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Thermal Analysis as a Microstructure Prediction Tool in Aluminum Foundry: A Literature Review

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Thermal analysis is one of the promising microstructure prediction techniques, with a high potential of improvement and accuracy. This paper aims at reviewing the available literature on using the thermal analysis and cooling curves as prediction tools in aluminum foundry. This review covers the relationships between parameters of thermal analysis and the quality of melt preparation, and hence the use of these relationships for the prediction of the major microstructural characteristics, such as the grain-refining potential, the eutectic modification, the formation of porosity in the cast products.

Keywords: *Thermal analysis, cooling curves, grain refining, Si modification, porosity.*

1. Introduction

The quality and properties of Al-Si cast products; such as the mechanical properties, the hot tearing susceptibility, the surface finish, the machinability, and the pressure tightness of products; are based mainly on certain microstructural characteristics. Therefore, the assessment and prediction of such microstructural characteristics before pouring the melt is of prime interest. Of these characteristics is the level of melt quality including the extent of grain refining; and the level of modification [1]; and the level of dissolved hydrogen. In this brief review, thermal analysis parameters related to these microstructural characteristics are discussed.

2. Cooling curves

Thermal analysis using the cooling curves is called conventional thermal analysis. In this technique, the molten alloy is allowed to cool down slowly (0.1 -0.8^{o}Cs^{-1} [2]), and the data are collected form the thermal analysis curve, see Fig. 1. Three regions are of significance in this curve: region A indicating the extent of grain refining, region B indicating the level of modification attained, and region C which determines the end of solidification. The general shape of the cooling curve gives an indication on level of grain refinement and if the grain morphology is columnar or equiaxed [3]. The thermal analysis can be done using either one or two thermocouples. The first thermocouple is placed at the center of the cub mold and the second one is placed near the mold wall.

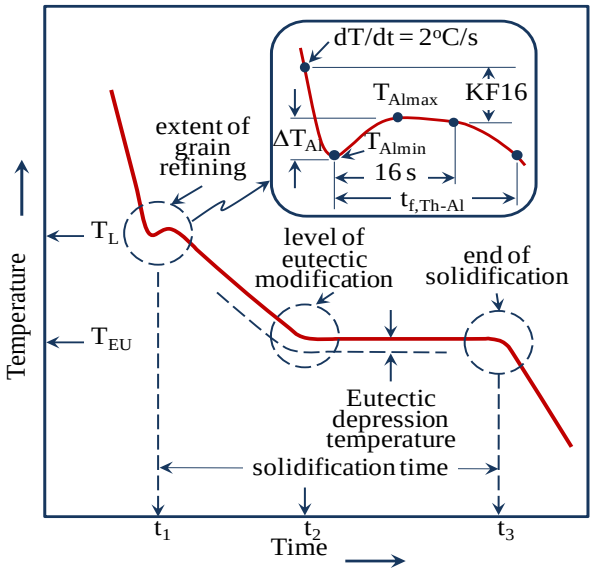

Fig. 1 Cooling curve obtained during thermal analysis and the main thermal analysis parameters.

3. Grain refinement

The grain refining process provides several advantages to alloy properties and processing [4], including better distribution of porosity and second phase particles, improved surface finish and machinability, greater fatigue strength, better pressure tightness, and reducing tendency of ingot cracking, and provides improved mechanical properties and several other beneficial effects. This is why monitoring of the extent of grain refining is necessary for quality assurance before pouring the melt.

Thermal analysis can be used as a technique to control the grain size in castings, and to determine the dendrite coherency point [5]. The relevant thermal analysis parameters used in the grain-size prediction (Fig. 1) of the hypo-eutectic Al-Si alloys [6], are (i) ΔT_{Al} is the recalescence, i.e. the difference between maximum T_{Almax} and minimum T_{Almin} temperatures,

(ii) KF16 is the difference between the temperature when the cooling rate is 2°C/s and the temperature recorded 16s later, and (iii) $t_{f,Th\text{-}Al}$ is the time difference between the moment corresponding to the minimum in temperature and the time at which that temperature is again reached after recalescence.

Several research works were carried to study grain refining potential using this technique [7]. The breaking points of cooling curves were calibrated against the growth temperature T_{Almax}. One the complexities that face this approach is that the growth temperature is a function of the cooling rate. Therefore, constant cooling rate should be experienced to obtain consistent data [5, 8].

When the nucleation undercooling, ΔT_{Al} is large, a relatively large grain size in obtained, and when this value is less than 0.3°C this indicates that there is no barrier for nucleation and the grain size is relatively fine [1]. Hence assessment and comparisons of the grain refining potential of the melts may be done. Grain refinement affects the other thermal analysis parameters such as nucleation and growth temperatures of various phases, *e.g.*, eutectic Si, the solidification range and total solidification time [9].

4. Si modification

During solidification of Al-Si alloys, the liquid phase ends with the eutectic reaction resulting in the formation of the eutectic phases. The unmodified alloy exhibits poor ductility leading to brittle fracture of castings, while the properly modified alloy by strontium or sodium shows ductile mode of fracture, with increased elongation and tensile strength [1].

The thermal analysis parameters related to the level of modification are the eutectic temperature depression and the time difference between eutectic nucleation and eutectic finish points (i.e., t_3-t_2 of Fig. 1). The amount of depression ΔT measured in degrees Celsius is a common indicative parameter for slow cooling rates. The larger the depression the finer and more fibrous is the eutectic structure. For example, well-modified structures occur at depression temperatures of more than 5.5°C in alloys A356.2 [1]. The eutectic temperature is a function of modifier level, and it is lowest at the optimum level of modifier, with over modified alloy showing smaller depression temperatures [10, 11]. The time difference parameter is useful at higher cooling rates [2].

5. Hydrogen level and porosity

The amount of dissolved hydrogen influences the cooling curve characteristics, so that certain parameters from the cooling curve can be used to assess the amount of porosity in as-cast aluminum products. These parameters are the characteristic nucleation temperatures: α-Al nucleation, the Al–Si eutectic and the Al–Si–Cu eutectic temperatures. The effect of different amounts of hydrogen on the Al–Si–Cu eutectic temperature is much more significant than the other two parameters, i.e., the dissolved hydrogen depresses the nucleation temperature of copper rich eutectic phases [12]. The depression reached 12.3°C for a melt containing 0.18 mL H_2/100 g Al [5].

Conclusions

Thermal analysis is a potential technique for the prediction of microstructure characteristics in Al-Si foundry alloys.

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