Journal of Thermal Analysis and Calorimetry, Vol. 67 (2002) 473–480

A STUDY OF PRECIPITATES FORMATION IN AA 380.0 ALUMINIUM ALLOYS MODIFIED BY THE ADDITION OF MAGNESIUM

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Abstract

A data acquisition system and the SAD2 software, that provide characteristic cooling curves, in combination with microstructure analysis were used to study precipitates formation in the AA 380.0 aluminium alloys modified by adding extra magnesium. The samples were solidified with distinct cooling rates caused by carrying out the solidification in shell and permanent molds. The mathematics processing of the cooling curves in agreement with the microstructure analysis have confirmed the remarkable presence of both the Al–Si dendrite network and the Mg_2Si interdendritic phase in the alloys with the addition of extra magnesium.

Keywords: aluminum alloys, precipitates, thermal analysis

Introduction

The solidification of metal alloys is a complex process that usually occurs under non-equilibrium conditions. The possibility of on-line quality control of the solidification process makes it possible to achieve the desired properties of the final product which is one of the goals of great importance for the foundry industry [1]. This control can be done using thermal analysis that is based in the thermal events present in the cooling curves. The mathematics processing of each cooling curve can be associated to the microstructural characteristics of the considered alloy in order to predict the mechanical properties of the casting product. The thermal parameters change with the alloy composition, cooling rate, supercooling and thermal gradients.

The as-casting AA 380-type alloys are frequently used for the fabrication of innumerable components by the automotive industry because they present good mechanical characteristics and appreciable castability. The concentration range of the following elements composes the typical AA 380.0 alloys [2]: Si 7.5–9.5, Fe 1.0, Cu 3.0–4.0 and Mg 0.1% in mass.

It is well known that the properties of AA 380-type alloys can be modified by the magnesium addition [3]. Furthermore, the addition of extra amount of magnesium

1418–2874/2002/ $ 5.00

Akadémiai Kiadó, Budapest
Kluwer Academic Publishers, Dordrecht

to the commercial aluminum alloys has been done to the fabrication of aluminum-matrix composites, since this element improves the wetness making the ceramic particle incorporation easier [4].

The main aim of our work was to study the magnesium effect in AA 380-modified alloy, during the solidification process, using shell and permanent molds by analyzing the cooling curves in combination with the microstructure information.

Materials and methods

In order to study the phase formation in aluminum alloys containing silicon and copper, as AA 380.0 alloy, using thermal analysis we utilized a data acquisition system (a 12 bits A/D converter) and the SAD2 software that was developed by the Laboratório de Medições Mecânicas at UFRGS [5].

AA 380.0 casting alloy was modified by the addition of 2% in mass of magnesium that was added in the elementary form in the basic alloy (AA 380.0). The Al–Si and Al–Cu master alloys and commercial aluminum were used to produce the basic alloy.

The studied samples were solidified using different cooling rates promoted by executing the solidification in shell and permanent molds.

The experiments were carried out using samples of AA 380.0 aluminum alloy and AA 380.0-modified alloy by addicting extra magnesium in order to relate the magnesium influence on the properties of the specified material.

In all experiments we used K-type thermocouples, quartz encapsulated, which were located in the center of the commercial shell sups and also in the center of the permanent molds, which were specially constructed for this proposal.

The experimental system was calibrated using pure aluminum.

In order to perform the microstructure analysis by optical microscopy, the samples were transversally cut from the center of the ingot, using conventional metallographic techniques. A HF 5% in distilled water solution was used to etch the samples during 5 s.

Results and discussion

AA 380.0 alloys, being an Al–Si hypoeutectic alloy, have the following typical precipitation sequence: formation of a dendritic network of α-aluminum, the Al–Si eutectic reaction and precipitation of secondary eutectic phases, such as Mg_2Si and Al_2Cu, followed by the precipitation of other more complex phases [2].

In Figs 1 to 6 the characteristics cooling curves are presented and their first derivatives for the samples from basic alloy as well as for the samples from the modified alloy by the addition of magnesium, for the solidification case in both shell and permanent molds.

The first aluminum dendrites formation, that corresponds to the first peak present in all cooling curves, occurred approximately at 590°C in the alloys solidified in shell mold, while, by using permanent mold this peak took place at 570°C, independently of the presence or not of high magnesium content.

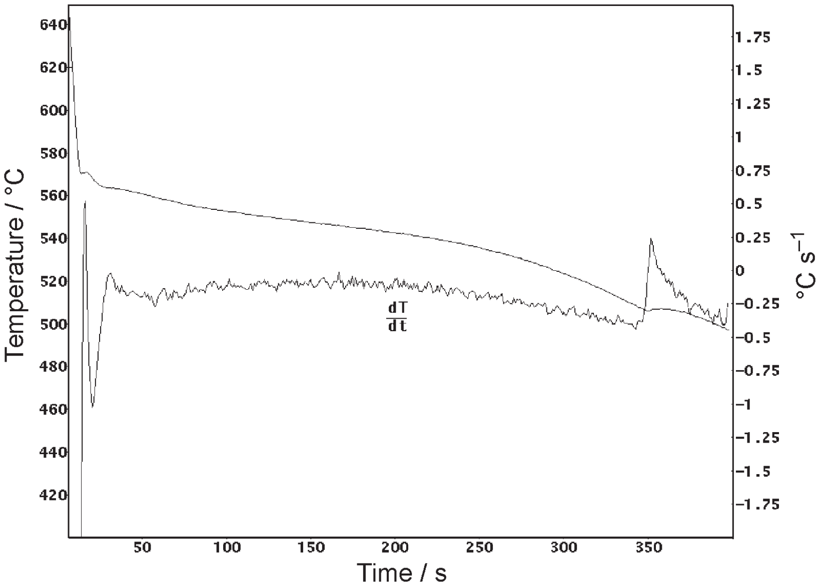

Fig. 1 Typical cooling curve for the AA 380.0 alloy solidified in shell mold

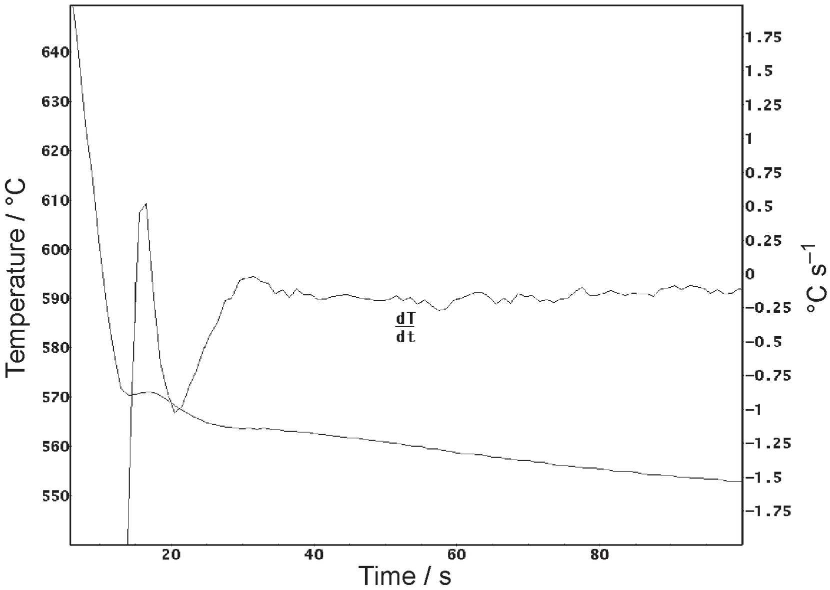

Fig. 2 A detail of Fig. 1 denoting the Si dendritic crystals formation on the AA 380.0 alloy solidified in shell mold

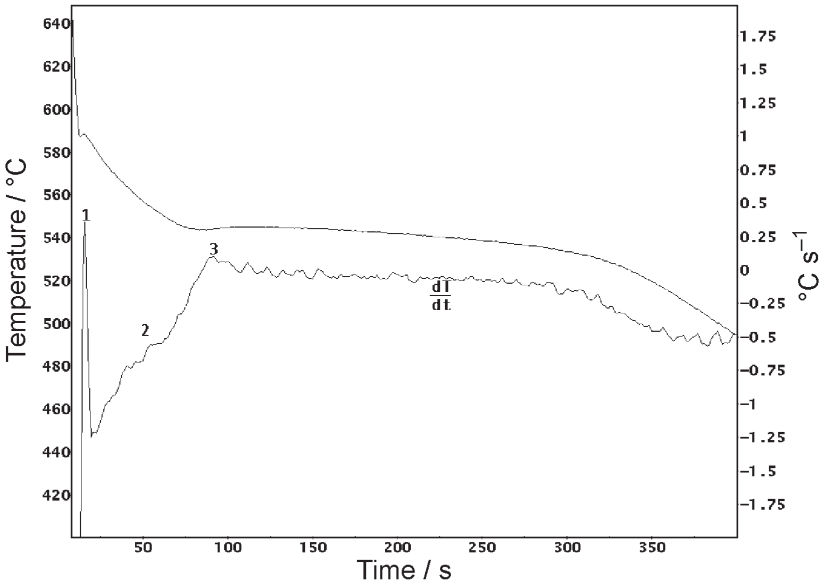

Fig. 3 Typical cooling curve for the AA 380.0 alloy modified by the addition of 2% of magnesium solidified in shell mold

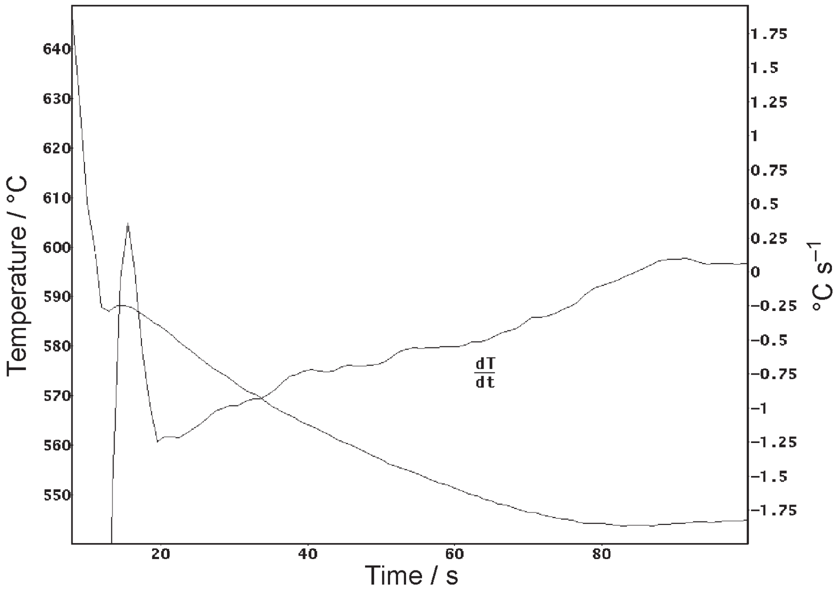

Fig. 4 A detail of Fig. 3 characterizing the Si lamellae dendritic formation

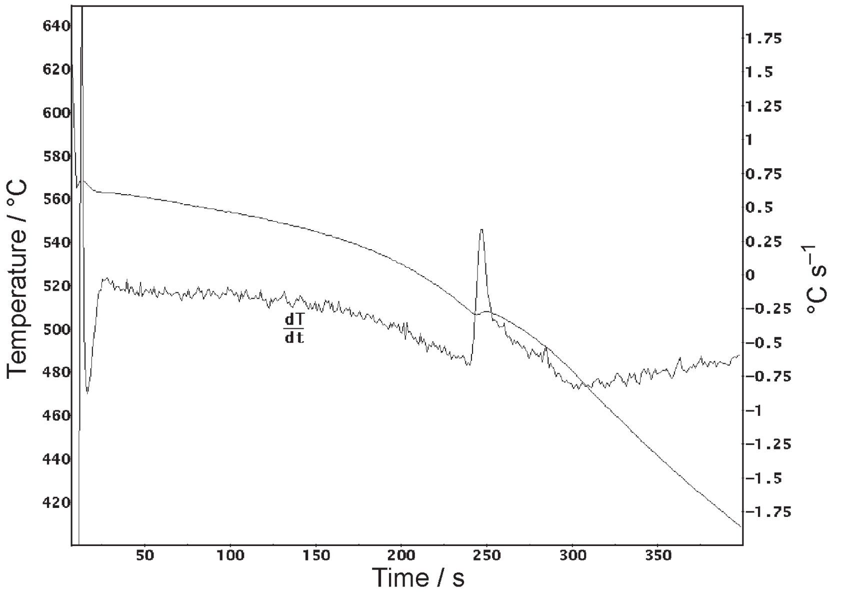

Fig. 5 Typical cooling curve for the AA 380.0 alloy solidified in permanent mold

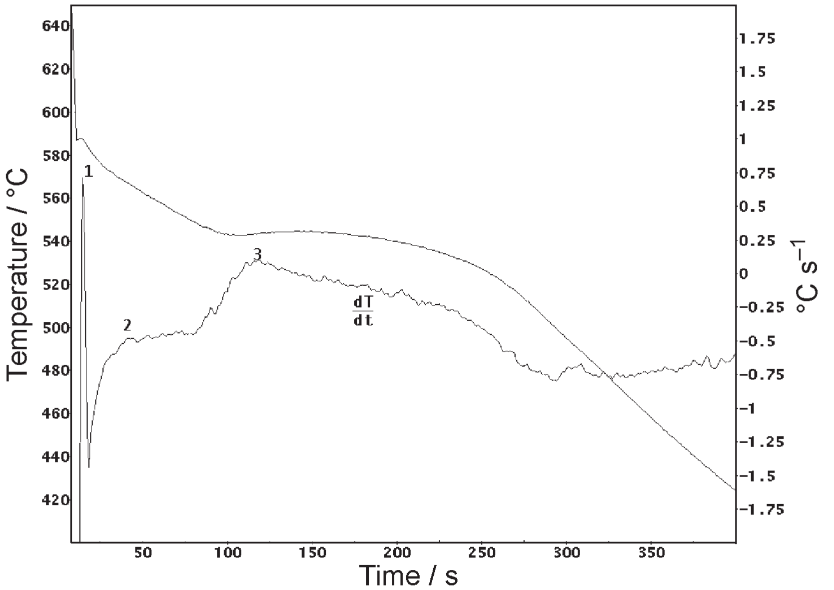

Fig. 6 Typical cooling curve for the AA 380.0 alloy modified by the addition of 2% of magnesium solidified in permanent mold

AA 380.0 alloys presented a typical peak characterizing the end of solidification at 510°C, while in the alloys with addition of magnesium it does not appear in the analyzed temperature range.

It was observed that the time necessary for eutectic reactions to take place in the basic alloy was less than 10 s as shown in Figs 1, 2 and 5. However, the alloys containing magnesium, as it can be seen in Figs 3, 4 and 6, there was an increase on that time, which corresponds to the eutectic reactions to form Al+Si, Al_2FeSi, Mg_2Si and $CuAl_2$, that is situated between peaks 1 and 3. The longest time necessary to these reactions proceed (around 100 s) was observed for the sample solidification in permanent mold, the solidification of which is fast.

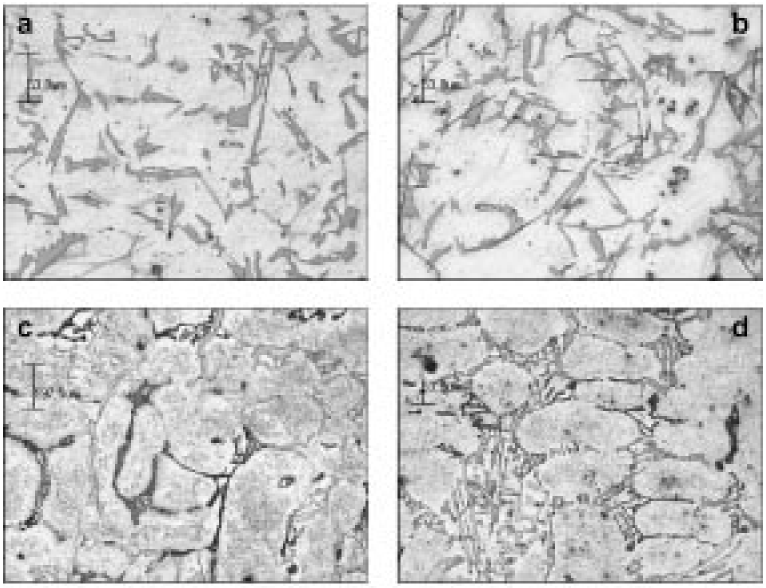

Fig. 7 Microstructures from samples corresponding to AA 380.0 alloy and AA 380.0 alloy with 2% of magnesium solidified in shell and permanent molds; a – microstructure from a sample of the basic alloy solidified in permanent mold; b – microstructure from a sample of the basic alloy solidified in shell mold; c – microstructure from a sample with addition of 2% of Mg solidified in permanent mold; d – microstructure from a sample with addition of 2% of Mg solidified in shell mold

In Fig. 7, the characteristic microstructures of the basic alloy and the alloy modified by the addition of magnesium solidified in shell and permanent molds are presented. In general, by comparing the microstructures for the same alloys (Fig. 7), no significant differences are observed on the phase configuration due to the solidification rate promoted by performing the solidification in shell and permanent molds. If compared to the microstructure of the basic alloy samples, we can observe the presence of more marked needles that correspond to the formation of Al_5FeSi phase [2] in the samples solidified in shell mold, which are characteristic of the AA 380.0 alloys. However, it is clear the magnesium influence on the microstructure formation. The basic alloy is essentially constituted by Al_5FeSi needles, gray Si crystals, pink Al_2Cu and other eutectic complexes while in the alloy containing high amount of magnesium, it can be observed the modification effect on the Si eutectic structure typical of this alloy group and the marked presence of black Mg_2Si phase instead of the Al_5FeSi needles.

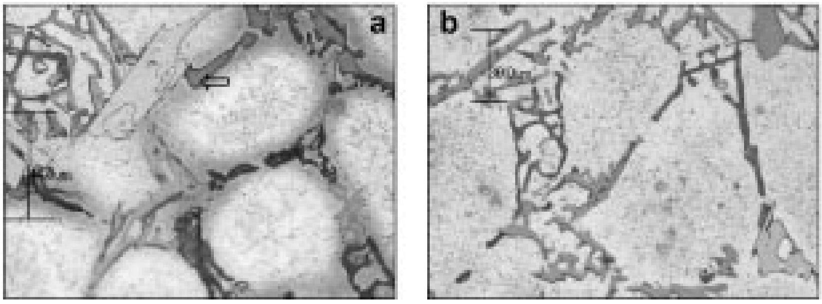

Fig. 8 A detail of the microstructures from samples corresponding to AA 380.0 alloy modified by the addition of 2% of the magnesium; a – solidification in permanent mold showing the presence of red Al_2Cu phase (indicated by the arrow) as part of eutectic formation; b – solidification in shell mold showing no evidences of the presence of red Al_2Cu phase as part of eutectic formation

In the microstructure of the alloy containing magnesium, shown in detail in Fig. 8a, it can be observed the presence of Al_2Cu besides Mg_2Si phase as part of interdendritic phase in addition to gray Si and brown Al_8Mg_3FeSi post-eutectic phase when the solidification is performed in permanent mold. This fact can be related to the presence of the isothermal indicated as number 2 in the cooling curve of Fig. 6. In the alloys solidified in shell mold, e.g., solidified with low cooling rate, the presence of Al2Cu in the interdendritic phases was not evident as shown in Fig. 8b.

In summary, the photomicrographs indicate that the solidification rates changed the precipitate form of AA 380.0 alloys containing high magnesium content (~2%), which was confirmed by the cooling curves and their first derivatives. The modification on the precipitate configuration can directly influence the mechanical properties of these alloys, as well known.

Conclusions

The thermal analysis and the microstructure analysis together are both indispensable tools to predict the mechanical behavior of the casting alloys in function of the solidification rate.

We observed that the presence of high magnesium content promotes the modification of the silicon crystals and the configuration of the eutectic Al_5FeSi needles in AA 380.0 alloy as confirmed by the respective cooling curves and their first derivatives.

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