THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N^{0}. 1 – 2014, ISSN 1453 – 083X

STRUCTURE OF THE EUTECTOID Zn-Al ALLOY OBTAINED BY DIRECTED SOLIDIFICATION

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ABSTRACT

This work analyses the structure of the eutectoid Zn-Al based alloy directionally solidified, with cooling rates ranging between 8.5-0.4 ^{o}C/sec. During cooling, the temperature gradient in the liquidus zone, respectively of the eutectoid transformation, changed within the ranges of 0.6-4.6, respectively 1.2-6.4 ^{o}C/mm. The results of the dilatometric analyses and of microhardness on different crystalline areas are presented.

KEYWORDS: Zn-Al alloys, directed solidification, microstructure, dilatometric analysis, microhardness

1. Introduction

Over the last years the category of industrial alloys based on the Zn-Al system has widely expanded, yielding standardised compositions with 8, 12, 22, 27 and 40% aluminium. Their properties have been studied in depth [1-6]. Zn-Al alloys have excellent castability, good wear and friction strength. The disadvantage of these materials is the instability of the solidification structure, what determines dimensional modifications of the castings over time. The analysis of phase transformation considered the Zn-Al thermal equilibrium diagram established by Presnyakov, Fig. 1 [3].

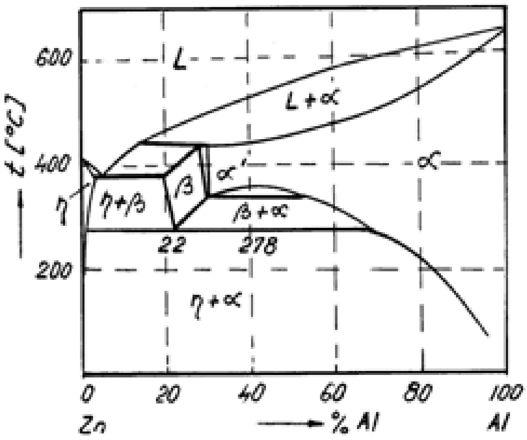


Fig. 1. *Zn-Al thermal equilibrium diagram*

According to the thermal equilibrium diagram, three important transformations occur in Zn-Al alloys rich in zinc:

- eutectoid transformation, at 278 ^{o}C (some authors indicate 272 ^{o}C, 275 ^{o}C):

$$\beta_{22\%\,Al} \rightarrow \alpha_{68.4\,\%\,Al} + \eta_{0.5\%Al} \qquad (1)$$

- peritectic transformation, at 443 ^{o}C:

$$L_{14\,\%\,Al} + \alpha_{30\,\%\,Al} \rightarrow \beta_{28\%\,Al} \qquad (2)$$

- eutectic transformation, at 382 ^{o}C:

$$L_{5.1\,\%\,Al} \rightarrow \alpha_{1.02\%\,Al} + \beta_{17.2\%\,Al} \qquad (3)$$

In a previous paper, we have analysed the structural and dimensional modifications in a binary Zn-Al$_{22}$ alloy, solidified at various cooling rates [7].

In casting important are the magnitude and ratio of the areas with columnar and equiaxial crystals [8]. The paper presents the results of research conducted on a bar shaped part of 30 mm diameter, obtained by directed solidification.

2. Experimental determinations

The device shown in Fig. 2 was conceived for the experimental determinations aimed at inducing directed solidification.

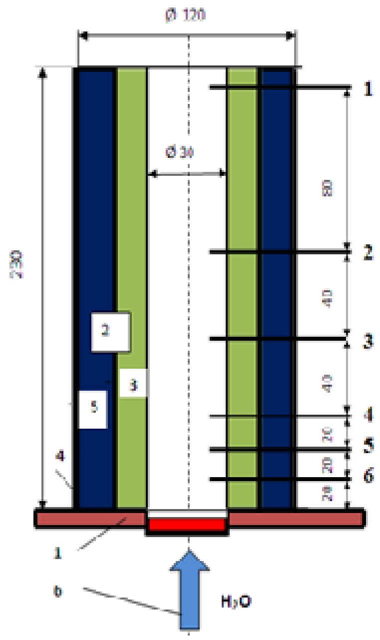


Fig. 2. *Schematic of the device used for directed solidification*

The device consists of a base plate (1) holding the casting mould (2) for a 30 mm diameter bar of maximum 230 mm height. In order to ensure directed extraction of heat as well as the mounting of thermocouples, the mould wall consists of two concentric cylinders, the inner one being made from heat insulating brick (3), while the exterior metal casting (4) and the interior cylinder encase a usual moulding sand.

The mould is heated by placing it over an electric heating device. Subsequently the mould is swiftly transferred from the heating to the cooling position by means of an adequate device. The base plate is cooled by a water jet (5) of adjustable flow and pressure.

Fig. 3. *Set-up for the recording of the cooling curves*

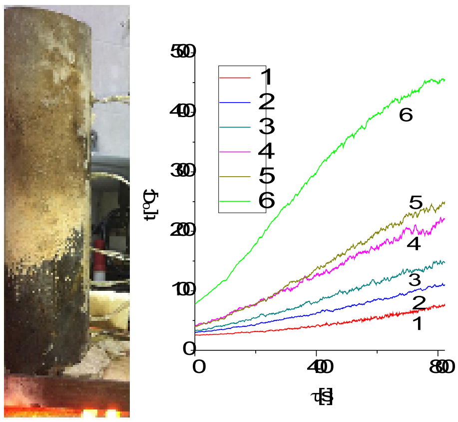
The temperature was recorded by K type thermocouples of 0.5 mm wire thickness. The tips of the thermocouples were introduced 10 mm deep into the mould cavity, as shown in Fig. 2.

The thermocouples were placed at distances of 20 (16), 40 (39), 60 (58), 100 (100), 140 (138) and 220 (218) mm from the base plate.

The real distances measured on the cylindrical cast part are indicated between brackets. Temperature recording was conducted via a ADAM - 4018 interface. Fig. 3 presents the set-up for the recording of the cooling curves.

The slightly hypereutectoid binary Zn-Al alloy with 25% Al was melted in an electrically heated crucible.

In order to ensure directed solidification, the mould assembly was preheated by means of an electric heating device, Fig. 4. a), to temperatures indicated in Fig. 4 b), while the casting temperature was of 730 ^{o}C.



a) b)

Fig. 4. *Preheating of the mould*

Fig. 5 shows the cooling curves recorded by means of the 6 thermocouples.

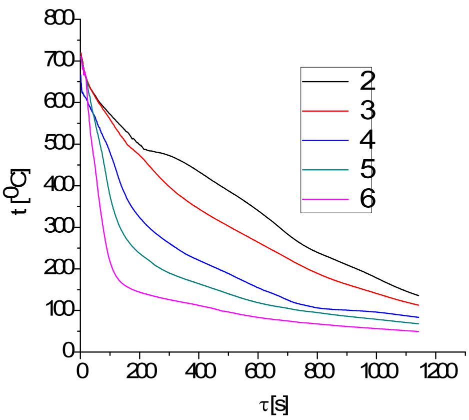


Fig. 5. *Recorded cooling curves*

The cooling curve for point 1 does not appear in the diagram, as the thermocouple of that area was located exactly at the level of the liquid alloy in the mould and the curve, while having certain irregularities, coincides as to its shape and quantity with the one recorded in point 2.

Only for thermocouples (TC) 2 and 3, where the cooling rates were smaller, the cooling curves feature inflection points corresponding to the structural transformations indicated by the thermal equilibrium diagram.

Based on the derivatives of the cooling curves for the extreme measuring points, namely points 6 and 2, it follows that in the melt preceding the solidification front the cooling rates range in the interval from 8.5 to - 0.4 ^{o}C/s, Fig. 6.

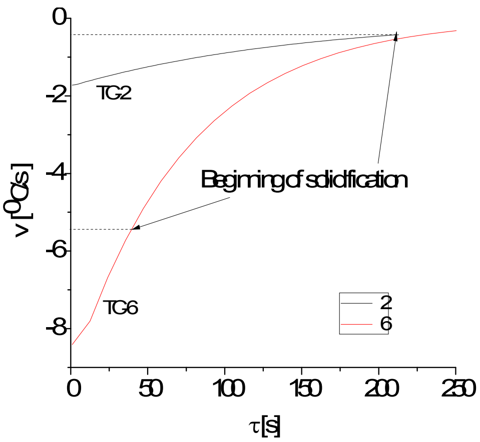


Fig. 6. *Variation of cooling rates versus time*

The completed computations revealed that during cooling the temperature gradient in the liquidus and the eutectoid transformation area, respectively, varied within the ranges of 0.6-4.6^{o}C/mm and 1.2-6.4 ^{o}C/mm, respectively.

The cast bar was cut by the segments corresponding to the thermocouples and samples were taken for structural, DSC, dilatometric, microhardness and wear strength analyses.

Fig. 7 presents the macrostructures obtained in the longitudinal section along the entire height of the cast bar.

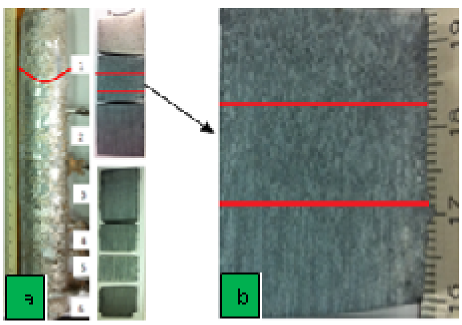


Fig. *7. Macrostructure of the cast bar: a) in longitudinal section; b) transition area, columnar – equiaxial crystals*

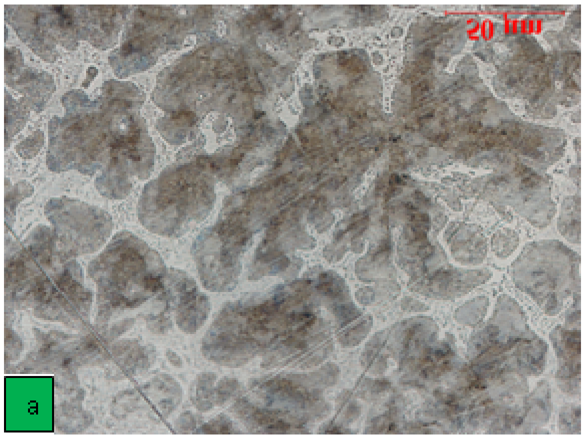
The area of columnar crystals covers nearly the entire height of the test piece.

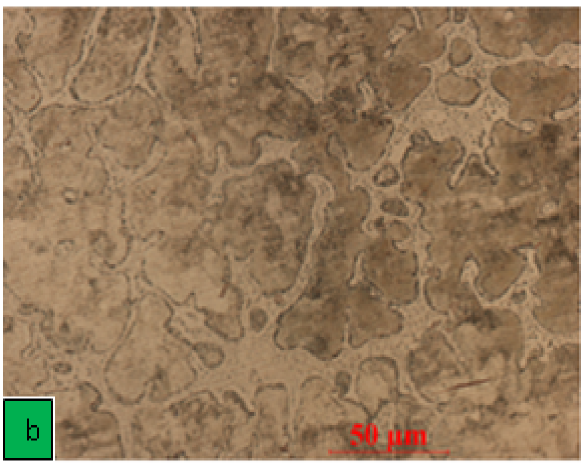
The transition from the area of columnar crystals to that of equiaxial ones occurs approximately at the centre of area 1, at 170 - 180 mm distance from the cooled end of the bar, whose limit is marked on the cast bar, Fig. 7.

At the inferior end of the bar, area 6, the columnar crystals are thin, and their diameter increases along the height of the bar from 0.5 mm to 2-3 mm in area 1. The length of these crystals exceeds 20-30 mm. In area 1 the diameter of the equiaxial crystals is 2-4 mm.

The effect of the directed cooling, under the conditions of the experiment, extends over a height of 170-180 mm. The microstructural analyses were conducted by means of a NIKON Eclipse MA100 microscope endowed with an *OMNIMET-BUEHLER* image analyser.

Fig. 8 shows the microstructure of the bar obtained by directed solidification in various cooling areas and in cross-sections, perpendicular to the direction of solidification (T) and longitudinal (L).





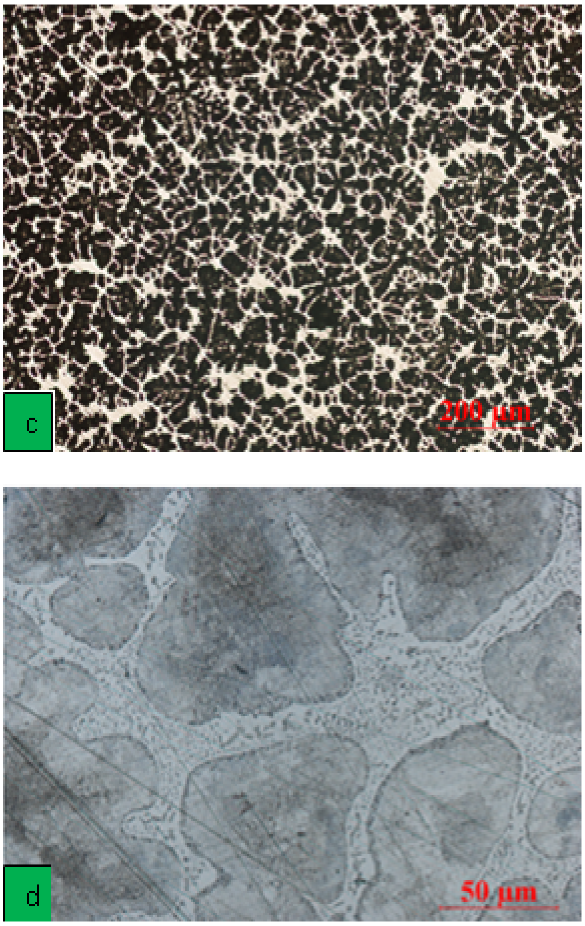
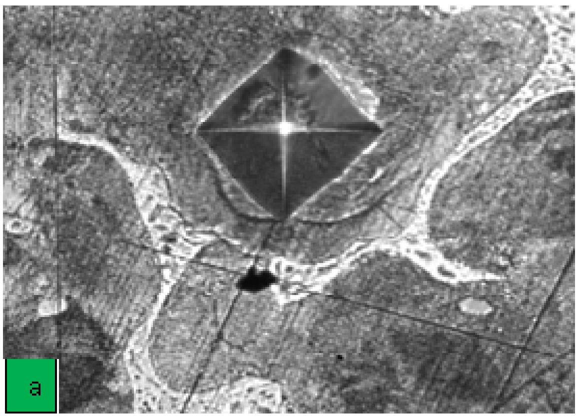


Fig. 8. *Microstructure of the bar obtained by directed solidification in various areas: a) 6 - L; b) 5 - L; c) 5 - T and d) 1 - L*

Microhardness was determined by means of an FM-700 AHOTEC device. The results are given in Fig. 9 and Table 1.

The values in the Table are the arithmetic mean of at least 3 measurements.



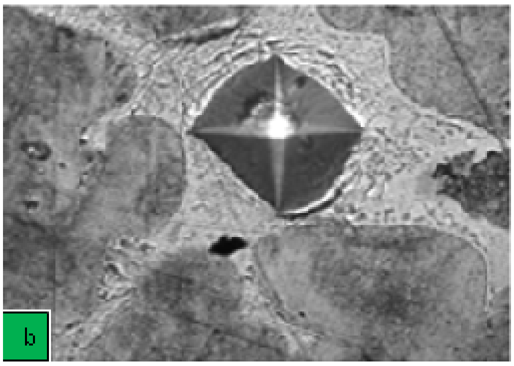


Fig. 9. *Microhardness of the Zn-Al alloy obtained by directed solidification: a) dendrites and b) eutectic*

Table 1. *Microhardness of the Zn-Al alloy obtained by directed solidification*

Crystalline area	dendrites	eutectic
5 - longitudinal	99.5	91
2 - transversal	89	80

Because of the high cooling rate, in area 5, the hardness of both dendrites and the eutectic is greater than the alloy solidified at smaller cooling rates, in area 2. The hardness of dendrites is greater than in inter-dendritic areas, which were enriched in zinc due to structural transformations during cooling. A LINSEIS L75PT/1400 °C dilatometer and a DSC 200 F3 – Maia - Netzsch differential scanning calorimeter were used for the analysis of microstructure modifications determined by phase transformations as well as by the diffusion processes brought about by the thermodynamic tendency of restoring the state of equilibrium. The diagram in Fig. 10 presents the results of the dilatometric analyses conducted on various cooling areas and for various states.

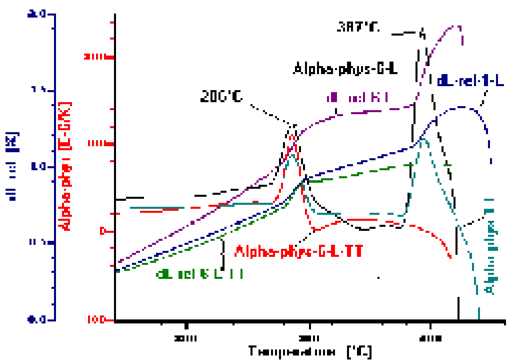


Fig. 10. *Dilatation curves (dl-rel) and the variation of the dilatation coefficient versus temperature*

In the case of the heat treated test piece, 6 – L - TT, the treatment entailed heating up to 420 ^oC. Both heating and cooling were carried out at a rate of 10^{o}C/min. There are significant differences between the dilatation of the test pieces in the area of columnar and that of equiaxial crystals.

DIL analysis results reveal the intensity of the segregation processes during solidification. This finding is in agreement with the observations published in [9] that indicate the presence of eutectic also in compositions with 8% aluminium content. The results of the differential calorimetric analysis shown in Fig. 11 confirm the presence of the phase transformations revealed by dilatometric analysis. In the calorimetric analyses as well as in the dilatometric ones the heating and cooling rates were of 10 ^{o}C/min.

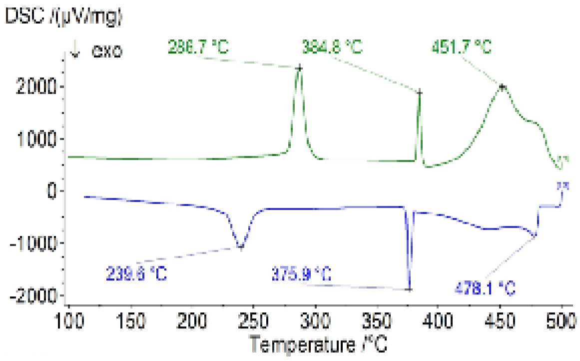


Fig. 11. *DSC curves for the heating and the cooling of the test piece in area 6*

The DSC curves indicate the presence of eutectoid, eutectic and peritectic transformations during both heating and cooling. It needs be pointed out that the 3 transformations occur with different intensities during heating and cooling, respectively, what is explained by the thermodynamic tendency of restoring the equilibrium structure.

3. Conclusions

By the directed solidification of the slightly hypereutectoid Zn-Al alloy, the area of columnar crystals extends over a very wide range.

With a decrease in local cooling rate the thickness of the columnar crystals increases.

In the case of directed cooling, the equiaxial crystals start forming at cooling rates smaller than 0.4^{o}C/s.

The completed analyses reveal significant differences in structure and properties between the areas formed of columnar and equiaxial crystals, respectively.

Because of segregation phenomena the eutectic transformation is present also in slightly hypereutectoid compositions.

Acknowledgements

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), ID137516 financed from the European Social Fund and by the Romanian Government.

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