

# Ablation casting

*J Grassi and Prof J Campbell, Alotech Limited; M Hartlieb and F Major, Alcan Inc.*

### Abstract

A new casting process is described in which the mould is formed by an aggregate bonded with a water-soluble binder. The liquid metal is poured into the mould, and whilst still molten, the mould is ablated away by water jets. Because the mould is progressively removed, the water is enabled to contact the metal casting directly, eliminating the air gap that limits the heat transfer from practically all other conventional casting processes. The high temperature gradient, moved progressively through the casting, assists to eliminate shrinkage porosity especially in thick sections. The outcome is solidification under unprecedented temperature gradients and solidification speeds, giving a unique microstructure characterised by extreme fineness of the last phases to solidify. Porosity can be controlled to be extremely low or effectively zero even in such features as isolated bosses by manipulation of freezing conditions, which are now under independent control. Mechanical properties are equal to or surpass the best competitive processes such as squeeze casting. Additional advantages appear to be competitive cost and rapid productive capability. Forward plans are for additional metallurgical advantages via the production of high quality liquid metal, transferred by counter gravity (for instance low pressure) into moulds to minimise the generation of defects.

### Introduction

Casting process are complex operations that are hedged about by a wide variety of constraints resulting in the industry and its customers having to compromise on more issues than either party would like.

For instance, for high cooling rates to obtain a fine structure and good mechanical properties, a metal mould must normally be chosen. This is usually costly, has a long lead time, and limited in its life to somewhere in the region of perhaps 80,000-150,000 shots for a pressure diecasting operation. Thus the tooling amortisation is a significant component of final costs (often up to 8-10% of the piece price). In addition, the extremely fast filling conditions can make properties and performance difficult to achieve and to some extent even unpredictable. In high pressure diecasting the effect of die soldering imposes another compromise on the alloy selection, i.e. the addition of Fe and Mn, which again has a negative effect on properties. Naturally, the industry is making strides to overcome these issues, but usually at the penalty of increased costs, and reduced productivity.

For sand castings (aggregate mould castings) and investment castings the filling can, in principle, be better controlled, but the freezing is now often unsatisfactorily slow or involves complicated chilling, giving relatively

poor and not homogeneous mechanical properties. The aggregate binder may be a clay/water mixture as in the so-called greensand moulding processes, characterised by rapid rates of production, but in general limited to castings of modest complexity and accuracy. In contrast, the core assembly type of processes deliver a product of excellent accuracy, and of great potential complexity, but whose resin-type binder systems, and aggregate reclamation, are a major component of the final cost.

Over and above all such detailed considerations, during freezing of the casting, the casting contracts away from the mould, and the mould expands, opening the so-called 'air gap' between the casting and the mould. This gap is a major barrier to the rate of escape of heat from the casting. Thus the air gap, above nearly all other contributors to cooling, controls the rate of cooling, and thus the fineness of the microstructures, and as an ultimate consequence, the mechanical properties of the casting.

This paper describes a new approach to the making of a casting in which this fundamental limitation to heat flow is removed by the application of coolant direct on to the surface of the casting. As a necessary prior step, of course, the mould had to be removable to allow direct access of coolant. This was achieved with the use of an aggregate mould bonded with a binder soluble in the coolant.

### Experimental

Moulds were made from silica sand of AFS 60 fineness, bonded with a proprietary binder based on sodium silicate. Rather than cast test pieces, the test casting in this study was an automotive steering knuckle from which was subsequently excised test bars.

A356 alloy from pre-alloyed ingots was analysed in wt% as Si 7.18, Fe 0.089, Cu 0.006, Mn 0.002, Mg 0.36, Cr 0.002, Ni 0.001, Zn 0.007, Ti 0.13, Sr 0.00044, Na 0.0014, B <0.00001, V 0.009, Zr 0.001.

The metal was melted in a resistance-heated crucible furnace in a SiC-Graphite crucible. Prior to the start of a casting shift the temperature was raised to the pouring temperature 730°C and rotary degassing with nitrogen was applied for 20 minutes. The melt was carefully transferred to the mould by hand ladle, the melt being transferred into the mould cavity via a glass cloth screen. The mould was tilted at about 20 degrees above the horizontal during pouring into the filling basin. Immediately the temperature in the basin reached the casting temperature of 720°C the mould was filled by starting the rotation of the mould, lowering its angle of tilt through the horizontal, to 20 degrees below the horizontal in five seconds.

Ablation, using overhead water sprays at 65°C was immediately applied to the far ends (the coolest end) of the casting, progressing upwards along its length (fig.1), and completing the ablation of the mould and the freezing of the casting (fig.2). The casting was fed by a feeder planted off the casting along one of the relatively narrow arms. The casting at this stage was clean and cold (although the feeder retained some residual heat as can be seen from the feeder sleeve in fig.2), and ready for subsequent dressing as necessary, and heat treatment.

The solution heat treatment was carried out at 540°C for two hours followed by aging at 155°C for four and 12 hours, and in Table 1 at 160°C for 3.5 hours. Test bars were then excised from the



*Fig. 1 The ablation of the mould in progress*

casting and were subjected to tensile testing at room temperature.

## Results

The optical microstructure of a test casting that was allowed to solidify without ablation is shown in fig.3, and is typical of a non-modified Al-Si eutectic. Typical ablation-cooled structures are shown in figs.4 and 5 illustrating limited regions of the dendrite spacing that have been refined. Fig.6 shows the extreme fineness of the eutectic spacing that is difficult to resolve even at 1,000 magnification in the optical microscope.

At four hours ageing the room temperature tensile properties averaged over three samples were 0.2% proof stress 215 MPa, UTS 310 MPa and 12% Elongation. At 12 hours the corresponding figures were 260, 340 and 9%. Table 1 shows the average results of a minimum of three samples per heat treatment condition, comparing the mechanical properties with typical results of competitive casting processes<sup>(3,4)</sup>.

## Discussion

Figs.4 and 5 illustrate the extent of freezing that has taken place before the ablation cooling has had time to reach these regions. Thus the secondary dendrite arm spacing (DAS) is in general rather coarse, and typical of a sand casting of that section thickness. In some instances, particularly in the centres of sections, it is at first sight curiously perverse that the DAS is fine. This of course is the result of ablation arriving in time to limit dendrite arm coarsening in these regions. Furthermore, such regions would often contain porosity, thus weakening the structure, whereas ablation tends to yield sound and fine grained interiors that would be expected to have enhanced properties. The fine DAS achievable if ablation arrives in time is plotted in fig. 7, although it has to be noted that most of the structure consists of a DAS significantly further to the left on fig.7, typical of conventional cooling rates in silica sand<sup>(1)</sup>.

Figs. 5 and 6 show the benefits of ablation to the eutectic structure, giving an inter-particle spacing under 1µm. It is to be noted that no significant chemical modification with Na or Sr is present in this case. Ablation cooling gives spacings that are consistent with an extrapolation of the previous<sup>(2)</sup> finest chill modified structures.

Secondary beta-iron particles can be discerned in the eutectic, but are extremely fine, and in general less than approximately 5µm long. This small size is partly the result of the low Fe content of the forging alloy melting stock, and partly as a result of the reduced time available for growth. This factor, probably more than any other, has contributed to the improved properties recorded in Table 1.

It is extremely significant that the improved properties are clearly not directly related to DAS, which in general is not improved. Improved properties appear to be a result only from improved control of the solidification of the eutectic. The current preoccupation focussing on the achievement of a fine DAS is therefore seen to be incorrect in assuming that DAS is the controlling parameter (although of course correct in the sense that DAS indicates freezing time).

## Notes on present achievements and future targets

The ablation technique is already in daily production in a licensee foundry. Two examples of ablation-cast products are shown in figs.8 and 9.

Alloys that are traditionally difficult to cast



Fig. 2 Ablation complete

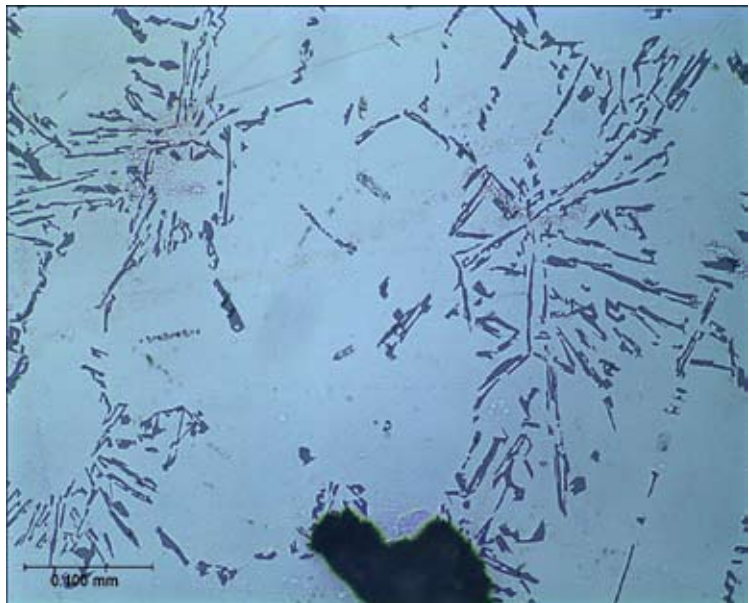


Fig. 3 Unmodified and unablated structure

such as the 206 series alloys prove to be straightforward with ablation. Furthermore, the wrought alloys including the 6000 and 7000 series have been demonstrated to be castable without problems. This unprecedented alloy freedom offers significant potential for properties unthinkable to obtain in conventional casting processes. A co-operation with Rio Tinto Alcan has therefore been created focussing specifically on the development of the alloy/heat treatment potential. Developments are planned to improve the products further by the use of a new melting and casting technique, involving the

	Sand Cast	Perm. Mould	Squeeze Cast	Pressure Counter Pressure	Ablation Cast
UTS MPa	228	262	312	334	325
Yield MPa	179	207	243	239	261
Elongation %	3.5	4	11.0	14.3	12.5

Table 1. Comparative mechanical properties

# Technical Paper

Fig. 4 (top left)  
Mixed DAS by late  
ablation

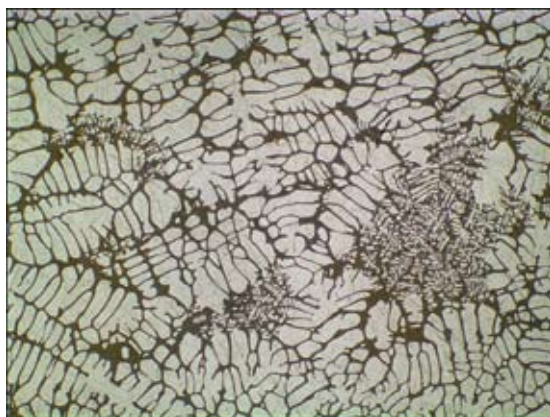


Fig. 5 (top right) DAS  
with traces of late  
ablation

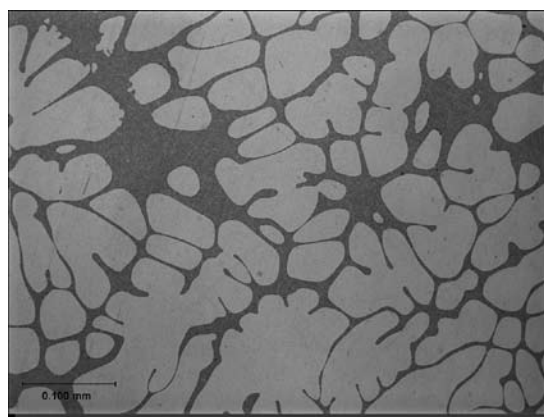


Fig. 6 (bottom right)  
Eutectic phase at  
1000X

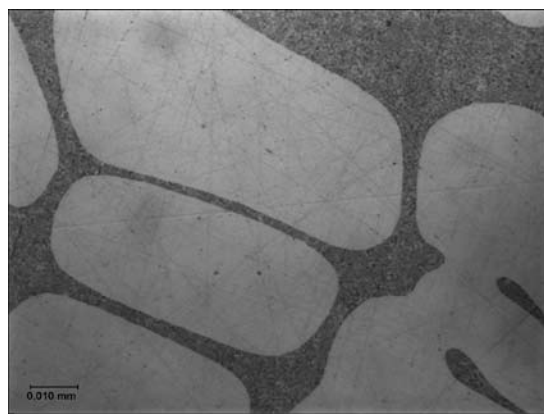
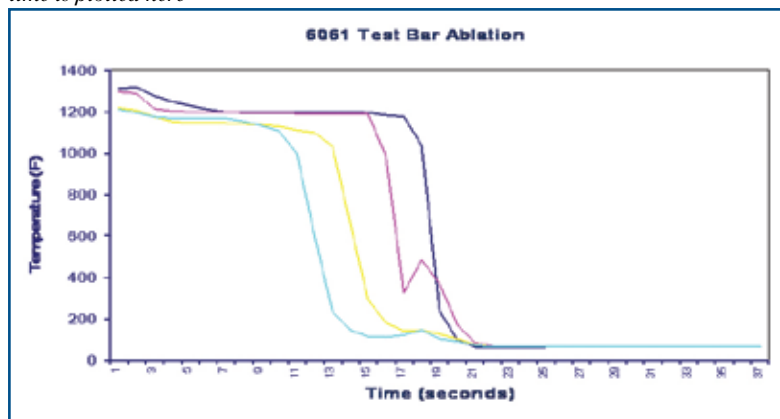


Fig. 7 (bottom left)  
Higher cooling rate  
achieved through  
ablation arrives in  
time is plotted here



production of low gas- and low oxide-containing melts and counter-gravity filling of moulds. A second round of enhancement in properties and reliability is expected to result.

The process is creating extensive interest in the industry for its technical breakthroughs as well as its economic advantages combined with the fact that it is extremely environmentally friendly. The major barriers of the process - surface quality of the castings and distortion during solidification - have successfully been addressed and numerous programs have been started with a number of major OEMs in various industries.

## Acknowledgments

Thanks are due to Buell Motorcycles for permission to publish images of their latest exciting products.

## References

- Spear R E and Gardner G R. Trans AFS 1963 Vol 71 pp209-215.
- Najafabadi M A A, Khan S, Ourdjini O and Elliott R; Cast Metals 1995 8 (1) pp35-42.
- Jorstad J, WPI / NTNU Summer School, Trondheim, August 2001.
- Ruff G, Prucha T E, Barry J and Patterson D. SAE World Congress, Detroit 2001, paper 0411, published in *Automotive Casting Processes and Materials* SP-1603.

Fig. 8  
Example of  
casting in  
production  
using ablation  
casting  
process,  
knuckle  
component



## Note

The ablation process and the melting and casting processes are protected by patents granted and applied for in the USA and other parts of the world.

*This paper was presented at the TMS (The Minerals, Metals & Materials Society) conference 2008, it is reprinted here with their permission.*



Fig. 9 An aluminium alloy B206 (Al-4.5Cu) alloy swing arm casting, 2.5 mm thick wall, with isolated unfed bosses, notably free from hot tearing, characteristic of this alloy