Materials Science and Engineering, Volume 42, No. 1 (2017), pp. 13–20.

INVESTIGATIONS TO REDUCE THE INCLUSION CONTENT IN AL-SI FOUNDRY ALLOYS

MARIANNA BUBENKÓ[1]–MONIKA TOKÁR[2]–
GYÖRGY FEGYVERNEKI[3]

The aim of the experiments with various Al-Si alloys was to examine how different experimental conditions affect the inclusion content of the molten alloys. The utilisation of two cleaning salts from different manufacturers were examined during degassing treatment, in case of *AlSi7MgCu0.5* alloy.

In order to determine the degree of purity, K-mould test were carried out and evaluated. To acquire more realistic results, several test bars were prepared for each technological step.

Beside K-moulds, test bars for density index (Dichte-index) measurement were also casted, to determine the dissolved hydrogen content of the melt.

Keywords: Al-Si alloy, inclusion, K-mould, cleaning salt, rotary degassing, electron microscope, aluminium accompanying elements

INTRODUCTION

The main issue of any melting and melt treatment technology is the reduction of the inclusion content in the melt. Casting defects can result in unfavourable mechanical properties, and the machine tools may be broken by the inclusions. The aim of the optimisation of melt treatment is to achieve such melt purity that reduces the inclusion content of melts as much as possible. The effects of various cleaning salts added during degassing were compared.

Non-metallic accompanying elements are usually oxides, nitrides and other intermetallic phases which develop into independent phases and damage the homogeneity of the metallic structure. The strength of the equipment part is drastically lowered because of the negative effect of the oxides, especially the oxide film, on the exterior notch sensitivity of the castings. To achieve adequately high casting quality, the prevention of impurities in the melt and the casting is essential. Thus, the determination of melt quality is necessary [1].

The presence of impurities in the structure may result in the development of stress concentrators which may lead to decreased mechanical properties. The most common form of impurities in aluminium melts are oxide films and fine disperse oxide inclusions [2].

The mechanical properties of castings are impaired by inclusions and other hydrogen porosities. Small fractures can arise at such impaired surfaces of castings as a result of pressure or other kinds of stresses, leading to even more damage [3].

Many types of inclusions can be in the melt. Oxides, membranes and films are the most common inclusions. These are formed during oxidation, or by reacting with steam [1, 3].

[1] University of Miskolc, Institute of Foundry Engineering
Miskolc-Egyetemváros 3515, Hungary
b.marianna1228@gmail.com

[2] University of Miskolc, Institute of Foundry Engineering
Miskolc-Egyetemváros 3515, Hungary

[3] University of Miskolc, Institute of Foundry Engineering
Miskolc-Egyetemváros 3515, Hungary

The quality of the base material is of high importance for the production of foundry castings, which can be significantly improved by melt preparation. The quality of Al-Si based foundry alloys relate to their accompanying element content. Secondary base material, which is made out of scrap metal, is used in higher and higher proportions and the effects of the possible accompanying elements are not fully understood [4].

1. EXPERIMENTAL

1.1. The reduction of gas content using flushing treatment with inert gas

The primary gases used for flushing metal treatment are nitrogen, argon and chlorine. The oxides present in the melt are flushed to the surface where they are bound by the previously applied salt layer. The gas is added mainly through graphite pipes during spinning rotary treatment. In order to achieve as much diffusion surface as possible, the bubbles floating to the melt surface should be as small and as many as possible [1, 2].

In case of the rotary metal cleaning equipment used, inert gas is added from above in the direction of the rotor shaft, where it exits to the melt on the bottom of the mixing head (rotor head). The purpose of the rotary movement is to create finer and more equal gas distribution, and to provide homogenous bubble ration in the melt. This is a widespread method for hydrogen removal from aluminium melts [3, 5, 6].

1.2. Lowering the inclusion content by salt addition during degassing

K-mould test were carried out to detect the inclusions and density index test to determine the dissolved hydrogen content.

K-mould tests were carried out to detect the inclusions by counting the number of impurities using a stereo microscope, then calculating the K-values using *Equation (1)*. K-values determine the purity of the melt. The melts were classified based on the given ranges of K-values in *Table 1* [2].

$$\mathbf{K} = \frac{S}{n} \tag{1}$$

where: **S** = the number of inclusions on the fractured surface; **n** = the number of fractured surfaces (n = 4) [2].

Table 1

Melt classification based on K-values [2]

Classification	*K-value*	*Melt quality*
A	< 0.1	Pure
B	0.1 – 0.5	Relatively pure
C	0.5 – 1.0	Somewhat pure
D_1	1.0 – 2.0	Impure
D_2	2.0 – 5.0	
D_3	5.0 – 10	Impure
E	> 10	Extremely impure

Density index tests are frequent measurement methods in foundries. These are indirect and discontinuous manufacturing tests. The results of the density index measurements give information on the effectiveness of the melt treatment. Density index can be determined based on the density of the test bar at 80 mbar pressure. Classification is based on the relation to theoretical density [2].

The density of the test bar has to be determined after cooling (the density is determined with Archimedes' principle) *(Figure 1)* [2].

Figure 1
"MK 2200" type precision scale for density index measurements (1 – Sample stage of the scale; 2 – Test bar container in distilled water) [2]

The density index values (DI %) were determined with the following equation:

$$DI = \frac{D_1 - D_2}{D_1} \cdot 100 \ (\%) \quad (2)$$

where: **DI** – density index (%), **D2** – the density of the test bar crystallised and cooled on the metal test bar holder of the "MK3VT" type equipment, at 1 bar pressure (g/cm^3) (reference density), **D3** – the density of the test bar crystallised and cooled inside the "MK2VT" type equipment, at 80 mbar pressure (g/cm^3) [2].

2. RESULTS

2.1. AlSi7MgCu0.5 alloy – the comparison of the effects of "A" and "B" cleaning salts

The aim of cleaning salt addition is to make the aluminium oxide inclusions of the melt less dense and easier to remove in the form of another compound. Because of their non-wettability, these compounds float to the surface either with or without the nitrogen bubbles.

The two types of cleaning salts used are named "A" type salt and "B" type salt. Technological test bars were prepared from 15–15 doses in case of both salts. Test bars were prepared for K-mould test, density index test, chill test and thermal analysis as well.

2.2. The results of K-mould tests

The average K-values of the test with the two cleaning salts at each technological step are illustrated on *Figure 2*.

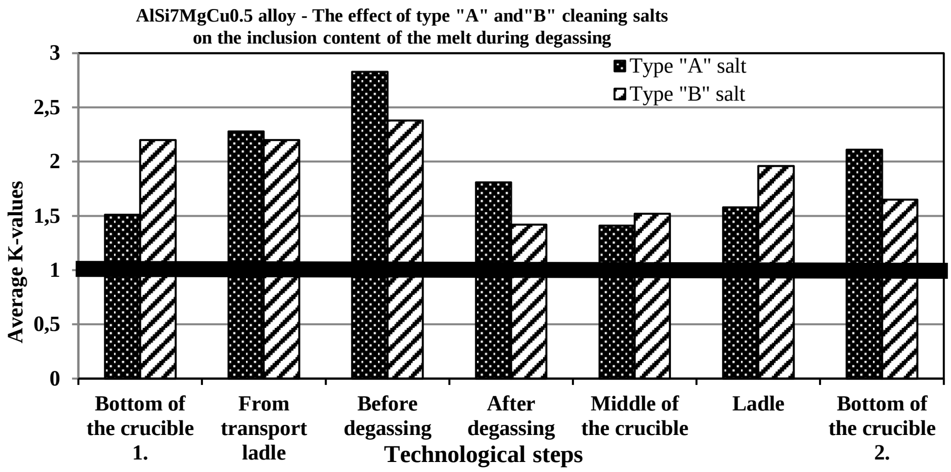

Figure 2

The comparison of the K-values of the two cleaning salts

The results show that the inclusion content of the samples from the melts treated with type “A” and “B” are almost identical. It can be observed that the inclusion content of both melts were decreased after degassing. This means that the use of cleaning salts is effective, as it resulted in decreased K-values and number of impurities.

The thick black line illustrates the level of impurity. Thus, the quality of the each melt sample is considered impure (based on the values in *Table 1*). However, these values are obviously improved, as it is confirmed by the results of the mechanical property analyses.

2.3. Density index test results

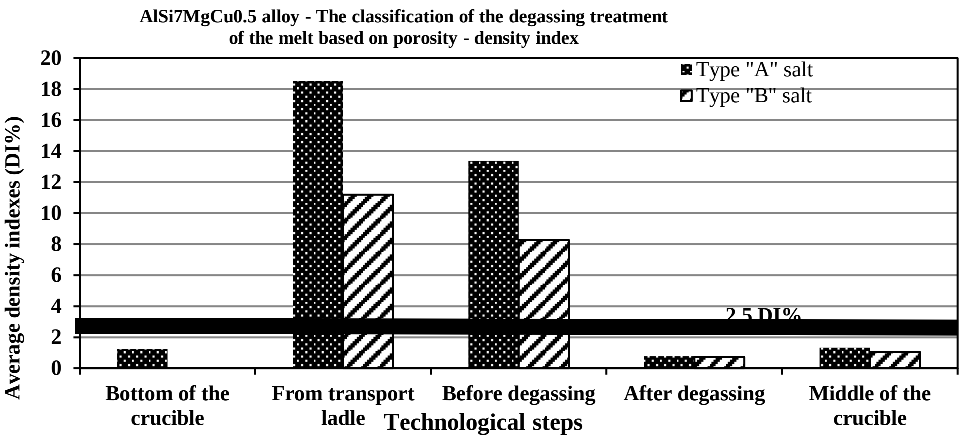

Figure 3

Density index results

In parallel with the preparation of K-mould samples, the density index test bars were prepared to determine the dissolved hydrogen content.

Figure 3 shows the density index values.

The specified values are not exceeded by the density index values. As a result of the effective degassing treatment, the density index values were within the limit after degassing.

2.4. Examination of mechanical properties

Castings made out of the previously selected melts were also selected. After heat treatment, tensile test specimens were prepared to determine the yield point, tensile strength and elongation of the specimens, also the Brinell-hardness of the experimental casting.

The measured values of yield point, tensile strength, Brinell-hardness and elongation are summarised in *Table 2*. The specification values are also given in the second column.

Table 2

The mechanical properties and specifications of the test bars

AlSi7MgCu0.5 alloy	Specification	Type “A” salt	Type “B” salt
Yield point (Rp 0.2 [MPa])	***min. 120***	168.9	168.1
Tensile strength (Rm [MPa])	***min. 200***	234.6	234.9
Brinell-hardness	***70–90***	79.4	79.5
Elongation (A [%])	***min. 1.5***	9.94	10.33

Based on the results, it can be concluded that the mechanical property values were almost identical in case of each salts. The Brinell-hardness values did not exceed the limit value, and the rest of the results were above the given minimum values. The elongation values were approximately ten times higher than the limit value. This is the result of the purity of the structure of the castings, the elongation values are high for this reason. If these values were higher, the inclusion content of the castings would be higher.

2.5. The examination of inclusions with scanning electron microscope (SEM)

The inclusions on the surfaces of the K-mould samples were examined with stereo and scanning electron microscopes. Typical K-mould samples with inclusions were selected for the scanning electron microscopy analysis.

Figure 4 shows the surface of the test bar for the K-mould test, prepared from the melt with **type “A” cleaning salt**, using the leftover melt on the bottom of the crucible after emptying the holding furnace. *Figure 5* illustrates the electron microscopic image (200X magnification) of the impurity on the surface.

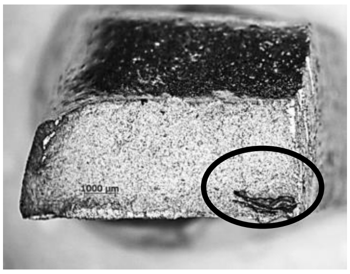

Figure 4

The impure surface of a K-mould test bar on stereo microscope

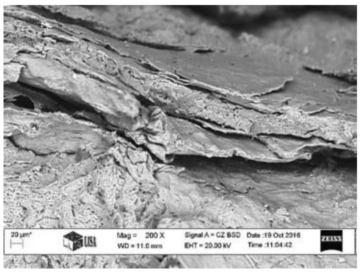

Figure 5

SEM image of the impure K-mould test bar surface, M = 200x

The results of the SEM analysis of the test bar in *Figure 5* can be found in *Table 3*.

Table 3
The results of the SEM analysis of the test bar

Elements (wt%)	C	N	O	Mg	Al	Si	Cl	Cu	Total
Average surface	**2.58**	**8.75**	**5.97**	**1.8**	**68.3**	**11.07**	**0.15**	**1.37**	**100**

Based on the SEM analysis of K-mould samples from the melt with type "A" cleaning salt it can be determined that the oxygen, nitrogen and carbon content of the section with inclusions, Al and Mg oxides developed.

Figure 6 shows the surface of the test bar for the K-mould test, prepared from the melt treated with **type "B" cleaning salt**, under the same condition as the previous test bar. The electron microscopic image of the inclusion with 500X magnification can be observed on *Figure 7*. The results of the SEM analysis can be seen in *Table 4*.

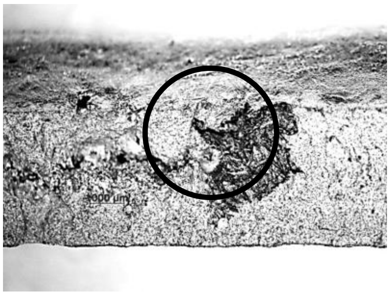

Figure 6
The impure surface of a K-mould test bar on stereo microscope

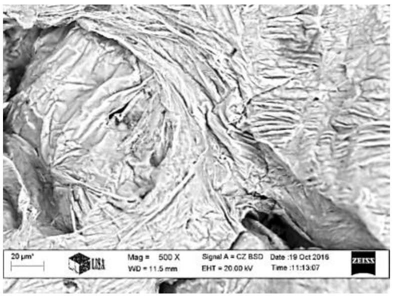

Figure 7
SEM image of the impure surface of the K-mould test, N = 500x

Table 4
Elemental composition based on the average surface analysis

Elements (wt%)	C	O	Mg	Al	Si	Cu	Total
Average surface	**1.1**	**8.74**	**3.3**	**69.25**	**16.53**	**1.09**	**100**

Based on the results in *Table 4,* the oxygen content suggests the presence of Al and Mg oxides on the fracture surface. The thick polyhedral oxide layer might be caused by the Mg content.

The fracture surfaces of the K-mould test bars contained Al and Mg oxide inclusions in both cases of type "A" and "B" cleaning salt treatments.

According to the tests using cleaning salts, the inclusion content is decreased during rotary degassing treatment. This is confirmed not only the K-mould tests and the density index values, but the results of the analysis of the slag removed after degassing as well. The slag samples collected after degassing from the melt with type “A” and “B” salts were powdery and their aluminium content was smaller than the slag’s of the non-treated melt. *Figure 8* illustrates the SEM image of the slag sample of the melt after degassing using type “A” salt, with 1000X magnification. The elemental compositions of the numbered spots can be found in *Table 5*.

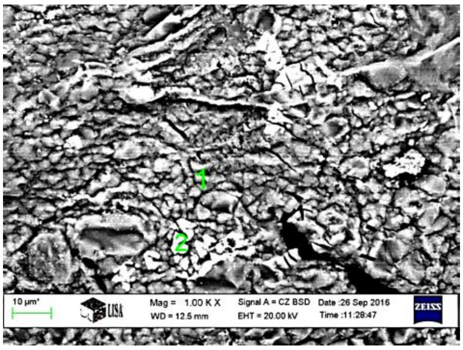

Figure 8

The SEM image of the slag from the melt, using type “A” cleaning salt, after degassing

Table 5

The composition of the slag from the melt with type “A” cleaning salt, after degassing

Test	*Type “A” cleaning salt*											
Elements (wt%)	**Na**	**N**	**O**	**Mg**	**Al**	**S**	**Sr**	**Si**	**Cl**	**Mn**	**Fe**	**Total**
Spot 1	**0.29**	**0.51**	**4.62**	**1.55**	**47.23**	**0.55**	**0**	**44.91**	**0.35**	**–**	**–**	**100**
Spot 2	**0.14**	**1.07**	**2.23**	**0.92**	**78.76**	**0.38**	**0**	**6.61**	**0.29**	**2.69**	**6.91**	**100**

The SEM image (25X magnification) of the slag from the melt, prepared using type “B” cleaning salt and after degassing can be seen on *Figure 9*, while *Table 6* contains the average surface values.

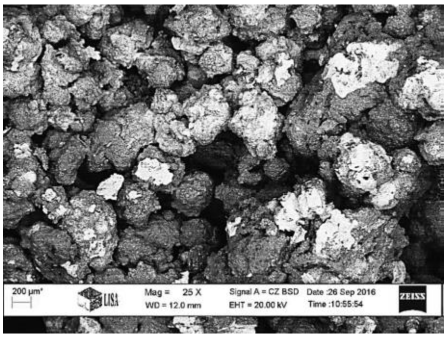

Figure 9

The SEM image of the slag from the melt, using type “B” cleaning salt, after degassing

Table 6

The results of SEM analysis of the slag from the melt, using type "B" cleaning salt, after degassing

Test	*Type "B" cleaning salt*									
Elements (wt%)	**C**	**O**	**Na**	**Mg**	**Al**	**Sr**	**S**	**Cl**	**K**	**Total**
Average	**8.64**	**38.01**	**18.39**	**3.34**	**9.50**	**2.05**	**0.30**	**14.76**	**5.00**	**100**

The slag obtained after the cleaning salt treatment contains various compounds. The oxide and chloride content of the slag from type "A" salt were lower, while slag from type "B" salt has low aluminium content but with relatively high strontium loss.

CONCLUSIONS

The effects of two cleaning salts on *AlSi7MgCu0.5* alloy were examined. It was concluded that the effects of type "A" and "B" salts on the inclusion content of the melt were almost identical. In both cases, the inclusion content were smaller after degassing than it was without salt treatment. The K-values were below 2.0 in case of both cleaning salts.

The tests confirmed that the hydrogen content decreased below the limit value because of the rotary degassing treatment.

According to the scanning electron microscopy analysis, Al and Mg oxide inclusions developed in case of both cleaning salts. Chlorine can be found in the melt treated with type "B" melt, which may be the result of a high dose of cleaning salt addition.

ACKNOWLEDGEMENT

The main author is thankful for the rest of the authors' help, patience and advice to make the realisation of this article possible.
The authors are grateful to Árpád Kovács from the Institute of Physical Metallurgy, Metal Forming and Nanotechnology at the University of Miskolc for carrying out the tests with scanning electron microscope.
The authors are grateful to Mária Ambrus for her advice.

REFERENCES

[1] SZOMBATFALVY A.: Járműipari öntészeti AlSi – ötvözetek tulajdonságainak vizsgálata – PhD-értekezés. 2012. 17., 23.

[2] JÓNÁS P.: Könnyűfém öntészeti ismeretek tankönyv, 2011. 182–183.

[3] KAUFMAN, J. G.–ROOY, E. L.: *Aluminium Alloy Castings – Properties, Process and Applications*. ASM International, 2004. 50.

[4] TOKÁR M.–TÓTH M.–DÚL J.–FEGYVERNEKI Gy.: Szennyezőelemek változékonysága az öntészeti Al-Si-ötvözetekben. BKL, *Kohászat,* 2012. 5. 25.

[5] Foseco Products & Services, Non Ferrous Foundry, Melt Treatment, Metallurgical & Pouring Coveral System, Degassing Equipment & Metal Treatment Station. https://www.vesuvius.com/en/our-solutions/international/foundry/non-ferrous-foundry/melt-treatment.html

[6] BROWN, J.: *Foseco – Non-Ferrous Foundryman's Handbook*. 1999. 73–74.