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Development of environmentally friendly cast alloys. High-zinc Al alloys

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ABSTRACT

Purpose: The main purpose of this paper is presenting the results obtained in years 2007 – 2010 in frame of the project Marie Curie Transfer of Knowledge – CastModel. The project was focused, among others, at elaborating new, environmentally friendly cast alloys based on the Al-Zn system. Particularly, efforts were aimed at improving ductility of the sand cast high-zinc aluminium alloys (HZnAl) by using the newly elaborated master alloys, based on the Al-Zn-Ti system.

Design/methodology/approach: The presented work is focused on the nucleation of the high-zinc Al-20 wt% Zn (HZnAl AlZn20) alloy, known as the high damping one, aiming at improving plastic properties of the sand castings. The melted alloy was nucleated with AlTi5B1 (TiBAl) and AlTi3C0.15 (TiCAl) refiners as well as with the newly introduced ZnAl-Ti3 one. During the research the following experimental techniques were used: LM, SEM-EBSD, EDS, TA, DSC, Quantitative Metallography, UTS, Elongation and Attenuation coefficient measurements.

Findings: During the performed examinations it was found out that significant increasing of the grain population of the inoculated alloy increases plasticity represented by elongation. The attenuation coefficient of the nucleated alloy, measured using an Olympus Epoch XT device, preserves its high value. The results obtained allow to characterize the examined AlZn20 alloy as promissive, having good strength and damping properties as well as the environmentally friendly alloy because of its comparatively low melting temperatures.

Practical implications: The grain-refined high-zinc aluminium alloys can be used as the high damping substitutes of the traditional, more energy consumable Fe-based foundry alloys.

Originality/value: The newly elaborated ZnAl-Ti based master alloys show high refining potency and quick dissolution in low melting temperatures of about 500°C, and are the promissive alternatives of the traditional AlTi-based ones.

Keywords: Metallic alloys; Cast AlZn-alloys; Grain refinement; Master alloy; Strength properties; Damping properties

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SHORT PAPER

1. Introduction

The castings production of the Mg and Zn alloys in Poland is still very small as compared to the Fe ones, though Poland produces significant amount of pure zinc - Fig. 1 [1-5]. Recent efforts of the European Community are aimed, among others, at energy saving and improving environmental protection at the same time. From this point of view, foundry industry production should be focused on wider application of the alloys, which are less energy consumable during their melting process. Replacing some amount of Fe-based castings with the AlZn-based ones is very important for environmental protection, because they are relatively cheaper according to lower melting temperatures - Fig. 2, which allows saving energetic expenses.

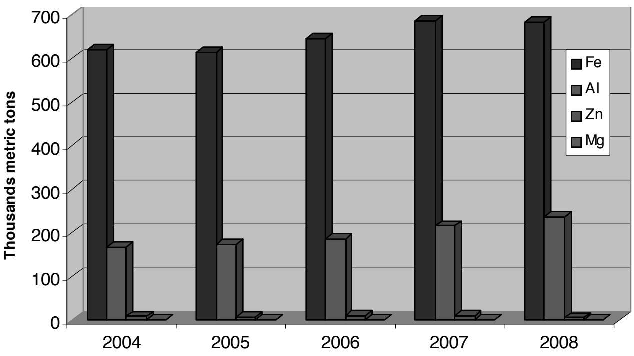


Fig. 1. Structure of casting production in Poland [1-5]

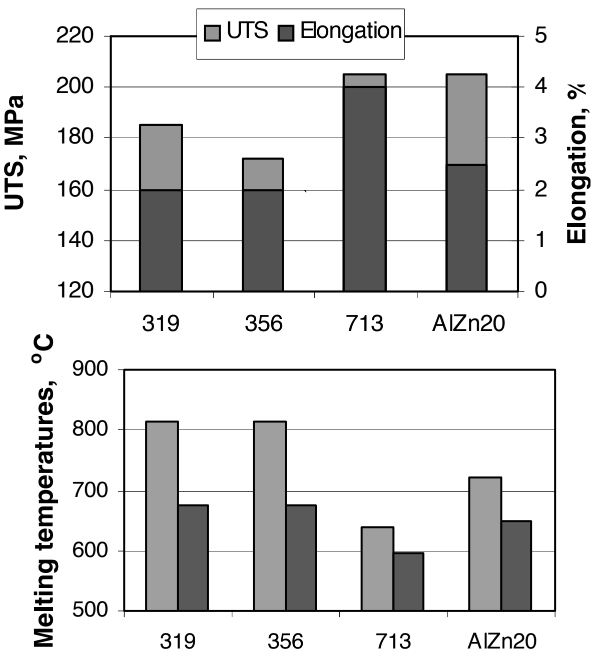


Fig. 2. Ultimate tensile strength UTS, elongation and melting temperatures of typical foundry sand-cast alloys 319 (AlSi6Cu4), 356 (AlSi7Mg0.3), 713 (AlZn8Cu1Mg) and the high-zinc AlZn20 aluminium alloy (Diagrams based on data published in [6] and [7])

The, so called, high-zinc aluminium cast alloys are a good example of these alloys, of good strenght and high damping properties, which could replace other, more energy consumable ones. However, wider implementation of the high-zinc aluminium cast alloys requires improving their plastic properties.

As it appears from Fig. 2, the AlZn20 alloy, selected here as the representative of the high-zinc aluminium alloys, requires increasing its plastic properties. On the other hand, it appears from Fig. 3, that die-cast Al-Zn alloys have higher elongation than the sand-cast alloys, which is most probably due to their finer structure. Thus, the high-zinc aluminium alloys require grain-refinement, which could allow improving their elongation. It is well known from literature, that Al-Zn alloys are numbered into the group of increased damping properties [8]. However, recent literature lacks information about the relationship between grain fineness, strength and damping properties of the High-Zinc Al foundry alloys. The presented work is focused on obtaining such information.

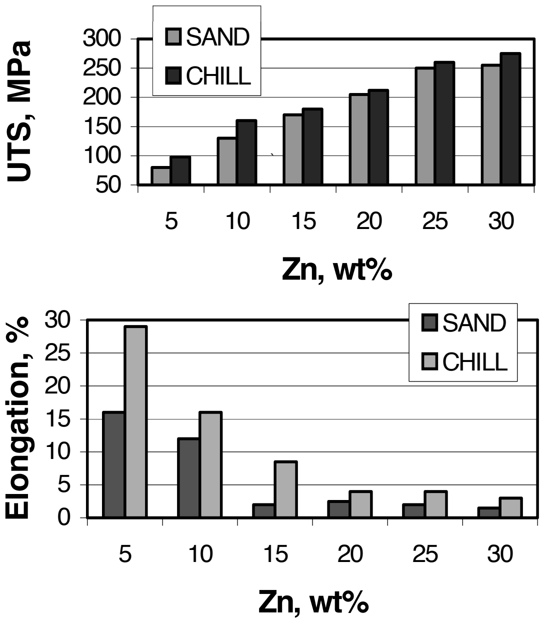
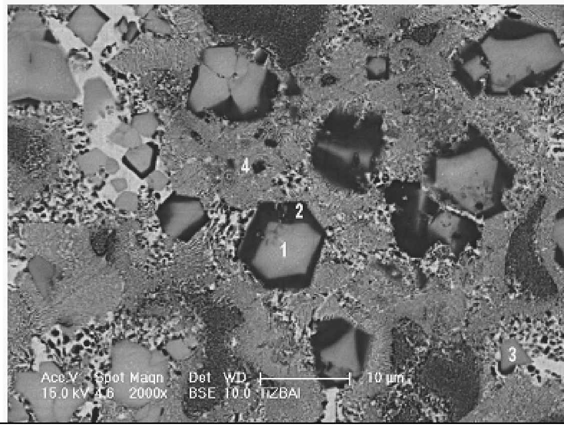


Fig. 3. UTS and elongation of cast Al-Zn alloys as a function of Zn content (Diagrams based on data published in [7])

2. Materials and methodology

The examined alloy AlZn20 and the master alloy AlZn-Ti3 were laboratory melted from electrolytic aluminium (minimum purity 99.96%); electrolytic zinc (99.995%) and titanium sponge (98-99.8%, from Johnson Matthey Alfa). The melting was performed in an electric resistance furnace, in an Salamander clay-bounded graphite crucible, of 1.5 litre capacity. The AlZn20 melt was superheated to ~740oC and purified by flashing with pure Argon for 10 min. Then a master alloy was added and the melt was held for 2 minutes to ensure complete dissolution of the master alloys added. Then the melt was stirred for next 2 minutes with an quartz-glass tube, and finally the alloy was cast into a dried sand moulds to obtain dog-bone shape samples (working part ∅12x60 mm) for tensile tests and ∅32x50 mm samples for damping tests. To monitor the melting process thermocouples NiCr-NiAl0.5 ∅0.20 mm were used. Temperatures (accuracy ± 1oC) were recorded using a multi-channel recorder Agilent 34970A (Agilent Technologies Inc., USA). Microsections for LM examinations were ground on abrasive paper (grit 200-1000) and then were polished using sub-microscopic aluminium oxide in water-alcohol suspension. 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. Meaurements of the attenuation coefficient were performed using the Olympus testing device Epoch XT, connected with a normal probe PF2R10 with a frequency of 2MHz. The examinations were carried out using oil as lubricant. The tensile tests were performed using an Instron 3308 device.



No.	1	2	3	4
Ti, At.%	24.4	21.9	23.8	23.3
Zn, At.%	66.0	16.8	67.6	16.3
Al, At.%	9.5	61.3	8.6	60.4
EDAX – Gemini 4000 EDS				

Fig. 5. SEM image og the ZnAl-Ti4 master alloy and chemical composition of the randomly chosen (Al,Zn)3 Ti particles

3. Results

Al-Zn foundry alloys solidify naturally with coarse primary dendrites of the α(Al) solid solution [9-14], which is clearly seen in Fig. 4. The ductility of these alloys can be increased by refinement of the α(Al) dendrites, which is common practice in casting technology of Al alloys. In industry, Al-Ti-B (TiBAl) and Al-Ti-C (TiCAl) master alloys are used to refine the α(Al) dendrites. A new alternative-a master alloy based on the Zn-Ti-Al system ((Al,Zn)-Ti3) has its density very close to the AlZn20 melt and introduces (Al,Zn)3Ti particles, of L12 crystal structure and lattice parameter nearly the same as that of the α(l) phase – Fig. 5. These features characterize the master alloys of good grain-refining performance.

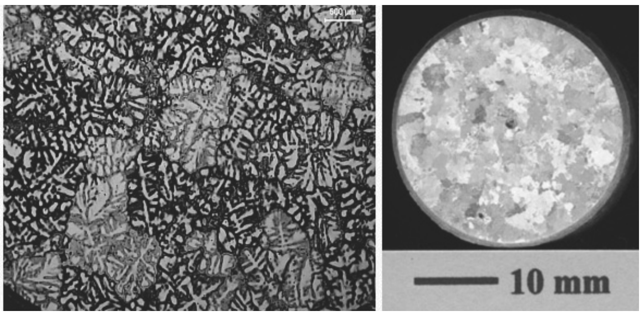


Fig. 4. Microstructure and macrostructure of the initial sand-cast AlZn20 alloy

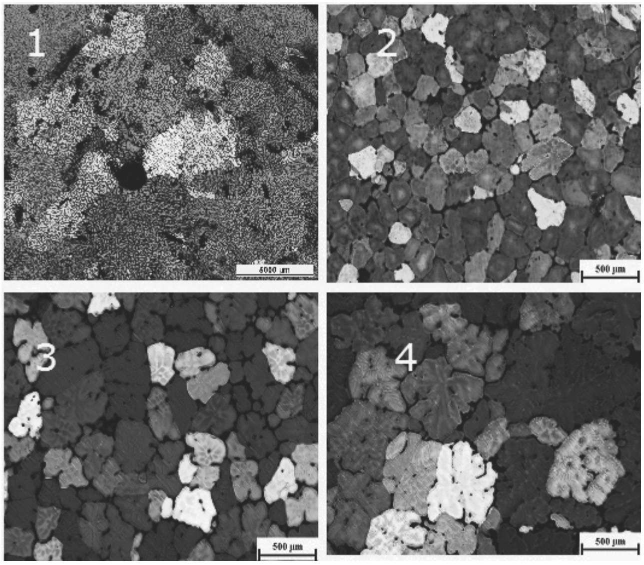


Fig. 6. Grain size of the sand-cast AlZn20 alloy. 1 - initial, non-inoculated; 2 - AlZn20 + TiBAl; 3 - AlZn20 + TiCAl; 4 - AlZn20 + ZnAl-Ti3. Barker's etched [16]

As it appears from Fig. 6, all of the master alloys which were used cause significat increase of grain population in the examined alloy. Namely, the initial, non refined alloy has its mean grain size of about 4500 µm - Fig. 6. 1, while the same alloy - inoculated with addition of 0.04 wt % Ti, introduced into the AlZn20 melt with the mentioned above master alloys – has its grain size only 300-550 µm - Figs. 6 (2-4) [15].

It is clear that grain refinement should be performed to an extent which allows improving plastic properties as well as improving or preserving other properties. As relates the high-zinc aluminium alloys, attention should be focused on preserving tensile strength and high damping properties. The dependence strength properties vs. grain size is presented in Fig. 7. Surprisingly, the TiBAl master alloy showed rather weak influence on the examined alloy elongation, while TiCAl and (Al,Zn)-Ti3 master alloy caused the increase of elongation by about 30%. On the other hand, all the master alloys used caused slight increase of tensile strength, which is beneficial. Fig. 8 shows dependence between grain size and damping properties, represented by attenuation coefficient. From Fig. 8 it can be seen, that performed grain refinement only slightly influences the attenuation coefficient. However, one can observe the slight increase or sligth decrease of attenuation coefficient of the refined samples in comparison to the initial, non refined alloy, which is unclear. Elucidation of this requires additional, more detailed examinations.

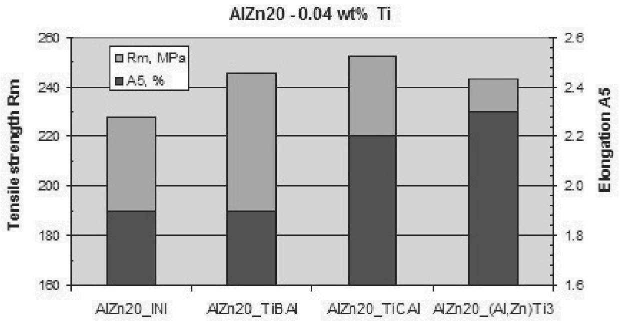


Fig. 7. Strength properties of the examined alloy

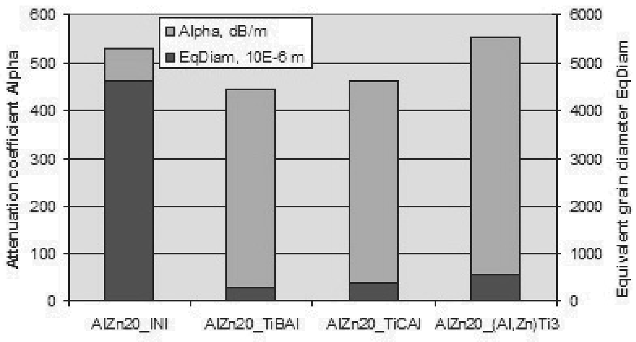


Fig. 8. Changes of attenuation coefficient vs. grain size of the examined alloy [17]

4. Conclusions

On the basis of the presented in the paper examinations the following conclusions can be formulated:

1. The used master alloys TiBAl, TiCAl and AlZn-Ti3 show good efficiency as the grain refiners of the examined sand-cast AlZn20 alloy - Fig. 6.
2. The AlZn-Ti3 master alloy has its density very close to the AlZn20 melt which allows to avoid difficulties connected with significant differences in densities between inoculated melt and a refiner.
3. The refined α(Al) phase allows improving elongation while ultimate tensile strength and attenuation coefficient remain basically preserved – Figs 7- 8, which are advantages of the performed grain-refinement process.

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