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The Effect of the Excess Titanium Content on the Microstructure of Al – Si Foundry Alloys

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Abstract. Grain refining is an important technological step for the nucleus growth of the melt, in order to increase the number of nuclei, to improve mechanical properties (tensile strength, yield strength, hardness, elongation), feeding conditions and to decrease the tendency of hot tearing and the degree of sintering. [1][2] The aim of the experiments was the determination of the grain refining effects of titanium (Ti) addition in the form of AlTi5B1 master alloy to the examined alloys (AlSi7MgCu0.5 – AC 42 000, AlSi9Cu3Fe0.5 – 46 500; AlSi9Cu1 – AC 46 400). The results prove that the addition of small amount of master alloy has a favourable effect on the foundry practice.

Introduction

Providing the uniaxial dendritic structure for cast alloys in fine – grained cast state is necessary. Thus, the regulation of the nucleus formation of the melt via grain refinement is an essential step to achieve the required quality and mechanical properties [1][2][3]. Grain refining is one of the strengthening mechanisms which provide higher mechanical properties to an alloy. Grain refinement would increase the number of grains and their boundaries, therefore, increase the yield strength of the material. [4][5] The addition of grain refiner increases the number of nucleation sites, thus, promoting equiaxed grain growth rather than columnar. Large grains of α – Al in the microstructure are responsible for a number of defects, like scattered porosity, microcracks, deterioration of mechanical properties, etc. [5] Grain refinement of α – Al has been obtained by the controlled addition of intermetallic compounds of the type: Al_3Ti, TiB_2, TiC, to the liquid metal. For this purpose, master alloys, like AlTi5B1, AlTi3B1 or AlTi3C015 can be used. [6] There are several theories describing the process of grain refinement, the most frequently adopted one claim that in the case of Al – Ti – B refiner, the main compound responsible for the grain refining effect is TiB_2. [6] According to the duplex nucleation theory (Mohanty and Gruzleski [7]), in case of the use of Al – Ti – B master alloys, a Ti rich melt layer is formed surrounding the TiB_2 particles in the melt. If the local Ti content is higher than 0.15 wt%, a solid $TiAl_3$ layer is formed on the surface of TiB_2 particles (Figure 1.). Then, the aluminium particles are formed through peritectic reactions on the $TiAl_3$ layer.

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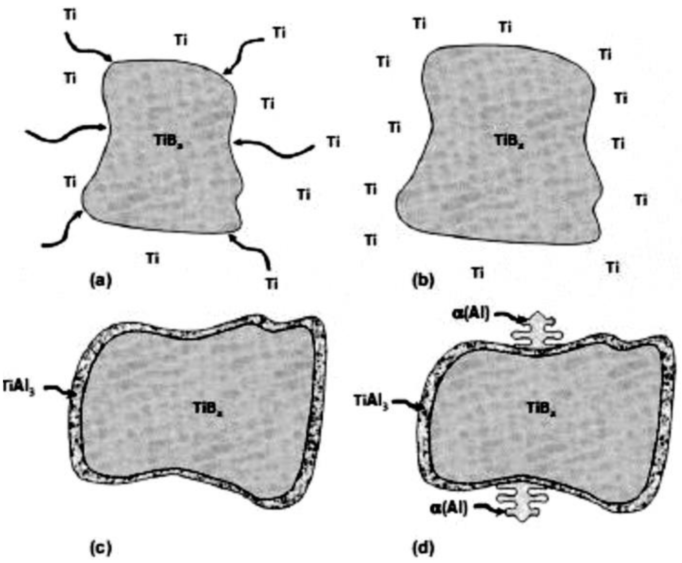

Figure 1. Duplex nucleation theory. (a) Excess Ti (Ti > 2.21) in solution, (b) Ti segregated to the TiB_2 – melt interface, (c) formation of $TiA1_3$ layer on TiB_2, (d) Nucleation of α – Al by peritectic reaction [7]

1. Experimental conditions and results

The three examined foundry alloy melts (***AlSi7MgCu0.5 – 1st alloy***; ***AlSi9Cu1 – 2nd alloy***; ***AlSi9Cu3Fe0.5 – 3rd alloy***) were alloyed with AlTi5B1 master alloy during the rotary degassing process (with nitrogen (N_2) inert gas). The initial Ti contents were between 900 – 1200 ppm. Based on the recommendation of the alloy manufacturer (Trimet GmbH), 750 g AlTi5B1 master alloy was added to 1000 kg melt (37.5 ppm Ti content in function of total amount). The effect of additional Ti content (in the form of AlTi5B1 master alloy) on the nucleus formation properties of the aluminium melt was examined.

Optical Emission Analyzer technique was used to determine the chemical compositions of the alloys and the amount of the beneficial AlTi5B1 master alloy. Thermal analysis was carried out to examine the degree of grain refinement. The equipment used for the thermal analysis and the dimensions of the casted test bar can be seen in Figure 2. The test bar was casted in a steel crucible preheated to 200 °C.

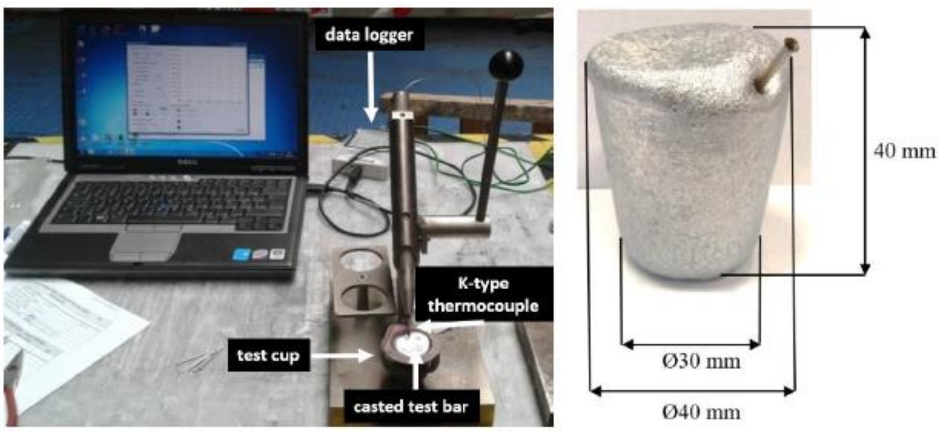

Figure 2. Thermal analysis equipment and casted test

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For the examination of the mechanical properties, so-called Diez–test bars were casted after melt treatment in a Diez–die, which die was prepared according to a German standard. [9] Tensile test specimens were made from the Diez–test bars according to industrial standard. The test bars were cylindrical, 5 mm in diameter and 50 mm long.

Diez – test bars are technological test bars which were used to examine the grain refining effect of AlTi5B1 master alloy on the alloys. In this case, certain external influences that emerge during casting and the affect the mechanical properties can be eliminated.

To examine the mechanical properties, the test bars were heat treated (1st alloy-T5, 2nd alloy-T6, 3rd alloy-was not heat treated) under operating conditions. The Diez – die and test bar with their locations where the tensile specimens were taken can be seen in Figure 3.

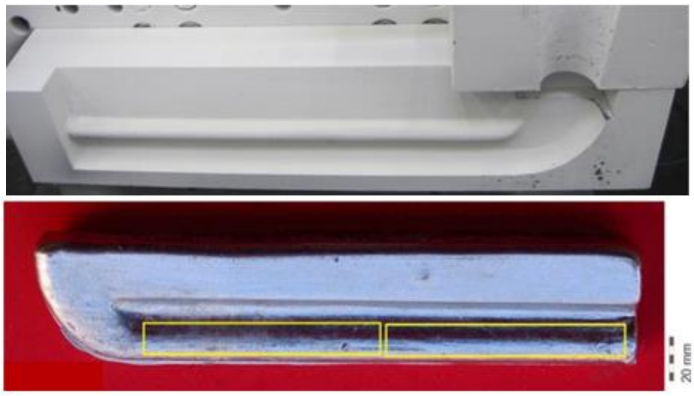

Figure 3. The Diez – die and test bar with the locations of the tensile specimens

1.1. Composition

The titanium concentration before and after the addition of AlTi5B1 master alloy, determined by compositional analysis, can be seen in Table 1.

Alloys	**Technological step**	**Titanium concentration**	**Titanium concentration**	**Difference of Titanium concentration**	**Casting temperature**
		wt%	**ppm**	**ppm**	**°C**
(1st) AlSi7MgCu0.5	Before Ti addition (series)	0.11935	1193.5	35.9	728
	After Ti addition	0.12294	1229.4		
(2nd) AlSi9Cu1	Before Ti addition (series)	0.10766	1076.6	11.9	737
	After Ti addition	0.10885	1088.5		
(3rd) AlSi9Cu3Fe0.5	Before Ti addition (series)	0.08911	891.1	37.5	716
	After Ti addition	0.09286	928.6		

Table 1. The titanium concentrations based on the compositional analysis

In case of the 2nd alloy, only 31.73% of the 37.5 ppm additional titanium was dissolved in 1000 kg melt. The cause of this might be the presence of other alloying elements which formed intermetallic phases with titanium. Thus, the titanium content of the additional AlTi5B1 master alloy could not have any beneficial effects on grain refinement [10].

1.1. Thermal analysis

By thermal analysis, the efficiency of grain refinement can be determined by the evaluation of the cooling curves of the solidifying melt. The thermal analyser is equipped with a thermocouple which is connected to a signal processing data logger. The data logger produces the temperature – time cooling curves from which the various processes in the solidifying metal can be determined.
The cooling curves of test bars in case of ***2nd alloy (AlSi9Cu1)*** are shown in Figure 4. As it can be seen on the curve with dotted line, the starting temperature of the nucleus formation is 4.87°C higher after AlTi5B1 addition.

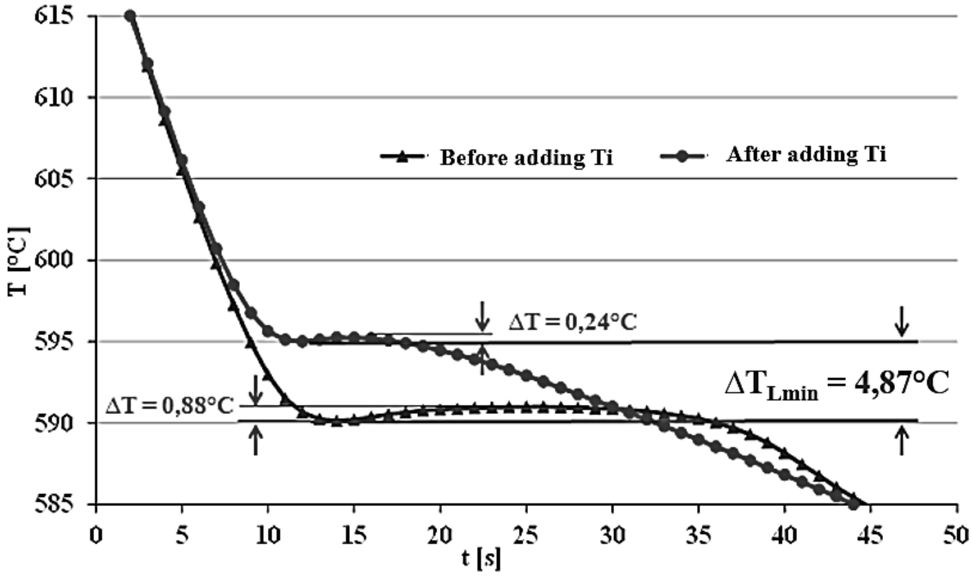

Figure 4. The liquidus temperature ranges of the cooling curves of the 2nd (AlSi9Cu1) alloy

The differences of the starting temperature of nucleation before and after AlTi5B1 addition are shown in Table 2.

Alloys	**Titanium concentration after AlTi5B1 addition**	**ΔT_{Lmin}**
	ppm	**°C**
(1st) AlSi7MgCu0.5	1229.4	3.03
(2nd) AlSi9Cu1	1088.5	4.87
(3rd) AlSi9Cu3Fe0.5	928.6	0.17

Table 2. The differences of the starting temperature of nucleation before and after AlTi5B1 addition

The addition of extra 750 g AlTi5B1 master alloy had a positive effect (mainly in case of 1st and 2nd alloys) on the nucleus formation and increased the $\Delta T_{Lmin,}$ cause the starting temperatures of the nucleation were increased.

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1.2. Grain numbers – thermal analysis test bars

The thermal analysis test bars were cut horizontally, polished and Barker etched before further microstructure analysis. On the etched test specimen 15 microstructural images (226.8 mm^2 examined area/specimen) were taken from each one test bar, using an optical microscope with 25x magnification. The number of grains was determined on each image. The number of (α)Al grains on the surfaces of the test bars can be counted due to the various colours caused by polarised light. The Barker colour etched micrographs in case of 3rd alloy can be seen in Figure 5.

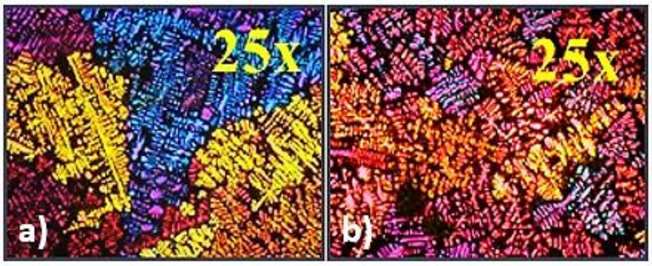

Figure 5. The Barker colour etched micrographs: (a) 3rd alloy before grain refinement, (b) after the addition of AlTi5B1 grain refining master alloy

The average grain number in case of the thermal analysis test bars are illustrated in Figure 6. The examination of the thermal analysis test bars revealed that the increased titanium concentration led to increased grain number. The grain number of the test bars with higher ΔT_{Lmin} (3.03°C and 4.87°C) temperature after AlTi5B1 addition was 2.8 – 2.9x higher. Based on the cooling curves and the microscopic particle analysis it can be stated that grain refinement occured in all three alloys. The objective of further research is to determine if the solved titan concentration of the second alloy was enough to achieve such effect.

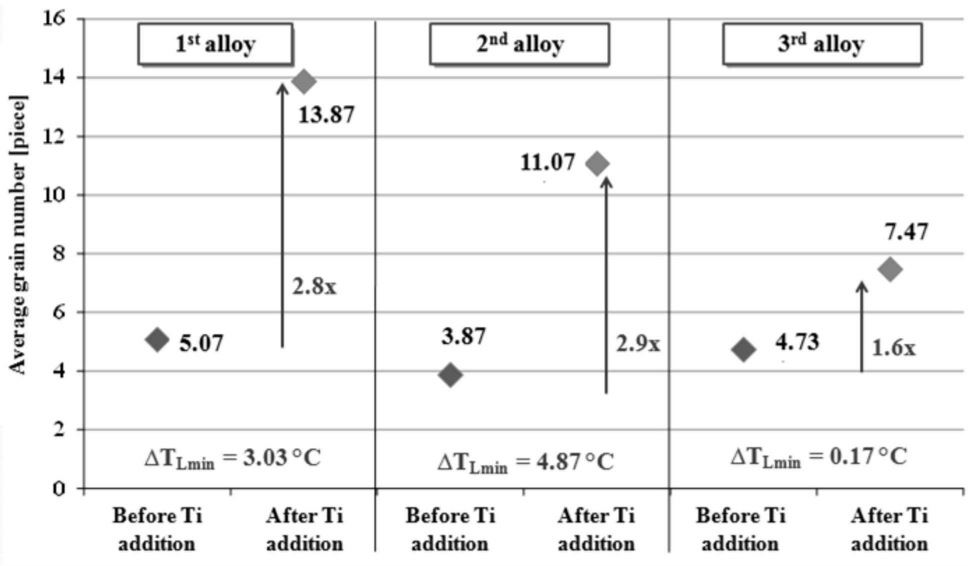

Figure 6. Average grain number in case of the thermal analysis test bars

1.3. The examination of Diez-test bars

Mechanical test and microstructure analysis were carried out on test specimens prepared from standard Diez–test bars. We determined the effect of extra 750 g AlTi5B1 master alloy addition on the mechanical properties and on the efficiency of the grain refinement.

Figure 7. shows the average grain numbers of the tensile test specimens made out of Diez–test bars. The AlTi5B1 addition resulted higher grain number.

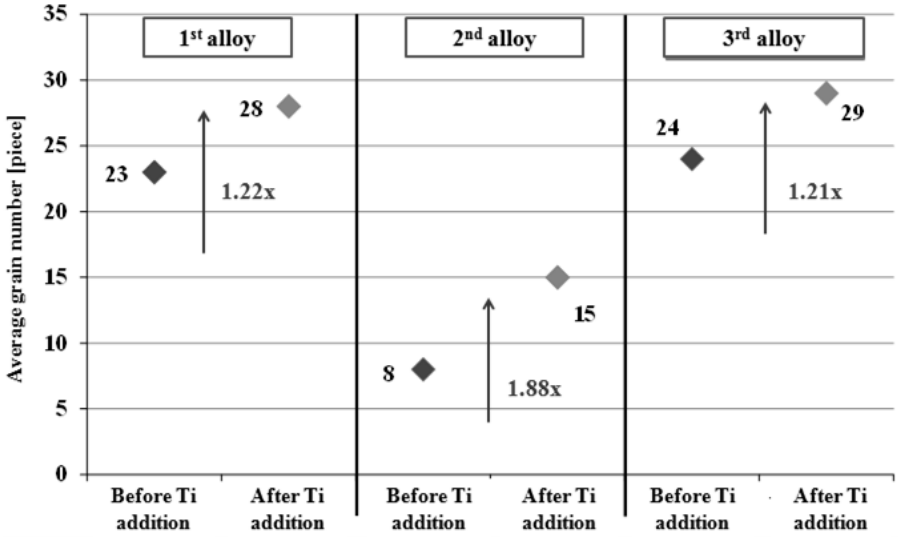

Figure 7. The average grain numbers of the tensile test specimens made out of Diez–test bars

During mechanical tests, the tensile strength, the yield strength and the elongation were determined. Three Diez–test bars were casted from each alloy, and two tensile test specimens were prepared from each Diez-test bars. The average values of six tensile specimens for each alloy can be observed in Figures 8 – 10. The results were compared to the required operational strength values.

It can be observed that after the addition of the extra master alloy, the tensile strength (Figure 8.) and yield point values (Figure 9.) increased by a few percentage. In case of the 2nd alloy, the grain number of which was almost two times higher (1.88x), the average tensile strength increased with almost 4.79%. The average elongation after the AlTi5B1 master alloy addition increased with 7% in case of the 2nd alloy. In case of 1st and 3rd alloys the elongation values were decreased.

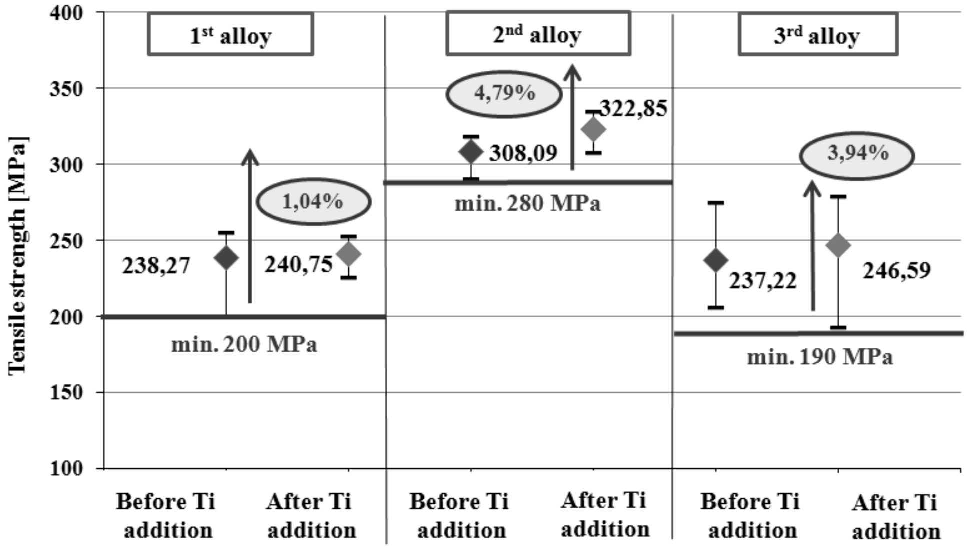

Figure 8. The average tensile strength of the specimens from the Diez–test bars

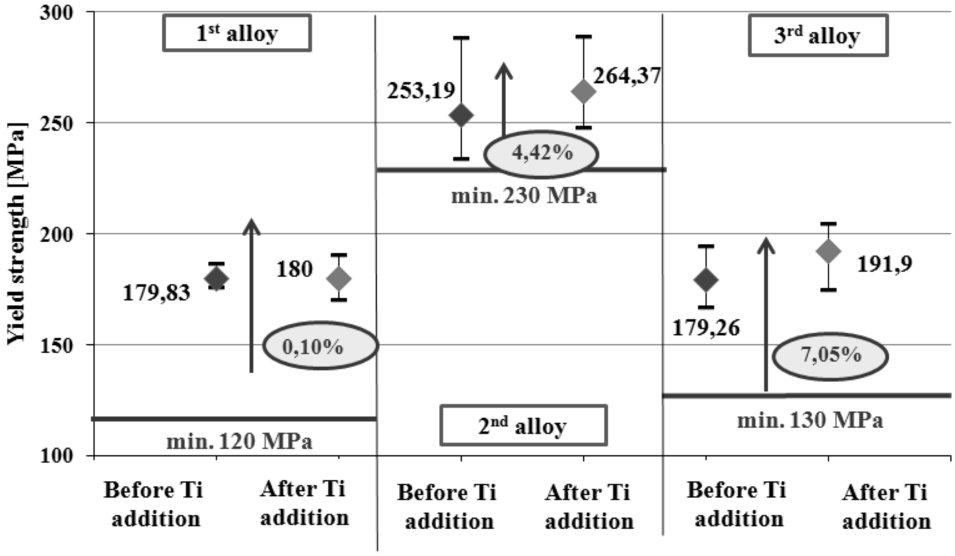

Figure 9. The average yield strength of the specimens from the Diez–test bars

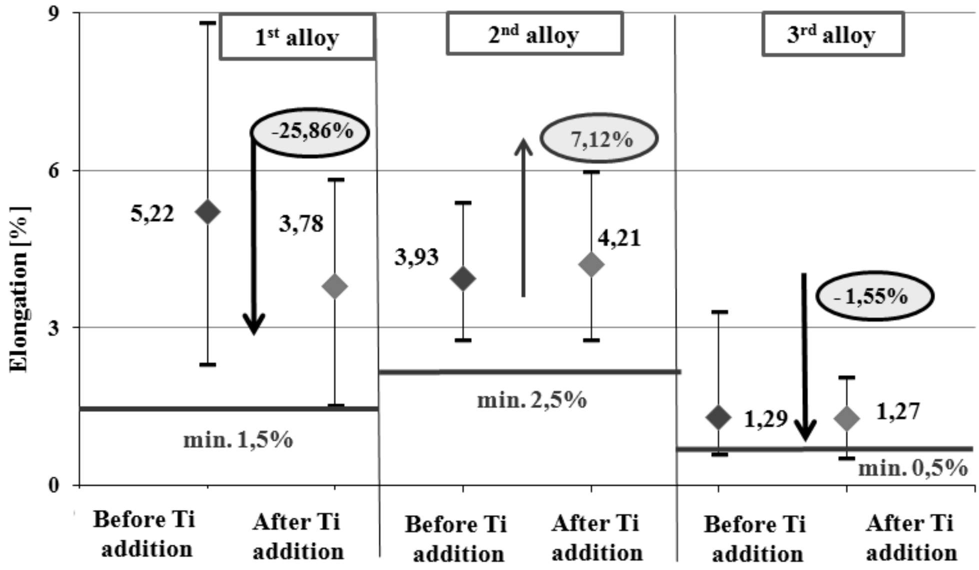

Figure 10. The average elongation of the specimens from the Diez – test bars

The average standard deviation of the elongation values was rather high. In order to determine the reason for the low strength values, the fracture surfaces of the tensile specimens were examined.

In case of all three alloys, the fracture surfaces of the specimens prepared from the Diez –test bars with mechanical properties below the limit values were examined with a stereo microscope. The following observations can be made based on the micrographs.

The stereo microscopic image of the test bar with Al_2O_3 oxide inclusions and porosities can be seen in Figure 11.

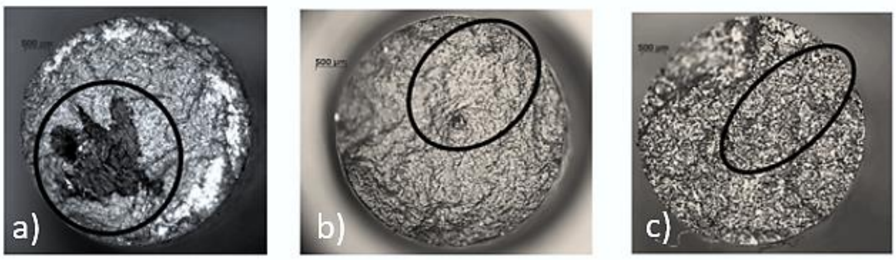

Figure 11. The surface of test bar prepared from the Diez –test bar of the melt of the a) 1st alloy before Ti addition with large Al_2O_3 oxide inclusion, b) 2nd alloy after Ti addition with small Al_2O_3 oxide inclusions, c) 3rd alloy after Ti addition with porosities

2. Conclusions

Based on the evaluation of the experimental test bars and the prepared diagrams, it can be concluded that the extra 750 g AlTi5B1 master alloy addition to the three Al – Si alloy melts (AlSi7MgCu0.5; AlSi9Cu; AlSi9CuFe0.5) had a positive effect on the nucleus formation and increased the starting temperature of the crystallization.

The additional titanium concentration resulted in increased average grain number. The grain number was 2.8–2.9 times higher of the thermal test bars after AlTi5B1 addition, in case of the alloys with higher ΔT_{Lmin} (3.03°C and 4.87 °C) temperatures.

The effect of the additional 750 g AlTi5B1 master alloy on the mechanical properties could be observed on the Diez–test bars. A correlation can be observed between the average tensile strength, yield strength and grain number of the series and the test bars with higher titanium concentration: the increased grain number resulted in higher tensile strength and yield strength value. However, the elongation values were greatly affected by the inclusion content of the melt.

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References

[1] Y Birol (2012) *Performance of AlTi5B1, AlTi3B3 and AlB3 master alloys in refining grain structure of aluminium foundry alloys.* Materials Science and Technology. 28 (4), pp. 481 – 486., 2012.

[2] K. T. Kashyap – T. Chandrashekar (2001*) Effects and mechanism of grain refinement in Al alloys*. Indian Academy of Science. 24 (4) pp. 345 – 353.

[3] P.S. Mohanty – J. E. Gruzleski: *Mechanism of grain refinement in Al, Department of Mining & Metal Engineering*. Acta Metallurgical Material. 43 (5) pp. 2001 – 2012., 1995.

[4] M. Deni Ferdian (2014) *Effect de la vitesse de refroidissement sur la tailla des grains, la modification eutectique et la precipitation d´intermetalliques riches en fer dans des alliages Al-Si hypoeutectiques*. pp. 10, PhD Thesis.

[5] M.J. Shabani – M. Emamy – N. Nemati (2011) *Effect of grain refinement on the microstructure and tensile properties of thin 319 Al castings*. Materials and Design. 32. pp. 1542 – 1547.

[6] Z. Zamkotowicz – T. Stuczynski – B. Augustyn – M. Lech-Grega – W. Wezyk (2004) *Investigation of grain refinement fading in hypoeutectic aluminium-silicon alloys*. Light Metals. pp. 807-816.

[7] P. S. Mohanty – J. E. Gruzleski (1995) *Mechanism of Grain Refinement in Aluminium*. Acta Materialia. 43 (5) pp. 2001-2012.

[8] F. C. Robles – Hernandez – J. M. H. Ramírez – R. Mackay (2017) *Al – Si Alloys – Automotive, Aeronautical, and Aerospace Application*. Springer International Publishing AG, pp. 214., ISBN 978 – 3 – 319 – 58380 – 8

[9] H. W. Rockenschaub – R. Gschwandter (2008) *Eigenschaftsprofil und Wärmebehandlung der kokillengusslegierung AlSi12 cunimg (EN1706 AC–48000)* – Österreichisches Gießerei Institut, Leoben.

[10] J. Campbell (2015) *Complete Casting Handbook.* 2nd Edition – Metal Casting Processes, Metallurgy, Techniques and Design. Boston: Butterworth – Heinemann.