesium alloys at cast state and after heat treatment:

- microstructure of the alloy in initial state is formed by solid solution and by minority phases $Mg_{17}(Al,Zn)_{12}$ in massive and dispersion form,
- microstructure has interdendritic character, minority phases are comparatively continuously distributed in interdendritic areas, which represent suitable places for initiation and propagation of cracks under load,
- 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 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, especially at higher temperatures,
- during increasing of plastic properties in the temperature interval from 250 to 300°C some role is played, among others, also by certain homogenisation of microstructure, their decrease at the temperature above 300°C can be connected with formation of continuous non-integrities, or with melting of residues (of eutectic) phase in interdendritic areas,
- failure occurs practically at all temperatures basically by inter-crystalline splitting along the boundaries of original dendrites exception temperature 361°C, where ductile hollow fracture prevailed.

Acknowledgements

This paper has been elaborated in the framework of the project „Support research and development in the Moravian-Silesian Region 2013 DT 1 - International research teams“ (02613/2013/RRC) - financed from the budget of the Moravian-Silesian Region Czech Republic and on the base of co-operation with VŠB – TU Ostrava, Faculty of Mechanical Engineering with Silesian University of Technology, Gliwice.

References

[1] M. Avedisian, H. Baker, Magnesium and Magnesium Alloys, ASM Speciality Handbook, 1999.

[2] T. Tański, L.A. Dobrzański, L. Čížek, Influence of heat treatment on structure and properties of the cast magnesium alloys, Journal of Advanced Materials Research 15-17 (2007) 491-496.

[3] L. Čížek, M. Greger, L. Pawlica, 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.

[4] C.B. Sruby, J.H. Speake, Acoustic Emission for Physical Examination of Metals, International Metals Reviews 2 (1980) 41-64.

[5] H.N.G. Wadley, R. Mehrabian, Acoustic Emission for Materials Processing: a Review, Materials Science and Engineering 65 (1984) 245-263.

[6] J.R. Zurbrick, Direct Nondestructive Prediction of Engineering Properties, Journal of Testing and Evaluation 1/1 (1973) 13-123.

[7] L.A. Dobrzański, W. Borek, Hot-rolling of advanced high-manganese C-Mn-Si-Al steels, Materials Science Forum 706-709 (2012) 2053-2058.

[8] L.A. Dobrzański, W. Borek, Hot-Working Behaviour of Advanced High-Manganese C-Mn-Si-Al Steels, Materials Science Forum 654-656 (2010) 266-269.

[9] F. Havlíček, P. Kozelský, J. Crha, Monitoring of tensile test by acoustic emission at elevated temperatures, Sborník mez. Konference „Spolupráce 2005“, Zakopane 7-9.04.2005, 75-84 (in Czech).

[10] T. Tański, L.A. Dobrzański, L. Čížek, Influence of heat treatment on structure and properties of the cast magnesium alloys, Proceedings of the International Conference on Processing & Manufacturing of Advanced Materials, Processing, Fabrication, Properties, Applications, THERMEC'2006, Vancouver, Canada, CD-ROM.

[11] L. Čížek, M. Greger, L.A. Dobrzański, I. Juřička, R. Kocich, L. Pawlica, T. Tański, Mechanical properties of magnesium alloy AZ91 at higher temperatures, Journal of Achievements in Mechanical and Materials Engineering, 18 (2006) 203-206.

[12] L.A. Dobrzański, W. Borek, Thermo-mechanical treatment of Fe-Mn-(Al,Si) TRIP/TWIP steels, Archives of Civil and Mechanical Engineering 12/3 (2012) 299-304.