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The Influence of Cooling Rate on the Damping Characteristics of the ZnAl27Cu2 Alloy

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Abstract

The paper presents the results of damping coefficient tests on the ZnAl27Cu2 alloy (ZL27). The tested alloy was cast into five types of molds made of different materials (a steel mold with an ambient temperature of 20°C, a steel mold with a temperature of 100°C, a humid green sand mold, a dried green sand mold and a mold made of foundry gypsum mass). The thermophysical properties of these materials are different, and that's affecting the rate of heat absorption from the cast. Different mold materials affect obtaining different cooling rates. The cooling rate significantly affects the microstructure of the tested alloy. The specimens of investigate alloy were subjected to ultrasound and microscopic tests to assess the alloy structure. The damping coefficient has been calculated on the basis of specimen measurements obtained with the use of the signal echo method. Research shows that high structural fragmentation adversely affects the damping properties of alloys is confirmed. On the other hand, very low cooling rate, resulting in the formation of large, overgrown dendrites, does not guarantee the highest vibration damping capacity for this particular alloy. It turns out in this case a humid green sand mold, (cooling rate of 5.1 K/s) guarantees the best damping properties for the ZL27 alloy.

Keywords: Zinc alloys, Damping coefficient, High-damping metals, Cooling rate, Ultrasound testing

1. Introduction

Damping is a phenomenon that can be observed in connection with many groups of casting alloys. The ternary zinc-aluminium-copper alloys, cast iron and bronzes have high damping properties and belong to the group of HIDAMETS (High-Damping Metals) [1, 2, 3]. The ZL27 alloy is the lightest of the commercial zinc alloys. It has a number of interesting properties, and its melting process uses less energy than aluminum alloys, making it more environmentally friendly. Due to where it is used, and these are sliding bearings, bushings, tight housings, bodies of precision tools and instruments [4, 5], a particularly desirable feature is its ability to damping vibrations. The parameter that indicates the damping properties of a specific material is the damping coefficient. The coefficient's value relies on the alloy's type and composition. Generally, the damping properties of a specific alloy are primarily influenced by its internal microstructure [6, 7].

The microstructure of alloys can be shaped by modifying or changing the cooling rate [8, 9]. The cooling rate during solidification plays a crucial role in shaping the macro and microstructure of alloys [10, 11].

The mechanism of damping mechanical vibrations is based on their dissipation or absorption. In metal alloys, the main factor is the dissipation of the energy of the vibrating wave. This is because the alloy has a complicated structure. The grains have different orientations, there are inclusions, structural disorders, dislocations and porosity. All these factors cause the energy of the vibration wave to dissipate.

This paper describes an attempt to measure the damping coefficient of the ZnAl27Cu2 (ZL27) alloy solidified at five different cooling rates. The tested alloy was cast into five types of molds made of materials with different properties. What's most important here is the ability to conduct and accumulate heat. Different mold materials allowed for different cooling rates. The materials were selected to allow the alloy to cool at a low and relatively high cooling rate. Plaster mold, green sand mold wet and dried and a steel mold at ambient temperature and heated to 100°C were used here.

2. Materials and methodology

ZL27 alloy with the composition as in Table 1 was melted in the electric resistance furnace. The alloy was cast into several types of foundry molds. A steel mold with an ambient temperature of 20°C, a steel mold with a temperature of 100°C, a humid green sand mold, a dried green sand mold and a mold made of foundry gypsum mass (Fig. 1.). The sample has a cylindrical shape with a diameter of 42 mm and a height of 100mm.

Table 1.
Chemical composition of the investigated alloy (spark emission spectroscopy)

Element	Al.	Cu	Mg	Pb	Fe	Si	Zn
Analysis [%]	26.8	2.1	0.018	0.004	0.05	0.03	the rest

Fig. 1. Types of foundry mold used in the experiment: dry green sand mold, humid green sand mold, plaster mold, metal mold

The alloy with a temperature of 620°C was poured into a mold. During solidification and cooling of the casting, the temperature of the casting was recorded. The K-type thermocouple is located in the axis of the casting in the middle of its height (Fig. 2). After cooling, the cast was knocked out of the mold and processed. From the part of the casting located under the thermocouple, a sample was cut out in the cylindrical shape with a diameter of 40mm and a height of 40mm. The front surface of the sample was sanded and finished with a grit of 1200.

Fig. 2. The K-type thermocouple location in the mold

The sample prepared in this way was subjected to ultrasonic tests in order to determine the vibration damping coefficient α (Fig. 3). The testing was carried out using a dedicated set consisting of a transceiver head, a vibration generator and a computer recording the results. The ultrasonic vibrations generated by the head had a frequency of 1MHz. In order to reduce signal losses at the sample-probe interface, a coupling fluid (paraffin oil) was used.

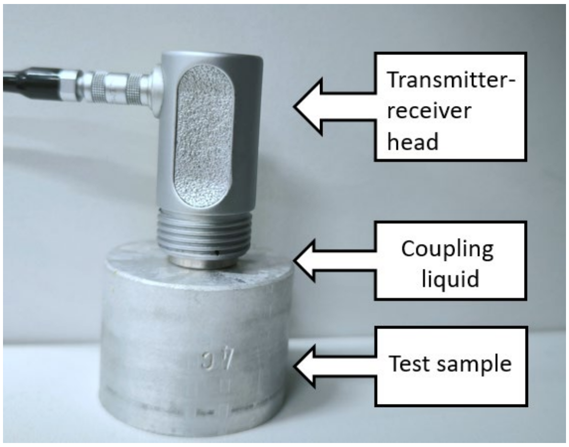

Fig. 3. Transmitter-receiver head on the tested sample

Due to the fact that the casting is not a homogeneous object. Having different grain orientation, inclusions and defects, twenty measurements were made at different locations of the sample. The measurements were made using the signal echo method. The determination of the vibration damping coefficient α of the signal is based on the comparison of successive signal echoes and their comparison with the length of the path travelled by the ultrasonic wave. Subsequent echoes on the recording device occur in the form of peaks with a specific value in dB. Subtracting two adjacent peak values gives the attenuation value of the signal after passing through the sample. In the echo method, the signal passes through the sample, reflected off its bottom surface, and returns to the transceiver head. The signal path in this case is double the height of the sample, i.e. 80mm. The values of the vibration damping coefficient α are obtained in dB/m. For each measurement, the values of the vibration damping coefficient are calculated, and then the average of the twenty measurements is calculated for each sample. After ultrasonic measurements, the samples were ground again on 1200 grit sandpaper, followed by 2000 and 4000 grit. After grinding a hardness test was also performed for the tested samples. Hardness was measured by means of the Brinnell method. The diameter of the indenter was 2.5 mm. The applied force is 147 N. After hardness test the samples were ground again on 4000 grit sandpaper. Next the samples were polished using a 3µm diamond slurry. The polished samples were etched for about 3 seconds in Palmerton's reagent. The etched samples were observed on the Carl Zeiss Axio Imager M2m light microscope in reflected white light.

3. Results of the investigation

During the cooling of the liquid alloy, solidification and cooling of the already solidified alloy, the temperature of the tested castings was recorded. The recording was carried out with the Agilent multifunctional meter. The thermocouples placed in the tested samples were attached. A summary of cooling curves recorded during the measurements is shown in Figure 4. Depending on the mold material, which has different heat transfer properties from the casting, the cooling curves have different inclinations. For each sample, the cooling rate was determined.

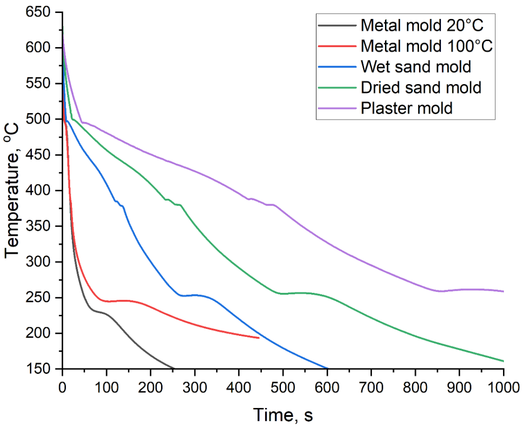

Fig. 4. Cooling curves of ZnAl27Cu2 alloy

A breakdown of the cooling rate for the tested sample casting depending on the mold material is shown in Table 2. The highest cooling rate was obtained in a metal mold with an initial temperature of 20°C. The slowest cooling rate was achieved in the foundry gypsum mold. After mechanical processing, the samples were a cylindrical shape with a diameter of 40 mm and a height of 40 mm. After grinding the front surfaces of the sample, ultrasonic measurements were performed using a 1MHz transceiver head. The measuring head had a diameter of 10mm, which allowed a series of 20 measurements to be carried out at different locations in the sample. The average results of measurements of the damping properties of the sample depending on the type of foundry mold material are presented in Figure 5. The ability of a tested material to dampen vibrations is determined by the vibration damping coefficient α determined in dB/m. The highest value of the vibration damping coefficient α was determined for samples cast into a moist green sand mold. The mold was poured immediately after forming, which gave it the moisture content of a fresh molding sand. The lowest value of the vibration damping coefficient was recorded for the metal mold with an initial temperature of 20°C. The cooling rate achieved in this mold was the highest, which also affected the structure and shape of the microstructure.

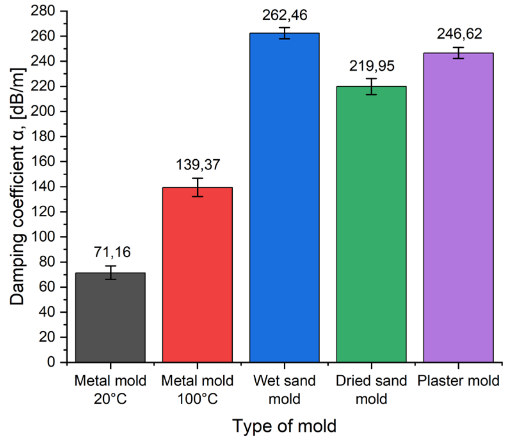

Fig. 5. Values of damping coefficient α related to the cooling rate

After polishing and etching in Palmerton's reagent [12], the samples were observed in reflected white light, at 200x magnification. Pictures of the microstructure of ZL27 alloy cast into molds made of various materials are presented in the figures 6.1 – 6.5. The alloy has a dendritic structure. The size of the dendrites and the secondary dendrite arm spacing depend on cooling rate. The chemical composition also has a major influence on this [13, 14, 15]. The composition of the investigated alloy is constant, so the cooling rate is the only factor influencing the size of the dendrites. A clear fragmentation of the structure of the alloy cast into metal molds can be seen (Fig. 6.1), in which the cooling rate was the highest and amounted to 23.2 K/s for a mold with an initial temperature of 20°C. The most extensive dendrites of phase a were obtained at the lowest cooling rate in the mold made of foundry plaster (Fig. 6.5). The cooling rate in this case was 1.8K/s. The components of the microstructure of the ZnAl27Cu2 alloy poured into the casting gypsum mold in magnification 500x show on Figure 7. Phase a dendrites and eutectics composed of phases α + η predominate here. There is still a small proportion of the η-phase between the grains. To determine the degree of microstructure refinement, the secondary dendrite arm spacing were measured.

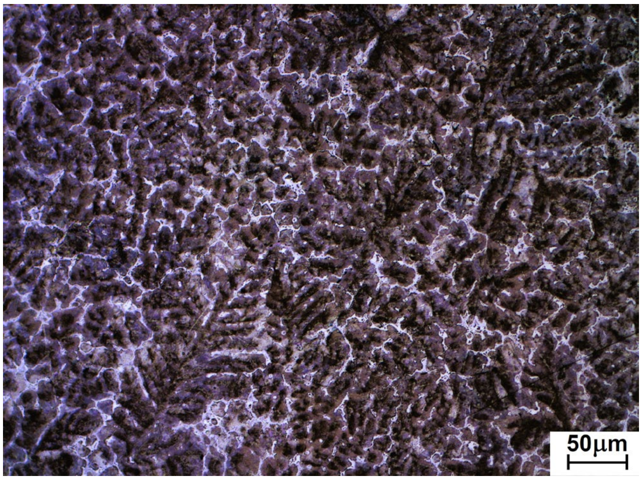

Fig. 6.1. Microstructure of ZnAl27Cu2 alloy cooling in the metal mold with an initial temperature of 20°C, magnification 200x

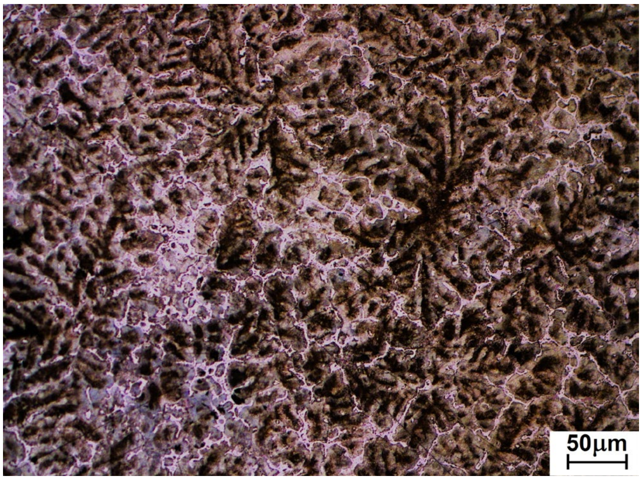

Fig. 6.2. Microstructure of ZnAl27Cu2 alloy cooling in the metal mold heated to the temperature of 100°C, magnification 200x

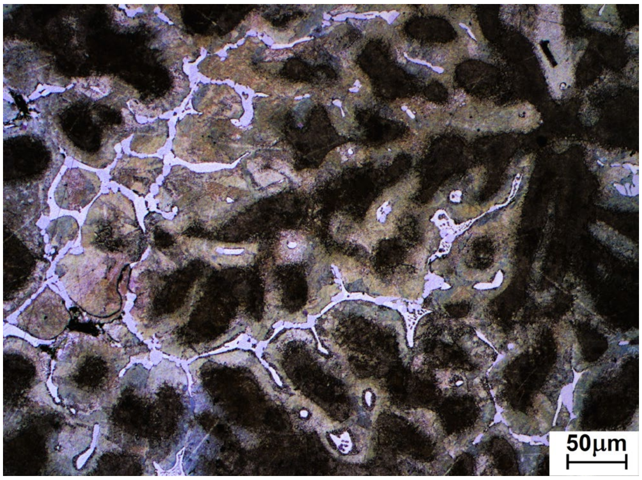

Fig. 6.3. Microstructure of ZnAl27Cu2 alloy cooling in the humid green sand mold, magnification 200x

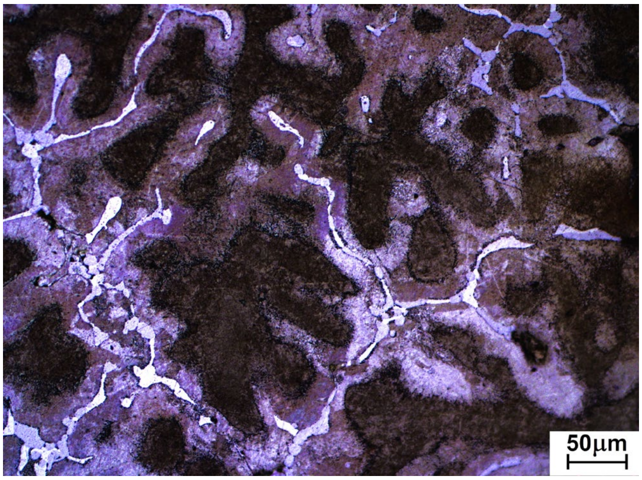

Fig. 6.4. Microstructure of ZnAl27Cu2 alloy cooling in the dried green sand mold, magnification 200x

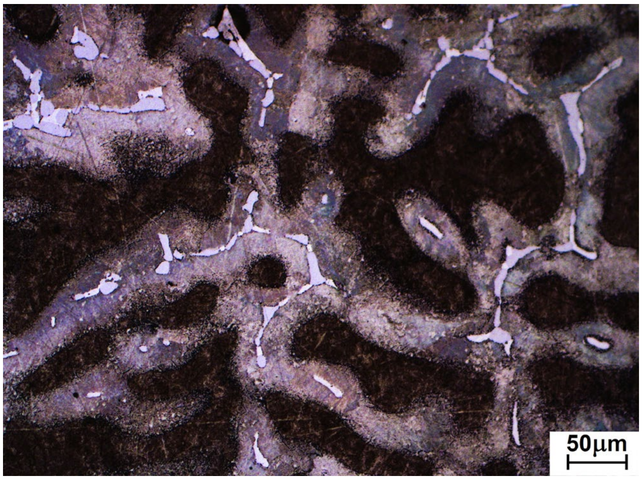

Fig. 6.5. Microstructure of ZnAl27Cu2 alloy cooling in the foundry gypsum mold, magnification 200x

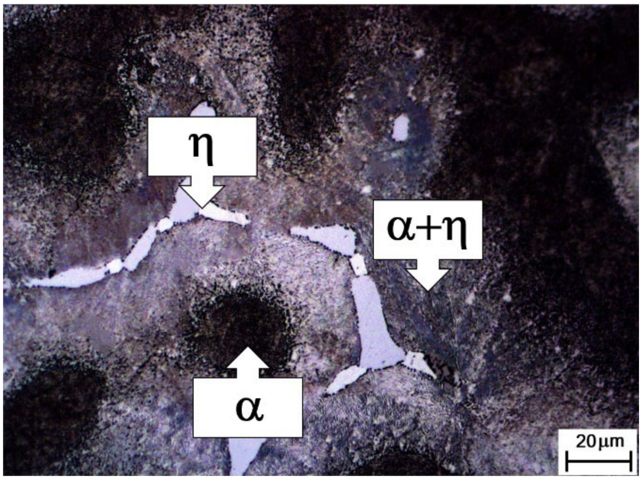

Fig. 7. Components of the microstructure of the ZnAl27Cu2 alloy poured into the casting gypsum mold , magnification 500x

As it results from the measurements, the secondary dendrite arm spacing increases with the decrease in the cooling rate. The highest cooling rate was recorded for samples cast into a steel mould at a temperature of 20°C and for this case the smallest distances between the secondary dendrite arm spacing were also measured. On the other hand, there is a mould made of foundry plaster, where the sample casting cooled the longest. This is reflected in the microstructure, where large, expanded dendrites are observed. Here, the largest secondary dendrite arm spacing were also measured. The distances between the dendrite arms are presented in Table 2 for each type of foundry mould material.

Table 2.
Dependency of the cooling rate, secondary dendrite arm spacing and Brinell hardness in relation to the mold material

	Metal mold 20ºC	Metal mold 100ºC	Humid sand mold	Dried sand mold	Plaster mold
Cooling rate, K/s	23.2	21.7	5.1	3.8	1.8
SDAS, μm	11.05	11.93	42.61	51.74	82.19
HRB	123	121	112	111	114

Also in Table 2 the hardness measurements results are presented. As can be seen, there is partly correlation between the mold material (cooling rate) and the hardness. For the highest cooling rate obtained in a metal mold we observe the highest hardness. It is undoubtedly related to the presence of the finest alloy microstructure. The correlation is not linear, as a slight increase in hardness was observed for the sample cast into a plaster mold, which has the most extensive dendrites in the microstructure.

4. Conclusions

The investigated ZL27 alloy is characterized by a dendritic structure that can be easily shaped as the cooling rate changes. The highest fragmentation of the structure was obtained at a cooling rate of 23.2 K/s. For this cooling rate, the smallest secondary dendrite arm spacing was obtained. The fragmentation of the structure also influenced the achievement of the highest hardness value from all tested samples. However, such a strong fragmentation of the structure adversely affected the alloy's ability to damping vibrations. The value of the vibration damping coefficient α dropped significantly below 100dB/m. This is the limit above which the alloy belongs to the group of materials with high damping properties. This is a known tendency, even from the modification of this type of alloys. Fragmentation of the structure causes a decrease in the damping properties of the alloy. The highest value of the vibration damping coefficient was obtained for the sample cast into a humid green sand mold. The vibration damping coefficient α is 262.46dB/m. The cooling rate in this case was 5.1 K/s and resulted in achieving average values for the tested samples in terms of secondary dendrite arm spacing. Interestingly, this was not the lowest cooling rate. Lower cooling rates, amounting to about 4 K/s and about 2 K/s, respectively, were obtained for the dried green sand mold and for the mold made of foundry gypsum. For the latter, the second-best results were recorded in terms of the value of the vibration damping coefficient α. The general tendency that high structural fragmentation adversely affects the damping properties of alloys is confirmed. The second conclusion is that even the very low cooling rate, resulting in the formation of large, overgrown dendrites, does not guarantee the highest vibration damping capacity for this particular alloy. It turns out that the appropriate microstructure, in this case obtained in a humid green sand mold, (cooling rate of 5.1 K/s) guarantees the best damping properties for the ZL27 alloy.

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