Spheroidization of the Al-Si Eutectic in a Cast Aluminum Alloy

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Samples from a cast aluminum alloy were heat treated at 470 °C for periods of times ranging from 2 to 40 h to study the spheroidization of the silicon particles of the Al-Si eutectic aggregate. The specimens were obtained from small ingots cast in metallic and sand molds with different amounts of strontium added to modify the aspect ratio of the silicon platelets. It was found that these particles have the tendency to change their shape from elongated to round as time elapses at the heat treating temperature, although small changes in length and width were observed at times shorter than 10 h. It was found that the interparticle separation distance increased with time; this effect was more pronounced in samples that contained the higher amounts of strontium and were cast in metallic molds.

Keywords aluminum, castings, heat treating, spheroidization, solubilization

1. Introduction

The broadest meaning of heat treating comprises all thermal practices intended to modify the metallurgical structure of parts and pieces to control their physical and mechanical properties and accomplish specific engineering characteristics. However, the term heat treating is often used in the aluminum industry to describe the procedures and practices required to achieve maximum strength or hardness in a suitable alloy. Normal practice involves a sequence of solution heat treating, rapid cooling (quenching), and precipitation hardening (aging).[1,2,3]

Solubilization of secondary phases, able to precipitate during aging,[2,3] is not the only microstructural change that takes place as the cast alloys are heat treated. It has been reported[4,5] that the morphology of intermetallic phases changes when the alloy is treated at high temperature for long periods of time, although the results indicate that the morphology of iron containing β-phase platelets changes through concurrent fragmentation and dissolution at the plate tips, whereas the α phase does not undergo any change.

Studies carried out on different types of eutectic aggregates[6–13] have shown that these structures can be modified during heat treating by a series of competitive mechanisms, which are related to the amount of discontinuities and interfacial aspects of the related phases. The most accepted mechanism to explain the modification that takes place in Al-Si eutectics is the fragmentation and rounding of originally sharp silicon platelets.[10–13] The aim of this work is to present the results found when studying such a phenomenon in a cast aluminum alloy subjected to solubilization during times ranging from 2 to 40 h at a temperature of 470 °C.

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2. Experimental Procedure

A series of samples from a type 319 aluminum alloy were cast into small metallic and sand molds to vary the solidification rate of the alloy. The metallic molds were 35 mm in diameter by 70 mm in height and the sand molds were 30 mm in diameter. The melts were degassed with nitrogen for 15 min in 5 tonne ladles before adding strontium to the liquid alloy. The ingots were cast with a low Sr content, of around 20 ppm (A and B), and with a higher one, around 180 ppm (C and D). Two of the melts were poured in metallic molds (B and D), whereas the other two were cast in sand (A and C). Table 1 shows the chemical composition for each of the samples, A, B, C, and D. Additional ingots were cast with K-type thermocouples inserted in the ingot cavity to record their solidification rates. The data obtained were numerically processed to obtain the instantaneous cooling rate (*dT/dt*), which is used in thermal analysis.[14]

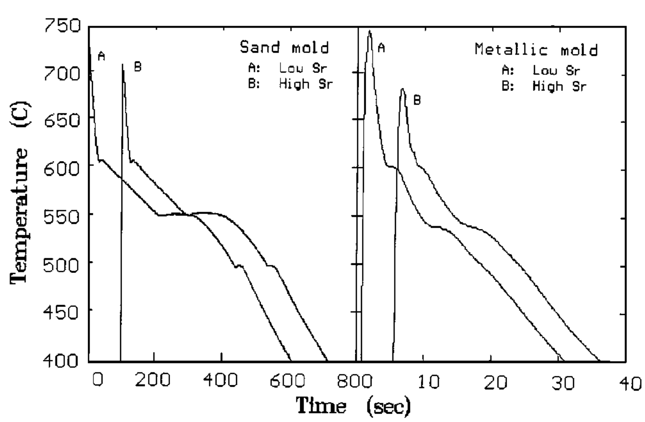

Fig. 1 Solidification curves registered during solidification. The curves for the samples cast with high Sr content were displaced 100 and 5 s, respectively

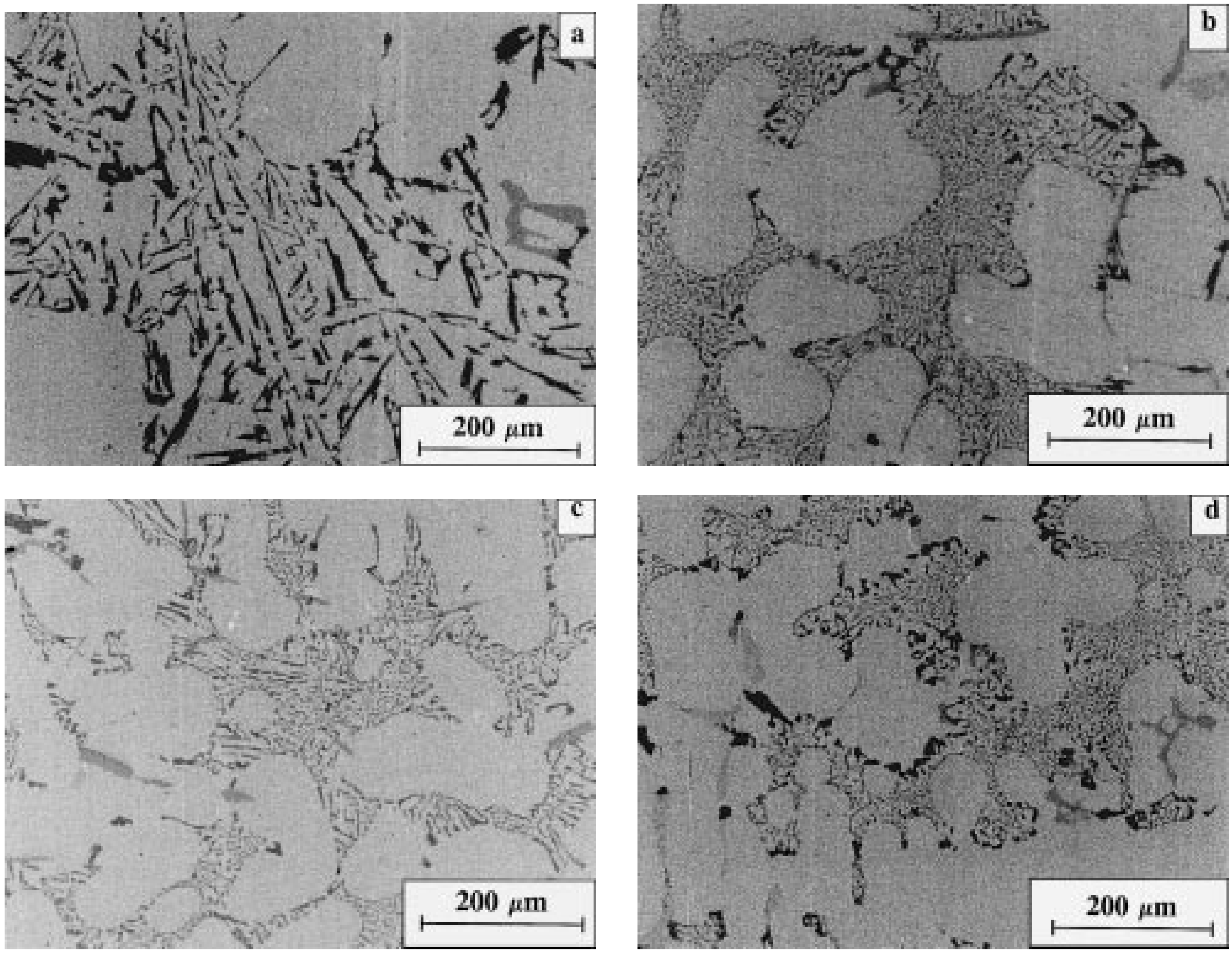

Fig. 2 Micrographs of the untreated samples cast in sand mold with (**a**) low and (**b**) high Sr and in metallic molds with (**c**) low and (**d**) high Sr

Table 1 Chemical composition of the studied samples (wt.%)

Mold	Heat	Si	Cu	Fe	Mn	Mg	Zn	Ti	Sr
Sand	A	7.36	3.28	0.773	0.456	0.267	0.641	0.122	0.00197
Metallic	B	7.28	3.65	0.759	0.426	0.240	0.695	0.102	0.00193
Sand	C	7.27	3.40	0.555	0.356	0.277	0.680	0.088	0.01630
Metallic	D	7.43	3.63	0.645	0.421	0.272	0.706	0.094	0.01935

The ingots were sectioned to obtain small 10 × 10 mm on a side cubes, which were solubilized at 470 °C for times ranging from 2 to 40 h. The temperature during heat treating was controlled by means of a K-type thermocouple placed close to the samples. The specimens were cooled to room temperature by quenching them in cold water.

The samples were polished in the conventional metallographic way and a series of image analysis measurements related to the silicon particles of the Al-Si eutectic were conducted. Ten different fields, all made at a constant magnification with a 20× objective lens, were recorded for each of the four alloys. The parameters that were registered were number of particles (N), their average width (W) and length (L) (defined each as the shortest and longest dimension of different particles), fraction of area (A_A) occupied by the particles, the interparticle spacing (σ) and mean free path (λ) between them, and their roundness (R), defined as

$$R = \frac{\pi \cdot L^2}{4 \cdot A} \qquad \text{(Eq 1)}$$

where L and A are, respectively, the length and area of each particle. It should be mentioned that the roundness of a perfect

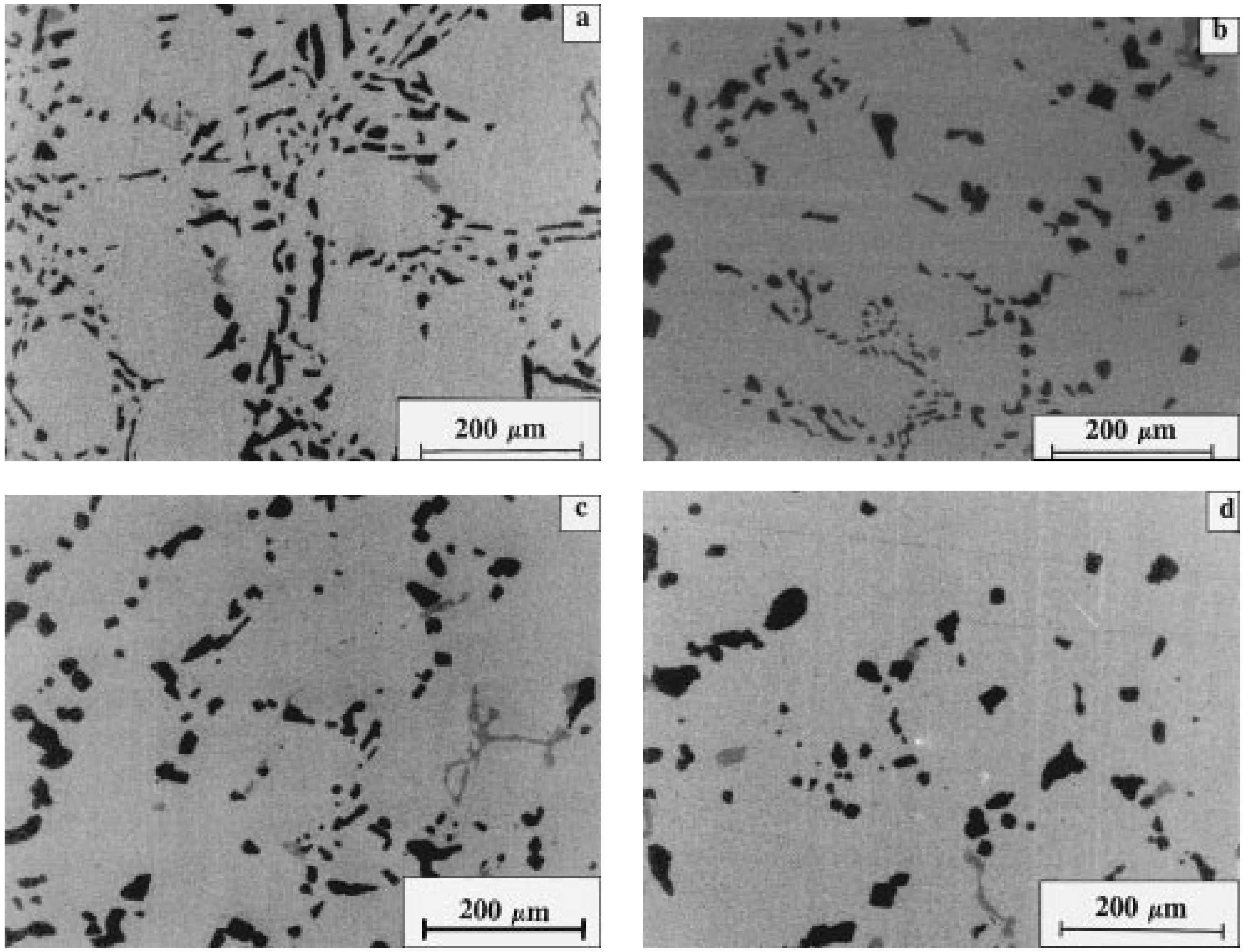

Fig. 3 Micrographs of the samples treated for 12 h at 470 °C; in sand mold with (**a**) low and (**b**) high Sr and in metallic molds with (**c**) low and (**d**) high Sr

Table 2 Temperatures and cooling rates detected at the start of the Al-Si eutectic reaction

Heat	A	B	C	D
Temperature (C)	555.6	553.7	548.9	547.3
Cooling rate (C/s)	0.37	10.03	0.37	6.89

circle is equal to one. All the observations were conducted following the practice established for quantitative analysis.[15,16]

3. Results

Figure 1 shows the temperature-time curves registered in samples cast with thermocouples in their interior; for the sake of clarity, the curves for the specimens with high Sr content were displaced 100 and 5 s, respectively. Figure 2 shows the as-cast microstructures observed in the four different conditions, and, as can be seen, the morphology of the silicon platelets varies from that of sharp needles in the sample cast in sand with low Sr content (Fig. 2(a)) to that of very fine globules in the sample obtained when it was cast in a metallic mold with high Sr content (Fig. 2(d)). Figures 3 and 4 show, respectively, the microstructures of samples held at 470 °C for 12 and 40 h, and, as can be seen, the morphology of the platelets transforms to a more rounded shape as they increase in size. It was found that the average number of silicon particles (observed in each of the ten fields) had the tendency to increase when the samples were held for periods of times shorter than 10 h and to be reduced toward longer times (Fig. 5). This phenomenon was more noticeable in the samples cast with the higher strontium content and follows the behavior described for Al-Fe eutectics.[17]

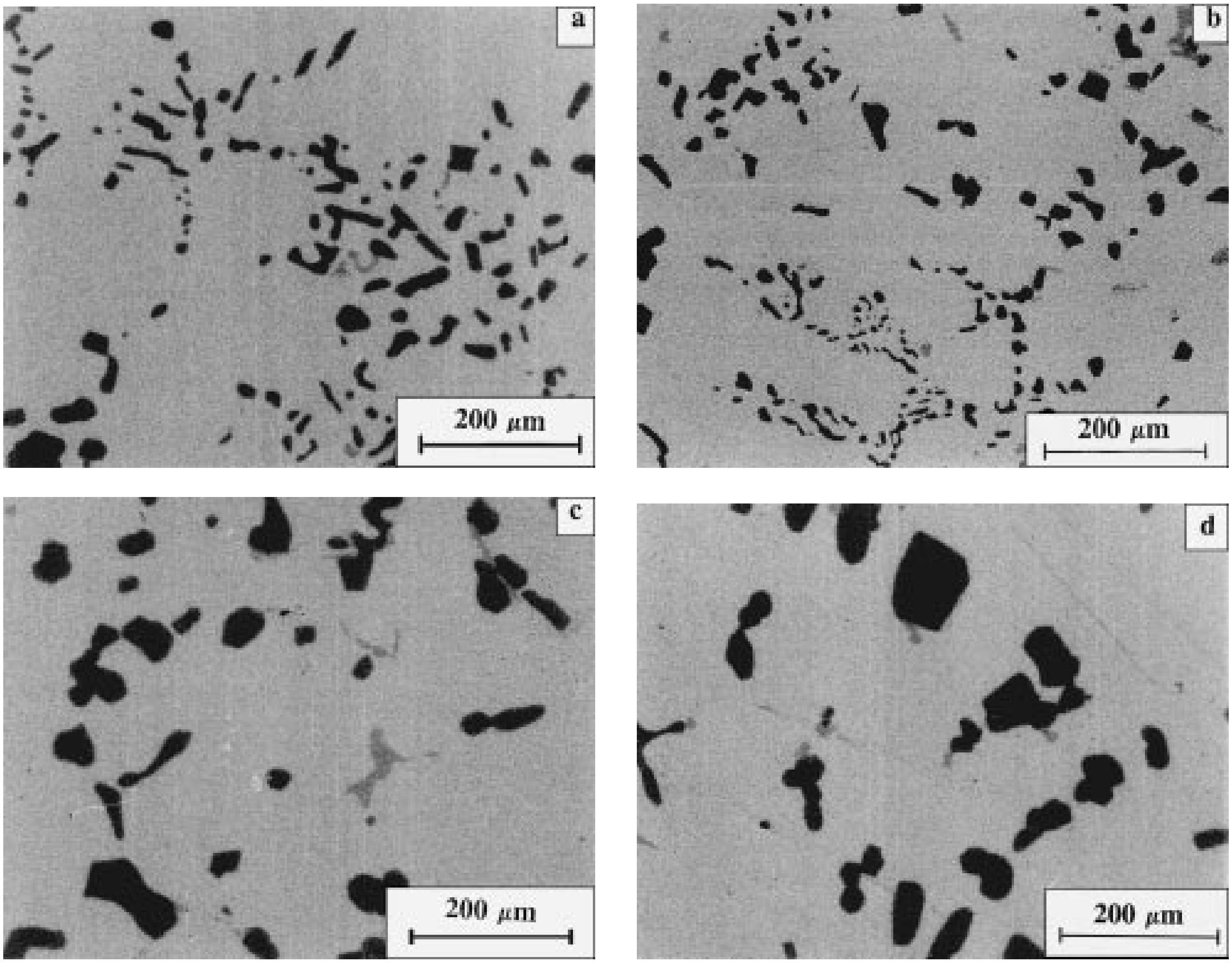

Fig. 4 Micrographs of the samples treated for 40 h at 470 °C; in sand mold with (**a**) low and (**b**) high Sr and in metallic molds with (**c**) low and (**d**) high Sr

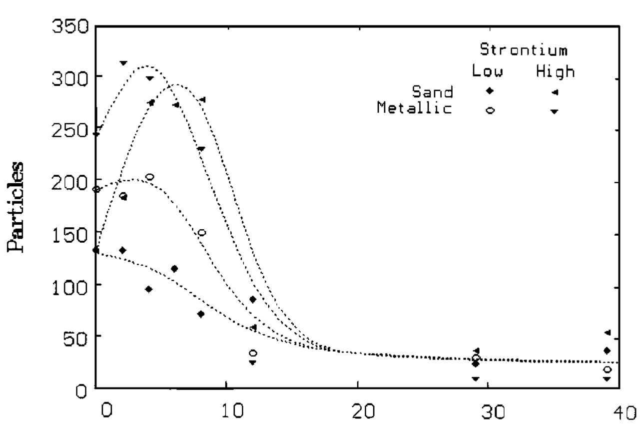

Fig. 5 Average number of particles found in each of the different fields analyzed

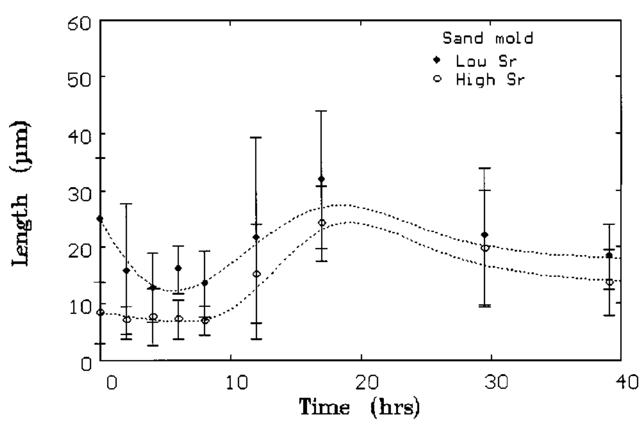

Fig. 6 Change in length of silicon platelets in sand-cast samples as a function of time

Figures 6 and 7 show, respectively, the changes in the length, plotted with 95% confidence limits, of samples cast in sand and metallic molds. Figures 8 and 9 show the corresponding changes of the averaged width, whereas Figures 10 and 11 show those

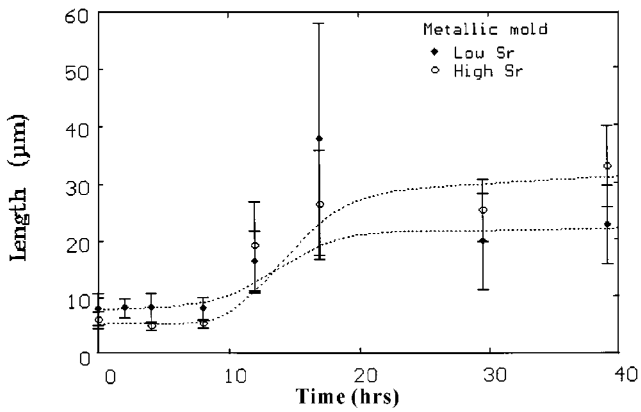

Fig. 7 Change in length of silicon platelets in samples cast in metallic molds as a function of time

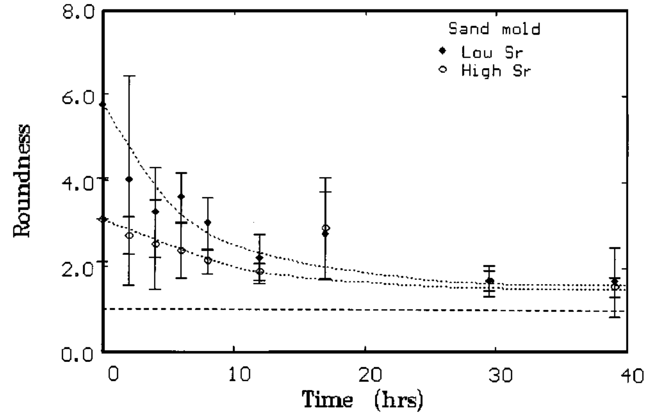

Fig. 10 Variation in roundness as a function of time in samples cast in sand

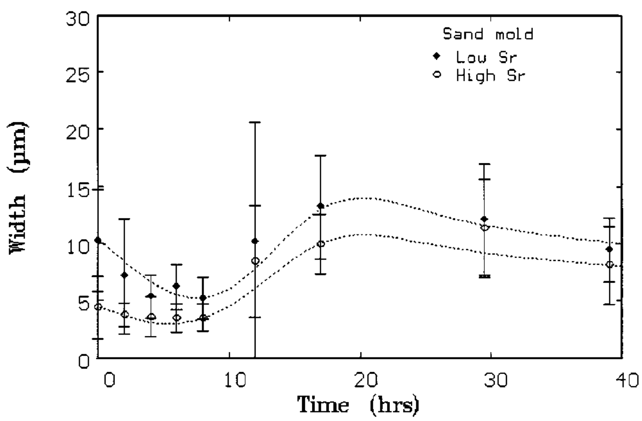

Fig. 8 Change in width of silicon platelets in sand-cast samples as a function of time

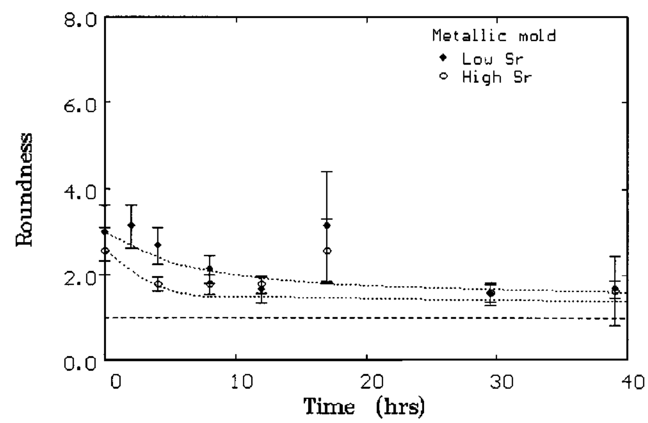

Fig. 11 Variation in roundness as a function of time in samples cast in metallic molds

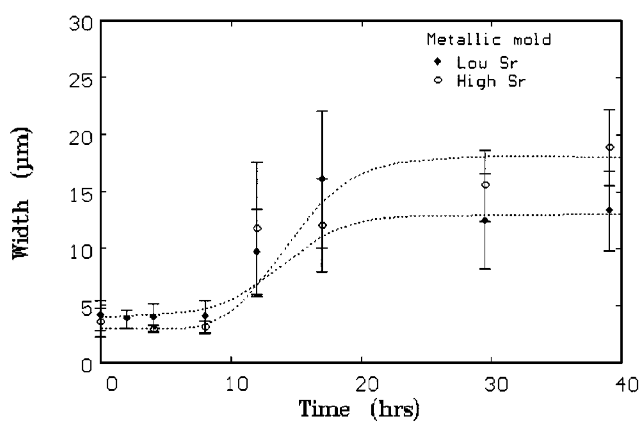

Fig. 9 Change in width of silicon platelets in samples cast in metallic molds as a function of time

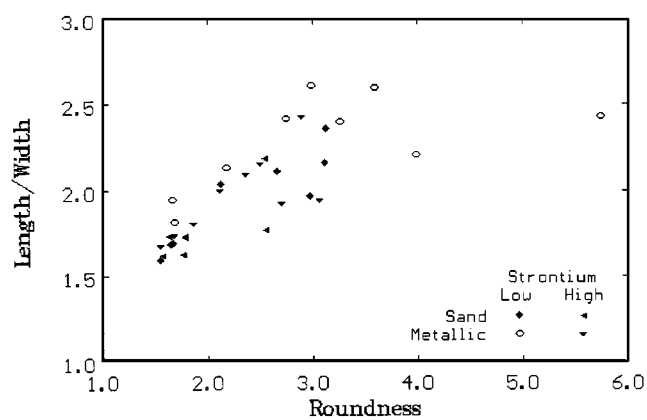

Fig. 12 Relationship between the ratio of the averaged length over averaged width and the roundness of silicon platelets

for the change in roundness of the silicon platelets. Figure 12 compares the ratio of the averaged length over averaged width (*L/W*) of the particles as a function of their roundness.

Figures 13 and 14 show the changes of the mean particle spacing (σ) and mean free path (λ) found in the different samples as a function of the treating time. These two parameters were obtained from lineal density analysis[15,16] carried out on as-cast and treated samples.

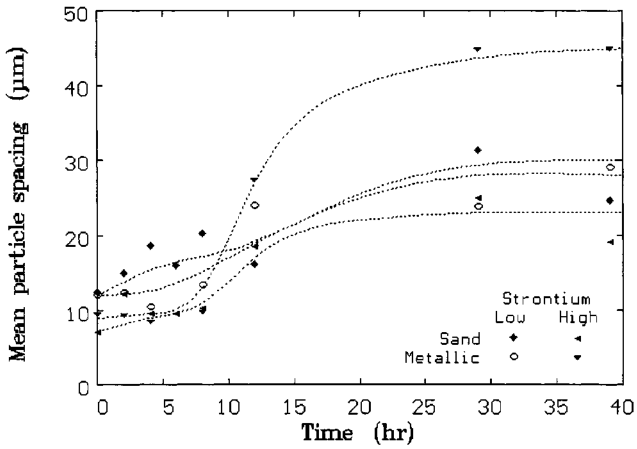

Fig. 13 Variation of the mean particle spacing as a function of time

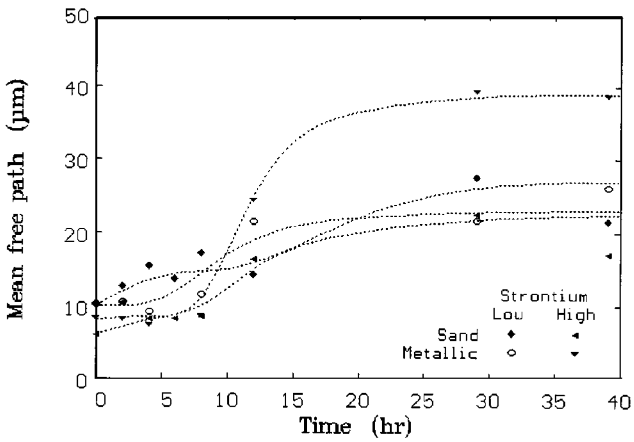

Fig. 14 Variation of the mean free path as a function of time

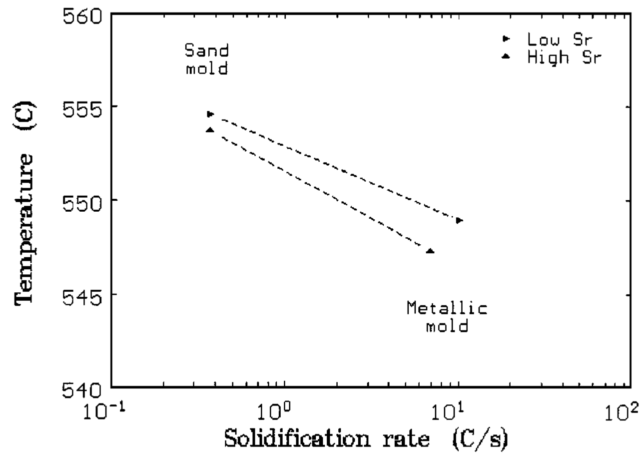

Fig. 15 Variation of the temperature at which the Al-Si eutectic starts with respect to the amount of Sr added and the cooling rate at that particular point

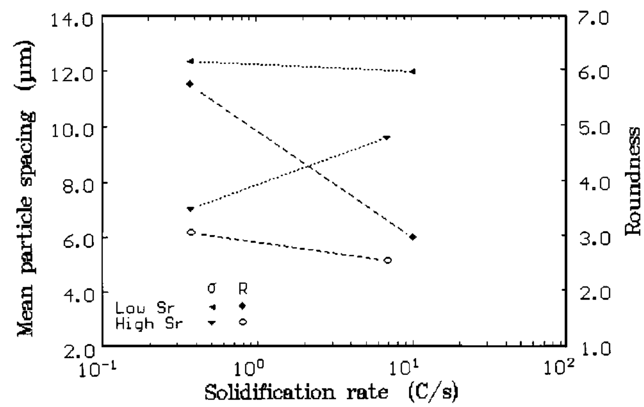

Fig. 16 Variation of the mean particle spacing and the roundness in the as-cast samples with respect to the cooling rate

4. Discussion

The cooling curves of Fig. 1 show the occurrence of at least three exothermic reactions taking place during solidification:[18]

- $L \rightarrow Al$,
- $L \rightarrow Al + Si$, and
- $L \rightarrow Al + Al_2Cu + Si$

although the last one may not be so clearly distinguished in the curves from the material cast in metallic molds. The temperatures and rates at which each reaction takes place can be obtained by means of thermal analysis.[14,18] Table 2 presents these particular data for the start of the Al-Si eutectic reaction, which is the one of interest in the present research.

Figure 6 shows that the temperature at which the Si-Al reaction starts depends on the amount of strontium added and in the instantaneous cooling rate at that particular temperature.[5,6,12–14,18] In the case of the samples cast in metallic molds, this cooling rate is more than one order of magnitude higher than that recorded in the sand castings. The reduction in the temperature at which this particular reaction starts is also reflected in the microstructural aspect of the eutectic aggregate (Fig. 2).

Figure 7 plots the variation of the mean particle spacing and the roundness in the as-cast samples as a function of the cooling rate. It is worth noting how the values of roundness and spacing are highest in the sand-cast samples with low strontium additions. The increase in either the cooling rate or in strontium content modifies the eutectic to a more rounded shape. The effect that the cooling rate exerts on the distance between particles in samples with low strontium content appears to be negligible.

Figure 7 and 9 show that the dimensions of the platelets in the samples cast in metallic molds have not changed to a great extent when the solubilization treatment is limited to less than 10 h; however, both the width and length of platelets from sand cast specimens with low Sr added are reduced to about half their size during their first 6 to 10 h. Once the 10 h have elapsed, all the particles start to coalesce and grow. The roundness of the platelets seems to change continuously, until a steady value of around 1.5 is achieved at around 20 h at the heat treating temperature. A tendency for the reduction in the L/W ratio is associated with the decrease in roundness, but the spread of the experimental data does not allow a for more precise analysis.

The changes in the mean interparticle spacing and mean free path between the platelets follow a trend similar to that of the length and width. These distances remain more or less constant within the first 8 to 10 h of heat treatment, although the spacing increases in the eutectic of the samples cast in sand with low strontium content. A steady value appears to be achieved after 30 h. The most significant increase in either distance was found in samples with high strontium content cast in metallic molds. The changes in distances and dimensions detected can be attributed to fragmentation and rounding of the platelets.[10–13]

5. Conclusions

A series of quantitative metallographic analyses carried out in the as-cast and solubilized samples of an aluminum type 319 alloy indicate that the shape aspect of the platelets is affected by the amount of strontium added to the melt and by the solidification rate.

The solubilization treatments ranged in duration from 2 to 40 h at 470 °C. It was found that the aspect ratio of the silicon particles of the eutectic changed from elongated to round as time elapsed. It was also found that the spacing between the particles increased with time. This effect was more pronounced in the samples with high strontium content cast in metallic molds. The present results indicate that the size and separation of the platelets do not change to a great extent when solubilization is limited to 10 h, although their shape (roundness) does change.

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