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Mechanical properties and structure of magnesium alloy AS31

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Abstract

Contemporary materials should possess high mechanical properties, physical and chemical, as well as technological ones, to ensure long and reliable use. The non-ferrous metals alloys used nowadays, including the magnesium alloys, meet the above-mentioned requirements and expectations regarding the contemporary materials.

Magnesium alloys are primarily used in aeronautical and automobile industry in wide variety of structural characteristics because of their favorable combination of tensile strength (160 to 365 MPa), elastic modulus (45 GPa), and low density (1 740 kg/m^3), which is two-thirds that of aluminum). Magnesium alloys have high strength-to-weight ratio (tensile strength/density), comparable to those of other structural metals. [1-6]

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. Temperature limits of materials where highest tension values are generated may be detected with tensile tests under high temperatures. The generated tensions in the casting are a cause of the creation and development of defects. At acoustic emission (hereinafter called 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 results of the temperature drop where tension at casting cooling is generated or its release at heating are basic data for controlled cooling mode (and temperature of casting knocking out of the form) as well as necessary for the thermal mode for the casting tension reduction. [7-9]

Knowledge of elastic-plastic properties at elevated temperatures is often important for complex evaluation of magnesium alloys. Objective of the work was focused on determination of changes of elastic-plastic properties of magnesium alloy AS31.

Keywords: Mechanical properties; Metallography; Magnesium alloy AS31; Relaxation properties at elevated temperatures.

1. Introduction

The still more demanding requirements in the production of vehicle moldings (decrease of fuel consumption, higher performance of car motors, safety issues, etc.) result in the use of materials which provide better mechanical, physical and technological qualities. To adhere to this trend, we may enhance the currently used materials or we may develop new ones, such as composite materials, inter-metal alloys or others. In the production of materials, frequently intended for the founding industry, the nucleation, modification, alloying and heat-treatment operations, including combinations of these technological procedures, are used mostly.

Due to the here above-mentioned reasons, the use of moldings, which are made of light and non-ferrous metals, starts to grow and even in the production of cylinder heads or blocks of compressor engines. In the production of machine parts prevails use of aluminum alloys along with use of alloys made of magnesium [2, 5, 6].

Magnesium alloys represent a group of nonferrous materials with the highest increase in their production (approximately by 12% per annum [4]). The reason for this growth is the low material density and great physical and mechanical qualities of these alloys. To reach the quality of these alloys, the casting under pressure is preferred. Despite this fact, this technological procedure is not used in the Czech Republic so often.

Another possibility to increase the quality of alloys is the improvement of production procedures and of the machines used in the production and development of new technologies which will enable treatment of metals in semi-solid state (squeezecasting, rheocasting, thixocasting) which combine casting and moulding operations. [4, 10]

2. Description of alloy

In our research, we have used magnesium alloy, which is used in the production of mouldings by means of their pressure casting. The alloy marked as AS31 has been tested for its possible use only.

The main advantage of this alloy is represented by its mechanical and founding qualities [1, 4, 11]. The chemical constitution of this alloy can be seen in the Table 1. This type of alloy represents a magnesium alloy used for casting under pressure, with Aluminum and Silicium (3% of Al, 1% of Si). The alloy distinguished itself by high mechanical qualities in higher temperatures and by a higher creep resistance. The increase of quality concerns exclusion of the inter-metal phase of Mg_2Si in which the alloy maintains a high stability.

Table 1.
Chemical composition of tested alloy AS31 (wt %)

Al	Si	Mn	Zn	Cu	Fe	Zr
3,35	0,82	0,32	0,16	0,002	0,002	0,0015

3. Description of methodology

3.1. Tensile test at elevated temperature

The measurement of solid and plastic qualities was performed with use of test samples, which were mechanically treated to the final dimensions (see Figure 1). The tested samples of magnesium alloy AS31 were obtained from the semi-products, which had been produced by means of gravity casting. Microstructure of source material is on Figure 2.

Heating of the test sample was performed inside a vertical electricity-run resistance oven with a pipe-shaped graphite heating body. The heating procedure is performed in two steps during the experiment. Firstly, the sample reaches the temperature intended for the measurement in speed of 10°C/min and when the demanded temperature is reached, a three minutes long isothermal time follows, in which the sample is applied load of 6 mm/min and of 0,6mm/min. Finally, the sample is placed into the oven which maintains a controlled atmosphere so that oxidation of fracture areas is limited, intended for further metallographic and fracture-graphic analysis.

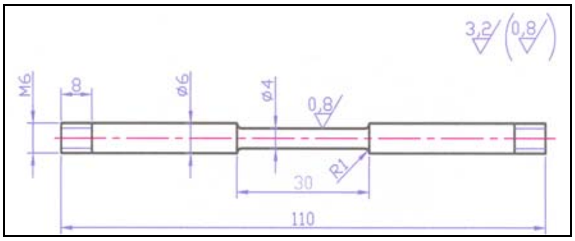

Fig. 1. Drawing of the test sample used in rupture tests

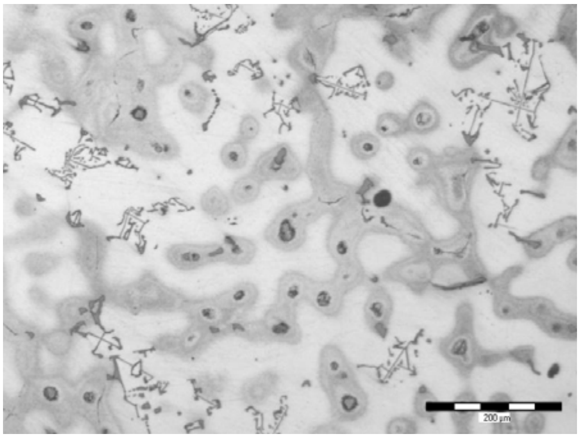

Fig. 2. Microstructure of source material – AS31

3.2. Acoustic emission

The AE is, during tensile tests at high temperatures, based on 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 [7-9]. The level of emitted elastic waves is, among other things, substantially influenced by the nature of the voltage field in the body because it determines the level of dynamics of the given process and thus various level of its discontinuity. The elastic wave that is 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 for its motion and creation of new surfaces is emitted in form of elastic waves and heat to the surface. The AE is thus an instrument for evaluation of mutual interaction between the supplied energy and actual process [12, 13]. 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. It is therefore necessary to monitor the strength influence of the loading system and pace of deformation by which the test body is stressed.

The tensile test may be generally divided into the following three basic parts:

- elastic stress up to the yield limit
- plastic deformation area
- 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, microcracks are initiated until cohesion is torn up – sample breaking at the end of the tensile test. That is confirmed by results of experiments.

3.3. Experimental construction

The measurement included material sample stress at the given temperature by tension at the INOVA electrohydraulic loading machine with a loading force of 20 kN with the acoustic emission monitoring. The test bar with ø 4 mm was warmed up in a graphite furnace in inert atmosphere (argon). The temperature on its surface 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 scanners fixing was designed and implemented so that a perfect acoustic link between the scanner and test sample was ensured. The acoustic link quality was checked according to an ASTM E 976 pen test. The temperature on scanners did not exceed the value of 80°C during testing and at highest testing temperatures and therefore it is not necessary to take additional measures for their thermal protection. Details concerning the experimental equipment are mentioned in Figure 3.

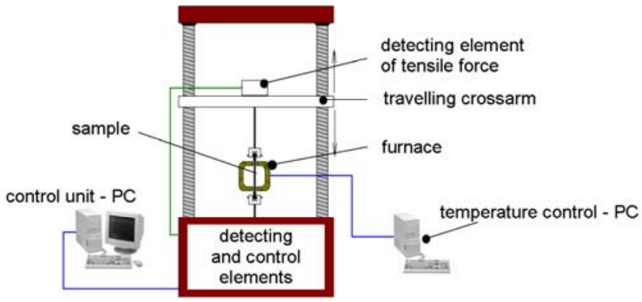

Fig. 3. Experimental set for measurement of solid and plastic qualities of ferrous materials treated in high temperatures

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 it is possible to be transferred to more far-reaching places. The signal is further carried to the EMIS 01 system and with an RS 485 serial channel thereout. The measured data are stored to the PC' s hard disk and they are processed in the EXCEL software after converting to a text form.

4. Description of achieved results of own researches

The magnesium alloy AS31 was researched with application of two speeds of loading, i.e. 6 mm/min and 0.6 mm/min. The measurement of solid-state and elasticity-plastic qualities with speed of loading 6 mm/min was performed in temperatures of 18, 100, 200, 300, 350 and 400°C. The results are shown in the Figure 4 and Figure 5. The samples, which were loaded with a speed of 0.6 mm/min and were performed in temperatures of 25, 150, 200, 250 and 300°C, are shown in the Figure 6 and Figure 7.

We may see that the Rm values rapidly decrease in relation to the increasing temperature of the test. The other tested values show a starting increase but exceed a low maximum, ranging from approximately 250°C in testing of fracture work, and approximately 300°C in the tests of drawing quality and area reduction. After the maximum is reached, a rapid decrease follows. Finally, when being tested in higher temperatures, the measured values were lower than being tested in the temperature of 200°C. (see Table 2)

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. That shows the initial stages of the tensile test.

The AE signal release is controlled by the dynamics of deformation processes at the tensile test. The self-evident increase in the frequency of emission overshoots is a response to the overcoming of barriers preventing development of deformation processes and integrity breaking. After obstacles overcoming, there is an area in which the character of the actual physical-metallurgical process nears to a balanced state. Example of record of tensile stress curve with AE is on Figure 8.

The share of the plastic deformation increases with a rising temperature and elastic stress level decreases. Inhomogeneity of the state of stress is decreased by that and frequency of emitted elastic waves and their energy decrease.

Macrostructure of fracture surfaces of tested samples loading by tensile test (speed 6 mm/min) are on Figures 9-14.

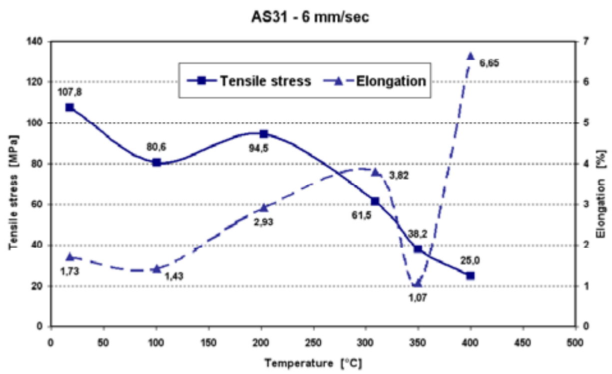

Fig. 4. Tensile stress, elongation – alloy temperature relation shown in graph; AS31

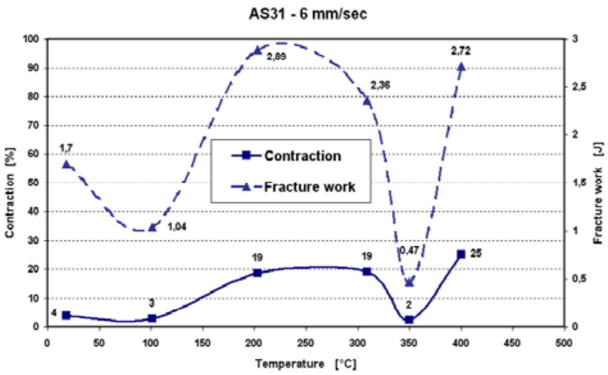

Fig. 5. Contraction, fracture work – alloy temperature relation shown in graph; AS31

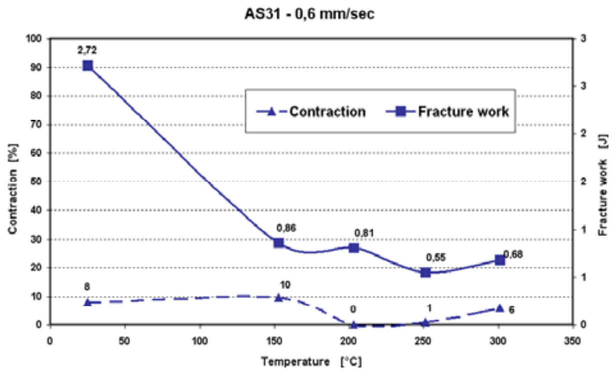

Fig. 7. Contraction, fracture work – alloy temperature relation shown in graph; AS31

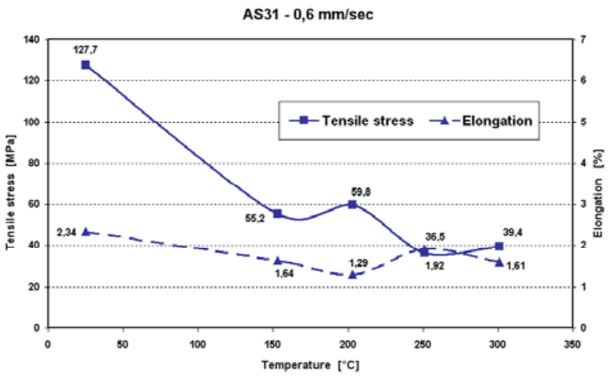

Fig. 6. Tensile stress, elongation – alloy temperature relation shown in graph; AS31

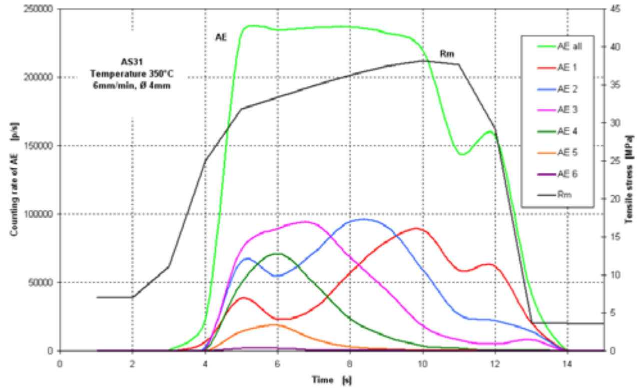

Fig. 8. Record of tensile stress curve with AE – 6mm/min, 350°C, AS31

Table 2.
Mechanical properties of experimental material

experimental temperature	tensile force	tensile rate	diametr of fracture surface	reduction of area	deformation to fracture	deformation energy
[°C]	[N]	[MPa]	[mm]	[%]	[mm]	[J]
			Feed rate 6 mm/min			
18	1353	107,8	3,92	4	1,9	1,7
101	1012	80,6	3,94	3	1,57	1,04
203	1187	94,5	3,61	19	3,22	2,89
309	773	61,5	3,60	19	4,20	2,36
350	480	38,2	3,95	2	1,18	0,47
400	443	25,0	3,46	25	7,31	2,72
			Feed rate 0,6 mm/min			
25	1603	127,7	3,84	8	2,57	2,72
153	694	55,2	3,80	10	1,8	0,86
203	751	59,8	4,00	0	1,42	0,81
251	459	36,5	3,98	1	2,11	0,55
301	495	39,4	3,88	6	1,77	0,68

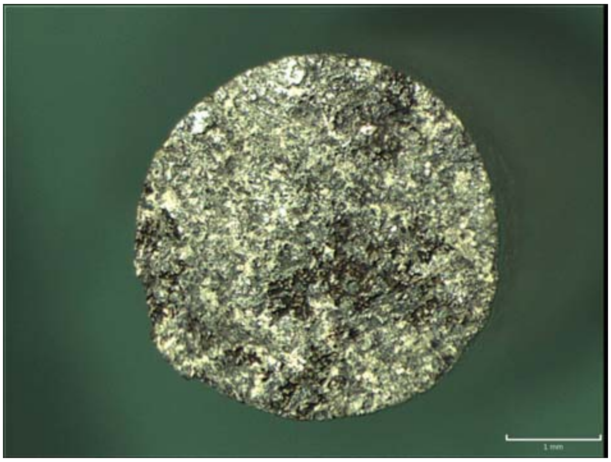
Fig. 9. Macrostructure of tested sample, 6 mm/min, 18°C

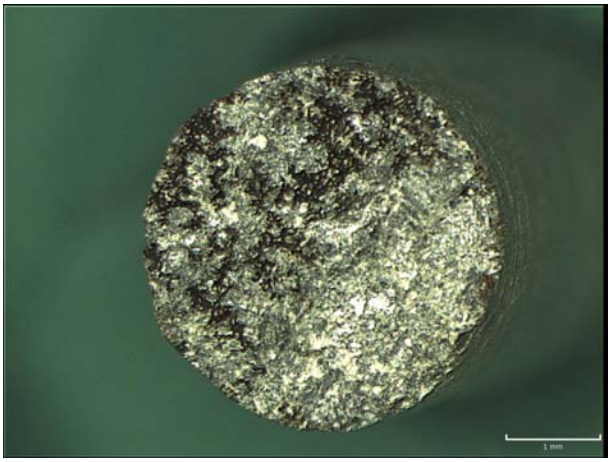
Fig. 10. Macrostructure of tested sample, 6 mm/min, 100°C

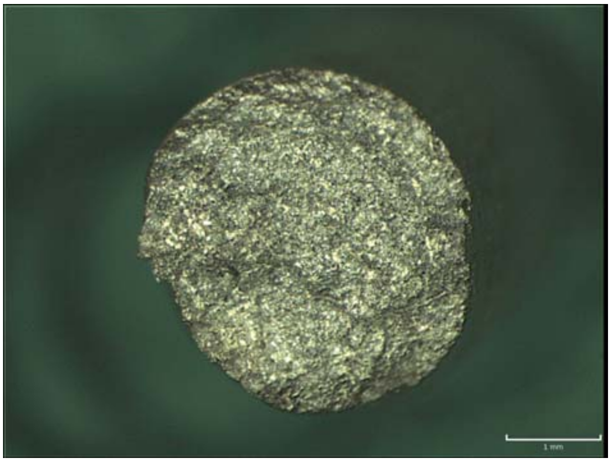
Fig. 11. Macrostructure of tested sample, 6 mm/min, 200°C

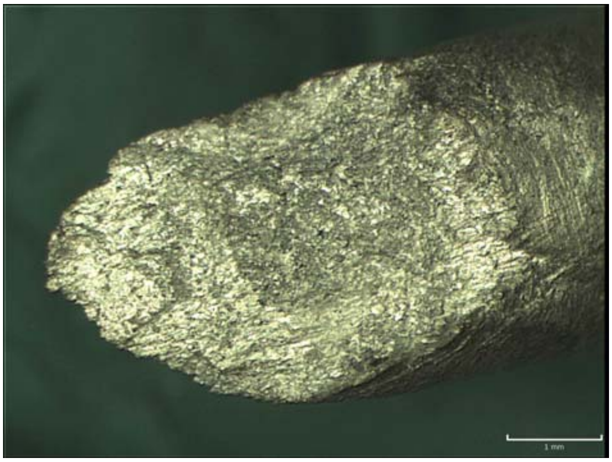
Fig. 12. Macrostructure of tested sample, 6 mm/min, 300°C

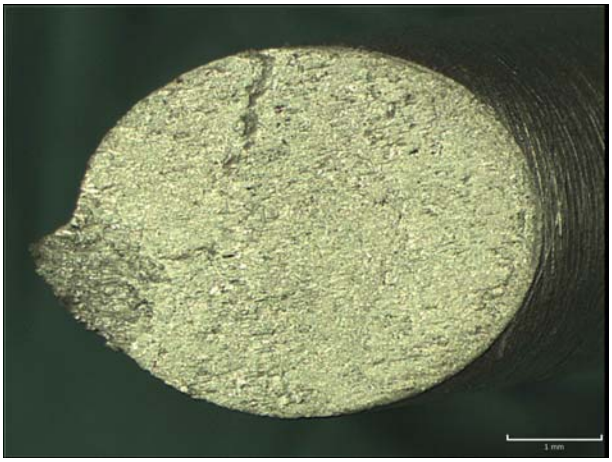
Fig. 13. Macrostructure of tested sample, 6 mm/min, 350°C


Fig. 14. Macrostructure of tested sample, 6 mm/min, 400°C

5. 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 especially enables a study of dynamics of these processes at various temperatures and at various loading manners. 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 showed to be very promising. It was found out that:

- The Rm values rapidly decrease in relation to the increasing temperature of the test (local maximum 200°C)
- The other tested values show a starting increase but exceed a low maximum, ranging from approximately 250°C in testing of fracture work, and approximately 300°C in the tests of drawing quality and area reduction
- The increased loading pace of a crosspiece shift of 6 mm/min generates higher strength than the pace of 0,6 mm/min

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