INFLUENCE OF SOLUTION HEAT TREATMENT TIME AND TEMPERATURE ON THE EUTECTIC SILICON PARTICLES IN AlSi FOUNDRY ALLOYS

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ABSTRACT

Al-Si alloys with 7% and 11% Si have been solution heat treated at 540°C and 560°C and the change in area of the eutectic Si crystals has been investigated by means of image analysis. Coarsening of Si crystals in modified alloys is observed after very short heat treatment times, while long heat treatment times are required to obtain changes in unmodified alloys. High temperature treatment is found to enhance the coarsening effect.

Keywords: *Aluminium, Casting, Al-Si, Foundry alloys, Heat treatment*

1 INTRODUCTION

The AlSiMg alloys is a series of alloys of increasing industrial importance, since these alloys show a good castability and may be heat treated to obtain improved strength. Before the aging process the alloys must be solution heat treated and this high temperature treatment leads to changes in the size and shape of the eutectic Si crystals.

2 EXPERIMENTAL WORK

Chemical composition of the samples are given in Table 1.

Sr was added for modification of the Al-Si eutectic as an AlSr10 rod type master alloy. Samples for heat treatment were cast in preheated cylindric graphite moulds at a cooling rate of 1 K/s. The samples were solution heat treated in a salt bath at 540°C of 560°C for various holding times. The samples were immediately quenched in water at 25°C. The temperature in the salt bath was checked before and after heat treatment by means of an external thermocouple.

The size and shape of the eutectic Si crystals was quantified by means of automatic image analysis. A minimum of 10 image fields or 1000 Si particles were measured in each sample. Area, perimeter and minimum and maximum feret diameter were measured.

Table 1: *Spectrochemical composition of the investigated alloys [wt%]*

Sample	Si	Fe	Mg	Cu	Sr	Zn	Mn
AlSi7Mg0.3	7.15	0.1	0.2365	0.001	0.0004	0.003	0.002
AlSi7Mg0.3(Sr)	7.27	0.1	0.2319	0.001	0.0075	0.003	0.002
AlSi7Mg0.6	7.35	0.247	0.569	0.0007	0.0004	0.002	0.0036
AlSi7Mg0.6(Sr)	7.25	0.321	0.528	0.0007	0.0126	0.002	0.0036
AlSi11Mg0.6	10.84	0.286	0.5645	0.002	0.0001	0.0138	0.0038
AlSi11Mg0.6(Sr)	10.92	0.377	0.5548	0.002	0.0281	0.014	0.00397

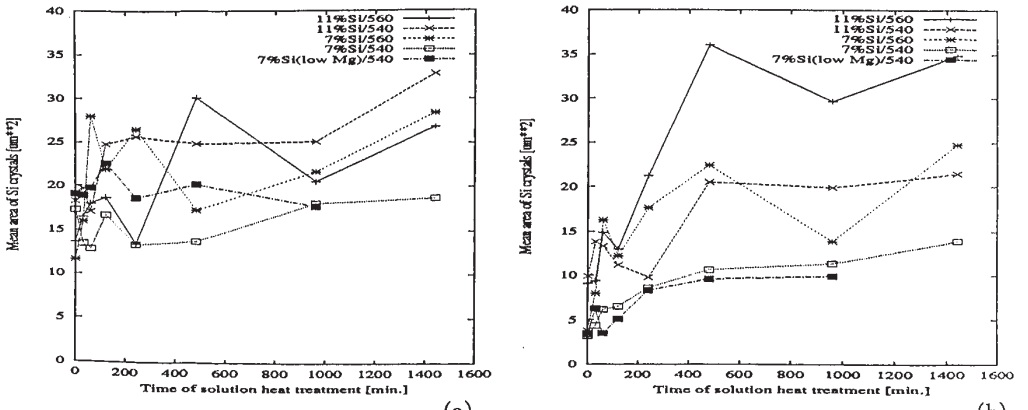

Figure 1: *Mean Si areas in unmodified (a) and modified alloy (b) after solution heat treatment*

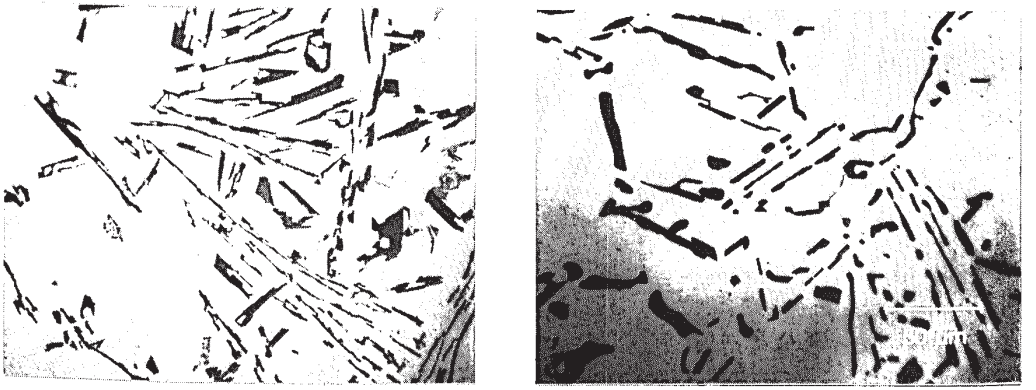

Figure 2: *Eutectic Si crystals in unmodified AlSi7Mg0.6 in as cast condition (a) and after heat treatment at 540° C for 480 minutes (b). As polished*

3 RESULTS

3.1 Influence of solution heat treatment on mean Si crystal area

The mean area of silicon crystals as a function of heat treatment time is given in Fig.1. Maximum change in the unmodified alloys is found to be approximately 15μm^2. As can be seen most alloys have an initial increase in mean area until 120 minutes heat treatment, then the changes are small for a long period until a heat treatment time of 1440 min.(24 hrs) is reached. As one should expect from the micrographs shown in Figs.2a and 3a the modified alloys shows an initially smaller particle area (5 through 10 μm^2) than the unmodified alloys(10 through 20 μm^2). Then the modified alloys mean particle area increases up to a heat treatment time of 480 minutes before the graphs stabilize. At this point the 11% Si alloys have reached the same crystal size as the one found in the corresponding unmodified alloys, while the mean area for the 7% alloys is still smaller in the modified alloys. Examples of the particle distributions for the AlSi7Mg0.6 alloys heat treated at 540°C are given in the Figs.4 (unmodified alloy) and 5 (modified alloy)

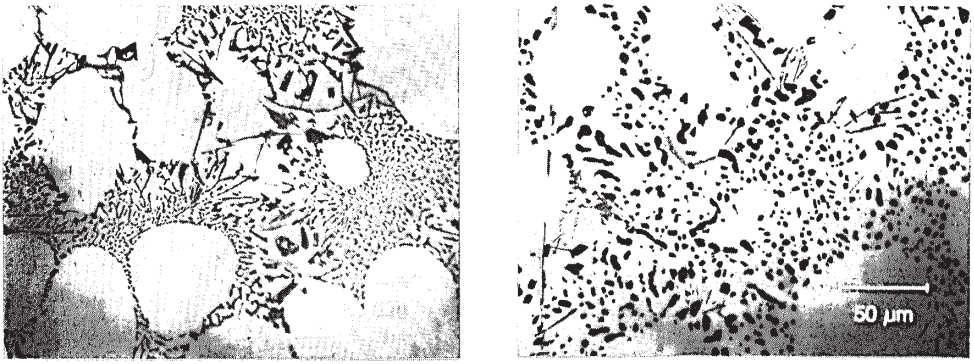

Figure 3: *Eutectic Si crystals in modified AlSi7Mg0.6 in as cast condition (a) and after heat treatment at* 540° *C for 480 minutes (b). As polished.*

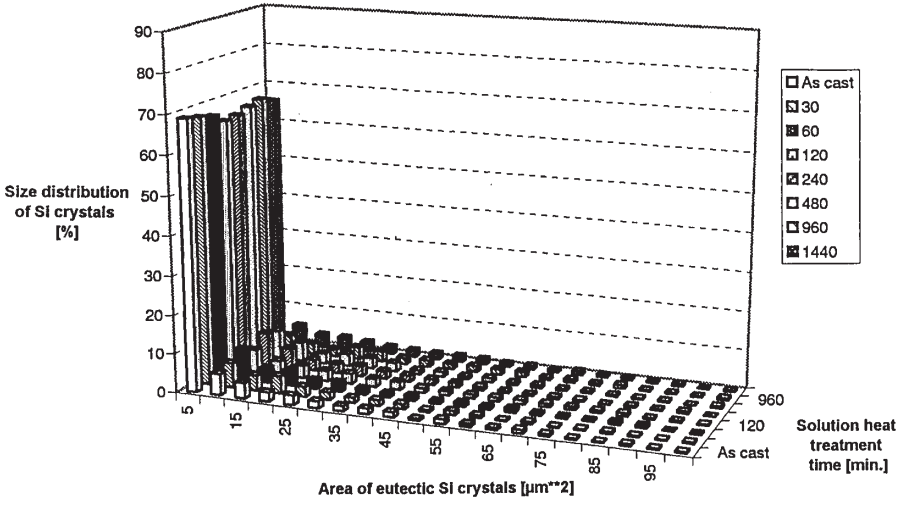

Figure 4: *Size distribution after heat treatment of the AlSi7Mg0.6 alloy in its unmodified condition. Size classes are given on the x-axis, time of solution heat treatment in minutes on the y-axis and amount of particles is given in % of the total number of particles within each sample on the z-axis. Heat treatment temperature:* 540° *C*

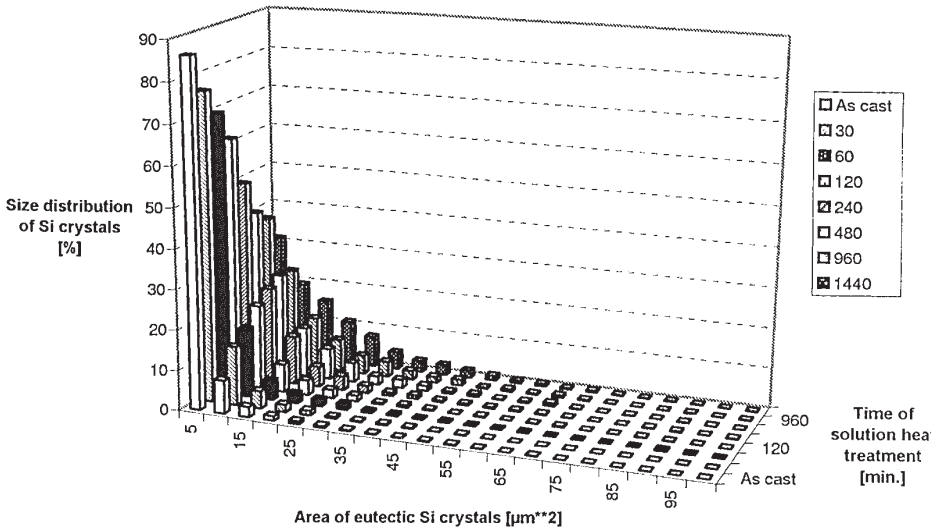

Figure 5: *Size distribution after heat treatment of the AlSi7Mg0.6 alloy in its modified condition. Size classes are given on the x-axis, time of solution heat treatment in minutes on the y-axis and amount of particles is given in % of the total number of particles within each sample on the z-axis. Heat treatment temperature:* $540°C$

3.2 Perimeter/Area relationship during solution heat treatment

During the heat treatment sequence the relationship between perimeter and area of the 2D particles are changed as can be seen from Fig.6.

Looking at the unmodified alloys in Fig.6a there is mostly a small change of the P/A relationship with time, even though a tendency of decreasing P/A is seen during the entire period. For the modified alloys as shown in Fig.6b, the most prominent reduction takes place during the first 60 minutes of solution heat treatment followed by a smaller reduction up to 480 minutes of heat treatment. increasing the heat treatment time up to 1440 minutes leads to a negligible further reduction in the P/A relationship.

4 DISCUSSION

4.1 Area of Si particles

Fig.1a shows only a slight increase in mean particle area as a function of heat treatment time and no significant changes due to temperature. A similar increase in mean Si crystal size has earlier been observed by Meyers [1] even though Meyers mean average in general were smaller than the ones found in this investigation. These differences may be a result of different cooling rates during casting of the base material. The increase in crystal size may seem strange since one reason for the heat treatment is to spheroidize and reduce the size of the silicon crystals. This observation corresponds fairly well with the size distributions in Fig.4 where a slight reduction of small crystals ($< 5\mu m^2$) by time is observed. A small increase of coarser crystals can be seen from the same graph. This may be a result of the change in shape of the coarser particles observed in Fig.2a and b and earlier shown by Apelian & *al.*[2] and Closset & *al.*[3]. "Corners" of coarse crystals dissolving leads to some increase of the area of smaller particles (20 through

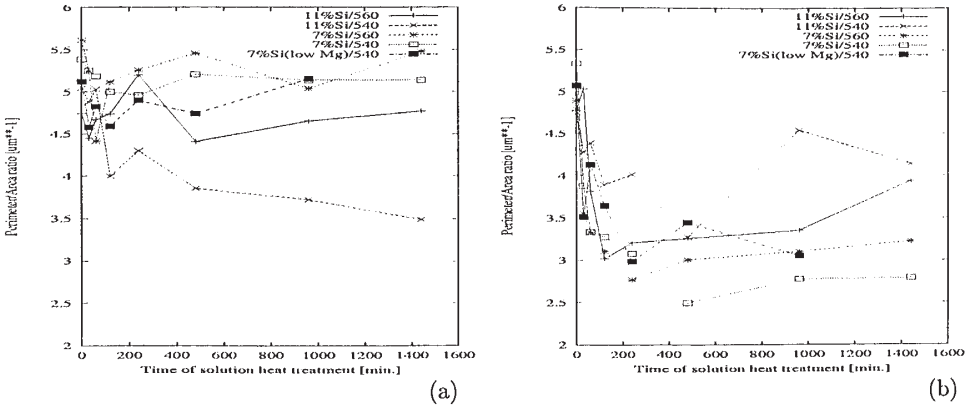

Figure 6: *Perimeter/Area relationship in not modified (a) and modified alloy (b) after solution heat treatment*

90 μm^2). The low number of coarse particles makes this hypothesis difficult to quantify and thereby verify.

A clear increase in area as a function of heat treatment time is found in the modified alloys as seen in Fig.1b. The most prominent coarsening of the Si crystals takes place during the first 480 minutes of the heat treatment as can be seen both from Fig.1a and in the example of the particle size distributions in Fig.5. An initial content of more than 60% small crystals in the as cast condition is reduced to 40% or less in after 480 minutes of heat treatment. The lowest coarsening rate is found for the 7%Si alloys heat treated at 540°C while the two alloys heat treated at 560°C obtain the most coarse Si crystals after heat treatment.

Another phenomenon which was observed but cannot be seen from the graphs is coalescence of some crystals which may have contributed to the increase in mean average area, especially for heat treatment times longer than 240 minutes. This was in particular observed in the alloys with 11% Si, probably as an effect of a smaller distance between the crystals in the eutectic areas.

Similar measurements on the AlSi11Mg0.6 alloys show that the amount of small particles ($< 5\mu m^2$) is lower in these alloys, about 60% for the as cast alloys in both unmodified and modified condition. Especially for the modified alloys this reduction of small particles is quite large, but the explanation here is that satisfactory modification is harder to obtain in these alloys compared to the AlSi7Mg0.6 alloys. Furthermore the amount of "medium coarse" crystals ($> 60\mu m^2$ is larger in the AlSi11Mg0.6 alloys probably due to shorter distance between the Si crystals and thus shorter diffusion lengths.

4.2 Perimeter/Area relationship

The P/A relationship is the two dimensional equivalent to the more usual surface area per volume relationship which relates to the total loss of energy obtained by minimizing the surface energy (expressed by the surface area) of particle. This leads to a coarsening of particles but since the energy required for increasing the volume is smaller than the energy lost by minimizing surface, the total energy of the system is reduced.

The unmodified alloys in Fig.6a show a small decrease during the first 120 minutes while the modified alloys has a strong reduction in P/A during the first 60 minutes of heat treatment as illustrated in Fig.6. Thus a high degree of coarsening takes place in the modified alloys

during the initial stages of solution heat treatment. For the unmodified alloys the relatively stable P/A relationship may be due to large Si crystals splitting up and neutralizing the effect of the coarsening of small particles.

4.3 Image analysis - some comments

Automatic image analysis may be a useful tool in microstructural analysis, but foundry alloys with their contents of both coarse and very fine crystals requires careful treatment of the collected data. Firstly, when measuring the same parameters in several alloys one must be sure that all alloys have the same minimum value of particles measured. In this examination crystals having an area less than $0.5\mu m^2$ are consequently scrapped. The error created by neglecting crystals smaller than this value is probably smaller than the error "false" small particles such as remainders of polishing defects or "edges" of other types of particles created when defining the thresholds for the measurements would have produced.

For several samples, especially in the unmodified alloys, there are areas containing basically small particles and areas containing mainly coarse particles. This requires several image fields to be taken from each sample. In this examination an absolute minimum of 10 image fields was defined. If the number of particles measured within these 10 images was less than 1000 more images were analyzed.

The mean area has been chosen as one important parameter, but some coarse particles measured will neutralize a large amount of small particles. A better parameter might have been the median value of the area, since the "neutralization effect" would have been removed.

5 CONCLUSIONS

- in modified alloys the mean particle area is increased up to 480 minutes of solution heat treatment. Nearly all Si crystals seem to grow with time
- higher solution heat treatment temperatures favours coarsening
- in modified alloys coalescence is quite often seen at heat treatment times over 120 minutes, particularly in alloys with 11% Si
- the strongest reduction of surface energy in modified alloys expressed by the P/A relationship takes place during the first 60 minutes of solution heat treatment. This indicates that the lowest solution heat treatment time that gives a satisfactory dissolution of Mg and Si into matrix will be preferable.

ACKNOWLEDGEMENTS

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