PRODUCTION ENGINEERING ARCHIVES

2014, Vol. 5, No 4, pp 36-41
ISSN 2353-5156 (print version)
ISSN 2353-7779 (online version)

Article history: Received: 13.11.2014 Accepted: 27.11.2014 Online: 31.12.2014

Available online on: http://www.qpij.pl **Exist since 4th quarter 2013**

Influence of the Mould Cooling Process on the Quality and Properties of Aluminium Alloy

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Abstract The article deals with the effect on the quality of casting moulds (metal, bentonite mixture) on the structure of the alloy AlZn5,5MgCu and selected mechanical properties of the alloy. The effect of foundry moulds can significantly affect formation and range of crystal segregation and the subsequent thermal process of homogenization which has an influence on the final quality of the alloy. The research focuses on the formation and range of crystal segregation and its removal with homogenization annealing, in which the observed influence of individual factors influencing the diffusion process and quality of the aluminium alloy.

Key words – cooling process, quality, aluminium alloy, casting moulds

1. Introduction

This article deals with the effect of casting moulds (metal, bentonite sand) on the structure of the alloy AlZn5,5MgCu and selected mechanical properties of the alloy. The effect of a foundry mould can significantly affect formation and range of crystal segregation and the subsequent thermal process of homogenization which has a big influence on the material quality. The research focuses on the emergence of a range of crystal segregation and its removal with homogenization annealing, in which the influence of individual factors influencing the diffusion process can be observed. These factors include the temperature of the homogenization treatment, the temperature holding time length and size of the diffusion pathways. The length of diffusion pathways directly related to the size of dendritic cells, which are dependent on the selected casting mould for casting a metal to form a bentonite.

AlZnMgCu alloys are the strongest aluminum alloy superdural (ultimate tensile strength 700 - 720 MPa) and have very good mechanical properties in welds, but their negative qualities are prone to all kinds of corrosion, lower fracture toughness and higher notch sensitivity. The disadvantage of these alloys is poor corrosion resistance and susceptibility to large crystal bandpass and segregation. The cause of the crystal segregation is selective crystal solidification during gradual change in the composition of the solid phase. Important parameters that affect the degree of crystal formation and segregation are: the chemical composition of the alloy, the diffusion in the solid and liquid phase, the rate of crystallization of the casting, or the intensity of heat removal from the casting, depending on the chosen form of the casting. Crystalline segregation significantly affects the mechanical and corrosion properties of the alloy. Crystal segregation can be suppressed by homogenization annealing. The process of homogenization annealing temperature and time influences the homogenization process, the diffusion co-efficients of the respective elements in the aluminum matrix and the size of the diffusion pathways. The temperature and duration of the homogenization process is chosen so as to dissolve the non-equilibrium intermetallic phases, which arose in the crystallization process and the subsequent diffusion of the respective elements in solid solution α.

Casting method and the correct choice of the form of the casting is crucial to the final structure, quality and properties of alloys. Material metal moulds must withstand relatively high temperatures, in some cases about 400 to 600°C. The big disadvantage of their production is the high cost and intensive labour and, therefore, their use is mainly for large-scale production of castings. For this reason small-scale production moulds are preferred which produce cheaper technologies based on sand. Bentonite sands allow casting of large forms in a raw state because they are serious and breathable. Compared with casting in metal moulds, costs are cheaper, but cast from metal moulds are characterized by excellent internal compactness, better surface quality, lower roughness finer structure, good dimensional values and mechanical properties of castings.

2. Experimental part

To prepare castings of the studied material aluminum of purity 99.8% was used and the necessary alloying metals. The cast alloys studied were prepared according to the chemical composition of the original standard CSN 42 4222 (according to current standards EN 573-3 corresponds alloy EN AW 7075 outside of Mg content).

The melting of the material took place in an electric resistance furnace for 70/13 at 730°C. The furnace temperature was measured by a digital thermometer with an accuracy of ± 2°C. The melt was treated during the melting and refining salt melt surface swabs were withdrawn.

The prepared material was gravity-cast into a metal mould preheated to 220°C and the mould bentonite prepared from bentonite sand.

Castings were in the shape of a conical cylinder with dimensions of 40/50x100 mm. For preparing the plaster mould gypsum Almodo modeller 60 was used, which was triturated with water in a ratio of 800 ml of water and 800 g of plaster. The draining of excess moisture from the plaster mould was carried out for a fortnight on the house’s central heating. The previous 24 hours prior to casting, the mould was dried by an oven Binder at 150°C. The value of residual moisture in the plaster mold was 4 wt. %. Chemical composition of experimental alloys prepared in wt. % is shown in Table 1.

Table 1. Chemical composition of the experimental alloy AlZn5.5Mg2.5Cu1.5

Chemical composition [wt.%] metal mold preheated		Chemical composition [wt.%] bentonite form	
Zn	5,210	**Zn**	5,250
Mg	1,887	**Mg**	1,935
Cu	1,465	**Cu**	1,590
Si	0,054	**Si**	0,059
Ti	0,002	**Ti**	0,001
Fe	0,062	**Fe**	0,064
Al	91,30	**Al**	91,10

For the purpose of recording the measured values during solidification temperature mapping of experimental alloys into prepared casting moulds, a paperless recorder JUMO LOGOSCREEN cf 500 was used, which is equipped with six analog inputs. For the temperature measurements NiCr-Ni (type K) were used on the sheath diameter of 6 mm. The courses temperatures were measured using four thermocouples that were located in different parts of the casting and foundry molds. All thermocouples were placed to a depth of 50 mm. Placement of thermocouples were as follows: 1 thermocouple thermal axis of the casting, thermocouple 2 face forms (interface cast - form), thermocouple 3 - middle wall casting moulds, thermocouple 4 - outer shell casting mould, Figure 1. The temperature drop of casting moulds is shown on the Figure 2.

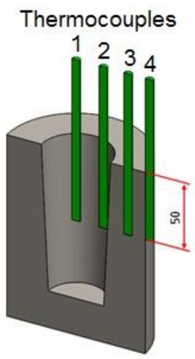

Fig. 1. Placement of thermocouples.

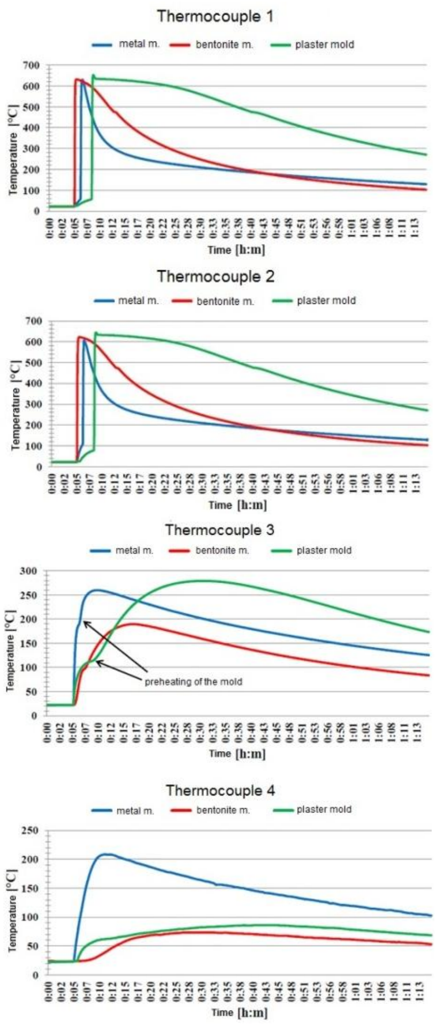

Fig. 2. The temperature drop of casting molds.

The structure of the prepared casting alloys was evaluated on a metallographic methods macrostructure (Fig. 3 and Fig. 4) and microstructure.

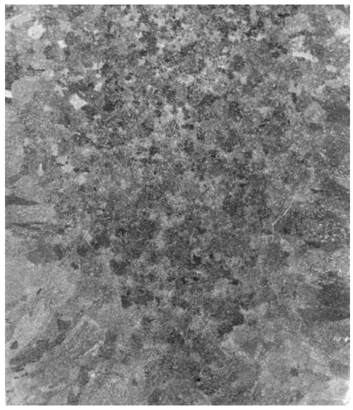

Fig. 3. Macrostructure of the AlZn5.5Mg2.5Cu1.5 alloy – metal mold.

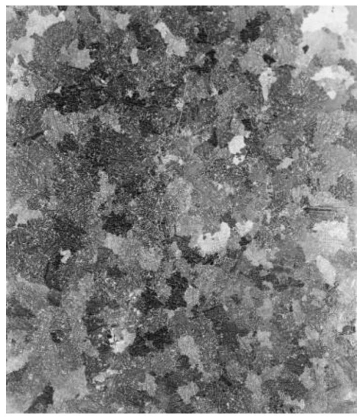

Fig. 4. Macrostructure of the AlZn5.5Mg2.5Cu1.5 alloy – bentonite mold.

For evaluation of the microstructure from the castings AlZn5.5Mg2.5Cu1.5 alloy metallographic samples were prepared. The microstructure of the prepared casting was observed in the central region and in the edge of the casting in the state of etching (Fig. 5 and Fig. 6).

For colour identification by colour, metallography methods were prepared from castings. The metallographic samples were mechanically grinded, polished and colour etched. Color etching was performed with a solution of potassium permanganate $KMnO_4$ in alkaline solution of sodium hydroxide NaOH for 30 - 40 seconds. The prepared samples were observed by confocal laser microscope OLYMPUS LEXT OLS 3100 (Fig. 7 and Fig. 8).

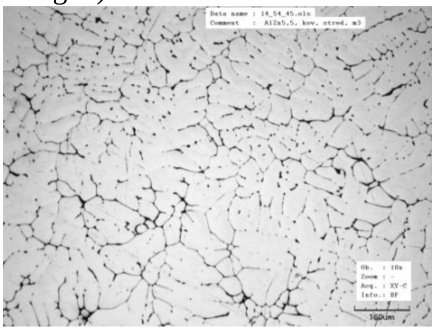

Fig. 5. Microstructure AlZn5.5Cu2.5Mg1.5 - metal form edge, mag. 100x.

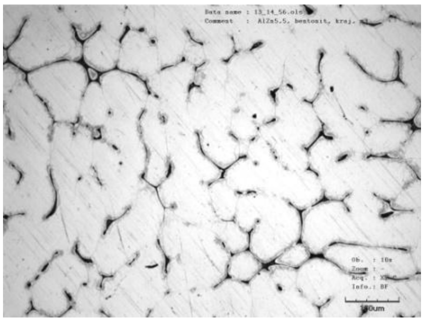

Fig. 6. Microstructure AlZn5.5Cu2.5Mg1.5 - metal form centre, mag. 100x.

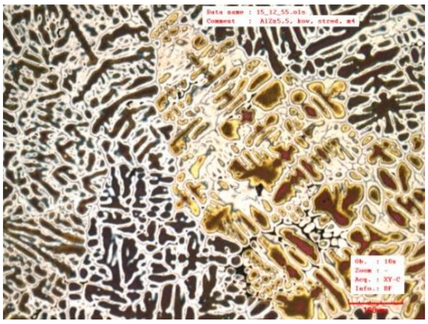

Fig. 7. Microstructure AlZn5.5Cu2.5Mg1.5 - metal form edge, color etching in KMnO4+NaOH, mag. 100x.

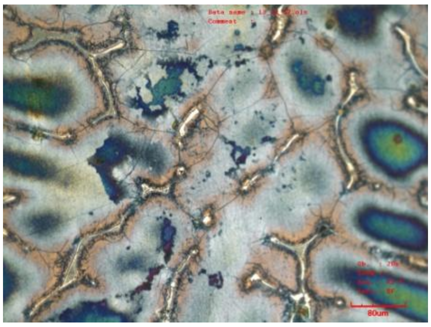

Fig. 8. Microstructure AlZn5.5Mg2.5Cu1.5 – bentonite mold, color etching in KMnO4+NaOH, mag. 200x.

The microstructures of the prepared samples casted into the metal mould and bentonite mould were measured by using the confocal laser microscope OLYMPUS LEXT OLS 3100 and numerically evaluating the size of dendritic cells (20 measurements, Table 2).

Table 2. The size of dendritic cells alloys AlZn5.5Mg2.5Cu1.5

Casting mold	Min. [μm]	Max. [μm]	Average
Metal preheated, middle	171	279	210
Bentonite, middle	274	756	490

Prepared samples of alloy AlZn5.5Mg2.5Cu1.5 were further heat treated with homogenization annealing at a constant temperature T = 470°C for annealing time from 2 to 24 hours. Homogenization annealing was carried out in a furnace with a digital thermometer with an accuracy of ± 2°C. From samples of alloys AlZn5.5Mg2.5Cu1.5 after homogenization annealing grindings were prepared, upon which the chemical composition occurring in the solid solution phase were analysed with EDX method.

The chemical composition of the basic structural components and the relative distribution of the base metal and the main alloying elements were made on scanning electron microscopes with help of EDX analysis (Fig. 9 + Table 3 and Fig. 10).

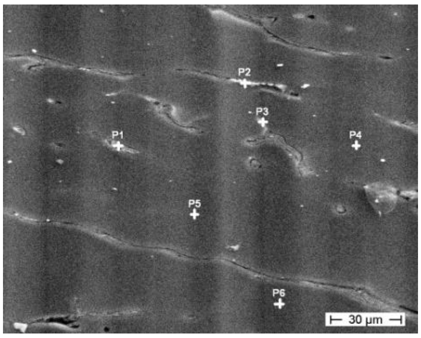

Fig. 9. Dendritic cell alloy AlZn5.5Mg2.5Cu1.5 - marked places of point EDX analyze.

Vickers microhardness HV0.02 of the material before and after homogenization was analyzed in a central region of dendritic cells at 20g load for a period of 5 seconds. The Vickers microhardness dependence of AlZn5.5.Mg2.5Cu1.5 alloy on the homogenization time is shown on the Figure 11 and Figure 12.

Table 3. The point EDX analyze of marked places of AlZn5.5Mg2.5Cu1.5 alloy (from Figure 10)

wt. %	Mg	Al	Cu	Zn
P1	1,77	76,14	7,43	14,67
P2	1,42	64,00	22,60	11,98
P3	2,17	76,66	4,68	16,49
P4	2,16	85,03	1,20	11,60
P5	2,17	85,07	1,28	11,48
P6	2,10	81,06	2,56	14,27

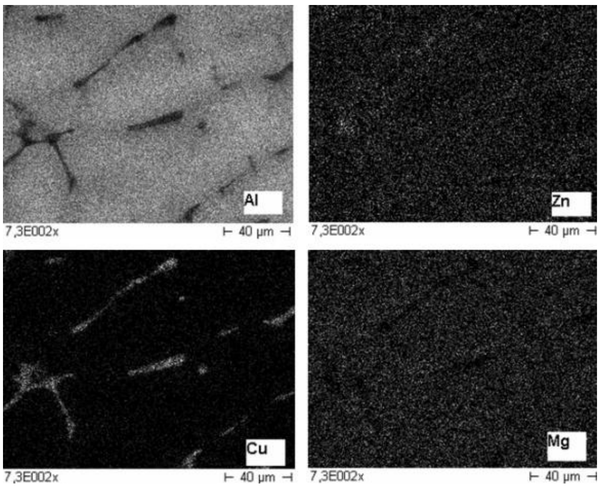

Fig. 10. Concentration maps of Al, Zn, Cu, Mg dendritic cell.

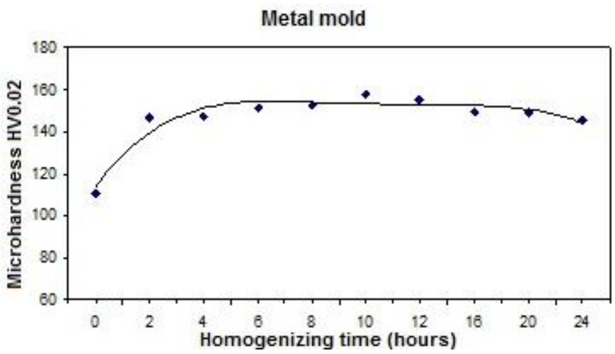

Fig. 11. The dependence of AlZn5.5Mg2.5Cu1.5 alloy hardness, according to Vickers, on homogenizing time with a constant temperature T = 470°C – metal mold.

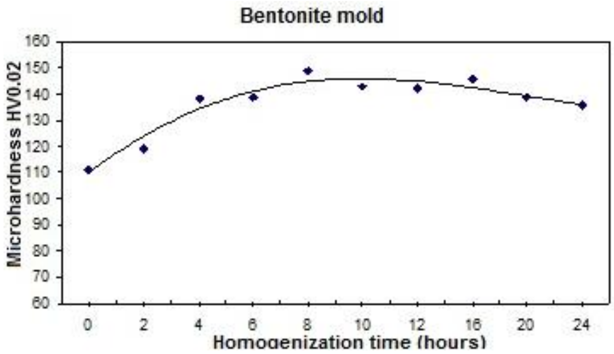

Fig. 12. The dependence of AlZn5.5Mg2.5Cu1.5 alloy hardness, according to Vickers, on homogenizing time with a constant temperature T = 470°C – bentonite mold.

3. Summary and conclusions

From the performed experiments of the AlZn5.5Mg2.5Cu1.5 alloy we can formulate the following partial results:

– In terms of performed macrostructures and microstructures of prepared casting AlZn5.5Mg2.5Cu1.5 alloys we can see that the size of the dendrites in the alloy cast to the bentonite form is on average twice higher than for alloys cast into metal mould.

– The average size of dendritic cells in the alloys cast into a metal preheated mold was 210 μm. In the alloy cast in the bentonite mould was determined the average size of dendritic cells 490 μm. It means the size of dendritic cells is by the casting of the experimental alloy casted into the bentonite mold twice bigger than by the casting of the alloy casted into the metal mold.

– From the results of EDX analysis of the experimental AlZn5.5Mg2.5Cu1.5 alloy before homogenization, it is evident that the structure of this alloy is created with α solid solution and soluble and insoluble eutectic of the type α + $Mg_3Zn_3Al_2$ (quasi-binary) and insoluble eutectic α + $CuMgAl_2$. It can be assumed the presence of the soluble tertiary eutectic α + Mg_5Al_8 + $Mg_3Zn_3Al_2$ and α + $Mg_3Zn_3Al_2$ + $MgZn_2$. Copper causes the origin of eutectic type α + $CuMgAl_2$+ $Mg_3Zn_3Al_2$ + $MgZn_2$, the predominant part dissolves during the heat treatment at $MgZn_2$ nebo $Mg_3Zn_3Al_2$. From Figure 9 (place 2) it can be concluded that the presence of eutectic type α + $CuAl_2$ that may arise after a short ageing process. Concentration maps of the elements Al, Zn, Mg, Cu show an increased concentration of copper in the interdendritic spaces (bright spots) which show a low concentration of aluminum. Analysis shows a relatively even distribution of the zinc and it is on the whole surface of dendritic cells. From the record it is evident that the distribution of magnesium in the interdendritic areas is poorer.

– From the Vickers micro-hardness of the investigated alloy in the central region of dendritic cells a significant effect of the casting mold on the microhardness HV0.02 of the given material was found. From the graphic dependence (Fig. 11, Fig. 12) it can be stated that by the alloy cast in preheated metal mould occurs after two hours of homogenizing annealing to a significant increase in microhardness HV0.02. This is related to the smaller size of dendritic cells (shorter diffusion path) during the homogenization process in which dissolution occurs non-equilibrium intermetallic phases and eutectic in matrix α and subsequent precipitation during cooling from the α matrix. In the case of samples of alloys cast in the form of bentonite, it is necessary that the process of homogenizing annealing is longer because the maximum values of microhardness HV0.02 thus prepared the alloy increase up to 8 hours after the homogenizing annealing.

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