STUDY OF AlSi10Mg ALLOY STRUCTURES AFTER MODIFICATION BY VARIOUS Sr AGENTS

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The goal of the paper was to observe structures of alloy AlSi10Mg, which was modified by strontium in amount of 400 ppm. It is widely known the influence of eutectic silicon, recent works describe also the influence on the morphology intermetallic phases, such as iron, manganese or copper containing phases. Present work focuses also to phases containing magnesium. The effect of strontium on the structure defects, namely cavities, is also observed. It has been proven that strontium affects the morphology of the phases containing iron, manganese and magnesium, in particular β-phase Al5FeSi, Al15(FeMn)3Si2, FeMg3Si6Al8 and Mg2Si. Findings of other authors were also confirmed, that strontium negatively affects the level of gas porosity and distribution of shrinkages.

Keywords
Aluminum Alloys, Modification, Strontium, Structure, Intermetallic Phases, Structure Defects

1. Introduction

Strontium is used as a modifier element, by which addition eutectic crystallization is affected in order to improve the mechanical properties, especially ductility of aluminum alloys. Eutectic modification is a major change in the quality of eutectic silicon crystals in the new organization structure. Specifically it is the change of nucleation, crystallization and subsequently resulting morphology of eutectic silicon. The final morphology of the targeted change in the so-called "modified" eutectic silicon mainly consist of refinement hexagonal tabular bodies of silicon, forming a solid skeleton with the common center of crystallization in eutectic cell, to the rod-shaped and fibrous formations. They also form a solid skeleton that grows from one center in the eutectic cell, but the crystallization of the modified eutectic silicon, however, is completely different growth mechanism – the modifier elements reduce the rate of diffusion of silicon in the melt, due to the small distribution coefficient, they are squeezed out of the cured particles of aluminum before the solidification front, blocking the growth of crystals at the interface level and the silicon melt, and thus they support the twinning of silicon particles. [Gruzelski 1999]

The principle described above, which is also called IIT mechanism (Impurity Induced Twinning), is one of the most accepted theories for explaining the modification principle. However, recent studies show that the modification is changing the dynamics of the nucleation rate and growth of eutectic grains with an associated effect on growth rate. In unmodified alloys Al-Si a large number of grains nucleates on the primary dendrites of solid solution of Al and eutectic aluminum is formed on the epitaxial primary dendrites. With the addition of eutectic modifiers, such as Sr, a dramatic decrease can be in the nucleation frequency of eutectic grains that are nucleated independently of the primary phase centers distributed in the interdendritic spaces. The eutectic reaction in Al-Si alloys begins with nucleation of silicon, which is leading phase of the growth of eutectic phases. Recent studies have confirmed that by the addition of strontium can be observed a significant reduction in eutectic grain nucleation rate, which is caused by "poisoning" potent nucleation germs. [Cho 2008]

Other studies have also confirmed that in addition to its effect on the growth of eutectic silicon, the addition of strontium causes a significant change in the nucleation behaviour of the eutectic phases. In addition to deactivating AlP germs, the addition of strontium also disables oxide bifilms as preferred nucleation seeds for eutectic silicon. Silicon is forced to nucleate at lower temperatures on so far unknown substrate and grow as a fine, fibrous eutectic silicon with high density of twins. [Timpel 2011] The current research works of material researchers therefore involve an analysis of the local distribution of the modifying element within eutectic and also on the interface of Al/Si.

1.1 Strontium vs. intermetallic phases in Al-Si alloys

Morphology of undesirable intermetallic phases, e. g. phases containing iron can be affected besides of influence of modification on the eutectic silicon morphology. As in the examples in [Cho 2008, Haro-Rodriguez 2011, Ashtari 2005, Shabestari 2007], some modifier elements e. g. strontium and potassium, have a positive effect on the morphology of β-Al_5FeSi, respectively on the conversion of this phase, the phase of α-and-Al_8Fe_2Si. A similar theme deals with, among others [Li 2004], which follows the interaction of strontium and copper. The available literature does not satisfactorily describe the relationship and influence of strontium and magnesium. In some works has been identified magnesium as element that facilitates the modification, some works attributed it a negative effect on the modification, but not any found work did pursue strontium affecting the morphology of the intermetallic phases containing magnesium. In Al-Si alloys is magnesium usually found in phase Mg_2Si, but may be present also in iron-containing phases such as phase $FeMg_3Si_6Al_8$, or in other complex eutectics.

2.2 Strontium vs. structural defects of Al-Si alloys

Negative effect, manifested by an increase in porosity, can be influenced by modification. One aspect is the porosity due to hydrogen. Another important aspect of the modification, however, is the change of the solidification temperature range. Modification may cause changes in the model of shrinkage and gas porosity. Experiments showed that the total volume shrinkage, which is a property of alloy, is not affected by modification. However, the way how shrinkages are distributed and if they are macro- or micro- porosity is strongly affected by the modification. Both sodium and strontium cause a fall in growth of focused shrinkages and increased growth of micro porosity. In other words, shrinking during solidification is redistributed by modification. [Gruzelski 1999] For example unmodified eutectic alloy AlSi12 solidifies from the surface of the casting inwards to form a concentrated shrinkage. Alloy with a needle like or partially modified eutectic solidifies mushy and has a tendency to create distributed porosity. Alloy with a well-modified or over-modified eutectic creates concentrated shrinkage again.

2. Experiment

The goal of the presented work was to analyze structures of non-binary Al-Si alloy influenced by strontium added in different forms of modification agents. Besides changes in the morphology of eutectic silicon, changes of the morphology of intermetallic phases were particularly monitored, namely phases containing iron and magnesium.

For the experiment alloy EN AC-43100 (AlSi10Mg) was chosen, batch consisted of only alloy ingots, no recycled material. Melt was neither refined nor degassed. Samples were cast in a green sand molding mixture, 4 casting samples in one mold for one modification agent. Reference samples were cast without modification. To modified samples 400 ppm of strontium was added in pre-alloys AlSr3.5, AlSr5, AlSr10 – all wrought agents, pre-alloy AlSr10 cast and pure strontium. Samples for metallography were taken from the middle part of castings.

3. Results

All structures (except of reference one without modification) are modified. On closer examination eutectic grain boundaries areas show coarse eutectic silicon and in addition these sites also contain coarse intermetallic phases in particular iron, iron and manganese and magnesium phases were expected.

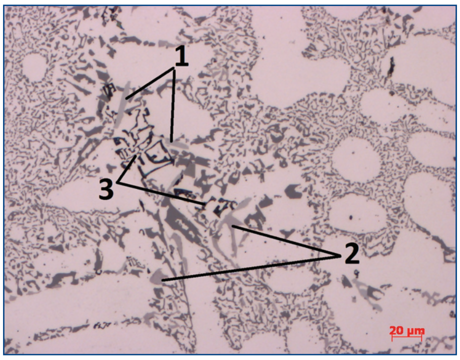
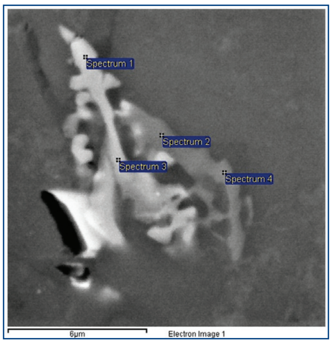


Figure 1. *AlSr3.5 modified sample – characteristic intermetallic phases at grain boundaries, 200x, 1 – phase of iron, probably β-Al_5FeSi, 2 – phase of iron and manganese, probably $Al_{15}(FeMn)_3Si_2$, 3 – phase of magnesium Mg_2Si*

In order to confirm assumptions about the composition of the intermetallic phases at grain boundaries, spectral analysis of selected phases was performed. It turned out that at the phases which were assumed as the type Al(FeMn)Si, magnesium is also present. Fig. 2 shows a detail of connected intermetallic phases. Position Spectrum 1 was defined as the phase, where in addition to aluminum and silicon chromium also occurs, but especially manganese and iron in the order of units to tens of per cent. Spectrum 3 shows in addition to the above indicated the content of 1.32 wt. % of magnesium. Positions 2 and 4 except of aluminum and silicon content also around a 6-wt. % of magnesium, 4 % iron, but very little or no manganese content.



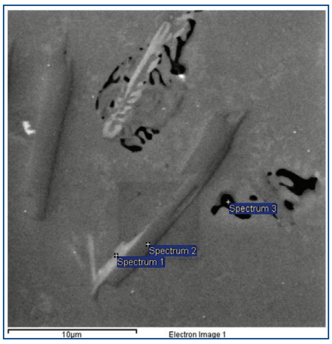


Figure 2., 3. *Detail of intermetallic phases of modified structure from electron microscopy and spectral analysis*

Similarly, in Fig. 3 is analysed as position 1 phase containing magnesium (12 %), iron (4.3 %) and manganese (0.83 %). Position 2 is the eutectic silicon phase, position 3 is rich in magnesium and silicon, while taking into account the morphology, it may be considered as Mg_2Si phase and confirm the original assumption.

When comparing the different structures obtained by modifying agents, different morphology of the various intermetallic phases and cavity structure defects can be observed. Here are shown typical details of intermetallic phases, the description is based on detailed study of structures under light microscope.

Unmodified structure (Fig. 4) contains in addition to the primary dendrites of solid solution and granular eutectic also intermetallic phases of iron, which are acicular to skeletal character, while the branches of those particles are quite massive. Occasionally there are "bone" particles of magnesium phase Mg2Si, always tied to the eutectic silicon or iron phase. There are "lace" phases containing different intermetallics, depending on colour can be judged on the phases of iron and magnesium phase.

In the structure modified by agent AlSr3.5 (Fig. 5) at the grain boundaries occur coarse needle to plain formations of iron and

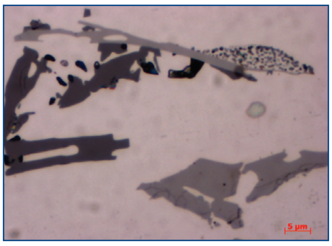


Figure 4. *Unmodified mag. 1000x*

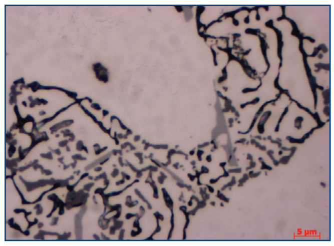


Figure 5. *Modified by AlSr3.5 mag. 1000x*

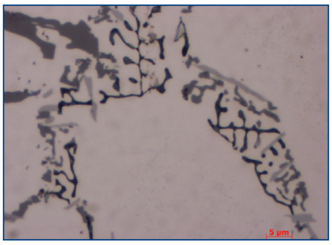


Figure 6. *Modified by AlSr5, mag. 1000x*

Figure 7. *Modified by cast AlSr10, mag. 1000x*

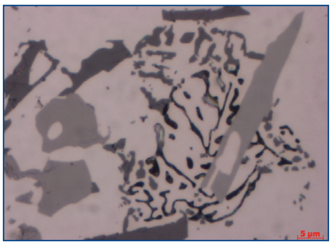


Figure 8. *Mod. by wrought AlSr10, mag. 1000x*

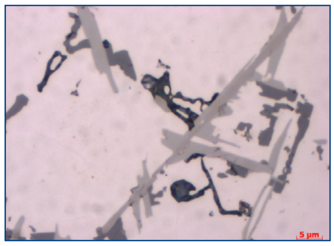


Figure 9. *Modified by Sr, mag. 1000x*

manganese phases and "bone" magnesium formations, which are always bound to the iron phase and the eutectic silicon. Cavities are present, usually a combination of interdendritic shrinkage and gas porosity.

In the structure modified by the agent AlSr5 (Fig. 6) occur needle to rougher surface formations phases of iron and manganese and "bone" magnesium formations. In all samples is high volume of cavities, mostly interdendritic shrinkage porosity combined with gas.

In the structure modified cast agent AlSr10 (Fig. 7) are rough needle to "bone" phases of iron and manganese and "bone" magnesium phases formations, which are always bound to the iron phase. Finer phase of iron formations extend to eutectic. In the structure appear interdendritic shrinkages combined with gas bubbles.

In the structure modified by wrought agent AlSr10 (Fig. 8, 10, 11) occur coarse acicular formations to "bone" phases of iron, manganese and "bone" magnesium phases, which are always bound to the iron phase. Phase interfere with iron eutectic. Cavities are present, usually a combination of interdendritic shrinkage and gas porosity.

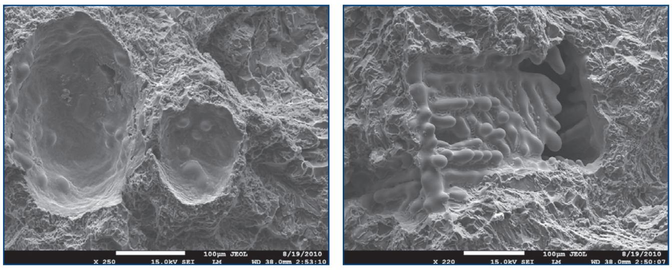


Figure 10., 11. *Hydrogen bubbles on fracture area (left), dendritic arms and interdendritic shrinkage on fracture area (right); both of sample modified by wrought AlSr10 agent*

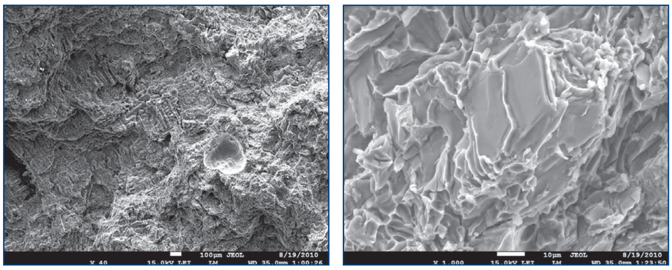


Figure 12., 13. *Characteristic fracture area of sample modified by wrought agent AlSr10 – interdendritic shrinkage and hydrogem bubble (left); fracture area of AlSr10 modified sample –coarse plates of eutectic silicon (right)*

In comparison to the structure modified by cast agent AlSr10 iron needle formations of iron are coarser.

Pure Sr affected structure (Fig. 9) so that there are needles to plain formations of iron phases which interfere with the eutectic. Often they are kept parallel. Phases of magnesium are "bone" like, gentle, always tied to a different phase. Also there are small circular to teardrop-shaped formations merged phases. The presence of porosity (combined).

4. Conclusions

The experiments and their subsequent evaluation yielded the following findings:

– All structures (except the reference structure without modification) were modified – the eutectic silicon morphology was qualitatively changed.
– Strontium affects the morphology of intermetallic phases, namely phase iron and manganese. This confirms the findings of other authors [Cho 2008, Haro-Rodriguez 2011, Ashtari 2005, Shabestari 2007]. It was found that strontium to some extent affects the morphology of phases containing magnesium.
– Differences between the effects of the modification agents were observed. Low-strontium agents (AlSr3.5, AlSr5, AlSr10) help to create "bone" like shaped phases of Mg_2Si and "bone" like to finer dispersed phase containing iron and manganese. The effect of pure strontium was limited by the difficulties in dissolving in the melt, resulting in its lower residual content in the casting and its lower recovery. This resulted in coarser morphology of intermetallics, similar to the unmodified alloy.
– The change of morphology of intermetallic phases can influence the mechanical properties of the alloy. Particularly phases of magnesium can influence not only the tensile strength or ductility, bur also the process of heat treatment, mainly hardening of Al alloys, which consists of solution annealing and aging. If the hardening phase Mg_2Si has a controllable suitable morphology and uniform distribution in the volume, the annealing could be shortened or the effect of heat treatment could be possibly greater. This assumption needs more studies and experiments to be proven.
– Modified structures showed a greater degree of porosity, which generally can be called a combined porosity (gas + shrinkage). Modification by pure Sr also resulted in porosity; although its recovery and residual content in samples were low.
– Strontium affects the structure of non-binary alloys Al-Si not only in terms of morphology of eutectic silicon, but also in terms of morphology of intermetallic phases and internal defects. Various modification reagent based on Sr behave differently as it is shown on above-described aspects of changes in the structure.

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