MICROSTRUCTURE OF ALUMINUM ALLOYS SOLIDIFIED BY ROTATING ELECTRIC FIELD

Mirela POPESCU (DRĂGOIU), Bela VARGA

Transylvania University of Brasov, Faculty of Materials Science and Engineering

E-mail: mireladragoiu1@yahoo.com

Abstract: *This paper is intended to be a study of structural change on nonferrous alloys solidified in rotating electric field. There are shown both the used assembly to generate the rotating electric field and the one for recording cooling curves. Multiple tests were conducted on various alloys compositions of Al-Si, Al-Cu and Zn-Al systems at different frequencies and intensities of the electric field. Assessment of the structure modification degree was achieved through both cooling curves analysis and by optical microscope microstructure analysis. The structural analysis pursued the quantitative determination of phases proportion (constituents) and their dimensions.*

Keywords: *rotating electric field, cooling curves, structure, nonferrous alloys.*

1. INTRODUCTION

To improve the alloys structure is a particularly important task for casting producers. Through structure improvement it is primarily intended, to increase the mechanical characteristics and the cutting property, too. Casting manufacturers prefer metallurgical methods to improve the structure by using transition metals for grain refinement (Ti, B) and active superficial elements (Na) to modify the eutectic phases. The disadvantage of structure improvement by metallurgical methods occurs on waste recycling when the elements used to guide structure become impurities for secondary alloys which, with maximum probability, result on waste processing. In the same time, some elements used to modify the structure of casting alloys are toxic, such as antimony, used for treating Al-Si alloys. In many cases the castings are characterized by very different local cooling conditions both in casting into moulds on moulding sand or permanent mould, these cause structural heterogeneity into the jobbing castings.

The submitted disadvantages justify the intensification of research to develop physical methods for cast products structure improving. Among structure, the most studied improving physical methods are melt vibration and solidify in rotating magnetic field [1-4]. Melt vibration can be achieved by mechanical or ultrasound way. Solidification in electric field is based on melt electromagnetic agitation. To both physical methods for structure improving the researches results are more applied to eliminate the columnar grains areas for Al-Si, Al-Zn, Al-Cu and aluminum bronzes casting alloys. It should be mentioned that the refinement and structure changing in semi-products (bars) for thixocasting method [5] are done by magneto-hydrodynamic melt treatment in biphasic area, which requires strict temperature control.

This work tries to establish some connection between the parameters of rotating electric field and the degree of structural characteristics modification for nonferrous casting with zinc and aluminum base alloys, in case of volume solidification.

2. EXPERIMENTAL INSTALLATION

In order to study the solidification of nonferrous alloys casted in rotating electric field it was developed a laboratory installation consisting: the stator of a three-phase motor and command block of the electric field and the recording system of the rotor speed rotation, Fig. 1.

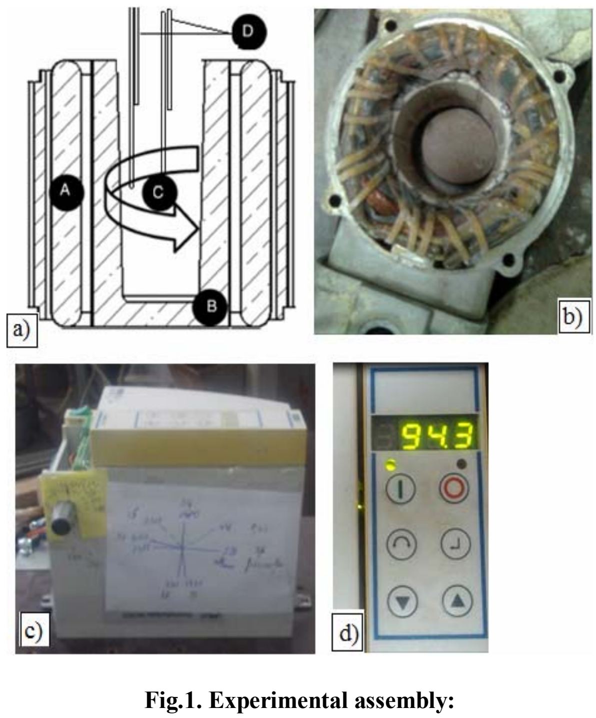

Fig.1. Experimental assembly:
a.) Fundamental circuit: (A) Inductor coil; (B) Refractory brick mould; (C) Aluminum alloy; (D) Thermocouples;

b.) Rotating electric field generator; c.) Command block, d.) Registration speed rotation system

The characteristics of inductor (electrical engine): Three-phase power 0.15 kW, frequency 50Hz.

The dimensions of the air gap: diameter (Ø) 50 mm, height (h) 100 mm.

The command block allows changing the frequency (f) between 3.6 to 94 Hz. Speed (rotation speed N) of the rotor is calculated from relation (1):

$$n = 60 \times f \quad (1)$$

Therefore, rotation speed can be adjusted within the range 220 - 5420 revs / min.

For casting (solidification) there were used cylindrical moulds obtained by refractory bricks processing, with exterior / interior dimensions: 50/30 mm diameter and height 110/100 mm, Fig.2. In order to perform structural analyzes samples were taken on the high of cast test specimen, with Ø30x100 mm (bottom, middle, top) and the radius (center area).

Fig.2. Casting mould of refractory material and way of place in rotating electrical field generator

To verify the hydrodynamic conditions of metal melt subjected to the action of the rotating electric field it was used a fusible alloy, Wood. The melting temperature for this composition (Bi=50%; Pb=25%; Sn=12,5% and Cd=12,5%) is about 71 ^{o}C.

Under the action of rotating electric field the melt in the mould is subjected to centrifugal forces which determine the rise of the melt on mould wall, as in the conventional centrifugal casting with an vertical rotation axis, Fig. 3a.

In its efforts to finish the structure by magneto-hydrodynamic agitating of melt the phenomenon of melt rising on the mould walls disadvantages us.

To prevent this phenomenon, in the upper part of the mould, it was applied a refractory material bushing, which limits the lifting phenomenon of melt on the mould walls during the action of rotating electric field, Fig. 3b.

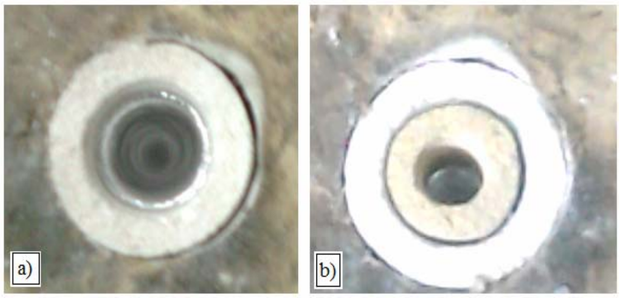

Fig. 3. Parabolic form of free surface of melt on the action of rotating electric field (a) and the limiting bushing (b)

Preliminary determinations performed on Wood alloy revealed that the rotating of metal liquid column in the mould occurs only at a certain frequency value of rotating electric field.

In the same time, after the electric field ignition, the casted metal column rotation speed is quickly decreases at 50-60 rev / min, which no longer ensures enough swirling of metal melt.

Therefore, on all experiments, the maximum melt agitation at a certain frequency of rotating electric field, was insured by coupling-decoupling power every 2-3 seconds.

3. EXPERIMENTAL DETERMINATION

In the experimental measurements were used hypoeutectic composition Al-Si and Zn-Al system alloys. The chemical compositions are shown in Table 1.

The alloys were casted in an electric furnace with forced bar resistors using crucibles of graphite. For all cases, the charging was composed on already-made compositions alloys pieces. After melting, the liquid alloy has been introduced into the mould fixed in the central portion of the device that generates the rotating electric field. In parallel, there were casted in moulds samples under normal cast conditions, meaning without rotating electric field.

Tabel 1. The chemical composition of the used alloys in %

No	Alloy	Cu	Si	Fe	Mn	Mg	Cr	Zn	Pb	Sn	Ni	V	Ti	Cd	Al
1	ENAC—42100 AlSi7Mg0.3	0.094	6.591	0.094	0.027	0.358	0.011	0.232	0.001	0.045	0.026	0.039	0.001	-	92.481
2	ZL5-ZnAl4Cu1	0.653	-	0.010	-	0.001	-	95.412	0.0073	0.0003	-	-	-	0.005	3.911

In Fig. 4 there are submitted the cooling curves recorded for AlSi7Mg0.3 alloy.

The layout of the thermocouple is presented in Fig. 1.a.

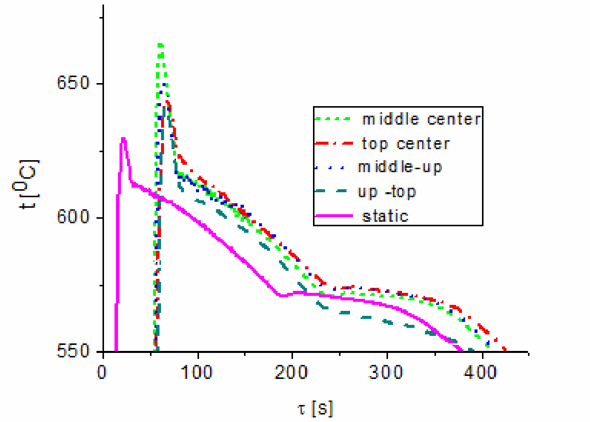

Fig. 4. Coolig curves for AlSi7Mg0.3 alloy

The variation of speed rotation of the liquid metal column depending on time at different frequencies of rotating electric field is shown in Fig. 5a.

In the same time it is also presented the working mode to record the form variation on free melt surface subjected to the action of rotating electric field, Fig. 5.b.

It should be mentioned that at 611 ^{o}C, the liquid alloy is still going in a rotating movement under the influence of the rotating electric field, Fig. 6.

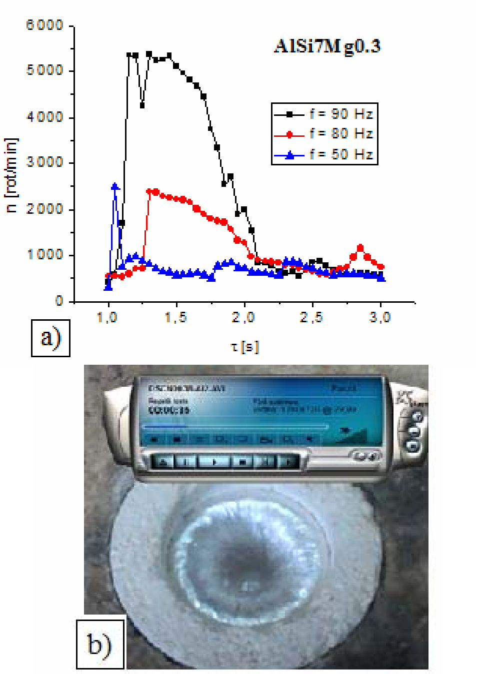

Fig. 5. Variation of rotation speed on liquid metal column depending on time (a) and the recording mode (b)

Fig. 6. Alloys temperature in the mould under the effect of the rotating electric field

Using the Tie Lines and Lever Rule is considered that at this temperature, the percentage ratio between the solid and the liquid phase is around 40/60.

The significant obtained structures on AlSi7Mg0.3 alloys are shown in Fig. 7.

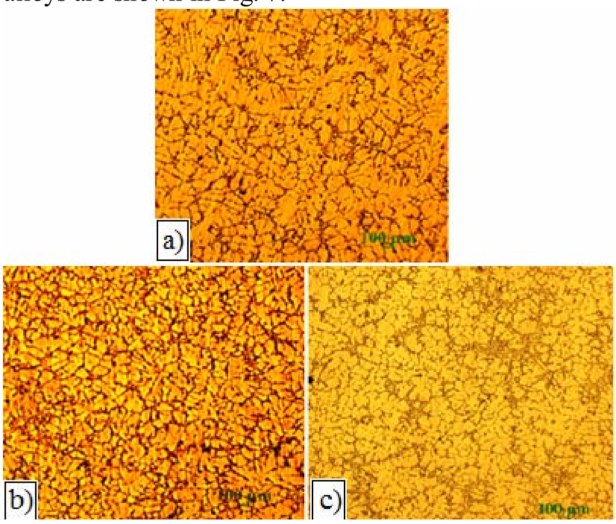

Fig. 7. structure of AlSi7Mg0.3 alloy solidified of rotating electrical field:
a.) without; b.) top and c.) middle

The significant results achieved in the processing of ZnAl4Cu1 alloy are shown in diagrams in Fig. 8, 9 and 10.

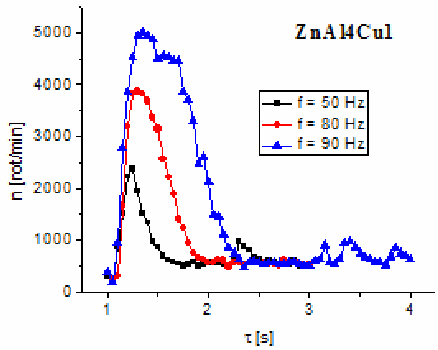

Fig. 8 Variation of rotation speed on liquid metal column depending on time

Fig.9.The temperature of ZnAl4Cu1 melt under the action of rotating electric field

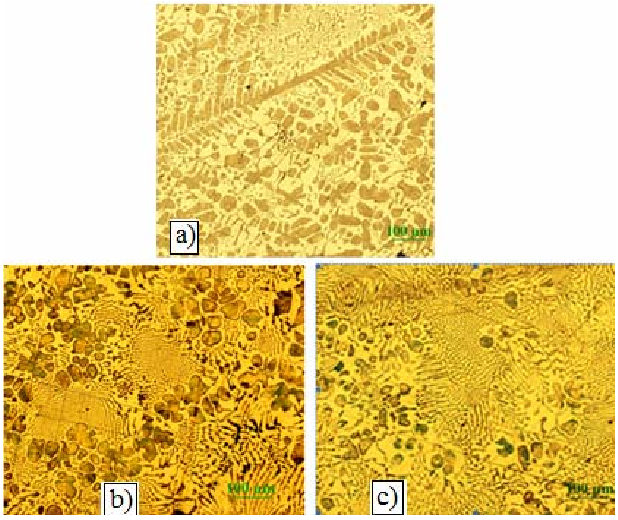

Fig. 10. Structure of ZnAl4Cu1 alloy normal and in rotating electric field solidification; a.) without; b.) top and c.) middle

4. DISCUSSIONS

Experimental determinations have aimed to analyze the influence of the rotating electric field under the structure where, due to the cooling conditions (thermal gradient of the melt: G = dT / dx and rate of increasing dendrites-V) it is formed a equiaxed structure. In Figure 11 are shown both morphology change of the liquid-solid interface depending of the solidification conditions and the correlation between thermal gradient from interface and interface morphology.

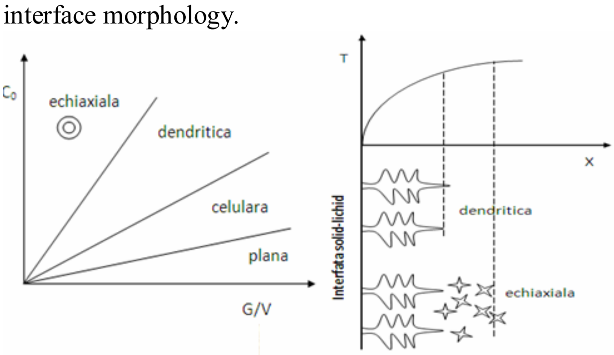

Fig. 11. The influence of composition (Co), thermal gradient and rise speed on the interface morphology and the correlation between the thermal gradient from interface and interface morphology

The cooling curves shown in Fig. 4 does not reveal significant differences between the thermal field from without rotating electric field solidification and the recorded ones in different areas of rotating electric field solidified sample. Is worth mentioning that for normal cast sample, on eutectic transformation, it appears the supercooling phenomenon, which is not observed in the sample casted under rotating electric field influence. Meanwhile, between the cooling curves registered at various points of the sample solidified under a rotating electric field, there are no significant differences.

It should be noted that in specified solidification conditions, the rotating electric field action has a very different manifestation for the two studied compositions. For AlSi7Mg0.3 alloys, with solidifying range, there is observed the spheroidization of alpha solid solution dendrites with the decreasing of their size. The shape and dimensions of eutectic silicon are not substantially altered. The specimens taken in the middle of cylindrical test are observed both finishing dendrites of α solid solution and increasing the eutectic proportion. For ZnAl4Cu1 alloy, an easily hypoeutectic composition, structurals changes are significant and there are marked both by disappearance of columnar dendrites and their spheroidization and by the eutectoid emergence in the alloy fine structure, a much higher proportion than indicated by Tie Lines and Lever Rule (18%). Structural changes on ZnAl4Cu1 alloy can be attributed to the action of rotating electric field on melt solidification by influencing the field distribution of alloying elements concentration.

5. CONCLUSION

The paper shows an own developed assembly for studying the alloy solidification under a rotating electric field action.

The results demonstrated that for solidification with minimum thermal gradient there can be observed on structure the rotating electric field action.

In case of hypoeutectic Al-Si alloy, rotating electric field eliminates the undercooling phenomenon.

For ZnAl4Cu1 alloy, easy hypoeutectic, action of rotating electric field occurs both the elimination of columnar dendrite and the formation of fine structure eutectoid colonies and, in a much higher proportion, than that specified by thermal equilibrium diagram.

6. ACKNOWLEDGMENTS

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