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The Effect of AlTi5B1 Masteralloy on Al-Si Alloy Casts Grain Size

Tomáš Vlach [1*], Roman Horký [2]

[1] Faculty of Mechanical Engineering, Department of Technology and Materials, J. E. Purkyně University in Ústí nad Labem, Pasteurova 1, 400 96, Ústí nad Labem, Czech Republic
[2] Faculty of Mechanical Engineering, Department of Technology and Materials, J. E. Purkyně University in Ústí nad Labem, Pasteurova 1, 400 96, Ústí nad Labem, Czech Republic

Abstract: This article deals with the issue of silumin inoculation. Two alloys, AlSi7Mg0.3 and AlSi10.5Cu1.2Mn0.8Ni1.2, were selected. 4 pieces of castings were cast from each alloy. One casting was not inoculated and 3 castings were inoculated using AlTi5B1 prealloy in concentrations of 0.05 wt. %, 0.1 wt % and 0.2 wt. % Ti. The castings were cast into metal molds preheated to a temperature of 200°C ± 5°C. In total, 8 pieces of metallographic cuttings were prepared for each alloy. Four samples were taken from the bottom part of the casting and four samples from the middle part of the casting. Secondary axes of DAS dendrites were measured using a microscope. Subsequently, the microhardness of the solid solution α was measured according to Vickers.

Keywords: inoculation, size of grain, Al-Si alloys, hardness, microhardness, DAS

1. Introduction

One of the most available elements on earth is aluminum. It has an important application especially in alloys, in combination with various elements. [1] Mechanical properties can be improved by alloying and grafting. [2] Refinement of grains in aluminum alloys can be achieved by inoculation. [3,4] Inoculation in aluminum alloys is mainly used to influence the α-phase of the metal matrix, specifically for its refinement. [5] Inoculation becomes most effective in Al-Si type alloys with a high proportion of solid solution α in the structure. They are Al-Si alloys that have a silicon content of 1–12 wt. % [3,6]. The grain size in the primary phase is an important parameter from which the subsequent properties of Al alloys depend. Several dendrites grow from a single nucleation seed to form a grain. The size of these grains ranges from 1 to 10 mm, DAS values are most often in the range of 10-150 µm. An important element that affects the resulting dendritic structure is the cooling rate. It is also closely related to the material of the mold. [1]

For hypoeutectic Al-Si alloys, titanium and boron are most often used for inoculation. These elements are added to the melt either in the form of inoculation salts, inoculation tablets or, as in our case, in the form of prealloys. [1] The elements titanium and boron are most often added to the melt in the form of intermetallic compounds that are contained in master alloys. A suitable prealloy can be, for example, AlTi6 containing an intermetallic compound. [8] A typical prealloy for boron addition is AlB4 containing the intermetallic compound AlB2. Aluminum-titanium-boron prealloys (in the form of Stick/ Coil / Waffle / Bar/ Piglet) AlTi5B1, AlTi3B1, AlTi5B0.2 are used for refining the grain of pure aluminum or aluminum alloys during melting. [9] Inoculation with substances based on Al-Ti or

Al-Ti-B is important for the industrial use of silumins. [10] In Al-Si alloys, the task of the inoculant is to suppress the formation of coarse columnar grains and to promote

*** Corresponding author:** Tomáš Vlach, ***E-mail address:*** *tomas.vlach@ujep.cz*

the formation of finer equiaxed grain structures during solidification. [4]

The DAS (Dendrite Arm Spacing) method was used to determine the dendritic structure. It is the distance between the secondary axes of the dendrites. These values are usually determined using a microscope. DAS values depend on the rate of cooling of the alloy in the solidification interval. The distance is usually between 10 and 150 µm. A schematic picture of the DAS method is shown in Figure 1. [1]

$$DAS = L / (n - 1)\ [\mu m]$$

L … distance between secondary axes
n … number of secondary axes

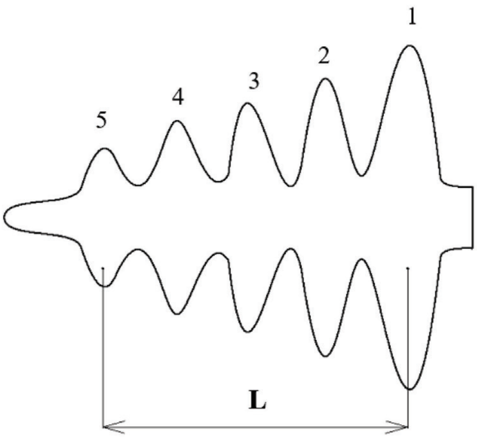

Figure 1: DAS measurement scheme

When monitoring the size of the DAS, it can be found that many structural phenomena are associated with it. Smaller segregation distances are for finer structure, i.e. when the DAS value is lower. If the extent of segregation is smaller, even smaller particles of intermetallic phases are formed. Inclusions and impurities are excluded in the form of separate particles in the interdendritic spaces and do not have the opportunity to form networks. In the case of alloys, the distribution of microporosity is better and, from a chemical point of view, the alloy is more homogeneous. [1]

2. Materials and methods

The first alloy to be investigated was the AlSi7Mg0.3 alloy. This alloy is marked according to the European standard as EN AC-42100 and belongs to the category of high-strength alloys. There are very few impurities and impurities in this alloy. It has excellent casting properties, ductility and toughness. Furthermore, good machinability and weldability. It is most often cast using gravity or low-pressure casting, either in metal or sand molds. It is suitable for grain refinement with Ti and B and modification. Its chemical composition is in Tab. 1. Measured chemical composition of AlSi7Mg0.3 is in Tab. 2 [1,11,12]

The second alloy was AlSi10.5Cu1.2Mn0.8Ni1.2, which does not have a marking according to the standard. European patent EP306352 was issued for this alloy. It is characterized by high values of mechanical properties at low, but also at elevated temperatures. The alloy contains a greater number of alloying elements. Thanks to its chemical composition and appropriate heat

Table 1: Chemical composition of AlSi7Mg0.3 [11]

Chemical el.	Al	Si	Mg	Ti	Fe	Mn	Zn	Cu
wt [%]	91.3-93.3	6.5-7.5	0.25-0.45	0-0.25	0-0.19	0-0.1	0-0.07	0-0.05

Table 2: Measured chemical composition of AlSi7Mg0.3

Chemical el.	Al	Si	Mg	Ti	Fe	Mn	Zn	Cu
wt [%]	base	6.85	0.28	0.23	0.15	0.09	0.05	0.04

Table 3: Chemical composition of AlSi105Cu1.2Mn0.8Ni1.2 [13]

Chemical el.	Al	Si	Cu	Mn	Ni
wt [%]	85.8	8.5-10.5	0.6-1.2	0,3-0.7	0.6-1.2

Table 4: Measured chemical composition of AlSi105Cu1.2Mn0.8Ni1.2

Chemical el.	Al	Si	Cu	Mn	Ni
wt [%]	base	10.4	1.1	0.65	1.2

treatment, it was possible to increase the strength limit compared to Al-Si alloys and Al-Mg alloys. The chemical composition of the alloy is summarized in Tab 3. Measured chemical composition of AlSi105Cu1.2Mn0.8Ni1.2 is in Tab. 4 [13]

2.1. Samples preparation

Both alloys were melted in an electric resistance furnace at a temperature of 730 °C ± 5 °C. Before pouring, the melt was freed of impurities using refining salt. After refining, one sample without inoculant and three samples with a concentration of 0.05 wt. %, 0.1 wt. % and 0.2 wt. % of Ti. The time of action of the inoculant before casting was 10 minutes. For gravity casting, a metal mold preheated to 200 °C ± 5 °C was used to remove moisture.

Table 5: Materials used for sample preparation

Alloy	Sample	Ti [wt. %]	Cast sampling area
AlSi7Mg0.3	1 ok	-	bottom part of the cast
	2 ok	0.05	
	3 ok	0.1	
	4 ok	0.2	
	1 st	-	middle part of the cast
	2 st	0.05	
	3 st	0.1	
	4 st	0.2	
AlSi10.5Cu1.2Mn0.8Ni1.2	5 ok	-	bottom part of the cast
	6 ok	0.05	
	7 ok	0.1	
	8 ok	0.2	
	5 st	-	middle part of the cast
	6 st	0.05	
	7 st	0.1	
	8 st	0.2	

Two samples were taken from each casting. One sample from the lower part of the casting, which was marked with the abbreviation "Ok". The second sample was taken from the centre of the casting, 40 mm from the bottom surface of the casting, which was marked "St". Schematic illustration of the sampling site is shown on Fig. 2.

DAS values for each sample were determined using an OLYMPUS Lext OLS 5000 confocal microscope, which is shown in Fig 3.

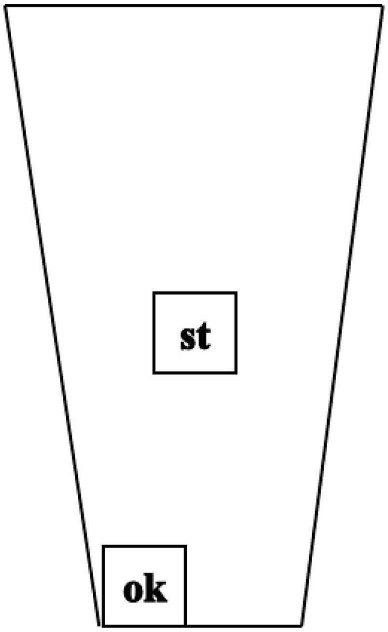

Figure 2: Schematic illustration of the sampling site

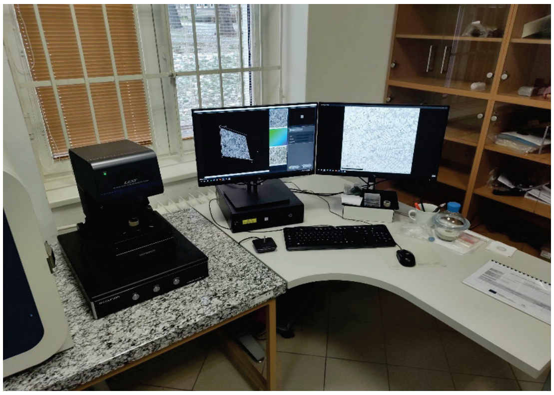

Figure 3: Laser Confocal Microscope OLYMPUS Lext OLS 5000

3. Results and discussion

3.1. Confocal microscopy

An OLYMPUS Lext OLS 5000 microscope was used to examine the microstructure of the samples.

The images Fig. 4-7 below show selected areas of the microstructures of individual AlSi7Mg0.3 alloy samples with different % Ti contents. In the images it is shown a solid solution of α(Al) (white particles) and the eutectic, which is excluded in the interdendritic spaces. There is also a significant amount of pores in the alloy.

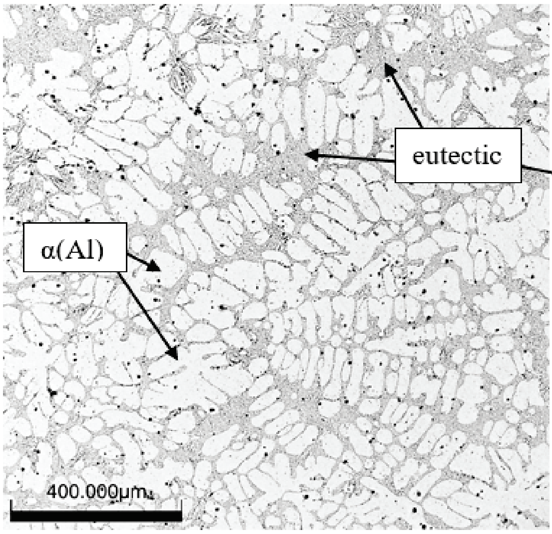

Figure 4: Microstructure of the 1Ok (0 wt. % Ti)

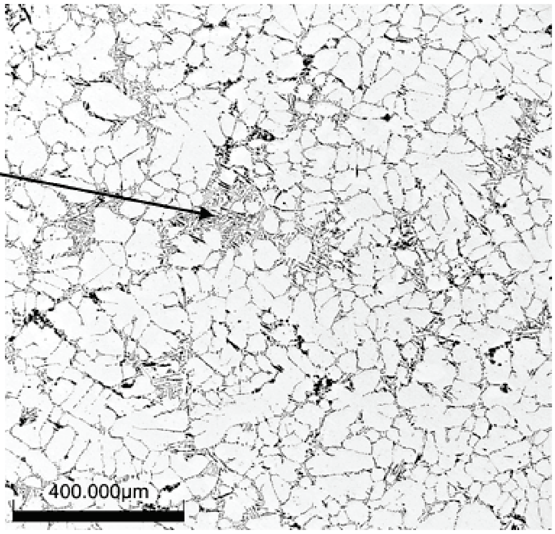

Figure 5: Microstructure of the 2Ok (0.05 wt. % Ti)

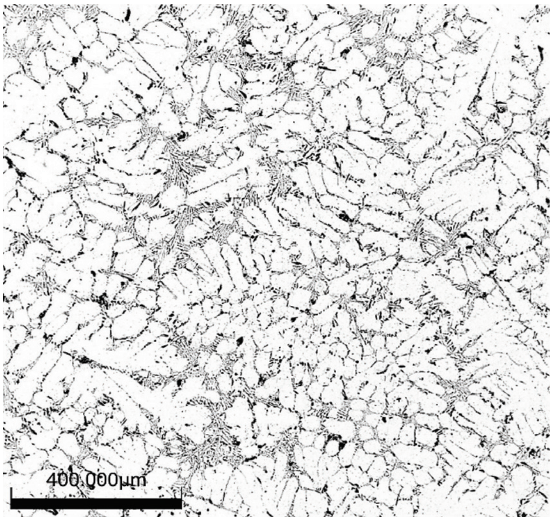

Figure 6: Microstructure of the 3Ok (0.1 wt. % Ti)

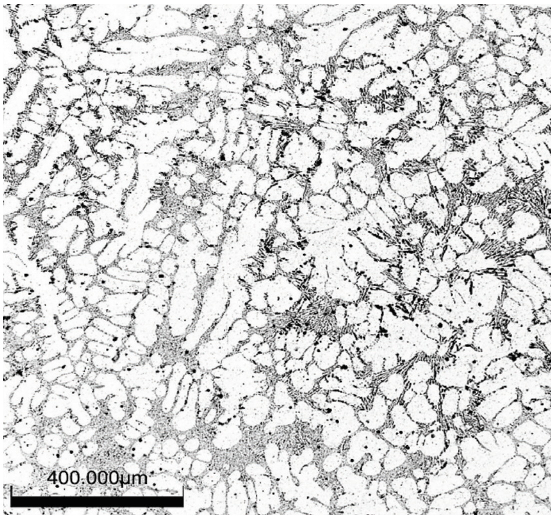

Figure 7: Microstructure of the 4Ok (0.2 wt. % Ti)

3.2. Scanning Electron Microscopy

In Fig. 8, the examined area of the 4Ok sample is marked. Fig. 9 shows the chemical map of sample 4Ok, made of AlSi7Mg0.3 alloy, from the marginal part of the casting. This sample contained 0.2 wt. % of Ti.

In Fig. 10, the investigated area of sample 7Ok is marked. Fig. 11 shows the chemical map of sample 7Ok, from AlSi10.5Cu1.2Mn0.8Ni1.2 alloy. This sample contained 0.1 wt. % Ti. Residues of inoculant were detected in the examined areas of both samples. EDX analysis was performed and these are TiB2 particles.

3.3. Microhardness of solid solution α(Al)

The microhardness values of the solid solution were always highest at the edge of the casting in the given castings. This statement applies to both alloys. The values in castings 1 and 2 differed only slightly between the edge and the center of the AlSi7Mg0.3 alloy. The same effect was present in sample number 4. The highest difference in the microhardness of the solid solution α between the edge and the centre was found in AlSi7Mg0.3 alloy casting number 3, which was inoculated with 0.1 wt. % of Ti. The smallest difference was for sample number 2 (0.05 wt.% of Ti). It is possible to see a

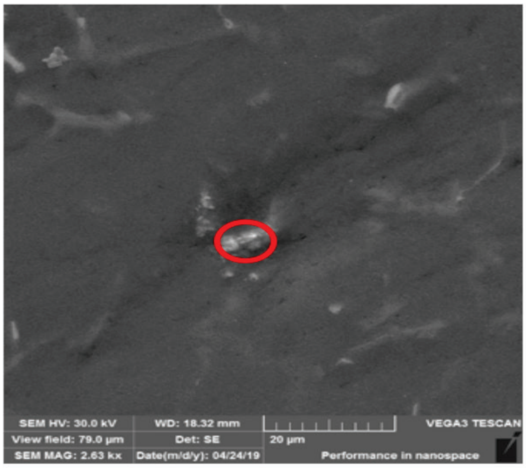

Figure 8: SEM of investigated area of 4Ok sample

Figure 9: Element map of 4Ok sample

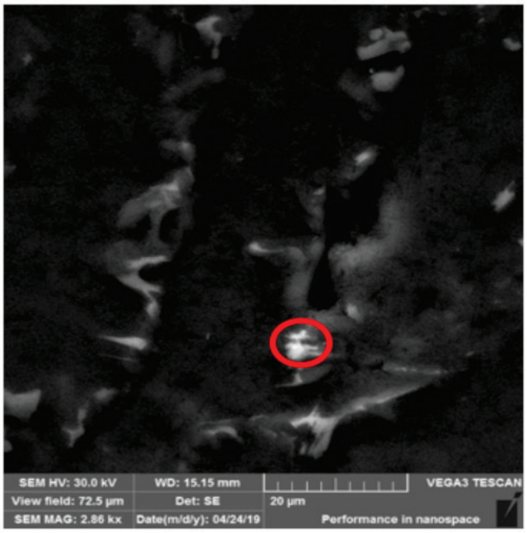

Figure 10: SEM of investigated area of 7Ok sample

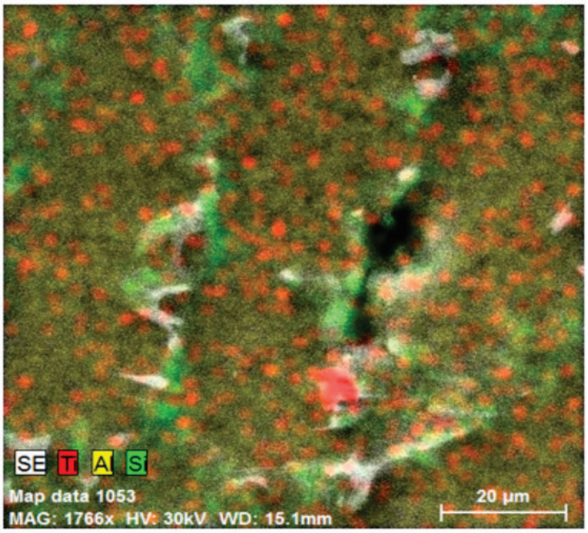

Figure 11: Element map of 7Ok sample

gradual increase in the microhardness of the primary phase α together with higher concentrations of the inoculant.

Similar inoculant effects were observed for AlSi10.5Cu1.2Mn0.8Ni1.2 alloy. The finer the structure, the greater the microhardness of the solid solution α. The highest microhardness of the primary phase in this alloy was cast number 8, with a concentration of 0.2 wt. % of Ti. Cast number 5, which was not inoculated, was the smallest. It can be seen from the Tab 5. that for this alloy the difference in values between the edge and the centre was 11 HV. Casting number 8 had the highest solid solution hardness. However, this hardness, compared to sample number 7 (0.1 wt.% of Ti), does not differ significantly. Taking into account the measurement deviation, the two samples have the same microhardness of the primary phase α.

Of both alloys, the highest microhardness of the solid solution α according to Vickers was found in casting 4, which was inoculated with 0.2 wt. % Ti. The smallest microhardness of the primary phase in the uninoculated casting number 1 from the AlSi7Mg0.3 alloy.

3.4. Dendrite arm spacing

The Fig. 13 demonstrates the expected influence of the inoculant in the AlSi7Mg0.3 alloy. The higher the concentration of Ti5B1 inoculant, the finer the structure will be. According to the DAS values, we see a gradual shrinking of the grains. The structure is

Table 5: Microhardness of the solid solution α(Al) of the prepared samples, data for the graph in Fig. 12

Sample		Ti [wt. %]	Cast sampling area	Average of 10 measurements [HV0.05]
AlSi7Mg0.3	1	0	Ok	54
			St	51
	2	0.05	Ok	55
			St	53
	3	0.1	Ok	73
			St	62
	4	0.2	Ok	86
			St	81
AlSi10.5Cu1.2Mn0.8Ni1.2	5	0	Ok	71
			St	60
	6	0.05	Ok	73
			St	62
	7	0.1	Ok	81
			St	70
	8	0.2	Ok	83
			St	72

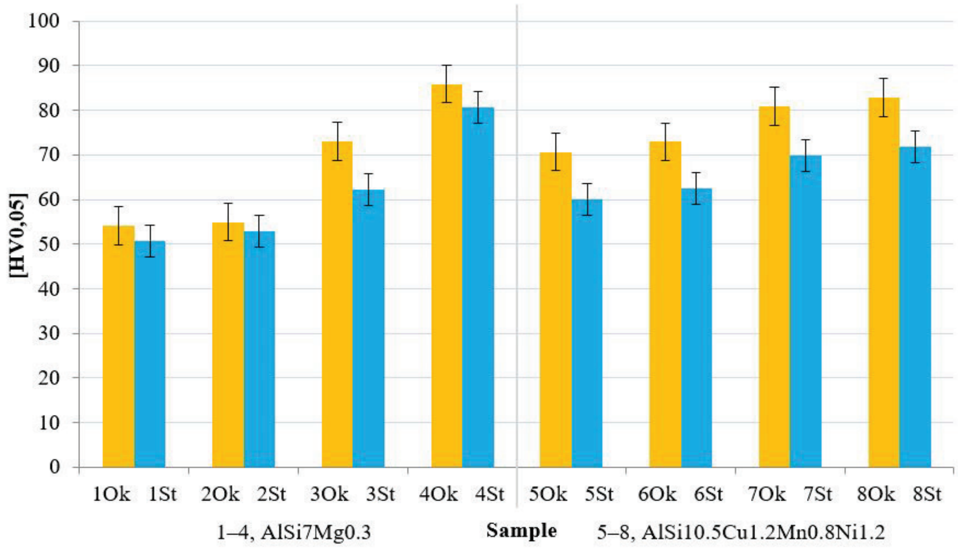

Figure 12: Microhardness of solid solution α(Al) prepared samples

always the finest at the edge of the castings. This is due to the larger cooling gradient. On the contrary, the structure of the central axis was not so fine. The grain size of the sample from edge 1Ok is more than double that of the sample also from edge number 4Ok. Samples from the edge of the casting 3Ok and 4Ok had a difference of 4 μm, on the other hand, for samples from the centre of 3St and 4St the difference was 30 μm.

In general, between samples 1 and 2, a significant decrease in grain size is observed. On the contrary, between samples 3 and 4 such a difference in grain size was no longer recorded. The grain size gradually decreased up to a concentration of 0.2 wt. % of Ti.

For the AlSi9CuNiMn alloy, a slight decrease in DAS values can be observed in samples from

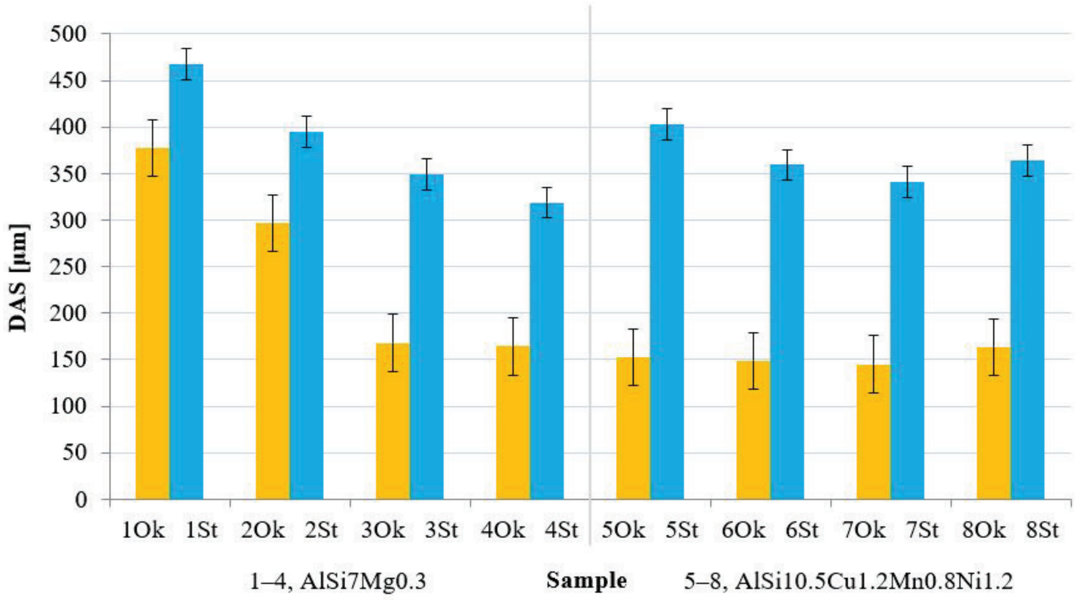

Figure 13: Dendrite arm spacing of prepared samples

the edge of the castings. The largest decrease was recorded in samples 5St and 6St from the middle part of the cast. These decreases in grain size were observed only in samples number 5, 6 and 7. Conversely, in sample number 8, a gradual increase in grain size was observed again. It can therefore be said and assumed that at inoculant values of 0.2 wt. % Ti and higher, there is no further refinement of the grain (on the contrary, the grain is larger).

4. Conclusion

On the basis of the performed analyses, it was found that the greatest grain refinement occurred in the AlSi7Mg0.3 alloy when the inoculant was used in a concentration of 0.2 wt. % of Ti. Compared to sample 1, without inoculation, the grain was refined by an average of 33%. At the same inoculant concentration, the highest α(Al) solid solution microhardness was measured in sample 4. Compared to sample 1, this is an increase in microhardness by about 50%.

In the case of the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy, the largest grain refinement occurred at a concentration of 0.1 wt. % of Ti, for cast number 7. Compared to sample 5, which was not inoculated, the DAS value decreased by an average of 14%. The highest values of microhardness of the α(Al) solid solution were measured for sample 8. There was a 23% increase in microhardness.

The use of Ti as an inoculant significantly affected the grain size especially in the AlSi7Mg0.3 alloy compared to the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy. For the AlSi7Mg0.3 alloy, they were identified at concentrations of 0.2 wt. % of Ti intermetallic phase TiB_2. Significantly more intermetallic phases were identified in the AlSi10.5Cu1.2Mn0.8Ni1.2 alloy, in this case of the Al-Si-Ti-Ni type. This is related to the larger amount of alloying elements.

It has been proven that seeding with Ti refines the grain and affects the microhardness of the primary α(Al) phase. The titanium contained in the inoculum diffused into the solid solution. The shape, but mainly the material of the mold, also has a great influence on the grain size. A finer structure is observable at the edge of the castings; this is due to the higher cooling rate.

Acknowledgments

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