

# Controlling the structure of aluminium alloys before casting with the thermal analysis equipment

## THERMATEST\* 5000 NG III

### Introduction

In the casting of aluminium, it is important to be able to quickly assess the degree of grain refinement and the type of eutectic structure. If this is done immediately after the addition of grain refining and modifying agents it gives the foundry the opportunity to make any necessary adjustments to grain refiner or modifier levels before casting, thus avoiding the risk of costly scrap due to shrinkage, leakage, porosity and hot tearing caused by poor treatment levels.

The thermal analysis of treated alloys is a widely recognised technique for assessing liquid metal quality before casting. The analysis involves recording the cooling profile of a sample of liquid aluminium during its solidification.

THERMATEST 5000 NG III is a well-proven thermal analysis device designed to quickly predict and subsequently control the structure of aluminium alloys before casting.

### Theory

Specifically for aluminium alloys, thermal analysis enables foundrymen to predict the grain refinement and type of eutectic structure before casting aluminium silicon alloys.

Grain refinement is dependant, to a large degree, on the number of nuclei of titanium boride and aluminium boride. These finely dispersed particles are highly efficient nuclei that promote a fine equiaxed grain growth during solidification. The spectrometer analysis gives only the chemical analysis element by element (Ti, B, etc..) and not any combination of the various elements. Thermal analysis on the other hand shows the alloy behaviour linked to the titanium boride nuclei quantity, which, in turn, directly influences the grain refinement efficiency. Whilst the levels of Titanium and Boron are extremely important they don't necessarily guarantee a good grain refinement.

As far as the modification of aluminium silicon alloys is concerned, good modification is essential to avoid leakages, shrinkage and to improve the machining and mechanical properties of the casting.

Specific elements such as sodium, strontium, calcium, antimony and phosphorus have a significant impact on the silicon form in eutectic structure. However, when combined together some of these elements can give an opposite effect to the one expected. The thermal analysis shows the influence on the structure. Thus any combination of incompatible elements will be immediately detected and shown. This is a major benefit and enhances the knowledge already obtained from the chemical analysis.

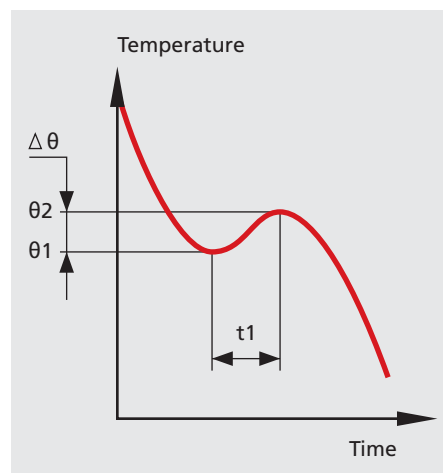
Thermal analysis is therefore able to assess :

- grain size in hypo and hypereutectic alloys
- eutectic structure in Al-Si alloys
- silicon contamination of Al-Cu alloys.

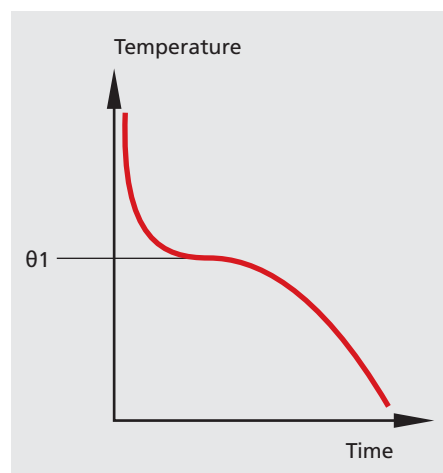
### Evaluation of the grain size

For a given cooling speed, the size of the grain depends on the amplitude and duration of the undercooling, which appears at the formation of primary aluminium crystals.

The graphs below show the profile of the cooling curve, during the solidification of the primary aluminium crystals in case of a hypoeutectic alloy.



Case N° 1



Case N° 2

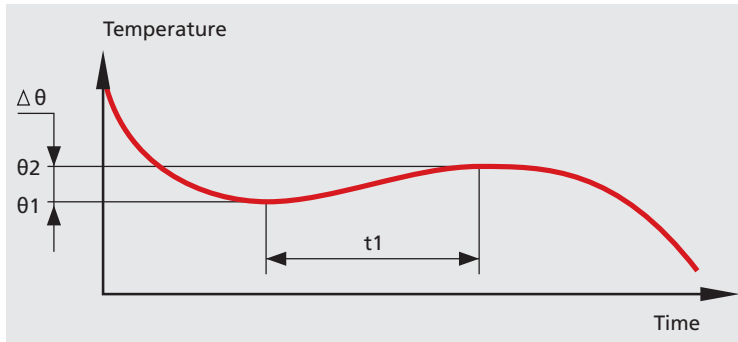
- $\theta_1$  is the temperature at which the solidification begins
- $\theta_2$  is the maximum temperature reached at the end of the undercooling
- $\Delta\theta$  is the apparent undercooling equal to  $\theta_2 - \theta_1$
- $t_1$  is the duration of undercooling.

When the undercooling is high and duration medium (case N°1), grain size is coarse.

When there is no undercooling (case N°2), grain size is very fine.

When undercooling is low but duration is high, the grain size can be very coarse.

### Nature of eutectic structure



The nature of the Al-Si eutectic phase for an alloy of given composition depends on:

- eutectic level temperature  $\theta_2$
- undercooling value  $\Delta\theta$
- undercooling duration  $t_1$

### The eutectic level temperature $\theta_2$

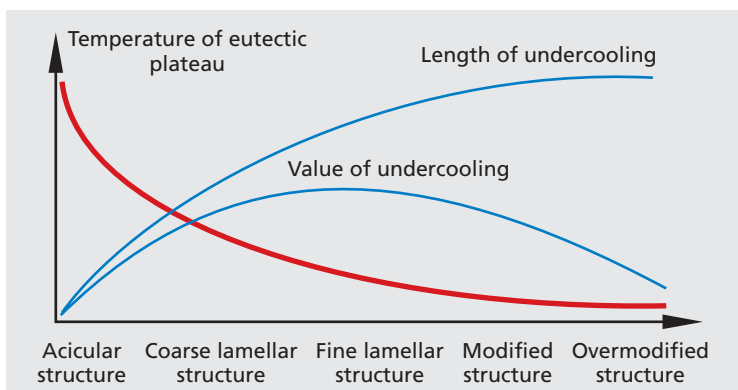
The lower the eutectic temperature is, the finer the eutectic phase will be.

### The undercooling value $\Delta\theta$

- is nil when the structure is acicular or needle-like
- rises when the structure becomes lamellar
- goes through a maximum when the structure is lamellar fine or under-modified
- is low when the structure is over-modified

### The undercooling duration $t_1$

The longer this duration is, the better the eutectic phase modification will be. The graph below shows the nature of the eutectic phase relative to the three parameters (eutectic level temperature, undercooling value and undercooling duration).



### Al-Si 12% Case Study

Al-Si12% is different from other aluminium-silicon alloys because it is a binary alloy, which only contains two elements (Al and Si), (beside impurities). Most other alloys have at least 3 major constitutive elements.

The composition range is such that the alloy can have either a hypoeutectic, eutectic, or hypereutectic structure.

For these reasons, the eutectic level is completely horizontal and undercooling duration has no influence on the structure.

The eutectic level temperature is sufficient to predict the structure if the:

- eutectic temperature above 573 °C indicates that the modification is insufficient
- eutectic temperature below 570 °C is characteristic of an over-modified alloy
- alloy is perfectly eutectic, then liquidus and eutectic are merging
- alloy is hypereutectic, then primary undercooling is nil or of a small duration
- alloy is hypoeutectic, the primary undercooling is visible but of a long duration
- in case the alloy is eutectic or hypereutectic, thermal analysis cannot predict if the structure is lamellar or acicular.

For the hypoeutectic alloys, the undercooling depends on the germination of silicon, which acts on the eutectic structure. Only in this case, we can see a correlation between the structure and the undercooling.

### Al-Si-Cu-Mg alloys Case Study

These alloys can exhibit a secondary eutectic phase depending on the Cu and Mg content. This eutectic phase Al-Cu solidifies around 507°C.

It is important not to forget about this low temperature eutectic phase at around 507 °C when carrying out heat treatment on these castings.

Al-Si11%Cu : this alloy belongs into the hypoeutectic group like Al-Si10%Mg  
 Al-Si12%Cu : this alloy behaves like Al-Si12% as it can have either a hypoeutectic or a hypereutectic behaviour.

**Silicon detection in Al-Cu5%MgTi**

The appearance of a second eutectic phase Al-Si indicates the alloy is polluted with silicon.

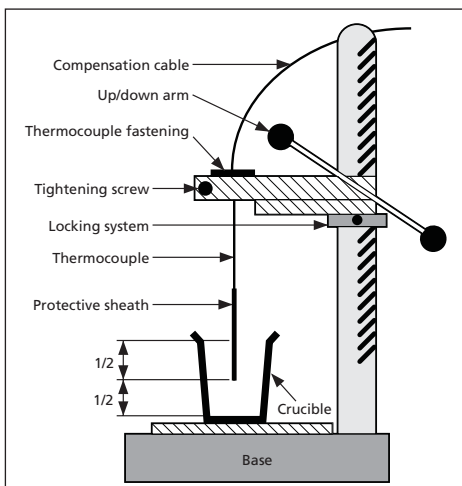
**The THERMATEST 5000 NG III System**

THERMATEST 5000 NG III is a device designed to predict the grain refinement and the type of eutectic structure when casting aluminium alloys.

This equipment is capable, within a few minutes, of assessing the melt quality before casting and allows the foundryman to make the correct additions thus avoiding costly defects such as scrap due to shrinkage, leakage, porosity, and hot tear.



THERMATEST 5000 NG III device



Schematic of Test Apparatus

**Application**

**Grain size evaluation**

THERMATEST 5000 NG III measures the following liquidus parameters :

- temperature  $\theta_2$  (in °C)
- undercooling  $\Delta\theta$  (in °C)
- duration of undercooling  $t_1$  (in seconds).

For these 3 measured parameters and using a proprietary model developed in-house by ALCAN, THERMATEST 5000 NG III is able to calculate a grain size index, which ranges from 1 to 9.

**Grain size reference pictures (Samples Ø 6,5 mm)**

**TEST OF GRAIN REFINING**  
 Standards plates with  
 cotation values



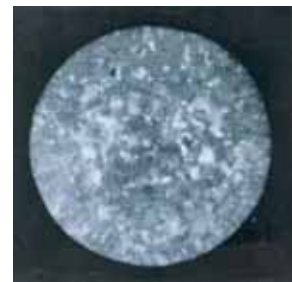
Cotation 0,5



Cotation 1



Cotation 2



Cotation 3



Cotation 4



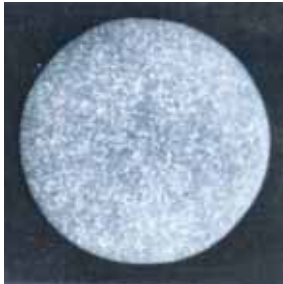
Cotation 5



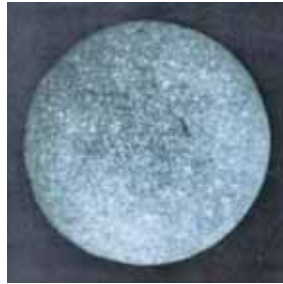
Cotation 6



Cotation 7



Cotation 8



Cotation 9

Grain refinement is considered optimum when the undercooling is nil and grain size index is equal to 9.

However, for certain alloys and thin walled castings in permanent moulds, we can accept a lower grain size index (5 to 9), because of the higher cooling rate created in permanent dies. We then recommend setting a minimum grain size index for each casting, correlated with desired elongation or mechanical properties.

For Al-Cu5%MgTi alloys, the absence of undercooling may not be sufficient to avoid hot tears. A stronger grain refinement is recommended to improve the alloy's performance.

#### Nature of the eutectic structure

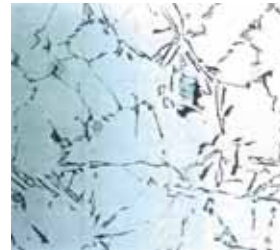
Similar to the grain size case, THERMATEST 5000 NG III measures the following eutectic parameters on the cooling curve:

- The temperature  $\theta_2$  (in °C)
- The undercooling  $\Delta\theta$  (in °C)
- The duration of undercooling  $t_1$  (in seconds)

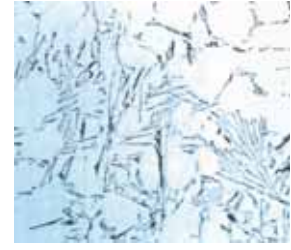
For these 3 measured parameters and using a proprietary model developed in-house by ALCAN, THERMATEST 5000 NG III is able to calculate eutectic structure index, which ranges from 1 to 7.

#### Micrographies (x200) of Eutectic Structures Figs NR 1 - NR 7

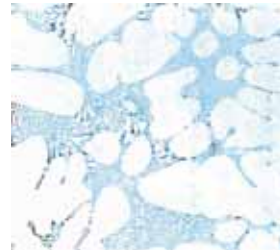
#### Alloy Al - Si 7 %



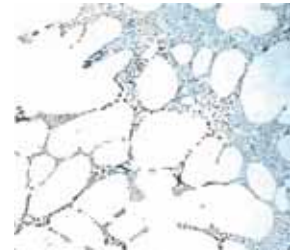
NR 1 Acicular structure



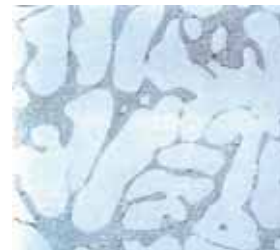
NR 2 Coarse lamellar structure



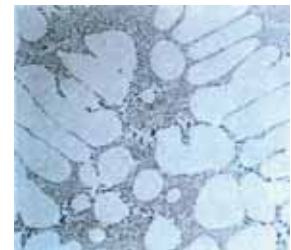
NR 3 Fine Lamellar structure



NR 5 Undermodified structure



NR 6 Fine fibrous structure



NR 7 Overmodified structure

#### Silicon detection in Al-Cu5MgTi

THERMATEST 5000 NG III is able to detect the existence of such a secondary eutectic phase and will indicate that the alloy is contaminated.

## System Capability

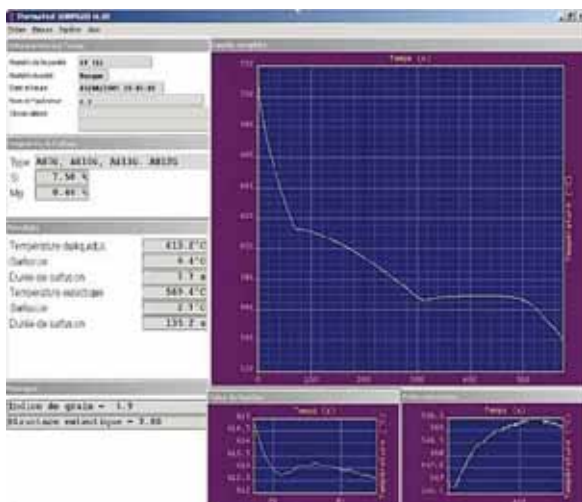
THERMATEST 5000 NG III is designed to analyse the following alloys and compositions:

- ❑ Al-Si-Mg alloys:  
Al-Si7Mg, Al-Si10Mg (6%<Si<12%) (0%<Mg<0.7%)
- ❑ Al-Si-Cu alloys :  
Al-Si5Cu3 (4%<Si<10%) (0%<Cu<3.5%) (0%<Mg<0.7%)
- ❑ Eutectic alloys:  
Al-Si12 (11.5%<Si<14%)
- ❑ Al-Cu-Mg-Ti alloys:  
Al-Cu5MgTi (2%<Cu<6%)
- ❑ Al-Si-Cu-Ni alloys for pistons:  
Al-Si11Cu and Al-Si12Cu (10%<Si<14%)

## Functions



THERMATEST 5000 NG III gives a real time and simultaneous viewing of the cooling curve as well as the results as shown below.



Screen view during analysis

The composition of the alloy influences the cooling curve, therefore to get the most accurate result the specific Si, Mg and Cu concentrations in the alloy must be taken into account. THERMATEST 5000 NG III has a calibration function that allows the exact chemical composition of the alloy in any given furnace to be inputted before analysis thus giving a more precise result.

The other functions are :

- ❑ easy printing of cooling curve and results on any printer installed under Windows XP
- ❑ possibility to transfer data into Microsoft Excel allowing easy reporting, batch traceability and charting to identify trends over time
- ❑ connection to most company networks using Ethernet card and RJ 45
- ❑ automatic saving of all data on the hard drive for future recovery or analysis.

## Cost Aspects

THERMATEST 5000 NG III costs very little to run. Indeed the only consumable items are the steel protection sheath for the thermocouple and the thermocouple itself.

## Conclusion

To maximise the technical benefits and cost effectiveness of grain refinement and modification, the foundry needs to ensure that the treatment agents are used at an optimum and consistent addition rate.

The use of the THERMATEST 5000 NG III, which is quick and easy to use by foundry personnel gives this facility, and with quantitative outputs ensures a consistent level of casting quality. These values can be used to set the optimum addition rates for all grain refining and modification additives and thus to avoid costly scrap due to shrinkage, leakage, porosity and hot tear.