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Effect of cyclic loading on the internal damping of magnesium alloy AZ31

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Abstract

The article focuses on the analysis of the internal damping changes depending on the amplitude of the magnesium alloy AZ31. Internal damping reflects the ability of the material irreversibly dissipating mechanical energy oscillations. It means that the material of high internal damping ability is able to significantly reduce the vibration amplitude. Internal damping is, generally, dependent on many factors (temperature, material purity, grain size, mechanical and thermal processing, etc.) and its value is determined by interactions between various mechanisms dissipation of mechanical energy. Ultrasonic resonance method was used in experimental measurements, which is based on continuous excitation of oscillations of the specimen, and the entire apparatus vibrates at a frequency which is near to the resonance. Starting resonance frequency for all measurements was about $f = 20470$ Hz.

1. Introduction

Magnesium alloys are the lightest commercial alloys. They are very attractive for automotive and electrochemical industry and their good combination of strength and damping makes them usable also for other applications. Engineering magnesium alloys are used especially for production of light weight-walled casting, lockers in automotive engines, parts of mobile phones, cameras or notebooks, etc. Magnesium alloys have also good damping properties (belong to the group of the HIDAMETS materials – High DAMping METals) (SCHALLER R. 2001, ZHANG Z. 2005).

Effect of gradual storage of mechanical energy in the material causes a change of mechanical and physical characteristics, which can cause degradation of material properties such as: reduction of the machine tools accuracy, initiation of fatigue cracks, generation of noise and vibration in the working environment, changes of material properties, reduction of corrosion resistance, degradation of regulatory devices and sensors, eventually damage of entire device. Measurement of the internal damping allows to monitor the ongoing structural changes and various mechanisms (BLANTER M. 2007, BELAN J. 2014).

Dispersion of mechanical energy in the material is just one of the ways of energy transformation, for example conversion of mechanical energy into heat energy. Total internal

damping affects a number of different, interacting and functioning factors, such as defects in the crystal structure, the movement of dislocations, plastic deformation, after slide of grain boundaries, elastodynamic and magnetoelastic phenomena. The research contributes to the understanding and development of new, improved and more accurate technologies for materials according to current needs of different industries (PUŠKÁR A. 1995, HURTALOVÁ L. 2014)

2. Experimental material

For experimental measurements of internal damping magnesium alloy AZ31 was used. Result of the spectrometer chemical analysis is shown in the Table 1. The AZ31 magnesium alloys was produced by the squeeze-casting method and was delivered without heat treatment.

The experimental material was submitted to metallographic analysis before measuring of internal damping, which allows to obtain information about the shape, size, type and quantity of structural components contained in the material, and, thereby, contributes to the understanding of the ongoing processes in the material during cyclic loading.

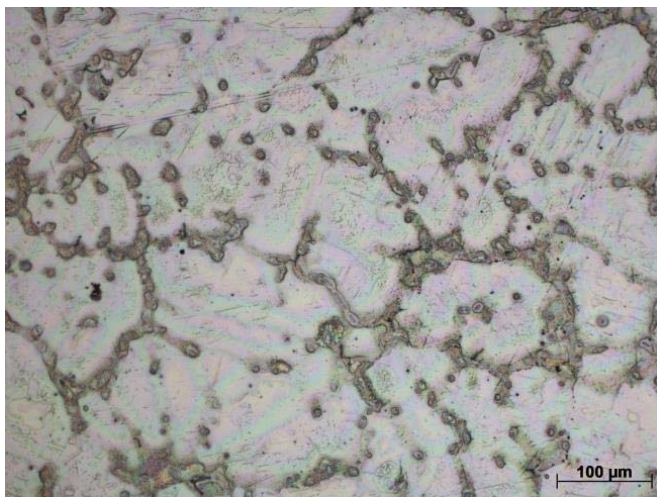
The microstructure of the magnesium alloy was analyzed in as cast state (Fig. 1a) and after homogenization annealing state (Fig. 1b). After squeezing the casting, the microstructure of material was dendritic. In interdendritic regions in-

homogenities occurred, as well as phase colonies of different type and origin, from which is the most important is intermetallic phase $Mg_{17}Al_{12}$.

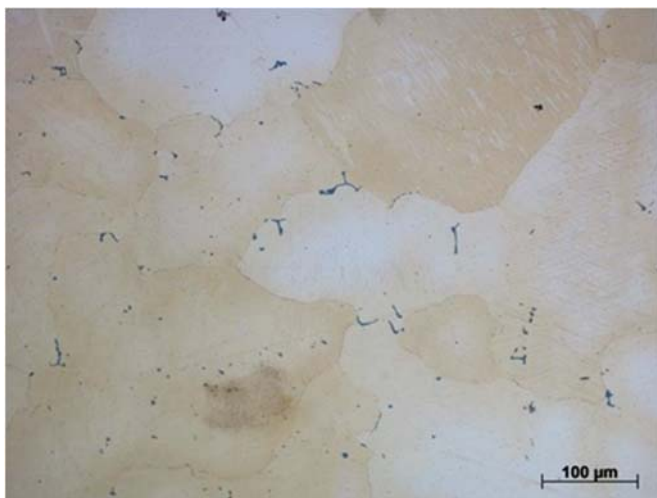
Table 1. Chemical composition of magnesium alloy AZ31

Element	[wt.%]
Al	2.980
Zn	0.655
Mn	0.202
Ca	0.180
Si	0.067
Fe	0.007
Cu	0.001
Mg	balance

Source: own study



a) as cast state



b) after homogenization annealing

Fig. 1. Microstructure of magnesium alloy AZ31, etch. Picral

Source: own study

Heat treatment consisted of a homogenization annealing at 390 °C for 22 hours followed by quenching in the water with the purpose to obtain a solid solution of aluminum and zinc and other elements in the magnesium matrix. Almost all intermetallic particles were dissolved and the microstructure of the alloy was homogenized. The microstructure after annealing is created by polyedric grains, and the grain boundaries are clearly visible. The homogenization annealing led to dissolution of intermetallic phases, diffusion equalizing of concentrations of alloying elements in the alloy and created polyedric structure.

3. Measurement method

The internal damping was measured using indirect ultrasonic method of determining the quality factor resonant system. This method is based on continuous excitation of oscillations of the specimen, and the entire apparatus vibrates at a frequency which is close to the resonance. Quality of the resonance system Q^{-1} is calculated (1) by measuring the resonance peak (Fig. 2) and determining its width for 3 decibel level.

$$Q^{-1} = \frac{\Delta f_{r3dB}}{f_r} \quad (1)$$

Where f_r is resonant frequency [Hz], $\Delta f_{r3dB} = f_2 - f_1$ is width of resonance curve for 3 decibel level [Hz].

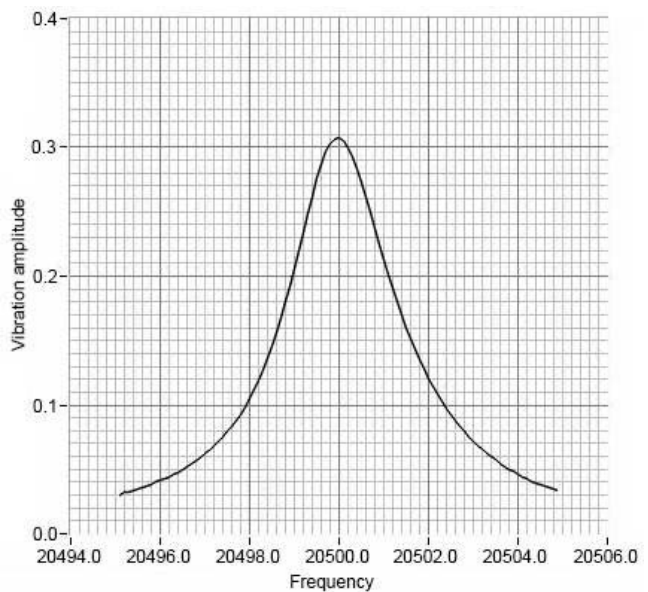


Fig. 2. Characteristic resonance curve

Source: own study

The original experimental equipment (Fig. 3) consists of electronic and mechanical part. One of the electronic parts is a generator which produces a sine wave. The electric signal is then amplified and transformed into a mechanical wave by using the piezoceramic transducer. The ultrasonic wave is amplified in aluminium horn and spreads into the specimen

by the titanium rod. After passing through the specimen the wave is reflected at the free end and spreads back through the

entire device. The amplitude of resulting oscillations is measured by multimeter.

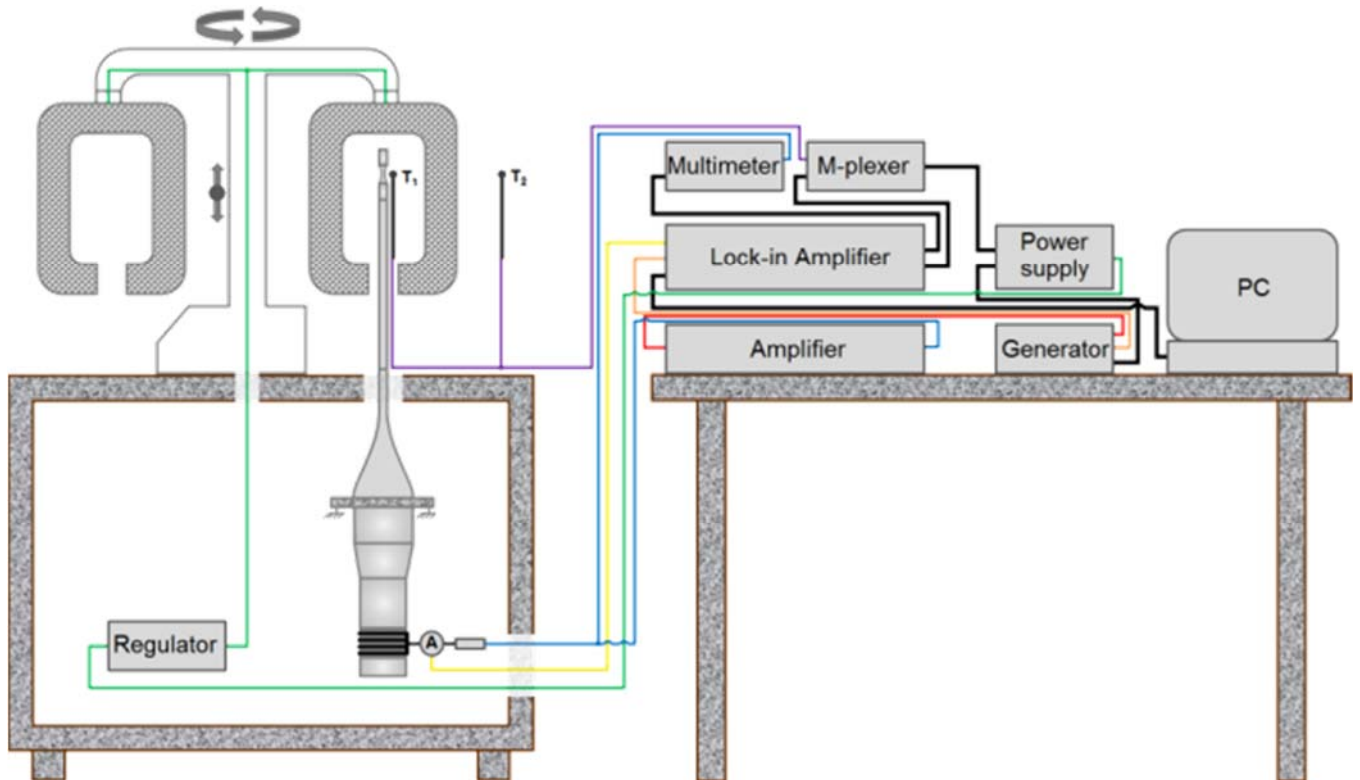


Fig. 3. Ultrasonic resonance device for internal damping measurement

Source: own study

The mechanical part is the core of the whole apparatus, consists of:

- Transducer is the most difficult part of the mechanical apparatus, which serves as the source, and, at the same time, as the detector of ultrasonic waves.
- Rod, which is made of titanium and has a cylindrical shape with a diameter of 12 mm. Its function is to isolate the heat from the specimen, which is heated in a furnace, and the transducer then maintains a constant room temperature.
- The last part is specimen. Dimensions and shape of the specimen are designed to fulfill the resonance condition that means the natural frequency must be approximately the same like the frequency of the test equipment.

4. Measurement results

Internal damping depending on the vibration amplitude was measured on specimens in cast state and after homogenization annealing. Vibration amplitude of the input excitation voltage was 100 mV. The measurement was performed at room temperature (20 °C) in increments of 50 mV to the finally chosen excitation voltage. Fig. 4, shows the results of measurement of the internal damping depending on the vi-

bration amplitude of the magnesium alloy AZ31 in as cast state and after homogenization annealing.

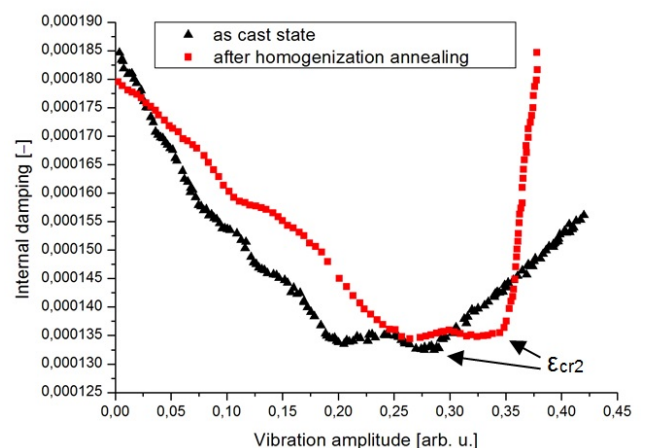


Fig. 4. Results of measurement of the internal damping depending on the vibration amplitude of the magnesium alloy AZ 31

Source: own study

The first measurement was performed on the specimen in cast state, then the same specimen was homogenization an-

nealed and the measurement was repeated. The value of internal damping for alloy AZ31 was at the beginning of the measurement $Q^{-1} = 1.85 \times 10^{-4}$. With the increase of excitation voltage the internal damping at first decreased and at vibration amplitude 0.28 there was a linear increase of the internal damping in material. At the same amplitude oscillations the magnesium alloy AZ31 reached slightly higher values of internal damping. Point of the curve from which there is an increase of internal damping represents the transition from the elastic range behaviour of the material to microplastic range behaviour and it is described as the second critical amplitude of deformation.

The initial value of the internal damping after heat treatment was approximately the same as in cast state. With the increase of excitation voltage, as in the previous case, the internal damping at first had a downward trend, but there was a difference in their growth. By comparing the measurements of the internal damping in as cast state and the measurements after homogenization annealing, it can be observed that an increase of the internal damping after homogenization annealing occurred at higher vibration amplitudes and this increase was steeper.

5. Conclusion

Based on experimental results from internal damping measurement of AZ31 magnesium alloys, it can be stated that:

- The value of the first critical amplitude of deformation ϵ_{cr1} (from which amplitude-dependent mechanisms begin) was not recorded during any measurement.
- With increasing of excitation voltage, the internal damping in both materials in cast state and after homogenization annealing at first decreased.
- After reaching a certain vibration amplitude linear increase of the internal damping occurred, which can be

explained that it has reached the second critical amplitude of deformation ϵ_{cr2} .

- After heat treatment, the second critical amplitude of deformation ϵ_{cr2} shifted to higher vibration amplitudes and the increase of the internal damping was steeper than in as cast state.

Acknowledgement

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循环负荷对内部阻尼的影响的镁合金 AZ31

关键词

镁合金
谐振频率
内部阻尼
循环加载

摘要

本文重点介绍了根据镁合金 AZ31 的幅度对内部阻尼变化的分析。内部阻尼反映了材料不可逆地耗散机械能振荡的能力。这意味着内部阻尼能力高的材料能够显著降低振动幅度。内部阻尼通常取决于许多因素（温度，材料纯度，晶粒尺寸，机械和热加工等），其值取决于机械能耗耗散的各种机制之间的相互作用。在实验测量中使用超声共振法，其基于样品的振荡的连续激发，并且整个装置以接近共振的频率振动。所有测量的启动共振频率约为 $f = 20470\text{Hz}$ 。