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The Influence of Grain Refinement and Feeding Quality on Damping Properties of the Al-20Zn Cast Alloy

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Abstract

The paper presents relationships between the degree of structure fineness and feeding quality of the Al – 20 wt.% Zn (Al-20 Zn) alloy cast into a mould made from sand containing silica quartz as a matrix and bentonite as a binder, and its damping coefficient of the ultrasound wave at frequency of 1 MHz. The structure of the examined alloy was grain refined by the addition of the refining Al-3 wt.% Ti – 0.15 wt.%C (TiCAl) master alloy. The macrostructure analysis of the initial alloy without the addition of Ti and the alloy doped with 50-100 ppm Ti as well as results of damping experiments showed that the structure of the modified alloy is significantly refined. At the same time, its damping coefficient decreases by about 20-25%; however, it still belongs to the so called high-damping alloys. Additionally, it was found that despite of using high purity metals Al and Zn (minimum 99,99% purity), differences in the damping coefficient for samples cut from upper and bottom parts of the vertically cast rolls were observed. These differences are connected with the insufficient feeding process leading to shrinkage porosity as well as gases present in metal charges which are responsible for bubbles of gas-porosity.

Keywords: High-zinc aluminium alloys, Grain refinement, Feeding quality, Damping properties

1. Introduction

Modification of cast aluminium alloys allows to obtain the refined structure and improvement in ductile properties. At present, many construction materials are required to have, apart from good strength properties, ductile properties in particular, also good damping properties. Ductile properties, represented e.g. by elongation, usually increase along with the structure refinement. In turn, damping properties usually decrease along with the structure refinement. The research conducted at present focuses on determining dependencies between the structure properties, particularly, the degree of the matrix grain refinement and the addition of three elements and strength (tensile strength and elongation strength), damping and tribological properties. Non-destructive testing (NDT) methods utilizing the ultrasound wave echo intensity analysis [1-5] occupy an important position among the investigative methods. The main purpose of this analysis is to reveal inner defects of the casting structure.

The next application of ultrasound waves can be determining mechanical properties of castings and relationships between these properties and casting structure features [6-14]. Investigations focusing on the microstructure [15-16] and macrostructure analysis, and particularly determining the grain size in castings [17-23] are prevalent. As is well known, that liquid metal before casting into a mould is subjected to procedures of grain refinement and modification. As a result of these procedures, the degree of the structure refinement and its morphology change, which causes also changes in the level of damping properties [24-28]. It must be noted that cast iron and Al-Zn, Zn-Al and Mg-Zn-Al matrix alloys belong to a group of high damping alloys [29-32]. The above mentioned Al-Zn matrix alloys are characterized by the structural and dimensional instability in the long term after casting, caused mainly by transformations of phases containing copper. For this reason, these alloys are subjected to the appropriate heat treatment, and modification of their composition (doping with trace elements) in order to obtain dimensionally stable materials. The structural effect of the above treatments is also the subject of investigations utilizing ultrasound methods [33-37].

In the group of Al-Zn matrix alloys, a group of high-zinc alloys which are included in materials with increased damping properties and good strength, but with rather low ductility distinguishes itself. As a result of this, it is recommended to apply the grain refinement in order to improve ductility. These alloys require good feeding, because they solidify in a quite wide range of liquidus-solidus temperature, which facilitates the occurrence of shrinkage porosity in their structure.

Within the scope of this paper, the analysis of the influence of grain size, feeding quality and presence of gaseous bubbles in the structure on the change in damping properties of a selected representative of high-zinc aluminium alloys was conducted. Namely, a two-component aluminium alloy with the addition of zinc, with the nominal composition of Al - 20 wt.% Zn (Al-20Zn), modified prior to casting into a sand mould with the variable addition of the Al-3 wt.% Ti-0.15 wt.%C (TiCAl) refining master alloy, was examined.

2. Research materials and methodology

The Al-20Zn alloy selected for the research was melted from electrolytic aluminium (99.99%) and electrolytic zinc EOS (99.995%) in an electric resistance furnace. A liquid alloy was overheated up to the temperature of about 720 ºC, and then a modifying master alloy was introduced and after its dissolution (on average after about 2 min.), the melt was mixed for about 2 min. in order to homogenize the alloy composition and uniformly distribute insoluble master alloy components within the melt. After the removal of dross, the alloy was cast into a dried green sand mould. The application of a sand mould allowed to a large extent to eliminate the influence of cooling rate on the castings' grain refinement which occurs during cooling in a chill mould and makes the evaluation of the modification treatment effectiveness difficult. The cast samples after cutting risers were cut at half of their height. The upper and bottom parts of samples obtained in this way - Fig. 1, were subjected to tests on the damping coefficient of a wave at frequency of 1 MHz.

Also, samples with the height of about 30 mm for structural analyses by light microscopy (LM) methods were cut from the middle castings' part. Metallographic samples for light microscopy (LM) examinations were prepared by means of a Struers LaboPol-5 device. Samples were ground with abrasive papers of 200-800 grit size and then were polished. The polished samples were electrolytically etched with a Barker's reagent. Observations of the examined alloy macrostructure were conducted by means of a Zeiss Axio Imager M1m microscope.

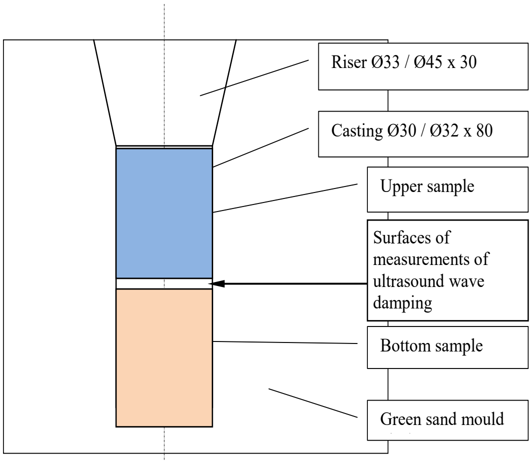


Fig. 1. A pictorial diagram of castings and samples cut out from them for structural analyses and the ultrasound wave damping coefficient tests

The intercept method was applied to determine mean diameters of the examined alloys' grains.

Grain linear density $\overline{N}_L$ and surface density $\overline{N}_A$ and the mean planimetrical diameter $\overline{D}_A$ were calculated from the formulas (1):

$$\text{(a)} \quad \overline{N}_L = \frac{\left(N_W + \frac{1}{2}N_G + \frac{1}{4}N_N\right)_L}{L}, \quad \left[\frac{1}{\mu\text{m}}\right]$$

$$\text{(b)} \quad \overline{N}_A = \frac{\left(N_W + \frac{1}{2}N_G + \frac{1}{4}N_N\right)_A}{A}, \quad \left[\frac{1}{\mu\text{m}^2}\right] \qquad (1)$$

$$\text{(c)} \quad \overline{D}_A = \frac{\overline{N}_L}{\overline{N}_A}, \quad [\mu\text{m}]$$

where:

A - the analyzed surface area of the sample

N_W – the number of grains located totally inside the analyzed area A or wholly cut by intercept L

N_G – the number of grains located partially beyond the boundaries of the analyzed area A or ends of intercept L

N_N – the number of corner grains

$$\overline{N}_V \cong 0.568\,(\overline{N}_A)^{3/2}, \quad \left[\frac{1}{\mu\mathrm{m}^3}\right] \qquad (2)$$

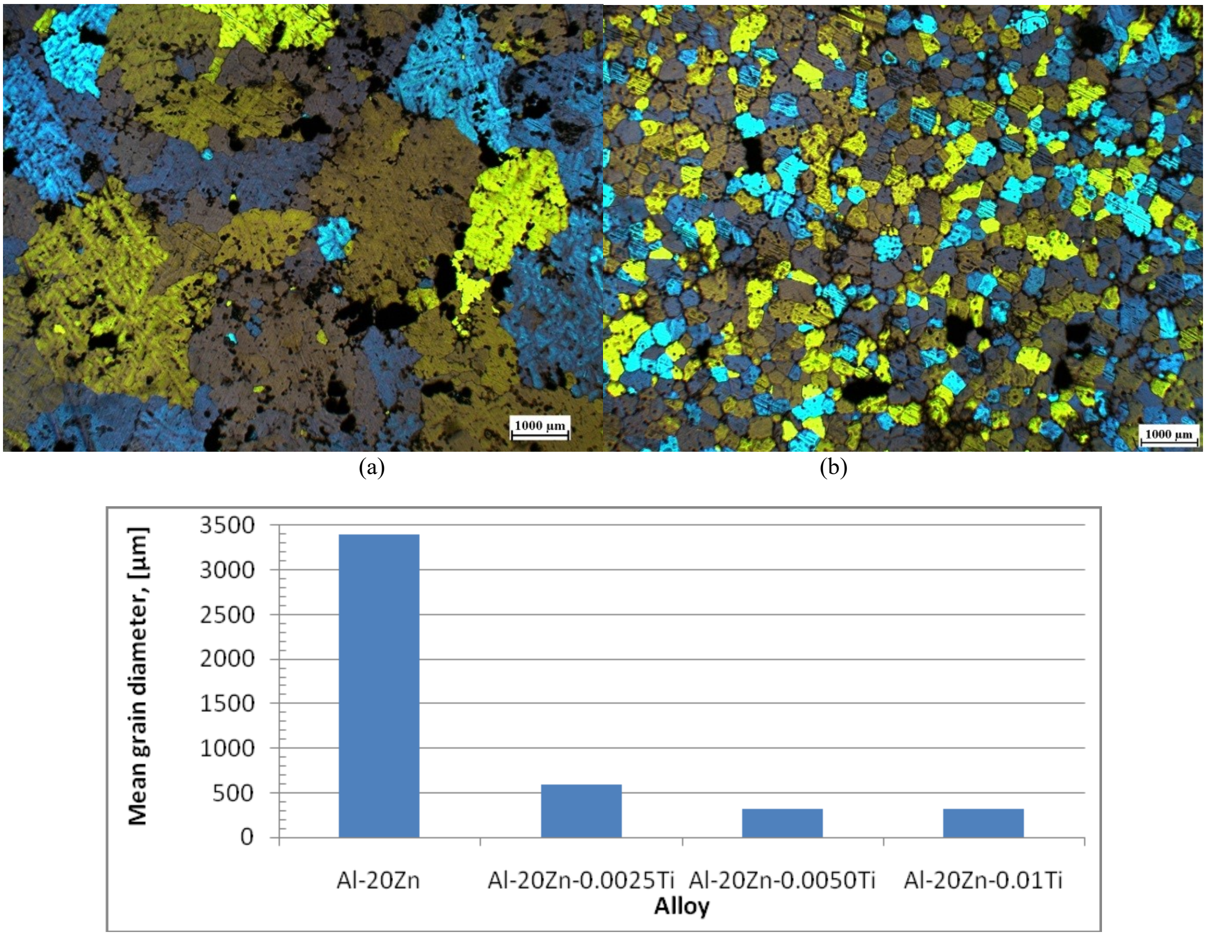
$$\overline{D}_V = \sqrt[3]{\frac{6}{\pi\,\overline{N}_V}}, \quad [\mu\mathrm{m}] \qquad (3)$$

Grain volumetric density $\overline{N}_V$ was calculated using Voronoi relationship (2), while the mean grain diameter for the spatial layout $\overline{D}_V$ was calculated from formula (3), assuming the spherical shape of grains.

Tests on the damping coefficient were performed by means of an Olympus Epoch XT measuring set with a transducer emitting 1 MHz longitudinal ultrasound waves. The *pulse - echo method*, utilizing the internal device software, was applied to specify damping intensity.

3. Test results

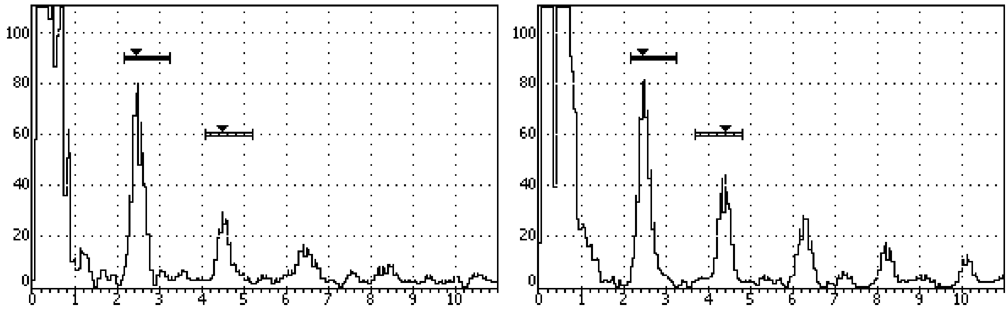
The unmodified initial Al-20 Zn alloy cast into a dried green sand mould has the coarse grain structure with a mean grain diameter (planimetric diameter) of about 3500 µm – Fig. 2(a). Such a structure form is unfavorable from the perspective of the examined alloy ductile properties' formation. The application of the treatment consisting in modifying with the addition of 50-100 ppm Ti introduced with the TiCAl master alloy causes about the 10-fold macrostructure refinement, that is up to the mean grain size of about 350 µm - Fig. 2(b-c).



(a) (b)

(c)

Fig. 2. The image of the Al-20 Zn alloy macrostructure; (a) the initial, unmodified alloy, (b) the modified alloy with the addition of 100 ppm Ti in the Al-3Ti-0.15C master alloy, (c) the mean planimetric diameter of the examined alloy grains



(a) (b)

Fig. 3. An exemplary image of peaks in the echogram of the Al-20 Zn alloy samples: (a) the initial alloy without any addition of Ti, (b) the alloy with the addition of 100 ppm Ti (both samples were cut out from the bottom part of castings)

The ultrasound wave damping coefficient testing was conducted for the same series of samples as was used in the analysis of the structure refinement degree. An exemplary image of peaks in the echogram for the initial Al-20 Zn (unmodified) alloy and the alloy modified with the addition of 100 ppm Ti is presented in Fig. 3, while the results of individual measurements are presented in Table 1.

The value of damping coefficient was calculated from the formula:

$$\alpha = \frac{(P_2 - P_1)}{2H}, \left[\frac{\mathrm{dB}}{\mathrm{m}}\right] \qquad (4)$$

where: P1 and P2 are heights of two neighboring peaks marked by arrows in the echogram - Fig. 3, while H is the height of the sample [m].

Collective summaries of mean values of grain size and mean values of damping coefficient corresponding to them are presented diagrammatically in Fig. 4.

Table 1.

The damping coefficient measurements results of the initial Al-20 Zn alloy and the alloy modified with the addition of 25, 50 and 100 ppm Ti in the Al-3Ti-0.15C master alloy. U-S and B-S, accordingly, are samples cut out from the upper and bottom part of the casting (Fig. 1)

Addition of Ti, [ppm]	Sample	H [mm]	P1 [dB]	P2 [dB]	Δ [dB]	α [dB/m]
0.0	U-S	29.4	28.7	37.1	7.4	252
	B-S	30.0	19.5	28.2	7.7	257
25	U-S	29.4	13	20	6	204
	B-S	30.0	14.2	18.8	3.6	120
50	U-S	29.8	15.1	21	4.9	164
	B-S	29.9	16.4	23.6	6.2	207
100	U-S	29.3	17.2	24.7	6.5	222
	B-S	30.0	11.3	16.7	4.4	147

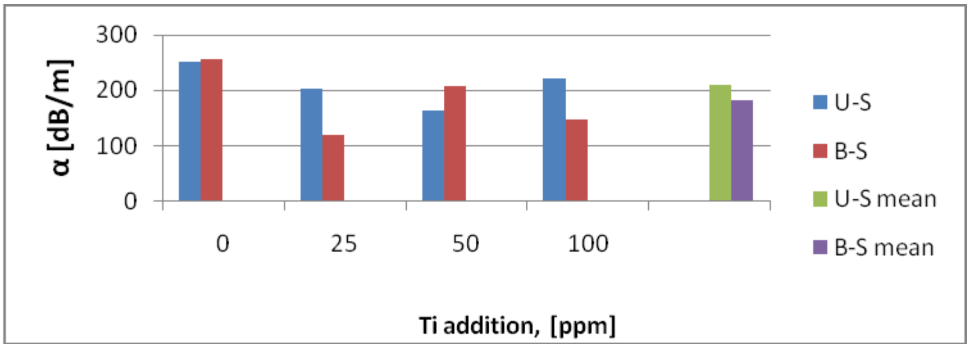


Fig. 4. A change in the ultrasound wave damping coefficient (f = 1MHz) in the Al-20 Zn alloy modified with the variable addition of the Al-3Ti-0.15C master alloy. U-S - the sample cut out from the upper part of the casting (below the riser), B-S - the sample cut out from the bottom part of the casting, U-S mean and B-S mean - mean arithmetical values of damping coefficient for the examined samples

4. Discussion of results

Based on the obtained results of the ultrasound wave damping in the analyzed alloys, it can be stated that the examined Al-20 Zn alloy belongs to the group of materials with high damping properties because its damping coefficient reaches the mean value of about 250 dB/m - Table 1. Having applied the modification treatment with the variable addition of Ti in the TiCAl master alloy, the structure refinement causes a decrease in the value of damping coefficient by about 20-25%, that is up to the mean value at the level of about 180 - 210 dB/m - Fig. 4. It was determined that damping properties of samples cut out from the upper and bottom part of castings are different, whereby the obtained results do not demonstrate a homogeneous trend of changes - Fig. 4. Mean values of damping coefficient of upper parts are higher. A cause of this can be identified as a slightly lower cooling rate below the riser and a slightly larger grain size related to it. The second justification for the observed difference can be a greater shrinkage of warmer metal below the riser and insufficient feeding of interdendritic spaces and the examined alloy grains' boundaries - Fig. 5. Another cause can be bubbles of gases given off from the solution, clearly visible in Figs. 2(a) and 2(b).

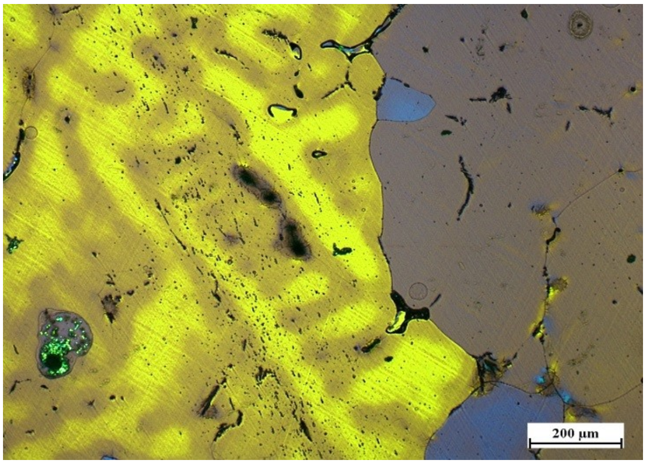


Fig. 5. Shrinkage porosity visible at grain boundaries and inside dendrites of the Al-20 Zn alloy

5. Conclusions

Based on the conducted tests and obtained results, it can be stated that the application of the modification treatment of the high-zinc aluminium Al-20 Zn alloy with the AlTiC0.15 master alloy, with the addition introducing about 100 ppm Ti to the modified alloy, causes the significant alloy structure refinement, the consequence of which is the decreased ultrasound wave damping coefficient.

Additionally, a strong relationship between damping properties and the quality of feeding the cooling down and solidifying casting, irrespective of the structure refinement degree was found and presented in the paper. The above observation leads to the conclusion that despite the application of the charge consisting of pure components, the optimization of the metal charge recasting consisting in the application of protective slags and the metal refining treatment before its modification is necessary. Additionally, the optimization of the shrinkage voids' feeding in the cooling casting, as well as the examination of the influence of the modifying master alloy addition on the metal gassing degree are necessary. The implementation of the above procedures should result in obtaining homogeneous properties in the whole mass of the cast samples.

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