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Comparison of temperature dependence of internal damping of selected magnesium alloys

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Abstract
The research is focused on the study of the temperature dependence of the internal damping of selected magnesium alloys with different contents of aluminium - AZ31 and AZ61. These alloys are currently widely used in various types of industry, mainly in the automotive industry. It belongs to a group of materials called HIDAMETS because they have excellent damping properties. The internal damping of the samples was measured on a unique ultrasonic device constructed at Žilina University in Žilina. Specimens were measured at baseline in the temperature range from 25 °C to 400 °C. Changes in internal damping caused by varying aluminium contents in investigated alloys were noted. As the aluminium content increases, maximum internal damping is achieved due to the formation, growth and subsequent dissolution of the continuous precipitate in the microstructure.

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1. Introduction

Gradual storage of mechanical energy in the material results in changes of mechanical and physical properties. These may cause degradation of materials properties, the beginning of fatigue cracking, the production of noise and vibrations in the working environment or the reduction of the precision of machine tools (Uhríčik, 2017).

Measurement of internal damping allows effective monitoring of structural changes occurring in the materials. Internal damping of materials belongs to the study of physic of condensed solids in the solid or liquid phase. Modern research into the study of physical properties predominates two phenomena that cause internal damping. The first occurs when the sound or ultrasound wave passes through the object. At that time, a wave reduction is caused by the dispersion of the mechanical wave on the non-homogeneities of the metallic material (precipitates, inclusions, dispersion particles or grains in the polycrystalline material). The second phenomenon and, therefore, the second cause of the wave reduction spreading by material is the internal physical phenomenon associated with the defects of the crystalline lattice (e.g. dislocations and their movement under tension). During this process electrons move and re-distribute. These are also physical processes that cause internal damping.

At present, it is of great interest to know the damping properties of materials in order to achieve a high or low material damping capacity. If the material was perfectly elastic, it would mean that it would not have a plastic deformation. Thus, there would be no movement of dislocations that are generally carriers of plastic deformation. The perfect elasticity of the material would mean that no plastic deformation under tension would occur in the material, and deformation would increase at the same time as increasing tension without phase shift (Oršulová, 2018).

Magnesium alloys are among leading materials used in construction practice. Due to their specific properties, magnesium alloys are widely used in various types of industry. Due to their advantageous strength/weight ratio, they are mainly used in automotive, aerospace, electro-engineering, and biomedical applications.

Most studies of magnesium alloys focus on precipitation hardening (Braszczyńska-Malik, 2009; Saikawa et al., 2014; Zhou et al., 2007). Precipitation processes can be investigated using standard imaging techniques. On the other hand, the connections between the changes of the microstructure and the physical quantities can be investigated by measuring the internal damping. The presence of precipitates in the microstructure influences on the internal damping of materials. The influence of precipitation on damping characteristics has been the subject of several studies (Göken et al., 2005; Hao et al., 2007; Liu et al. 2010; Riehemann; 1998).

2. Experimental part

Internal damping is a very sensitive method that is successfully used to investigate structural defects and their mobility. It allows examining the transport processes in materials and phase transformations in the solid state, which cannot be recorded in other ways.

Experimental equipment consists of the measuring and control part, heating and ultrasonic part. Ultrasound generator creates a sine wave. The electric signal is then amplified and transformed into mechanical wave with a piezoceramics transducer.

The ultrasonic wave is concentrated in aluminum horn and spreads to the specimen through a titanium rod. After passing through the specimen the wave is reflected at the free end and spreads back through the entire apparatus until it is again reflected at the free end of a steel mirror situated under the transducer. The amplitude of mechanical wave is decreasing during the propagation due to the internal friction of material. After the second reflection the mechanical wave interfere with itself. The standing wave is set up in the apparatus. The amplitude of resulting oscillations is measured by a multimeter because the current in piezoceramics transducer is proportional to the strain rate.

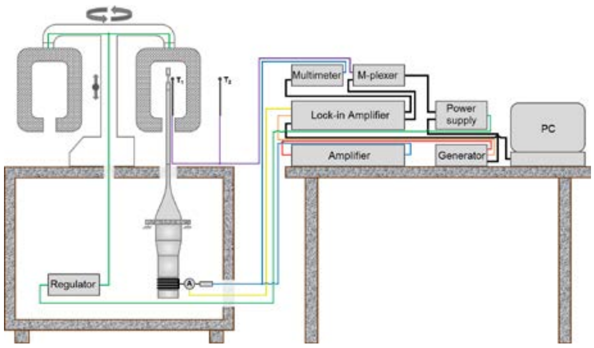

Fig. 1. Experimental equipment for measuring of internal damping

Experimental works were carried out on magnesium alloys AZ31 and AZ61. The chemical composition of the experimental materials is shown in Table 1. Samples were delivered without previous heat treatment.

Table 1. Chemical composition of experimental materials (wt.%)

	Al	Zn	Mn	Si	P	Mg
AZ31	2.980	0.655	0.202	0.067	0.002	balance
AZ61	6.880	1.200	0.229	0.079	0.004	balance

Before the measurement of internal damping, a metallographic analysis was carried out on the samples. The mentioned analysis allows to obtain information about the shape, size, type and amount of structural components contained in the materials. Metallographic analysis is necessary in order to understand the processes taking place in the material during the internal damping process.

The AZ31 alloy microstructure in the initial state without heat treatment (Fig. 2) is formed with the base δ phase, i.e. a solid solution of aluminium and zinc in the magnesium. At the border of the grains, there is visible excluded γ phase ($Mg_{17}Al_{12}$). In the microstructure, discontinuous precipitates are not visible.

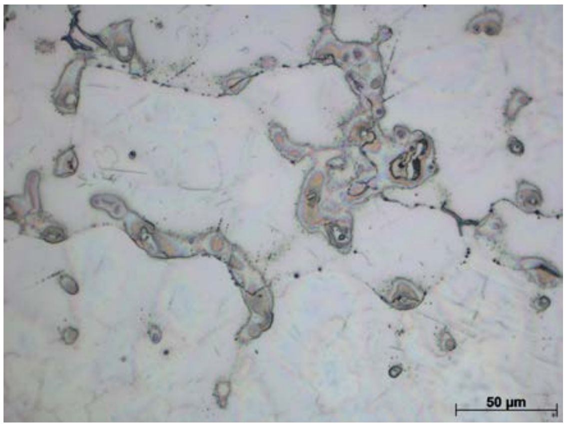

Fig. 2. Microstructure of AZ31 in initial state

The AZ61 alloy contains a higher amount of alloying elements, so its microstructure is also different (Fig. 3). In the initial state, the following structural components are visible: base δ phase, γ phase $Mg_{17}Al_{12}$ excluded along the grain boundaries, and other phases resulting from the combination of additive elements in the matrix (precipitates).

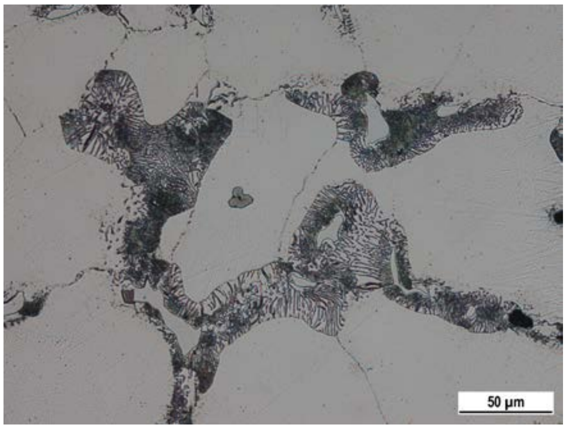

Fig. 3. Microstructure of AZ61 in initial state

3. Results and discussion

In case of AZ31, the measured values of the internal damping can be divided into a temperature-independent and temperature-dependent region. Measurement of experimental material AZ31 showed the following: in the first region, i.e. temperature-independent, there are no significant local maximums. In the second region, which is already temperature-dependent, the temperature of approximately 250 °C results in an exponential increase of internal damping (Fig. 4).

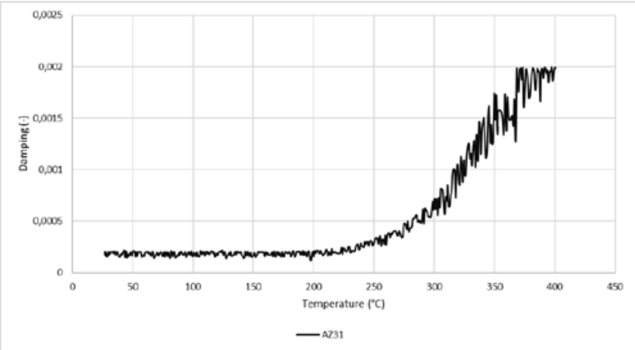

Fig. 4. Internal damping of AZ31

The aluminium content in the magnesium alloys affects the internal damping value. Therefore, for comparison an alloy with a higher content of aluminium AZ61 was chosen (Fig. 5). In temperature range from 25 °C to 225 °C, the internal damping achieved the unchaining values without significant local maximums and the internal damping phones remained unchanged. With a rising temperature, a slow increase in internal damping due to precipitation in the alloy was recorded. From a temperature close to 370 °C, an exponential increase of the damping occurred until the measurement finished at 400 °C. This increase was caused by the dissolution of precipitates in the alloy.

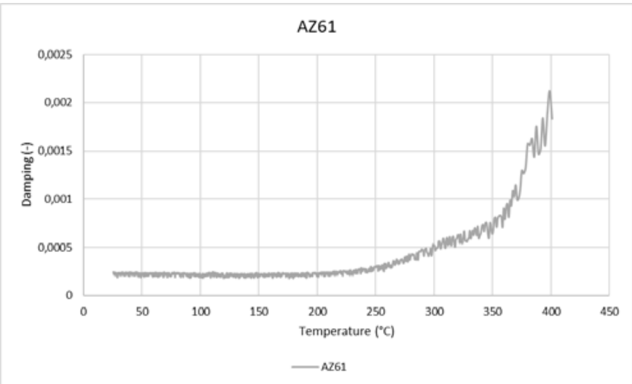

Fig. 5. Internal damping of AZ61

Comparison of the curves showed considerable differences in the internal damping of the experimental materials (Fig. 6). The effect of chemical composition and microstructure on internal damping has been confirmed. Differences in internal damping are due to higher content of discontinuous precipitates in AZ61 alloy that block dislocation movement. Dissolving of the precipitates in this material caused an exponential increase in internal damping at a temperature close to 370 °C. AZ31 alloy contains a lower γ phase. Due to the lower amount of alloying elements, solid solution was not saturated and decaying. The increase of internal damping with increasing temperature is, thus, only conditioned by mechanisms of movement of dislocations.

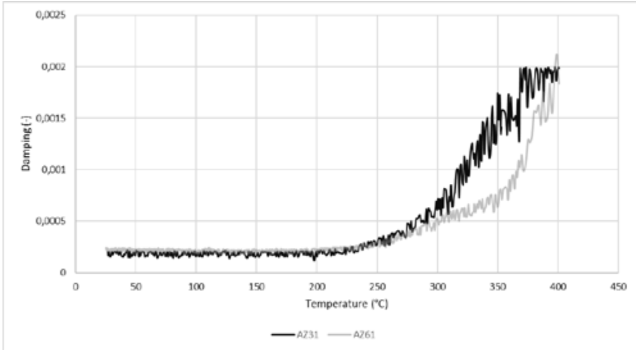

Fig. 6. Comparison of internal damping of experimental materials AZ31 and AZ61

4. Summary and conclusion

Internal damping of the AZ31 magnesium alloy measured by ultrasonic resonance apparatus with a heating rate of 1 $°C.min^{-1}$ was characterized by an exponential increase in internal damping from 250 °C. There were no significant local maximums in the above-mentioned processes due to the low amount of alloying elements that would prevent movement of dislocations at higher measurement temperatures. The presence of alloying elements limited the possibility of slipping along the grain boundaries and, for this reason, the maximum internal force was not created and its value was determined only by mechanisms of movement of dislocations. The measured values of internal damping on the AZ61 magnesium alloy can be divided into three regions. The first region is the temperature independent region of the internal damping, the second region is the temperature dependent region of the internal damping and the third area is exponential region where the damping exponentially increases with the increasing temperature. The resulting internal damping patterns had, in all the cases, a temperature independent region in which the internal damping values did not change significantly.

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選擇鎂合金內阻尼溫度依賴性的比較

關鍵詞
溫度依賴性
內部阻尼
鎂合金
HIDAMETS
沉澱

摘要
本研究的重點是研究不同含量鋁 – AZ31和AZ61的鎂合金內阻尼的溫度依賴性。這些合金目前廣泛用於各種類型的工業，主要用於汽車工業。它屬於一組稱為HIDAMETS的材料，因為它們具有出色的阻尼特性。在Žilina的日利納大學建造的獨特超聲波裝置上測量樣品的內部阻尼。在基線處在25℃至400℃的溫度範圍內測量樣本。注意到所研究的合金中鋁含量變化引起的內部阻尼變化。隨著鋁含量的增加，由於連續沉澱物在微結構中的形成，生長和隨後的溶解，實現了最大的內部阻尼。