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The Assessment of Modification of High-Zinc Aluminium Alloy

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Abstract

The results of examinations of the influence of titanium-boron inoculant on the solidification, the microstructure, and the mechanical properties of AlZn20 alloy are presented. The examinations were carried out for specimens cast both of the non-modified and the inoculated alloy. There were assessed changes in the alloy overcooling during the first stage of solidification due to the nuclei-forming influence of the inoculant. The results of quantitative metallographic measurements concerning the refinement of the grain structure of casting produced in sand moulds are presented. The cooling rate sensitivity of the alloy was proved by revealing changes in morphology of the α-phase primary crystals. Differences in mechanical properties resulting from the applied casting method and optional inoculation were evaluated.

Keywords: Aluminium alloys, Inoculation, Solidification, Mechanical properties

1. Introduction

The Al-Zn alloys are presently the frequent object of scientific reports, which recommend their multiple advantages and possibilities of application. These materials alloyed with various elements exhibit good mechanical and plastic properties, which can be controlled by the suitable heat treatment [1-8]. They found a wide field of application as structural materials in aircraft and automotive industry, as well as in the railway sector; they are applied for bridge and overpass girders, armours of military vehicles, cryogenic pressure vessels etc. [7, 8]. Another important factor contributing to the attractiveness of AlZn alloys is their good weldability after being enriched with magnesium addition [8, 9]. Unlike other precipitation-hardened aluminium alloys, the Al-Zn alloys are not sensitive to the cooling rate during the solution heat treatment [7]. The ageing process can be carried out either in ambient temperature, or in elevated temperature exceeding 373 K. The aluminium-zinc alloys can be divided into two groups: the low-zinc aluminium alloys containing up to 10 wt% of Zn and the high-zinc aluminium alloys with Zn content 10 - 30 wt%. The low-zinc alloys exhibit better corrosion resistance than the high-zinc ones, but both mechanical properties in the as-cast state and technological properties of the former ones are lower. The high-zinc Al-Zn alloys with addition of various alloying components surpass other aluminium alloys and many casting alloys in general in their damping qualities in comparison to their density. The additional advantages of these materials are their high tribological properties [10-15].

The Al-Zn alloys, however, exhibit also some significant weaknesses, which restrict their applications. The main disadvantages include their high decrease in strength properties with temperature rise, susceptibility to cracking under impact load and susceptibility to corrosion. Therefore the multi-component Al-Zn alloys containing such additions as Mg or Cu are widely investigated. These elements influence favourably some properties, but they simultaneously reduce the plasticity of the alloys [5, 10-14].

The primary structure of castings made of the high-zinc alloys exerts significant influence on their properties, being itself dependent on the refining and modification treatment, quantity and the type of impurities, etc. The high-zinc aluminium alloys are, as a rule, either gravity or pressure cast, and they exhibit great cooling rate sensitivity. Their tendency to form the coarse grain microstructure is particularly easy to observe in castings produced in sand moulds, but occurs also in those cast in metal dies. Therefore the Al-Zn alloys are frequently inoculated [15, 16]. Al-Ti, Al-Ti-B, or Al-Ti-C master alloys are used for refining of the structure. The purpose of the present work was the evaluation of the modifying effect of titanium-boron master alloy on the solidification, microstructure, and mechanical properties of the high-zinc AlZn20 alloy.

2. Materials and methods of investigation

The experiments were carried out for synthetic AlZn20 alloy. The design of experiment included production of casting both of the non-modified alloy and the alloy after the inoculation treatment. The inoculation was performed using the industrial AlTi5B1 master alloy in the form of rods 10 mm in diameter. The AlZn20 alloy was made of primary aluminium of 99.8% purity (0.02% Si, 0.05% Fe, 0.02% Cu, 0.015% Mn, 0.012% Mg, 0.01% Zn) and primary zinc of 99.5% purity (0.47% Al, 0.005% Pb, 0.004% Fe, 0.002% Cd, 0.002% Cu, 0.001% Sn). The metal charge was melted in silicon carbide crucible in the Leybold Heraeus IS1/III medium-frequency electric induction furnace. The molten alloy was overheated up to 750°C, then the titanium-boron inoculant was added in the amount of 0.05 wt% with respect to the mass of charge. The pouring temperature was equal to 700°C. The rod-like test specimens were cast both in sand moulds and in dies, their diameter being either 28 mm or 20 mm, respectively. Derivative differential thermal analysis (DDTA) was performed during the pouring of sand moulds. The temperature was measured by means of the sheathed NiCr-NiAl thermoelements placed in the thermal centres of castings. The temperature was recorded in the range of 700°C - 400°C for sampling intervals equal to 0.2 s. The quantitative metallographic examinations were also performed for sand-cast specimens. The dispersion degree of the alloy grain structure was assessed according to the Jeffries-Saltykov method, using the CSS MULTI SCAN BASE 8.08 program. Mechanical properties were examined according to the PN-EN 10002-1:2002 Standard by means of Zwick 1488 tensile testing machine. Mechanical parameters were determined for both sand-cast and die-cast specimens.

3. Results of examinations

The influence of the inoculating master alloy on the solidification course of the AlZn20 alloy and on the degree of dispersion of the primary structure is presented in Figs. 1-4. Figures 1 and 2 show cooling and solidification curves for the non-modified and the inoculated alloy along with the indication of characteristic temperature points (T_P – the temperature of the solidification beginning, T_M – the temperature at which the maximum overcooling $\Delta T = T_L - T_M$ in the initial stage of solidification is achieved, T_L – the equilibrium liquidus solidification conditions, segregation of alloying additions, the temperature – determined in ThermoCalc program) used for the assessment of inoculation. The titanium-boron inoculant changes the solidification kinetics of the examined alloy, causes an increase in T_M temperature and the reduction of overcooling (ΔT). The T_M temperature for the non-modified and inoculated alloy is equal to 619°C and 625°C, respectively, while the relevant overcooling is 9°C and 3°C. This effect is related to the nuclei-forming influence of the inoculant. The TiB_2 compound contained in Al-Ti-B master alloy creates– as in other aluminium alloys – a substrate for nucleation of the primary α-phase crystals, thus increasing the grain density in a solidified casting.

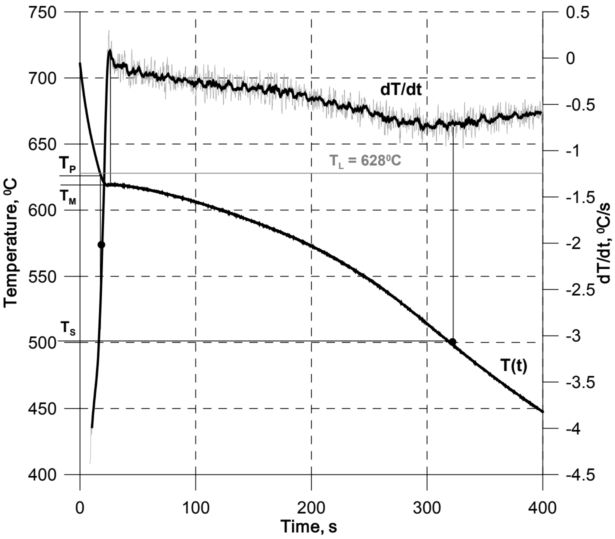

Fig. 1. The cooling curve T(t) and its derivative dT/dt for the non-modified AlZn20 alloy

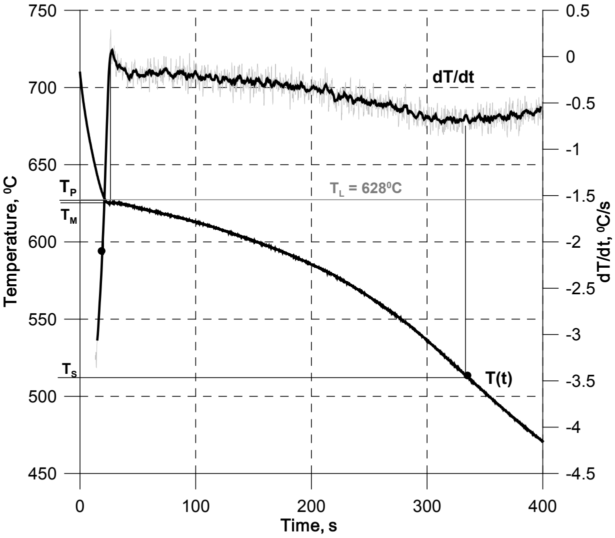

Fig. 2. The cooling curve T(t) and its derivative dT/dt for the inoculated AlZn20 alloy

The refinement characteristics of grain structure of AlZn20 alloy estimated on the basis of quantitative metallurgical examinations and the exemplary microstructures are presented in Figs. 3 and 4.

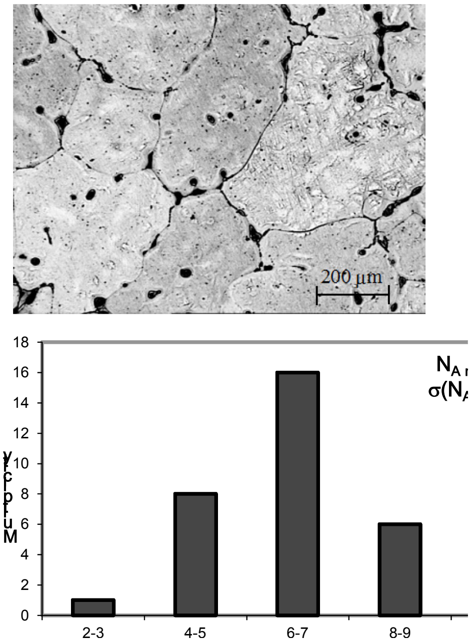

Fig. 3. Microstructure of sand-cast castings of the non-modified ZnAl20 alloy (magn. 50×) and the grain number distribution (N_A) for the examined surfaces of metallographic specimens, N_{Am} – mean grain number

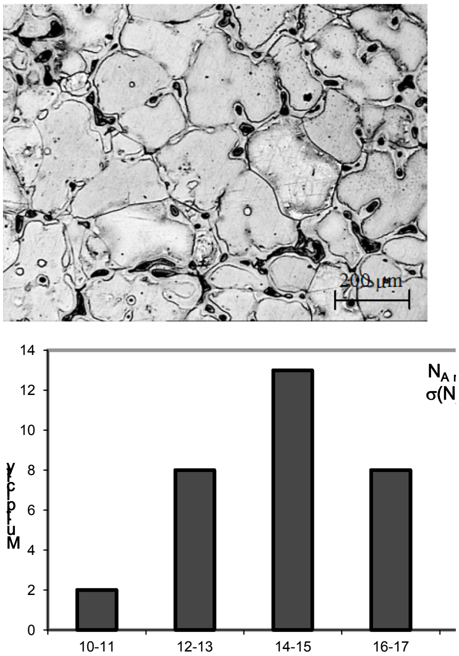

Fig. 4. Microstructure of sand-cast castings of the inoculated ZnAl20 alloy (magn. 50×) and the grain number distribution (N_A) for the examined surfaces of metallographic specimens, N_{Am} – mean grain number

The average number of grain (N_A) in the non-modified alloy is equal to 6.8 grain/mm^2, while in the inoculated alloy it rises to the value of 14.7 grain/mm^2, what means that the inoculated microstructure is refined by more than twice.

The castings produced in metal dies of either the non-modified or the inoculated alloy exhibit the dendritic form of the primary α-phase.

As far as these castings are concerned, the modifying influence of titanium-boron inoculant is indicated both by the increase in quantity of dendritic grains and by the change in their morphology. Dendrites become more globular, their arms are shorter and their shape is less intricate (Figs. 5, 6). The presence of the dendritic structures in die cast products is a result of great cooling rate. This involve the precipitation of zinc-rich phase within the interdendritic spaces at the end of the solidification process. The segregation of additions is related to the wide range of solidification temperature and the low value of diffusion coefficient of zinc in aluminium.

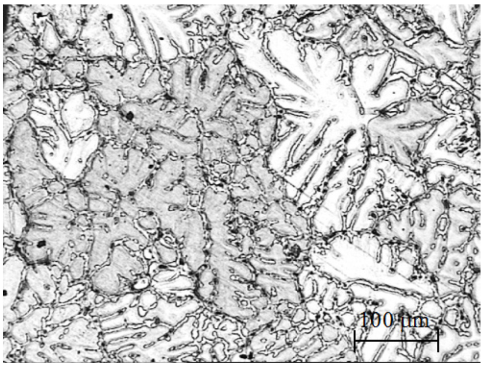

Fig. 5. Microstructure of die-cast castings of the non-modified AlZn20 alloy, magn. 100×

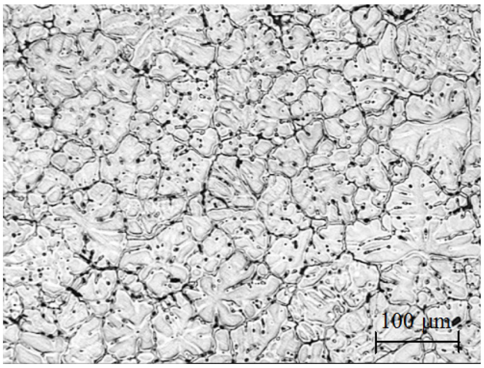

Fig. 6. Microstructure of die-cast castings of the inoculated AlZn20 alloy, magn. 100×

Fig. 7 illustrates the influence of both inoculation and the casting method on the tensile strength and unit elongation of the specimens made of AlZn20 alloy. The quick cooling and solidification of the alloy in a metal die implies a distinct increase in mechanical properties of castings. The casting method affects particularly the plasticity of the alloy. Specimens cast in the metal die exhibit the unit elongation almost twice the one achieved for castings produced in sand moulds. It can be found while estimating the effect of modification on the strength properties that the applied addition of AlTi5B1 master alloy results in 17% increase in R_m for castings produced in sand moulds and in 21% increase in R_m for castings made in dies.

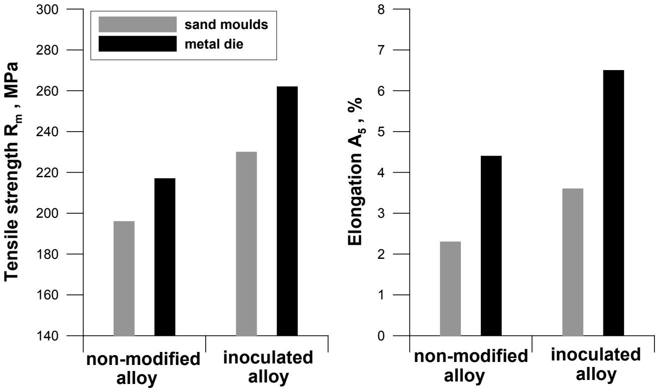

Fig. 7. The influence of inoculation and the casting method on the tensile strength (R_m) and unit elongation (A_5) of the specimens cast of AlZn20 alloy

The plastic properties are advantageously influenced by the inoculation with titanium and boron even to the greater degree. The increase in unit elongation A_5 reaches about 50% for castings produced by either of the applied technologies. Die casting of the inoculated alloy allows for achieving the highest mechanical properties of the castings – the tensile strength at the level of 260 MPa accompanied by the unit elongation exceeding 6%.

4. Final conclusions

1. The AlTi5B1 master alloy effectively modifies the microstructure of AlZn20 alloy increasing the mechanical properties of castings. The increase in tensile strength due to the inoculation treatment is equal to 20%, and the unit elongation rises by 50%.
2. The introduction of 0.05 wt% of titanium-boron inoculant into the AlZn20 alloy increases grain number N_A by twice for castings produced in sand moulds.
3. The nuclei-forming influence of TiB_2 particles on the solidification of the α solid solution is proved by the reduction of overcooling from $\Delta T = 9°C$ for the non-modified alloy to $\Delta T = 3°C$ after the inoculation treatment.
4. The AlZn20 alloy exhibits great cooling rate sensitivity so that its microstructure and mechanical properties are strongly influenced by the casting method. The castings which solidify at low cooling rates exhibit the grain structure, while those solidified at great cooling rates reveal the dendritic structure.

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