THE INFLUENCE OF THE INHOMOGENEITY OF AL ALLOYS ON THE TRANSMISSION OF STRUCTURAL CHARACTERISTICS IN CASTINGS

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Abstract: *The paper studies the influence of chemical and structural inhomogeneity of aluminum alloys on the mechanisms of formation and transmission of microstructural characteristics in castings. The phenomena of micro- and macrostructural segregation and the non-uniform distribution of intermetallic phases are also analyzed.*

Initial inhomogeneities are correlated with the appearance of areas with different mechanical properties, which can favor the initiation of internal defects and reduce the operational performance.The results emphasize the importance of controlling solidification processes in order to minimize segregations and obtain an uniform microstructure, with a direct impact on improving the mechanical properties of aluminum alloy castings.

Keywords: *aluminum alloys, inhomogeneity, structural characteristics*

1. INTRODUCTION

Cast aluminum alloys are highly sensitive to variations in casting conditions. This sensitivity leads to the appearance of chemical and structural inhomogeneities [1].

Deviations from the chemical composition of the alloy, the cooling rate, the thermal gradient or the casting conditions lead to the appearance of chemical segregations, randomly distributed intermetallic phases or to variations in morphology or crystal size [2, 3].

The transmission of heredity in cast parts depends on the evolution of the solidification front and the interaction between the solid and liquid phases [4, 5]. Initial inhomogeneities can lead to the development of areas with different mechanical properties, which leads to the appearance of internal defects (porosity, inclusions or solidification cracks) [4, 6, 7].

2. METHODS

For the proposed study, samples were taken from an Al-Si-Mg aluminum alloy bar that was continuously cast and a piece obtained by casting from that bar.

In order to highlight the hereditary transmission of inhomogeneity, microscopic analysis was used.

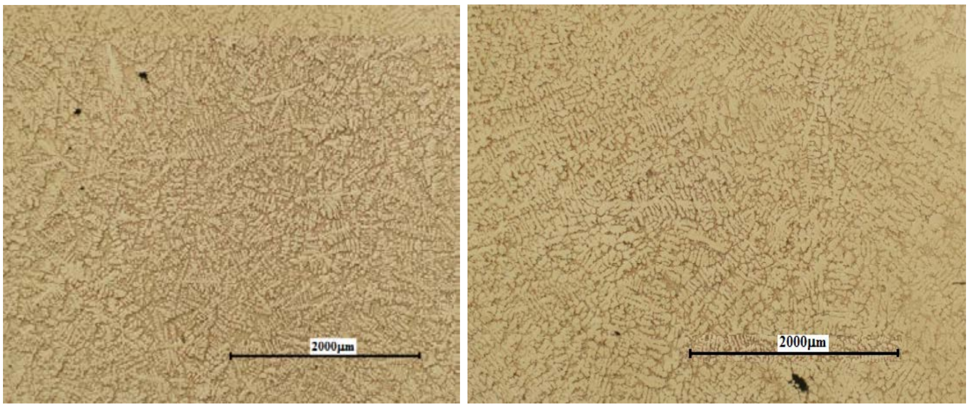
The samples (taken both from the bar and from the cast piece) were properly prepared for the analysis of structural characteristics by optical microscopy. Within this, the following were evaluated: the shape and dimensions of the dendrites and of the α crystals, the characteristics of the defects at the limits of the dendrites and the morphology of the phases or constituents.

On polished and unetched samples, the characteristics of the α solid solution dendrites were analyzed at a magnification of 25x. The aim was also to highlight the shape and size of the dendrites in each sample and, at the same time, a comparative analysis between the samples was also made. The results found are presented in table 1 and Fig. 1.

Table 1. Shape and dimensions of α solid solution dendrites at 25x magnification

No.	Sample	Dendrites' shape	Average dendrite dimensions [μm]		Observations
			lenght	thickness	
1	Cast piece	elongated	1500	300	Very similar to those in the bar
2	bar	elongated	1300	300	

The comparison of the dendrite characteristics between the continuously cast bar and the parts that were cast from it is very important. As it can be seen from table 1 and figure 1 there is a significant similarity of the dendrite characteristics from the cast part and the bar used in the load. This resemblance indicates that for some reason the cast bars used in the load have inherited, to a large extent, their structural characteristics to the parts obtained subsequently by casting.



a) b)

FIG. 1. Appearance of the shape and dimensions of the dendrites in the structure. Unetched samples: a) - cast part; b) - bar semi-finished product; Magnification: 25x

The shape and size of the α solid solution crystals were also studied at a magnification of 100x. The results of the study are presented in table 2 and Fig. 2.

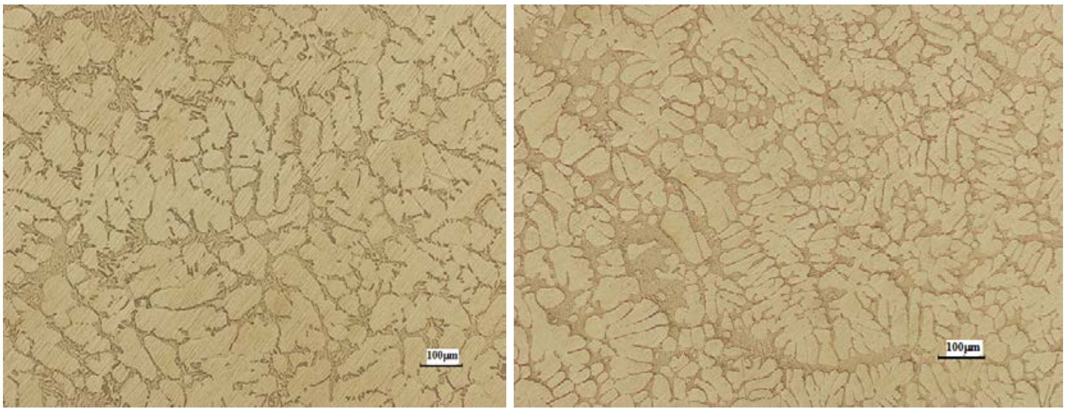
Table 2. Shape and dimensions of α solid solution crystals at 100x magnification

No.	Sample	Crystal shape	Average crystal sizes [μm]		Observations
			lenght	thickness	
1	Cast piece	elongated	150	60	Very similar to those in the bar
2	bar	elongated	120	40	

The analysis of the intersection of the dendrite branches with the sectioning plane of the sample indicates that the α solid solution crystals present characteristics correlated with those of the dendrites, i.e. the transmission of structural characteristics, as a hereditary phenomenon, is pronounced.

In this context, only void-type defects were analyzed, which can essentially be contraction microporosities (micro-shrinkage), porosities due to gases or other causes.

As can be seen in Fig. 1, at the limits of the α solid solution dendrites, porosity-type defects are present, in larger quantities and sizes, both for the castings and for the bars used in the load.

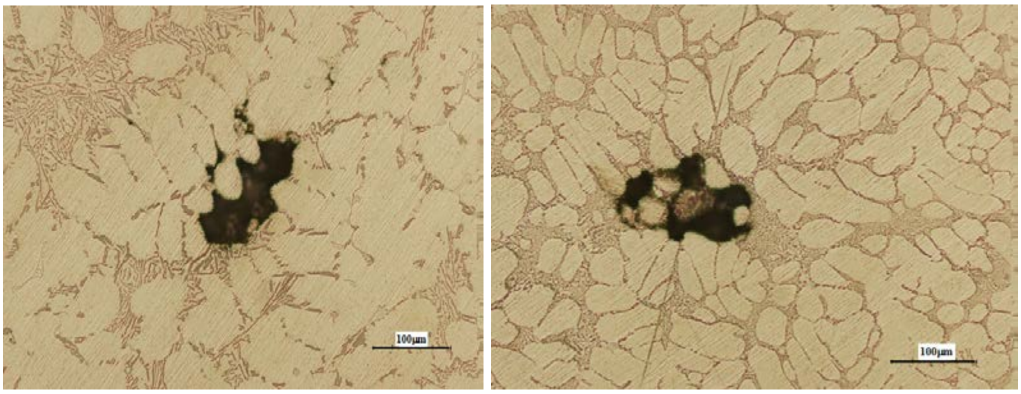


a) b)

FIG. 2. Shape and dimensions of crystals in the structure. Unetched samples: a)-cast part; b)-bar semi-finished product; Magnification: 100x

For a clearer observation of the shape and dimensions of the porosities, the study was carried out on polished and unetched samples at 200x magnification. Indicative images of the shape of the porosities are presented in Fig. 3.

In Fig. 3.a and 3.b, the porosities are predominantly microshrinkage porosity, so they are due to shrinkage during solidification and have much larger dimensions reaching up to 200µm. It is important to note that they have similar dimensions and shapes in the cast parts and in the bars used as a load. This fact confirms the hereditary transmission of the structural characteristics of the bars to the cast parts.



a) b)

FIG. 3. Shape and dimensions of bordering defects (microshrinkage porosity). Unetched samples: a) -cast part; b)-bar semi-finished product; Magnification: 200x

Following the dendritic segregation process, at the limit of the α solid solution dendrites, towards the end of solidification, a series of elements with lower solubility in the solid solution than in the liquid alloy (Fe, Mg, O, Sb, C, etc.) are concentrated.

These can form eutectic phases or compounds (intermetallic or stoichiometric) with properties different from those of the solid solution and therefore with an important influence on the overall properties of the cast parts.

The shape that these borderline phases take is closely linked to the shape of the α solid solution dendrites. On polished and unetched samples, such borderline phases can be observed, easily distinguishable from Si separations.

The reason is related to the different cooling rates during solidification. The cast pieces solidified with lower cooling rates, which allowed a more pronounced evolution of the segregation phenomenon and thus a more important quantitative development of the borderline phases.

The effect of the bordering phases could also be determined by following the behavior of the material during preparation in order to study the structure through optical microscopy. There are borderline phases with very high hardness, much higher than the α solid solution, which when grinding with abrasive materials can fragment and detach from the alloy, generating apparent pores, or having destructive effects on the neighboring areas. These phases can have the same behavior during the mechanical machining operation by chipping causing difficulties related to ensuring the quality required for the processed surfaces through these operations.

In order to better highlight the shape and composition of the adjacent phases of the α dendrites, an electron microscopy study (SEM and SEM-EDS) was carried out on samples taken from the castings obtained using continuously cast bars.

Figures 4 and 5 show the aspects of the borderline phases at higher magnifications than those provided by optical microscopy. Areas where phases other than Si can be observed were selected from the samples (especially 1000x at 5000x magnifications).

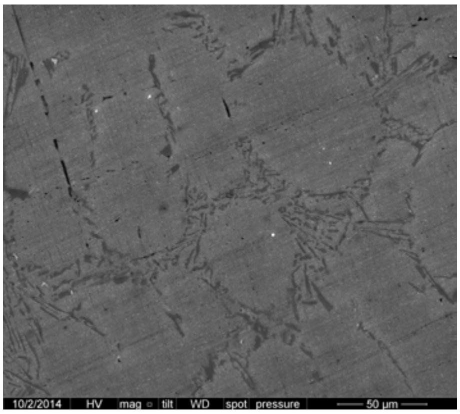


FIG.4. Appearance of the structure at 1000x magnification: cast part

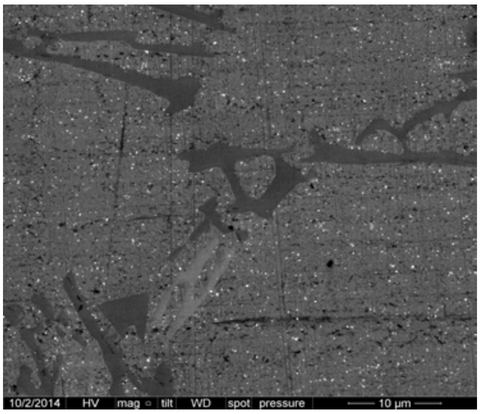


FIG.5. Appearance of the structure at 5000x magnification: cast part

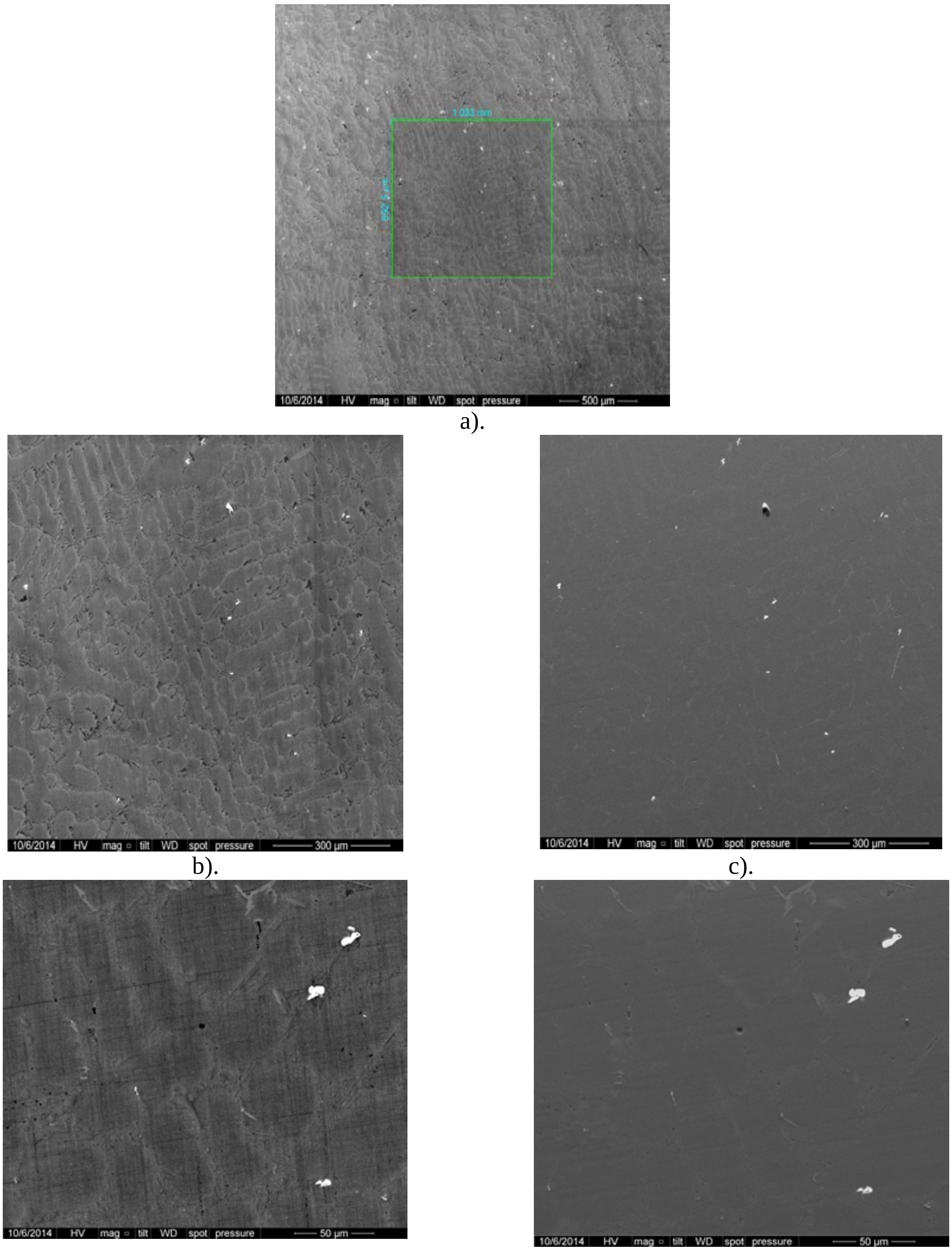
The study showed that the borderline phases have acicular (light gray), polyhedral shapes combined with acicular (dark gray), compact polyhedral and equiaxed agglomerations. Through their shape and properties, these phases can greatly influence the mechanical and technological properties of the material.

To validate the conclusions drawn, we also identified the chemical nature of the borderline phases by SEM electron microscopy with EDS.

Thus, an area was selected from the surface of the samples on which the average chemical composition was first determined by the electron microscope and then the surface distribution of the elements identified in the chemical composition was determined. The selected areas were studied at magnifications of: 250x and 1000x respectively. These are presented in Fig.6. The average chemical compositions of the areas selected in the study, expressed in weight percentages (%Gr) and in atomic percentages (%At) are shown in table 3 and figure 6 respectively.

Table 3. Average chemical composition in the areas selected for study presented in Fig. 6

No.	Piece type/area	Chemical comp. expressed in	Chemical element								
			C	O	Mg	Al	Si	Sb	Ti	Fe	Total
3	250x	%Gr	0,00	1,20	1,00	87,61	9,65	0,17	0,14	0,23	100
		%At	0,00	2,01	1,10	87,40	9,25	0,04	0,08	0,11	100
4	1000x	%Gr	0,19	1,24	0,94	86,63	9,88	0,72	0,25	0,15	100
		%At	0,42	2,09	1,04	86,59	9,49	0,16	0,14	0,07	100

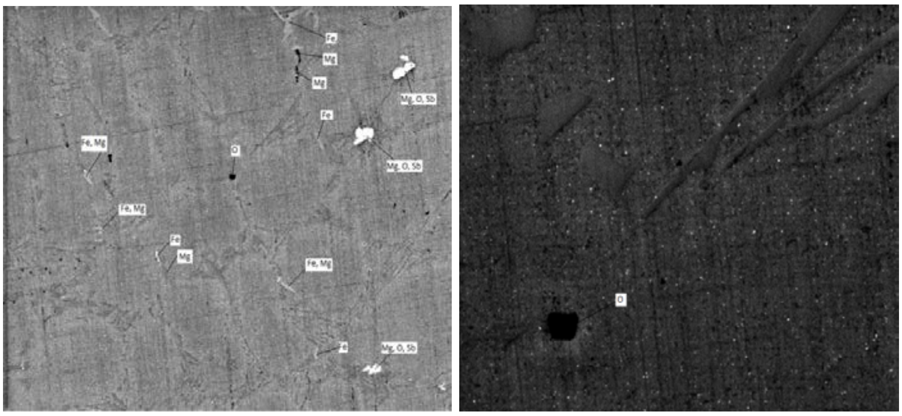


a).

b). c).

d). e).

FIG.6. Appearance of the area studied by SEM microscopy with EDS for the piece: a) general image of the area at 100x magnification; b) image of the selected area created by secondary electrons, 250x magnification; c) image of the selected area created by backscattered electrons, 250x magnification; d) image of the selected area created by secondary electrons, 1000x magnification; e) image of the selected area created by backscattered electrons, 1000x magnification



a) b)

FIG. 7. Chemical nature of the borderline phases in the case of the cast part: a) the area studied at 1000x magnification; b) the area studied at 5000x magnification

From the analysis of the elements distribution in the studied areas, it was possible to establish the specific locations where each of them is found in higher than average concentration, thus identifying the chemical nature of the borderline phases (figure 7).

The non-uniformities in the chemical compositions given in table 3 are due to the fact that the areas chosen for the study are located in the regions where the effects of dendritic segregation are maximal (dendrite limits).

CONCLUSIONS

The following conclusions can be drawn from the analysis of the studied microscopies:

1. The chemical nature of the phases bordering the α solid solution dendrites is complex. In relation to the local conditions of agglomeration of the elements following the dendritic segregation process, they can be grouped into various associations: Mg-Al, Fe-Mg-Al, C-O-Al, O-Al, Fe-Al, Mg-O-Sb;
2. In the piece cast from the bar, the amount of borderline phases is large. At the same time, associations are present between the bar and the piece. These phases are agglomerations of the Mg-O-Sb, O-Al type.
3. The presence of phases such as Mg-O-Sb, as well as others with O (C-O-Al, O-Al) indicates an inadequate preparation of the alloy before casting by specific metallurgical treatments (degassing, filtration).
4. In the borderline phases, the coexistence of eutectic compositions with intermetallic compounds of the respective elements is possible.

REFERENCES

[1] S. Duan, M. Tang, W. Chen, et al. Microstructure evolution and mechanical properties of as-cast Al–Mg–Si alloy induced by Fe addition, *Journal of Materials Research and Technology*, 2025;

[2] MaoYuan Han, HaiTao Wang, Yu Guo, Ming Chen, Wei Zhao - A Review on Microstructure Control and Performance Enhancement of Aluminum Alloys via Directional Solidification, *Metals* (MDPI), 2025;

[3] A. Datta, A. K. Rana, Chemical composition design in cast aluminum alloys for enhanced microstructure and functionality, *Discover Chemistry*, 2025;

[4] H. Yang, et al. Effect of homogenization treatment on microstructure and properties of Al-Mg-Zn-Sc-Zr alloys, *Journal of Alloys and Compounds*, 2025;

[5] Y. Qi, et al. Microstructure and Mechanical Property of 6082 Aluminum Alloy via Sc and Zr Addition Combined with Squeeze Casting, *Materials*, 2025;
[6] Yuling Lang et al. Evaluation of fatigue behavior of a casting aluminum knuckle considering influences of inhomogeneous microstructure, *Engineering Failure Analysis*, 2025;
[7] Zhanwei Su et al. Spatial heterogeneity of microstructure and mechanical properties in high-pressure die-cast aluminum alloys, *Journal of Alloys and Compounds*, 2025.