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Strength properties examination of high zinc aluminium alloys inoculated with Ti addition

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Abstract: This paper includes studies on the influence of grain refinement treatment with respect to the composition and structure of high zinc aluminium casting alloys on the changes of their tensile properties. The Al-20wt.%Zn alloy was inoculated with master alloys AlTi5B1 and AlTi3C0.15 to determine the impact of a variable titanium addition on the tensile properties of AlZn20 alloy, and determine on this basis an optimal addition of Ti that would ensure the improvement of elongation of alloys cast in the sand mould, at the same time maintaining high tensile strength. Within the studies, light microscopy (LM) and strength tests were applied. Experimental results showed that the inoculation of high zinc aluminium alloy AlZn20 with the master alloys AlTi5B1 and AlTi3C0.15 causes intensive structure refinement, while the intensity of reaction of both master alloys is comparable. The AlTi3C0.15 master alloy addition, selected for further studies, introducing about 100 ppm Ti, enhances the tensile properties of the alloy; the elongation increases about 20% and tensile strength increases about 10% against the initial values (uninoculated alloy). Further increase of the Ti addition up to 500–600 ppm leads to the "over-inoculation" effect that is accompanied by the decrease of elongation. Therefore, the Ti addition should be reduced to the level of about 100 ppm which ensures obtaining a set of optimal properties.

Key words: high zinc aluminium alloys; grain refinement; grain fragmentation; strength properties; elongation

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Castings are present in almost all machines and appliances. At present, among the materials used for castings, aluminium alloys are particularly important as they have the continual tendency to weight reduction within the final product and reductions in energy consumption in the production of castings, which in turn has a strong link to environmental protection. In general, most aluminium alloys after being cast have relatively low strength properties. However, the exception is a group of high zinc aluminium alloys with the composition of Al-(10–30)wt.%Zn, which features high tensile strength, acquired both in the sand and metal moulds, e.g. tensile strength of the Al-20wt.%Zn alloy exceeds 200 MPa, while physical elongation reaches relatively low values, usually below 4% [1, 2].

High zinc aluminium alloys, similarly to high aluminium zinc alloys, feature coarse-grained structure of sand mould castings and therefore a series of treatments are applied in order to improve the properties of alloys. One of the treatments is the grain fragmentation process, called grain refinement treatment. It should be mentioned that the fragmentation of the structure is inextricably linked with the nucleation and crystal growth processes in casting alloys [3]. Grain refinement treatment is commonly used in the production process of most castings and aluminium ingots as well as aluminium alloy ingots. The application of grain refinement treatment allows, together with the fragmentation of the structure, to improve the material properties of the alloy, improve the feeding properties of the alloy, as well as to obtain more robust machinability of the casting. Currently, most of the works in the scope of grain refinement treatment refer to an alloy based on Al-Si [4-7]. Some of the studies are also devoted to Al-Mg and Al-Cu [8-10], but very little attention was paid to Al-Zn alloys [11-13]. It should be noted that currently the interest in Al-Zn alloys is increasing also because of their good damping properties [14], as well as lower density when compared to traditional high damping alloys such as cast iron and high aluminium zinc alloys, e.g. ZA27 alloy.

This study aims at determining the reasonable boundaries of fragmentation of AlZn alloys structure that guarantee obtaining a group of inoculated alloys with high strength properties.

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Table 1: Compositions of master alloys (wt.%)

	AlTi5B1 (TiBAl)	AlTi3C0.15 (TiCAl)
Ti	5	3
B	1	-
C	-	0.15
Al	Balance	Balance

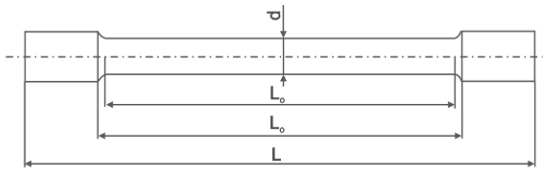


Fig. 1: Sample used for examinations of mechanical properties: d=12 mm, L_o=60mm, L_c = 65 mm, L=160 mm

1 Materials and methodology

The Al-20wt.%Zn (AlZn20) alloy for studies, the composition of which is in the middle of the so-called high zinc aluminium alloys, was inoculated with traditional master alloys, Al-5wt.%Ti-1wt.%B (AlTi5B1) and Al-3wt.%Ti-0.15wt.%C (AlTi3C0.15). Their compositions are shown in Table 1.

The alloy was heated to a temperature of about 750 °C and then was refined with argon for 10 min. After refining was completed, the molten metal was held further for 10 min to allow the impurities to go into the slag. Then, the modifying master alloy was introduced and after its dissolution, the molten metal was stirred for about 2 min to create a uniform composition and distribution of the master alloy. Then the alloy was poured into a green sand mould. The composition of the moulding sand was as follows: quartz sand 92wt.%, bentonite 5wt.%, water 3wt.%. The moulds were dried at 120 °C for about 12 hours. The application of sand mould in large measure enabled the elimination of the influence of the cooling rate on grain refinement of castings which occurs in case of cooling in permanent metal moulds and hinders the evaluation of the modifier efficiency. The bar samples (Fig. 1) were made for the examinations of the mechanical properties.

Tests for tensile strength R_m and elongation A_5 were conducted on the samples. The samples, after cutting off the feeders, were machined to obtain the size of Φ12 mm × 60 mm. For each group of examined alloys, 8 samples, 4 in each mould, were cast. Short pouring time interval (about 10 s) guaranteed the similar temperature conditions of metal cast into both moulds. The strength tests were performed using an Instron 3308 device after natural aging process (18 months since filling the moulds) was finished.

Additionally, the cylinder-shaped castings with the dimensions of Φ32 mm × 80 mm were cast in the sand mould (Fig. 2). The bar samples with the dimensions of Φ30 mm × 25 mm were cut from the middle parts and used for structural studies with the light microscopy (LM).

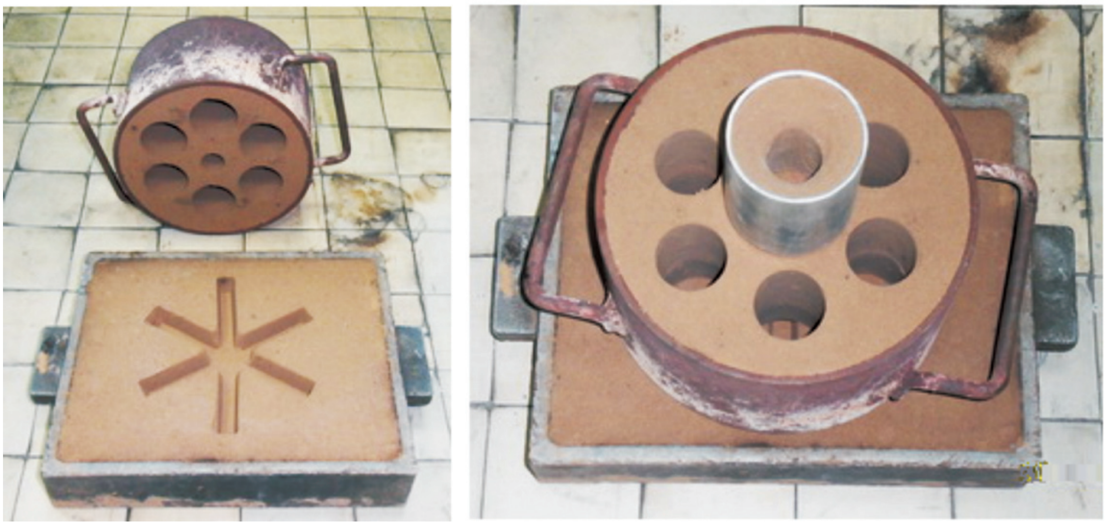


Fig. 2: Sand mould used for casting of samples for structural studies [15]

The polished samples were chemically etched with Keller's reagent or electrolytically with Barker's reagent. The microstructure of the samples was analysed with Zeiss Axio Imager M2m optical microscope.

2 Results

2.1 Efficiency analysis of applied master alloys

The impact of the master alloys AlTi3C0.15 and AlTi5B1 on the structure refinement of the alloy AlZn20 is shown in Figs. 3 and 4.

Ti addition in the master alloys AlTi3C0.15 and AlTi5B1 causes significant refinement of alloy AlZn20 macrostructure, and the grain size at the cross-section area of bar samples is decreased from about 100 grains per cm^2 of the alloy without inoculation, Fig. 3(a) and Fig. 4(a), to 2,000–2,500 grains per cm^2 of the alloy with Ti addition, Fig. 3(c) and Fig. 4(c). The effectiveness of structure refinement is comparable in both master alloys, while the addition above 0.01% Ti fails to have an essential impact on the refinement.

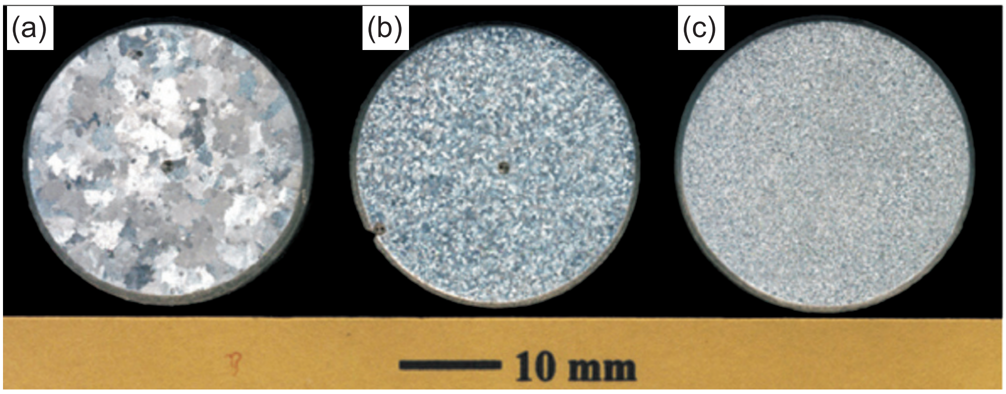


Fig. 3: Macrostructure and grain thickness of alloy AlZn20 with different Ti additions: (a) without Ti, ~100 grains per cm^2; (b) inoculated with AlTi3C0.15 (0.01wt.% Ti), ~2,000 grains per cm^2; (c) inoculated with AlTi3C0.15 (0.04wt.% Ti), ~2,500 grains per cm^2

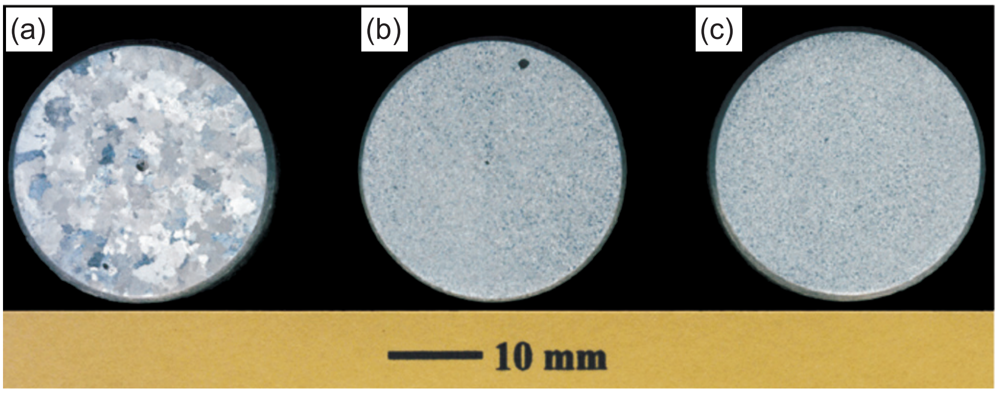


Fig. 4: Macrostructure and grain thickness of alloy AlZn20 with different Ti additions: (a) without Ti addition, ~100 grains per cm^2; (b) inoculated with AlTi5B1 (0.01wt.% Ti), ~2,500 grains per cm^2; (c) inoculated with AlTi5B1(0.04wt.% Ti), ~2,500 grains per cm^2

2.2 Tensile properties of alloy AlZn20 inoculated with AlTi3C0.15 and AlTi5B1

The examination results of tensile properties showed that the initial alloy AlZn20, cast into the sand mould, has an average tensile strength of about 213 MPa and an elongation A_5 of about 2% (Fig. 5). These values are similar to the ones from the literature [2].

The applied grain refinement treatment with the master alloys AlTi3C0.15 and AlTi5B1, that involved introducing of similar Ti addition of about 0.06wt.% to the modifying alloy in both cases, causes comparable effect, namely the increase of tensile strength by about 6%–10% and decrease of elongation by about 10%–15%, compared to that of the initial alloy. The observed decrease of elongation may mean the Ti addition of 600 ppm (0.06%) leads to an alloy over-inoculation effect. This assumption is in agreement with literature [2] where the recommended Ti addition is in the range of 400 – 500 ppm. When a similar structure refinement for both master alloys is taken into consideration, the lower decrease of elongation for the alloy inoculated with AlTi3C0.15 and the observed increase of gas porosity for the alloy inoculated with AlTi5B1 indicated that AlTi3C0.15 is more suitable for the inoculation of AlZn20 alloy. Thus, AlTi3C0.15 was selected for further studies.

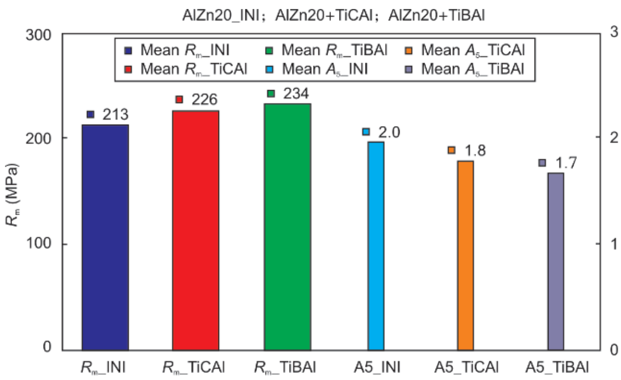
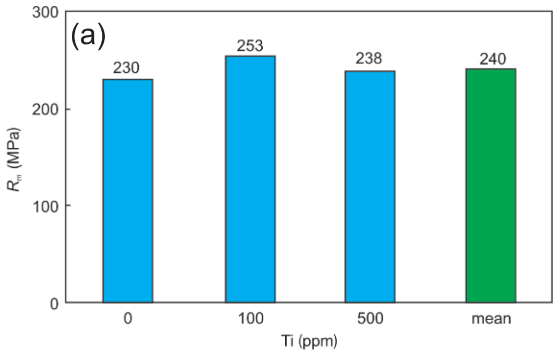


Fig. 5: Comparison of average values of tensile strength R_m and elongation A_5 of AlZn20 samples without Ti addition and with 0.06% Ti addition introduced in AlTi5B1 or AlTiC0.15

The measurement results of tensile properties of the alloy AlZn20 samples of uninoculated and inoculated with the addition of master alloy AlTi3C0.15, introducing 0.01 wt. % (100 ppm) and 0.05 wt. % Ti (500 ppm), are shown in Fig. 6.

This again confirms the previously suggested over-inoculation of the alloy because it can be seen that the average value of elongation decreases from 2.42% for the alloy inoculated with the 0.01wt.% Ti addition to 1.52% for the alloy inoculated with the 0.05wt.% (which is mentioned as the recommended limiting value) Ti addition. A probable reason for the decrease in elongation is the presence, in the structure of the alloy



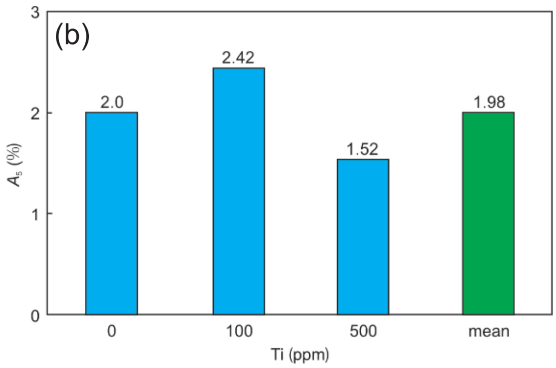


Fig. 6: Comparison of average values of tensile strength R_m (a) and elongation A_5 (b) of alloy AlZn20 uninoculated and inoculated with 0.01wt.% (100 ppm) and 0.05wt.% (500 ppm) Ti in master alloy AlTi3C0.15

inoculated with 0.05wt.% Ti, of an excessive amount of Al_3Ti and TiC particles introduced with the master alloy, which failed to take part in the nucleating process (as the Ti addition exceeded 0.01 wt.%, the grain density remains the same). These particles can be absorbed by growing grains or pushed away by the crystallisation front to the grain edges (Fig. 7), so their presence decreases the alloy's plasticity.

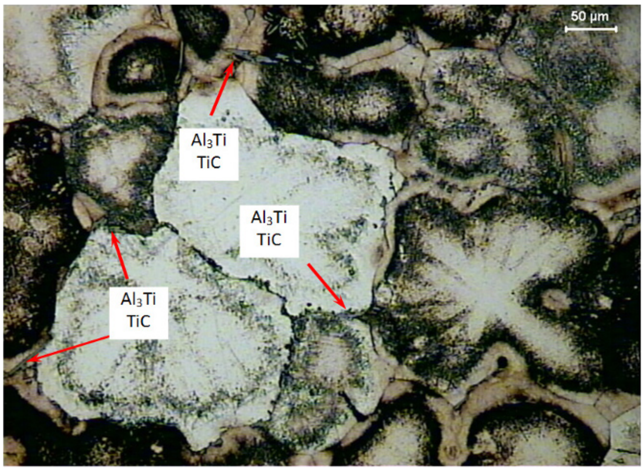


Fig. 7: Structure of alloy AlZn20 inoculated with 0.05wt.% Ti in master alloy AlTi3C0.15

The results obtained in the tensile properties examinations, in turn, clearly show that for the AlZn20 alloy, the Ti addition in the master alloy AlTi3C0.15 should be reduced to about 0.01wt.% Ti, which allows the obtaining of a significant increase of elongation by about 20%, at the same time maintaining high tensile strength of 230–250 MPa (Fig. 6).

3 Conclusions

From the available literature it is known that in practice, the grain refinement treatment of casting Al alloys is conducted with the use of the addition of 0.04–0.05wt.% Ti (400 – 500 ppm Ti). The obtained results clearly indicate that for the examined alloy AlZn20, the addition should be reduced to about 0.01wt.% Ti, as indicated above.

Based on the analysis of tensile properties of the AlZn20 alloy as a function of grain size and Ti addition in the master alloys AlTi5B1 and AlTi3C0.15, the following conclusions can be made:

The inoculation of high zinc aluminium alloy AlZn20 with the master alloys AlTi5B1 and AlTi3C0.15 causes intensive structure refinement, while the intensity of reaction of both master alloys is comparable. The inoculation with the master alloy AlTi3C0.15, selected for further studies, causes approximately twenty times decrease in size of grains of the alloy AlZn20 in the case of 100 ppm Ti addition. Further increase of the master alloy addition does not lead to a significant increase of grains refinement. The AlTi3C0.15 master alloy addition, introducing about 100 ppm Ti, enhances the tensile properties of the alloy; the elongation increases about 20% and tensile strength increases about 10% against the initial values (uninoculated alloy). Further increase of the Ti addition up to 500–600 ppm leads to the "over-inoculation" effect that is accompanied by the decrease of elongation. The observations of microstructures revealed the presence of Ti phases on the edges of grains of the AlZn20 alloy inoculated with the addition of 500 ppm Ti. These phases have an adverse effect on the plasticity and cause the decrease of elongation.

The obtained results show that the inoculation should not be conducted in this way to achieve the grain refinement per se, however, to raise the level of a group of properties, e.g. mechanical properties, while maintaining high levels of other properties, e.g. damping.

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