Materials Properties for the Improved Manufacture of Automotive Components

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The casting industry is increasingly reliant on prediction software to simulate their processes in order to improve productivity and reduce energy usage and scrap. For casting models, the knowledge of the freezing range and thermal properties of the metal or alloy to be cast is particularly important – and the model is only as good as the input data. One established method of obtaining such data is Differential Power Scanning Calorimetry (DPSC). Here it is compared with a method of Single Pan Calorimetry currently being developed at NPL. The results from the Single Pan Calorimeter are then compared with the NPL "Virtual Measurement System", a software tool that predicts properties including melting temperatures, heat evolution during solidification and fraction solid.

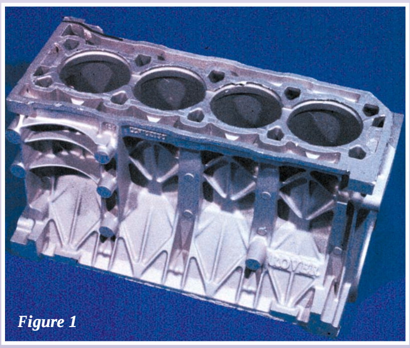


Figure 1

Alloy A356 is an Aluminium – Silicon – Magnesium alloy which has excellent casting characteristics and is the general purpose high strength light casting alloy. Its range of uses is increased by its availability in both the as-cast and partially heat conditioned treatment. A356 is mainly used where good mechanical properties are required in complex castings. The alloy is also used where resistance to corrosion is an important consideration, particularly where high strength is also required.
Several heat treatments are used and provide the various combinations of tensile and physical properties that make it attractive for many applications. This includes many parts in both the auto and aerospace industries, for example aircraft wheels and airframe castings. It is also used in nuclear energy installations and for structural parts requiring high strength such as bridge railings.
The component shown is a car engine cylinder block (courtesy of Rover).

The DPSC chart for A356 shown in Figure 2 shows how the rate of testing affects the shape of the curve obtained.
The DPSC operates by changing the temperature of the sample and a reference cell at a constant rate, and recording the heat difference between the two cells. This difference is recorded beneath the sample crucible, which means there is a delay between a transition happening in the sample and the detection of the transition. This changes the perceived melting range, and affects the calculation of heat evolved.

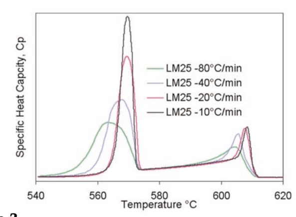


Figure 2

These heat capacity (Cp) curves for A356, shown in Figure 3 were obtained in the Single Pan Calorimeter (SPC). The single pan has a thermocouple recording the temperature inside the sample, eliminating the need for corrections to be applied to the curve. This is possible because a much larger sample is used (4 g compared with 40 mg).

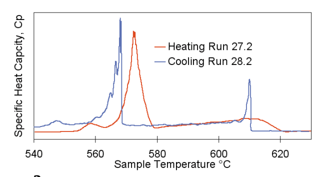
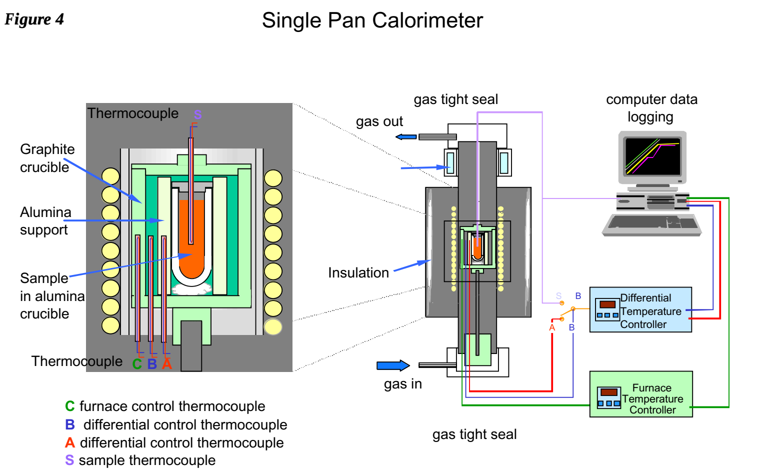


Figure 3

The SPC shown in Figure 4 can be operated in a mode similar to the DPSC, by simply using a furnace to increase the temperature of the sample and record any changes. However it can also be used in a constant heat flux (or 'Smith') mode.

The 'Smith' mode of operation uses thermocouples at two different points in the equipment, and the furnace is programmed to maintain a constant temperature difference between these two points.
When a pure metal melts, it does so at a distinct temperature, either absorbing or evolving energy until the entire sample has transformed to the new phase. Thus, when a transition occurs in the sample, energy will be either absorbed or evolved, affecting the temperature difference across the thermocouples.

Figure 4



The SPC controller will allow for this, and continue to maintain the constant temperature difference, allowing any transition in the sample to go to completion before the entire system changes in temperature. This differs from the DPSC, because in that case the sample has no bearing on the control of the system, leading to another instrumental correction that has to be made.

A prediction by the NPL Virtual Measurement System of the Cp for A356 is shown in Figure 5
The NPL Virtual Measurement System calculations are based on critically assessed data which are used with very robust thermodynamic models developed and compiled by NPL and collaborating organisations over a number of years. The equilibrium data are based on pure thermodynamic data for the elements and assuming that there is infinite time for the sample to reach equilibrium. Thus the onset of freezing agrees very well with the other methods, but the complete transformation into solid phase is not reached on this scale. The Scheil prediction makes some allowance for the kinetics of the reaction – and also calculates minute composition changes occurring within the alloy while the sample is freezing, that affect which intermetallic phases are formed. This is shown by the extra peak in the curve – which is not seen under the equilibrium calculation.

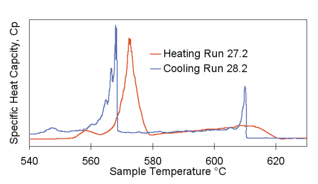


Figure 5

The chart shown in Figure 6 compares the results for A356 from the Single Pan Calorimeter with the prediction, and shows that the Single Pan has detected the intermetallic Cp peak that was not picked up in the DPSC.

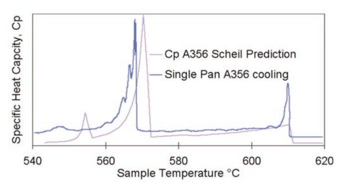


Figure 6

CONCLUSIONS

DPSC is a convenient method of obtaining information on the melting range and heat evolution of alloys. However, because of instrumental effects and problems inherent in the technique, corrections must be applied to the results.

The Single Pan Calorimeter provides a method of obtaining both more accurate and additional information on the alloy. These improved data can be used to make a significant improvement to the Virtual Measurement System.

The Virtual Measurement system is a useful tool for predicting thermophysical properties of commercial alloys. It is to be used to provide key data to solidification modelling packages such as MAGMASOFT and Procast.

The VMS is for use by engineers who are not experts in thermodynamics and it provides an easy to use graphical interface on a standard personal computer, shown in Figure 7

It is hoped to develop the Single Pan Calorimeter for use at higher temperatures, to encompass other industrially important alloys such as steels and nickel based superalloys, where the melting range is of particular importance in determining the temperature at which heat treatment can be performed.

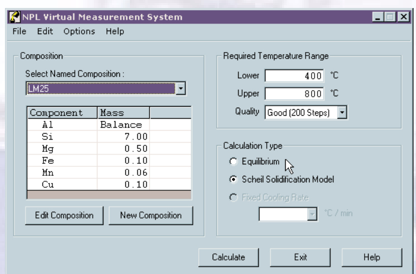


Figure 7

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