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Damping Properties vs. Structure Fineness of the High-zinc Aluminum Alloys

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Abstract

The subject of this study is the presentation of relation between the degree of structure fineness and ultrasonic wave damping coefficient for the high-zinc aluminium alloys represented in this study by the sand mould cast alloy Al - 20 wt% Zn (AlZn20). The studied alloy was refined with a modifying (Al,Zn)-Ti3 ternary master alloy, introducing Ti in the amount of 400 pm into metal. Based on the analysis of the initial and modified alloy macrostructure images and ultrasonic testing, it was found that the addition of (Al,Zn)-Ti3 master alloy, alongside a significant fragmentation of grains, does not reduce the coefficient of ultrasonic waves with a frequency of 1 MHz.

Keywords: High-zinc aluminum alloys, Grain refinement, Damping properties, Damping coefficient

1. Introduction

The modification of casting alloys based on aluminium is a common practice that allows obtaining a fine-grained structure, alongside the improvement of their strength properties. On the other hand, it is required that many construction materials currently in use have, apart from good strength properties, good damping properties. However, damping capability and strength properties are likely to be mutually exclusive. From literature, it is known that casting alloys based on Al - Zn are included in the materials with increased damping properties. High-zinc aluminium alloys are a group of alloys relatively poorly examined despite a number of attractive properties for the user, particularly high strength and high damping properties. For Al - Zn alloys, except for publications covering the results of preliminary studies [1-3], it is noted that the literature rather lacks information on the simultaneous effect of the degree of structure fineness, obtained as a result of a modifying procedure, on strength and damping properties. For other aluminium alloys, e.g. A356, contemporary literature provides information on the observed increase in damping properties following the structure fineness due to the modifying procedure [4]. Such an effect of fineness is opposite to the expected one. According to general ideas developed to date, the structure fineness reduces the value of the coefficient. The above inconsistency calls for actions in order to investigate the effect of modifying procedure on the formation of the high-zinc aluminium alloys' damping properties, as exemplified by the AlZn20 alloy. The Al - 20 wt% Zn (AlZn20) alloy, modified before casting into a sand mould with new modifying master alloys, represented by the (Al,Zn) - 3,0 wt% Ti master alloy type, hereinafter referred to as (Al,Zn)-Ti3 MA, was tested. The ultrasonic wave damping coefficient as a function of grain size was investigated as part of the study.

2. Materials and methodology

The Al-20 wt% Zn (AlZn20) alloy selected for testing, and composed of the so-called medium-range high-zinc aluminium alloys, underwent the modifying procedure by the new modifying master alloy, represented by the (Al,Zn)-Ti3 master alloy. The AlZn20 alloy was melted from AR1 electrolytic aluminium (min. purity 99.99%) and EOS electrolytic zinc (99.995) in an electric resistance furnace and then pig sows 70x130x(10-15) mm and rolls Ø 20 mm x 200 mm were cast. Pig sows and rolls were uniform charge which was then, during testing, melted in a PT12 electric resistance furnace, prod. by Czylok, Poland. The PT12 furnace comes standard with an automatic thermal control system and system of protective atmosphere and allows single melting of about 4 kg aluminium alloys. The weight of the melted charge was about 0,5 kg or about 3 kg. Melts with a smaller amount of charge were used for casting test samples for structural analysis, whereas those with a bigger amount were used for casting test samples for strength and damping properties tests. A metal bath was overheated to a temperature of about 740 °C and then was refined with argon for 10 min. After refining was complete, 10 minutes wait was done to allow the impurities go into the slag. Then, the modifying master alloy was introduced and after its dissolution (on average about 2 min.), the bath was stirred with an alundum rod for about 2 min. in order to create a uniform composition and distribute the master alloy in the bath evenly. Then, after removing melting losses, the alloy was cast into a dry sand mould. The use of the sand mould made it largely possible to eliminate the effect of cooling rate on the fragmentation of castings' grains, which takes place during cooling in a metal mould and makes it difficult to assess the effectiveness of the modifier. From the middle part of the sample cast in the sand mould, 25 mm high samples were cut for structural testing by the methods of optical microscopy (LM), scanning electron microscopy (SEM) and for damping tests. Microsections of samples for optical microscopy LM *(light microscopy)* tests were sanded and then polished. The polished samples were chemically etched with Keller's reagent or electrolytically - with Barker's reagent. The observation of the AlZn20 alloy microstructure was performed with Zeiss Axio Imager M2m microscope. Damping coefficient tests were carried out using the Krautkramer's measurement set, model USLT 2000. The entire study was conducted to investigate the longitudinal wave with the frequency of 1 MHz. To determine the attenuation intensity, the echo method *(pulse – echo – method)* was sed, using the Krautkramer's USLT 2000 internal software. Prior to testing, the Krautkamer's USLT 2000 device was calibrated with a sample cast in pure zinc. Additionally, the instrument calibration was carried out for each series of the AlZn20 alloy samples.

3. Results

The initial AlZn20 alloy cast into the dry sand mould has a coarse-grained structure - Fig. 1. Grain size reaches dimensions of about 2 mm, which was observed in Fig. 1(a). The microstructure of the initial, unmodified AlZn20 alloy consists of large branched dendrites of a zinc solid solution in aluminium α(Al) - Fig. 2(a) Such a structure is unfavourable from the point of view of shaping the plastic properties of the high-zinc aluminium alloys cast into sand moulds and needs to be fragmented by applying the modifying procedure. The effect of titanium introduced in the (Al,Zn)-Ti3 modifying master alloy on the degree of the AlZn20 alloy structure fineness is shown in Fig. 1(b). The addition of titanium in the (Al,Zn)-Ti3 master alloy causes about 10 - fold fineness of the AlZn20 alloy macrostructure, which can be observed in the graph - Fig. 3.

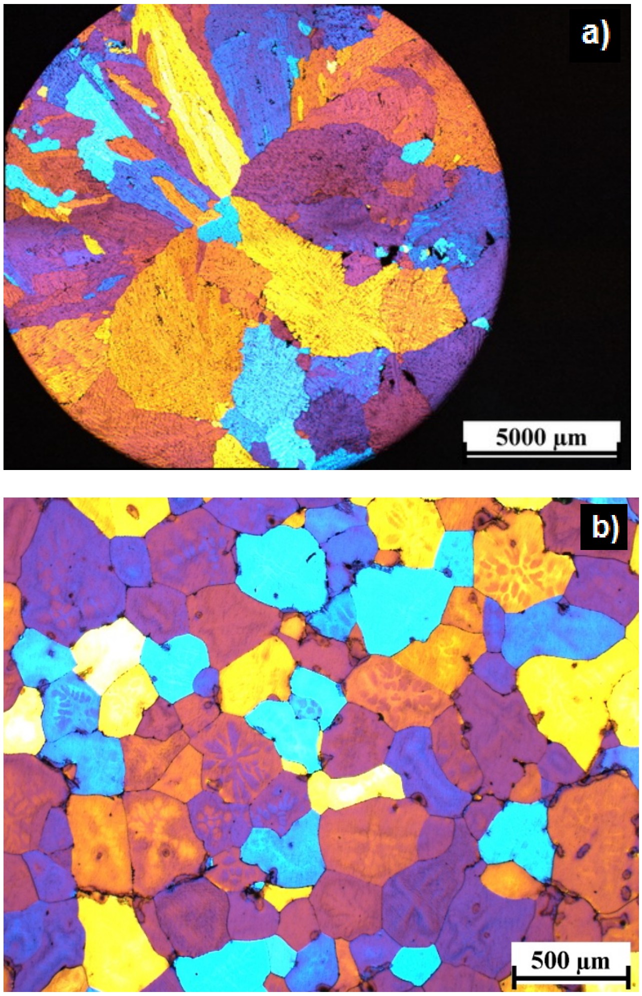
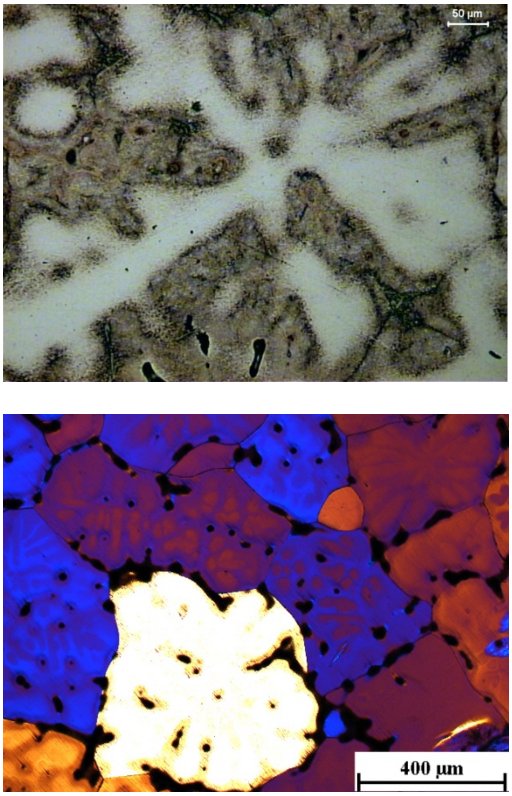


Fig. 1. LM picture (Zeiss Axio Imager A.1m) of the AlZn20 sand cast alloy, Barker’s etchant; (a) – initial alloy, non-inoculated; visible coarse-grained structure; (b) the AlZn20 alloy inoculated with 400 ppm Ti, introduced to the melt with (Al,Zn)-Ti3 MA [5]

After the addition of titanium in the amount of 0.04 wt% in relation to the weight of the modified alloy introduced in the (Al,Zn)-Ti3 master alloy the fineness of macrostructure Fig. 1(b) and the significant fineness of microstructure dendrites can also be observed. The used modifying master alloy causes, along with the structure fineness, a change in the microstructure morphology, namely the shape of dendrites of the zinc solid solution in aluminium α(Al) is changed from a branched "linear" form to a "compact" form - Fig. 2 (b).



a)

b)

Fig. 2. The AlZn20 alloy microstructure image; (a) initial unmodified, (b) modified with (Al,Zn)-Ti3 MA, introducing 0,04 wt% Ti to the solution [6]

The damping coefficient tests were performed for the same series of samples which were used in the investigation of the degree of structure fineness. A sample image of peaks in an echogram for the initial, unmodified AlZn20 alloy is shown in the figure - Fig. 3.

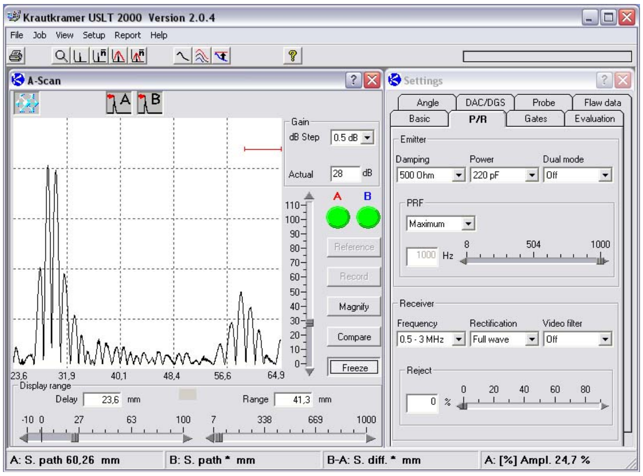


Fig. 3. Sample image of peaks in an echogram for the initial, unmodified AlZn20 alloy [7]

Table 1.
Attenuation coefficient α of the initial, unmodified AlZn20 alloy and the same alloy inoculated with (Al,Zn)-Ti3 MA addition introducing 0.04 wt% Ti into the melt; Transducer frequency 1 MHz; Coupling material – water; P1 and P2 - height, accordingly, of the first and second echos

AlZn20 alloy non-inoculated			AlZn20 alloy grain-refined by the (AlZn)-Ti3		
P1 [dB]	P2 [dB]	α [dB/m]	P1 [dB]	P2 [dB]	α [dB/m]
27.5	40.5	217.39	19.5	29	190
28	40.5	209.03	21	32	220
27	40	217.39	20.5	30	190
29	40.5	192.31	20.5	33.5	260
29	43.5	242.47	21	35.5	290
29	43	234.11	20	32	240
29.5	41.5	200.67	20	33.5	270
28	43.5	259.20	19.5	30	210
27	41.5	242.47	20	32	240
Mean α = 224.00 dB/m			**Mean α = 234 dB/m**		

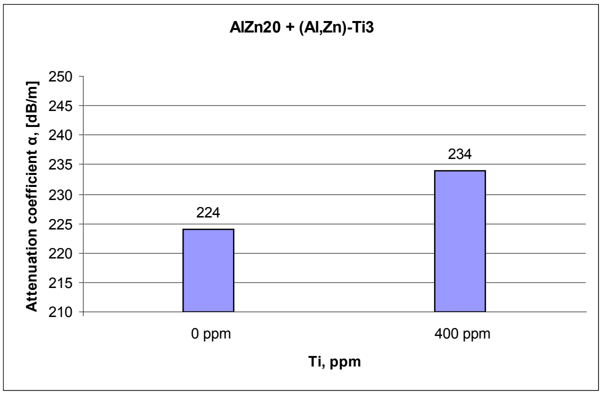


Fig. 4.1. Summary of the effect of the addition of Ti in the (Al, Zn)-Ti3 master alloy on the mean value of damping coefficient

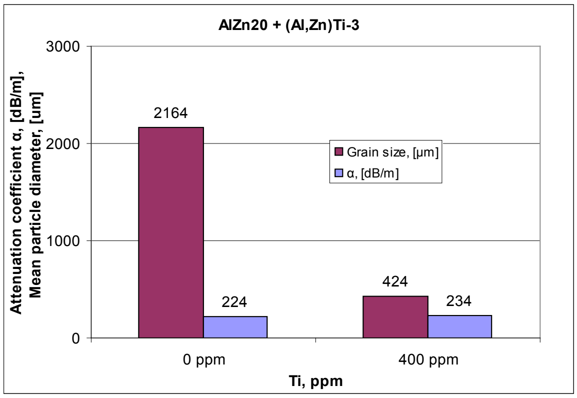


Fig. 4.2. Summary of the effect of the addition of Ti in the (Al, Zn)-Ti3 master alloy on the mean value of damping coefficient and grain size

Based on the obtained results of ultrasonic wave attenuation tests in the analysed alloys, it can be concluded that the tested AlZn20 alloy belongs to a group of materials with high damping properties, because the damping coefficient reaches a value greater than 100 dB/m - Tab.1. In the unmodified AlZn20 alloy and in the same alloy modified with the (Al,Zn)-Ti3 master alloy introducing 400 ppm Ti into the solution, the structure fineness generally does not change the value of the damping coefficient and does not differ from the mean initial value of about 200 dB/m at such a titanium addition in the master alloy - Figs 4.1 and 4.2. The samples of cast alloys are characterised by a structural heterogeneity, which causes a large value dispersion within a given series, despite the same conditions of melting and casting - Fig. 5.

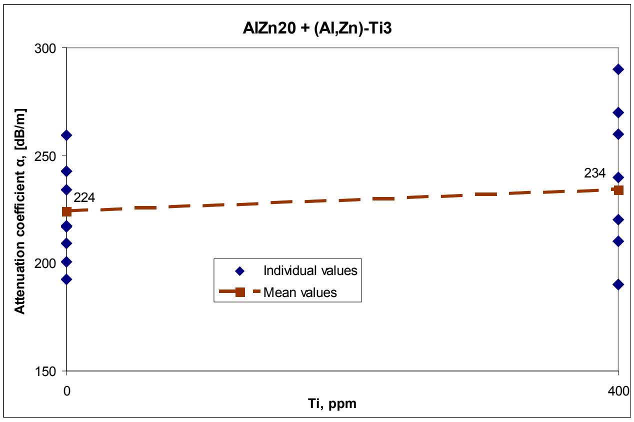


Fig. 5. Individual values dispersion around the mean value of the damping coefficient of the initial AlZn20 alloy, modified with 0.04 wt% Ti in the (Al,Zn)-Ti3 master alloy.

4. Conclusions

Based on the performed tests and obtained results, it can be concluded that the use of the (Al,Zn)-Ti3 master alloys, with the addition introducing 400 ppm Ti into the modified alloy in the modifying procedure of the high-zinc aluminium alloys, causes a significant structure fineness (about 7-fold) of the alloy, although not so intensive as in the case of applying traditional modifying master alloys such as TiBAl or TiCAl master alloys [7] (about 10-fold). The structure fineness by the addition of the master alloy in the amount of about 400 ppm generally does not change the value of the damping coefficient, which reaches the values observed for the unmodified alloy. The used method of ultrasonic wave echo is a very sensitive method, giving a large dispersion of values even within the same sample, but showing the structure heterogeneity in a form of various sizes of grains, as well as the heterogeneous distribution of phases, inclusions or dislocation in the structure. It requires performing large series of measurements and averaging them. The modifying procedure performed by means of the above-mentioned addition of 400 ppm Ti causes a significant change in the structure fineness, which allows to improve the alloy strength properties, with maintaining high level of damping properties, defined by the modern method of ultrasonic wave damping, which was the primary objective of this study. The results of the presented tests should contribute to the description of the relation *structure features - damping properties* for the Al - Zn cast alloys.

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