THE EFFECT OF Ti ON HIGH-ZINC Al CAST ALLOYS STRUCTURE AND PROPERTIES

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Abstract
The paper comprises investigations of binary Al – 20 wt% Zn sand cast alloy (AlZn20) doped by 0.04 wt% Ti, introduced into melt with the AlTi5B1, AlTi3C0.15 and AlZn-Ti3 MA (master alloy). The LM (Light Microscopy) structural examinations, UTS (Ultimate Tensile Strength) and Elongation (A5) as well as DP (damping properties) tests were performed for the initial, non refined alloy, and for the grain refined ones. On the basis of these examinations it was stated that the implemented inoculation process causes significant increase of grains population. Elongation of the grain refined alloys increases from the range of 1.7 – 2.1 % (initial, non refined samples) to the range of 2.1 – 2.9 % (grain refined samples). At the same time, UTS and attenuation coefficient remain basically preserved.

Keywords: aluminium alloys, grain refining, grain size, heterogeneous nucleation of phase, mechanical properties

1 Introduction

Development of the technology requires new construction materials possessing still better strength, technological and service properties. These requirements are fulfilled by elaborating completely new materials or by improving properties of the already existing ones. An example of the materials whose properties have been being improved for nearly 100 years are zinc-aluminium based foundry alloys introduced to industry at the beginning of the twenties of XX century. Among the alloys based on the Al-Zn system the high-aluminium zinc alloys of increased to 8 - 30 wt% Al content [1-7] and the high-zinc aluminium alloys of increased to 10 – 30 wt% Zn content deserve special attention [8-10]. They have good strength and casting properties, and very good damping properties. They display great potential possibilities of their practical application, which results from their universality and possibility of processing with numerous techniques, including most sophisticated ones, belonging to the group of *high technology*, like rheo-casting or squeeze-casting.

Recent efforts of the European Community are aimed at energy saving and improving environmental protection at the same time. Replacing some amount of Fe-based castings with the AlZn-based ones can satisfy these requirements because they are relatively cheaper according to lower melting temperatures – **Fig. 1**, which allows saving energy expenses.

However, the sand-cast high-zinc aluminium foundry alloys solidify naturally with coarse primary dendrites of the α' Zn-Al solid solution, which detrimentally influences their plastic properties. The ductility of these alloys can be significantly increased by refinement of the α' dendrites [11-13].

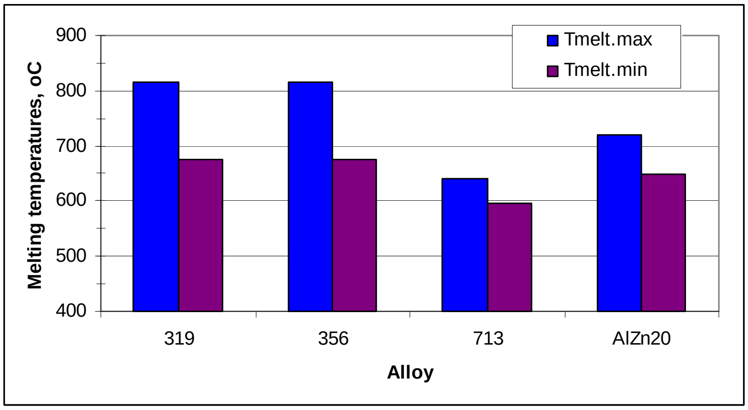

Fig.1 Melting temperatures of typical foundry sand-cast alloys 319 (AlSi6Cu4), 356 (AlSi7Mg0.3), 713 (AlZn8Cu1Mg) and the high-zinc AlZn20 aluminium alloy.(Diagrams based on data from [14] and [15])

The presented paper is devoted to grain-refinement of the high-zinc aluminium alloys, represented by Al-20 wt% Zn (AlZn20) alloy, inoculated by the traditional AlTi-based master alloys and by a new master alloy based on the Al-Zn-Ti system. The changes of the grain size, strength properties, and also the attenuation coefficient as the effect of employed inoculation are presented and discussed. The paper brings also results of the analysis concerning the extent, to which the inoculation should be performed, to ensure improved strength and preserved damping properties of the examined alloy.

2 Materials and Experimental Methods

Chosen for the investigations AlZn20 alloy and modifying Al-Zn-Ti based master alloy, named in this paper AlZn-Ti3 MA, were melted from the electrolytic aluminium AR1 (99.96%), electrolytic zinc EOS (99.995%) and high purity titanium (m3n8; 12N8: Johnson Matthey Alfa Products).

AlZn-Ti3 MA was melted in electric resistance furnace, in alumina crucible of 0.2 dm^3 capacity. To the melted and overheated to 750^{o}C AlZn20 alloy, Ti was introduced in small portions and the bath was stirred with graphite rod. After complete dissolution of titanium, melt was stirred and refined with the addition of 0.2wt% of $ZnCl_2$, next, after removing melting dross, it was poured into metal moulds. Melting of the whole portion of the AlZn20 alloy was conducted in the induction furnace, in clay – graphite crucible of 25 kg Zn capacity. First, total amount of Al was melted and overheated 720 – 740 ^{o}C, next Zn was introduced in portions. After dissolution of Zn, alloy was stirred for 2 minutes in order to unify the composition, and then it was poured into metal moulds obtaining plates 130 x 70 x 15-20 mm. During melting neither protective flux, nor gas refining, were used.

Obtained plates were used as charge, which was gradually melted during experiments, and the mass of melted charge of AlZn20 alloy was average 1500 g. Charge, after melting in electric resistance furnace, in clay – graphite crucible of 1.5 dm^3 capacity, was overheated to about 740^{o}C and then the melt was degassed by bubbling Ar through it for 10 min. After dross removing, a master alloy was added and the melt was held for 5 minutes. Then the melt was stirred for next 2 minutes with an alumina rod, and finally the alloy was cast into a dried sand mould to obtain dog-bone shape tensile test-pieces (working part ∅12x60 mm) and ∅32x50 mm samples for damping tests. Application of the sand mould allowed eliminating the effect of the cooling rate on casting grains size. This effect occurs during cooling in metal mould, making determination of grain-refiner effectiveness difficult. The inoculation was performed using three different master alloys, i.e. described earlier the AlZn-Ti3 one, and commercially available AlTi3C0.15 (TiCAl) and AlTi5B1 (TiBAl). The master alloys were introduced in the amount needed to obtain 0.04 wt% of Ti in the melt.

The AlZn20 samples used in macrostructure examinations were etched chemically with Keller's or electrochemically with Barker's reagent. LM observations of microstructures were performed using Leica-DM IRM and Zeiss Axio Imager A1m light microscopes. The grain size was determined by measuring the real grains with the software NIS Elements Br 3.0, Nikon. Measurements of the attenuation coefficient were performed using the Olympus testing device Epoch XT, connected with a normal probe PF2R10, with a frequency of 2 MHz. The examinations were carried out using oil as lubricant. The tensile tests were performed using an Instron 3308 device.

3 Results and Analysis

Grain size

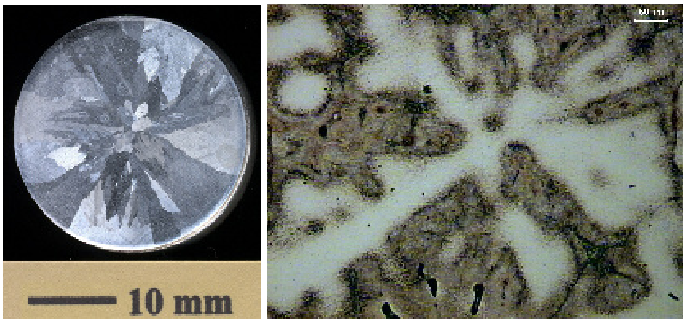

Fig.2 Macrostructure (left) and microstructure (right) of the initial non refined AlZn20 alloy

From **Figures 2** and **3**, and from data collected in **Table 1** it appears, that together with the addition of Ti-containing master alloys the modified alloy shows significant increase of its grains population, i.e. the average grain size decreases from about 4600 μm for the initial, non refined alloy up to 275 – 550 μm for the inoculated one. Also the microstructure morphology changes significantly due to the inoculation process, i.e. dendrites of the α' solid solution of zinc in aluminium, which is the main structure component in the high- zinc aluminium alloys, undergo a refinement and change their shape from linear to the more compacted one.

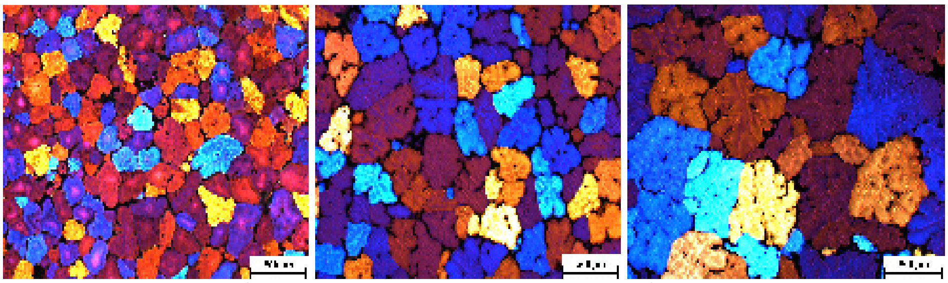

Fig.3 Macrostructures of the AlZn20 alloy inoculated with TiBAl (left), TiCAl (middle) and AlZn-Ti3 (right) master alloys

Table 1 Results of the grain size examination. EqDiameter represents average grain size

Alloy	EqDiameter [μm]	Area [μm²]	Perimeter [μm]	Length [μm]	Width [μm]	Circularity [--]
AlZn20	4 610	17 710 476	19 190	-	-	-
minimum deviation [μm]:	1 832	11 649 087	7 679			
maximum deviation [μm]:	1 460	11 232 965	10 488			
AlZn20+TiBAl	275	61 025	1 103	404	154	0.65
minimum deviation [μm]:	91	34 606	408	174	62	0.39
maximum deviation [μm]:	155	83 673	1 557	807	101	0.22
AlZn20+TiCAl	360	104 599	1 503	564	189	0.61
minimum deviation [μm]:	81	43 355	456	248	66	0.40
maximum deviation [μm]:	180	124 259	2 056	1 092	90	0.23
AlZn20+AlZn-Ti3	549	244 988	2 447	1 030	227	0.48
minimum deviation [μm]:	148	118 622	890	527	60	0.24
maximum deviation [μm]:	298	318 844	1 566	1 313	252	0.26

Strength Properties

As it was mentioned above, the examined high-zinc AlZn20 alloy, inoculated with the TiBAl, TiCAl and AlZn-Ti3 master alloys, undergo a considerable grain refinement of the α' ZnAl solid solution dendrites. This structural change causes a ductility increase, observed as an increasing elongation with tensile strength basically preserved – **Figure 4**.

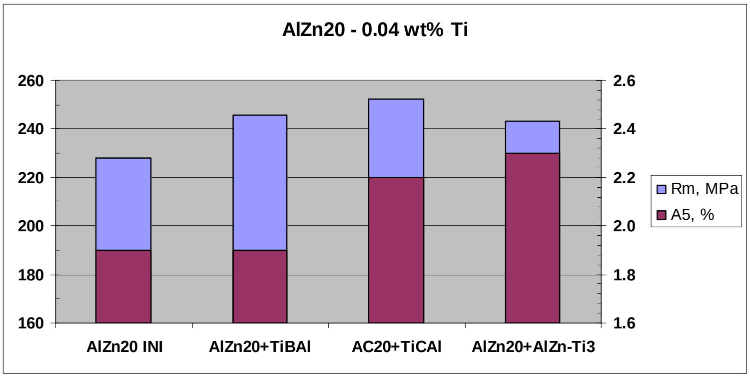

Fig.4 Ultimate tensile strength Rm and Elongation A5 of the initial non-refined AlZn20 alloy and its inoculated alternatives

Using the AlZn-Ti3 master alloy to the inoculation process gives numerous advantages apart from obtained positive changes both in the macrostructure and microstructure of the modified alloys. It shows good solubility in melted zinc-based alloys at the melt temperature already of about 500 °C and it shows similar density to the densities of the high-zinc aluminium alloys. These features of the AlZn-Ti3 master alloy allow to decrease a detrimental overheating of the Zn-Al alloys melt, which avoids melt oxidation, reducing the costs of energy and materials, and improving the mechanical properties of castings. Additionally, the AlZn-Ti3 master alloy, with density very close to that of the modified melt, allows avoiding technical difficulties due to high density difference between the common Al-Ti master alloys (about 3 g/cm^3) and Zn-Al melted alloys (5-6 g/cm^3).

DampingProperties

The high-zinc aluminium cast alloys are numbered to the group called High-Damping Alloys. It is clear, that the inoculation should be performed not to obtain marked grain - refinement per se, but to improve ductility and improve or preserve other properties, e.g. preserve high damping properties. During initial examinations, the relationship between average grain size and value of the attenuation coefficient was evaluated. The results obtained in these examinations are shown in **Figure 5**. As it appears from Figure 5, the significant grain refinement of the inoculated alloy does not influence the attenuation coefficient, whose value remains basically preserved.

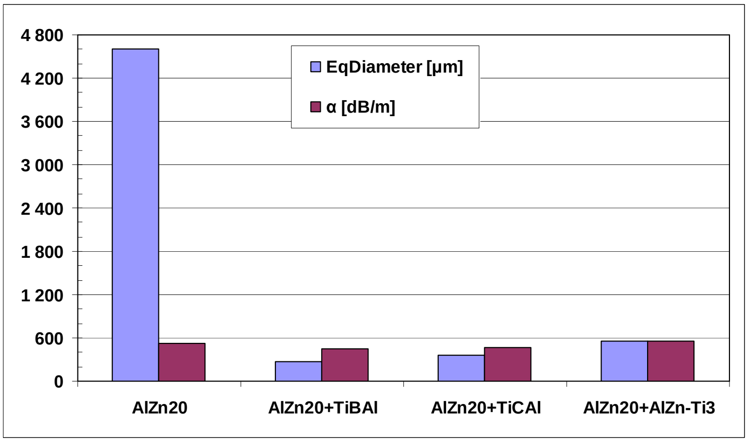

Fig.5 Changes of the attenuation coefficient together with changes of the average grain size

4 Conclusions

On the basis of the results obtained in the presented preliminary examinations the following conclusions can be formulated:

- The refining master alloys based on Zn-Al-Ti system show high effectiveness of structure refining of the high-aluminium zinc alloys and are promising alternatives for the traditional Al-Ti-B and Al-Ti-C refiners.
- All the used master alloys cause significant refinement of the α' primary dendrites of solid solution of zinc in aluminium, which is beneficial for improving plastic properties.
- The improved properties of the inoculated high-zinc aluminium alloys make them attractive group of the foundry alloys, which can be used as substitutes for the other, more energy consumable ones.

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