Practical experiences with the MAVIS solidification simulation software

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Since its introduction in January 1992 the MAVIS solidification simulation software has been extensively adopted throughout the UK foundry industry as a practical design tool. The software, developed in the Department of Materials Engineering at the University of Wales, Swansea, was initially introduced as a rapid simulator for the prediction of macroscopic defects in castings. However, recent improvements in the processing power available on the PC platform have enabled a full numerical finite difference simulator to be also incorporated into the package. The MAVIS software can now provide the foundryman with additional information on, for example, solidification times, temperatures in the casting and mould, Niyama coefficients, dendrite arm spacings and cooling rates. This information combined with macroshrinkage predictions from the rapid simulator can help to enable tooling designers to produce right-first-time castings, improve yields, reduce scrap and considerably reduce tooling lead times and development costs. Although the predictive capabilities of the software have been considerably improved the MAVIS package remains extremely user-friendly, an important consideration when evaluating software.

This paper reviews the software and describes some of the practical solutions to typical founding problems achieved using the MAVIS solidification simulation software in a variety of commercial foundries.

The MAVIS software

The first stage is to create the solid model. This can be carried out manually from 2D drawings using the integral solid modeller or automatically from any ASCII STL (stereolithography) CAD file. The casting geometry is created within a variable grid of elements where the number of elements in any of the three major axes can be specified by the user. Models can contain up to 16 million elements. The drawing tools contained within the modeller are operated by the use of a standard PC mouse making modelling extremely easy and fast. Most casting geometries and runner / feeder systems can be modelled within a few hours. When the casting geometry has been generated it can be viewed from 6 different angles to aid product visualisation (fig.l).

Fig 1. Six views of a solid model

The MAVIS rapid simulator requires no material properties data, instead parameters are selected using sliding scales for mould conductivity, insulator conductivity, chill conductivity, shrinkage % and gate effects (localised heating of ingates due to mould filling). For a new installation the parameters for a particular alloy and process must be fine-tuned by simulating castings where the defect locations are known and adjusting the values to obtain an accurate prediction. This can usually be accomplished within 2 to 3 weeks. When the appropriate values have been selected the solidification simulation can be run. The rapid simulator can predict the likely locations of macroscopic defects and also the macroscopic freezing pattern. The simulation results can be displayed in both X-ray and sectional format using the post processors. If design modifications are required to improve casting quality or yield these can be made with the solid modeller and further simulations carried out.

When the tooling design has been refined using the rapid simulator, further simulations can be carried out using the numerical finite difference simulator to obtain more detailed information. The user is required to input materials properties data for the casting alloy and mould materials e.g. specific heat capacity, latent heat of fusion, liquidus and solidus temperatures, pouring temperature etc. and also the boundary conditions for the simulation. The software is supplied with a comprehensive materials properties database which may be modified by the operator. The numerical simulator can predict the solidification time to a user-defined critical-fraction solid, temperatures in the casting and mould, temperature gradients, cooling rates, Niyama coefficients, local solidification times, and dendrite arm spacings for aluminium alloys in which primary aluminium solid solution is the first phase to solidify. The MAVIS software can also calculate the weights of castings, moulds, dies and cores and the cast / mould surface area for pressure diecasting applications.

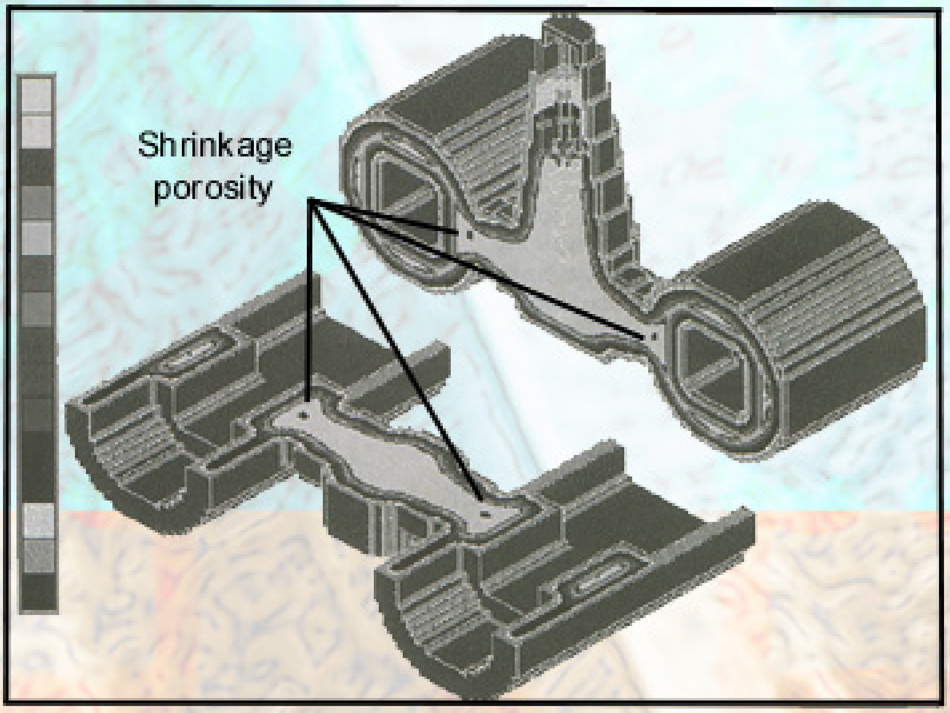

Fig 2. Macroscopic freezing pattern of the original method revealing shrinkage porosity in the gate area

Case study 1

An engine component in B S 2789 Grade 500/7 spheroidal graphite iron weighing 4.3kg with ten castings per moulding box. This part was an existing component, produced by Bryan Donkin Company Ltd when the MAVIS software was purchased in May 1994, which suffered from medium to high foundry and machining scrap rates. The main problem area was the heaviest section of the component which when machined to produce an oil control groove frequently revealed shrinkage porosity in the gate area (fig.2). The original method had been designed using the normal practice of feeding the heaviest section with one feeder situated between two castings in the box. During the course of production the neck area had been enlarged in order to address the porosity problem, however satisfactory scrap rates had not been achieved.

The part was modelled with the MAVIS system in order to determine whether the shrinkage porosity could be successfully eliminated by increasing the feeder neck further. The simulation results showed a small improvement in casting quality by increasing the feeder neck however the porosity could not be removed completely with this method. It was decided to model the casting with the feeder located away from the heaviest section with a reduced neck size. This was easily achieved by importing the feeder and necks between the two castings previously modelled. The trial simulation revealed that the porosity could probably be eliminated using this method.

Further simulations were made with different feeder locations in order to determine the optimum position and achieve directional solidification towards the feeder (fig.3). From the simulation results it was decided to locate the feeder across the heavy / thin section junction. The pattern equipment was then modified and significant improvements were made for both foundry and machined scrap rates.

The solution achieved with the MAVIS software would not have been attempted using trial and error methods in the foundry. The rule of thumb approach 'feed the heaviest section' would have prevailed and consequently a significant scrap reduction would not have been achieved.

Modelling time for initial design - 1.5 hours
Modelling time for all modifications - 1.5 hours
Simulation time (per method) - 30 minutes
Original foundry scrap rate - 8%
Current foundry scrap rate - 1%
Original machined scrap rate - 33%
Current machined scrap rate - 6%

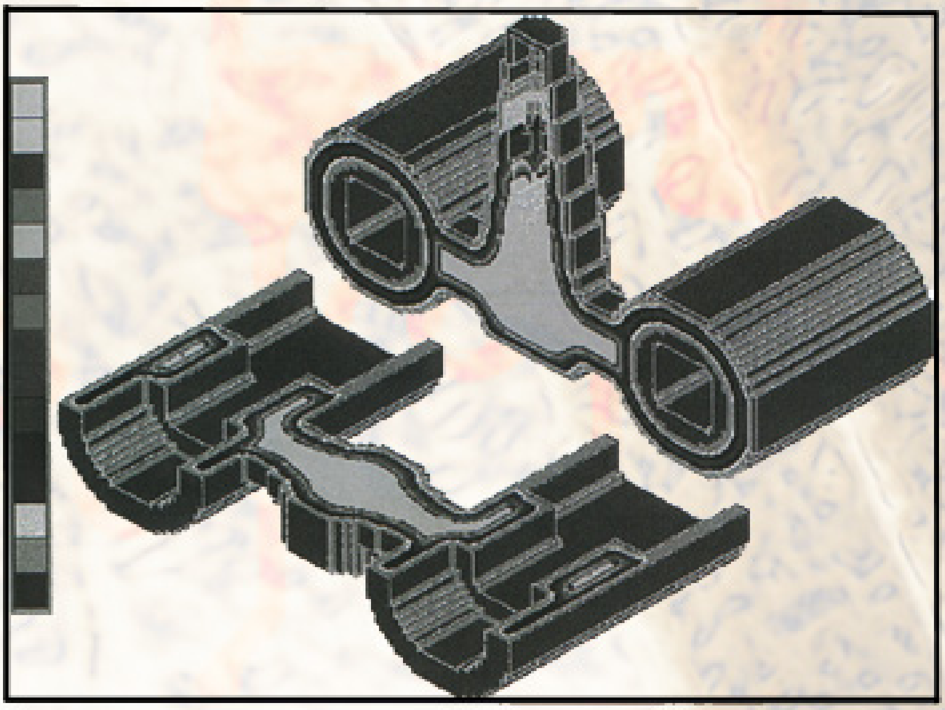

Fig 3. Macroscopic freezing pattern of the current production method shows directional freezing towards the feeder, eliminating the porosity in the gate area

Case study 2

A base plate casting in B.S. 2789 Grade 5OO/7 spheroidal graphite iron weighing 6.1 kg in a single impression pattern plate produced on a Disamatic moulding machine. This was a new part for W. Lucy & Co Ltd which sampled right-first-time with the use of the MAVIS software. The component shape was modelled and an initial simulation carried out with a single feeder located on the top face of the casting and an in-gate positioned immediately above a bolt hole. The simulation results showed that the neck of the feeder was not of sufficient size to feed the casting adequately and that macroscopic defects were likely to occur near to the top bolt hole adjacent to the in-gate (fig.4). The next stage was to model the casting with a larger feeder neck and to move the in-gate up in an attempt to feed the top bolt hole. The porosity below the feeder was effectively eliminated with this method however the bolt hole area still suffered from porosity. A feeder was situated above the bolt hole and the casting simulated again, improvements were made but it was decided to simulate a hot bleed into the feeder from the running system which MAVIS had shown on previous occasions to work very well, The simulation result showed a sound casting (fig.4) and consequently the Disa plate was produced,

Modelling time for initial design
1 hour

Modelling time for all modifications
1.25 hours

Simulation time per method)
20 minutes

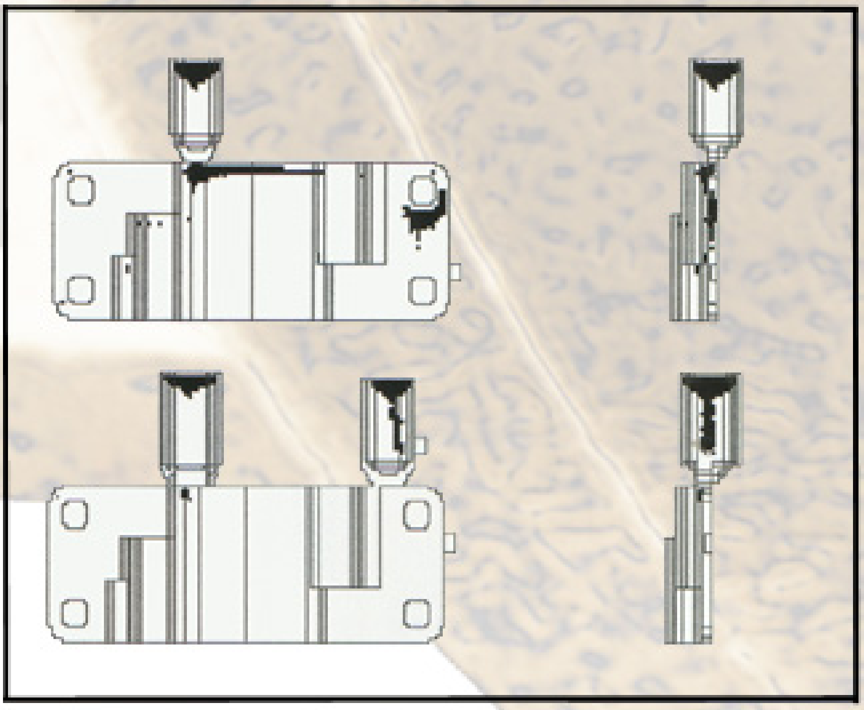

Fig 4. Comparison of the macroshrinkage predictions for a base plate casting

Case study 3

A cup casting in A316 casting alloy weighing 250g produced by the investment casting process. This part was an established component at Lost Wax Development Ltd which suffered from very high scrap rates due to leakage when pressure tested after machining. The casting was modelled on the MAVIS system in order to establish the reason for the porosity occurring and to suggest modifications which would improve the scrap rate. The simulation results of the initial production method revealed that the feeder design was not correct to feed the casting sufficiently and also that the component design was largely responsible for the porosity formation (fig.5). It was decided to simulate both modifications to the component design and the feeder geometry in order to create directional solidification towards the feeder. The MAVIS software was used to determine the most economic design modifications and the optimum feeder geometry required to produce a sound casting (fig.6). The results were presented to the customer and design concessions granted for the tooling to be modified. The machined scrap rates have been reduced significantly.

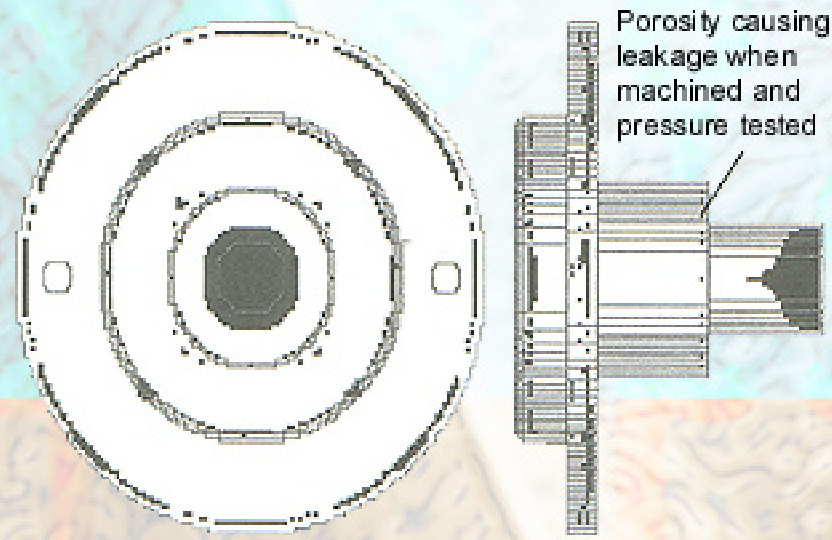

Fig 5. Macroshrinkage prediction for a cup casting of the original component design and method

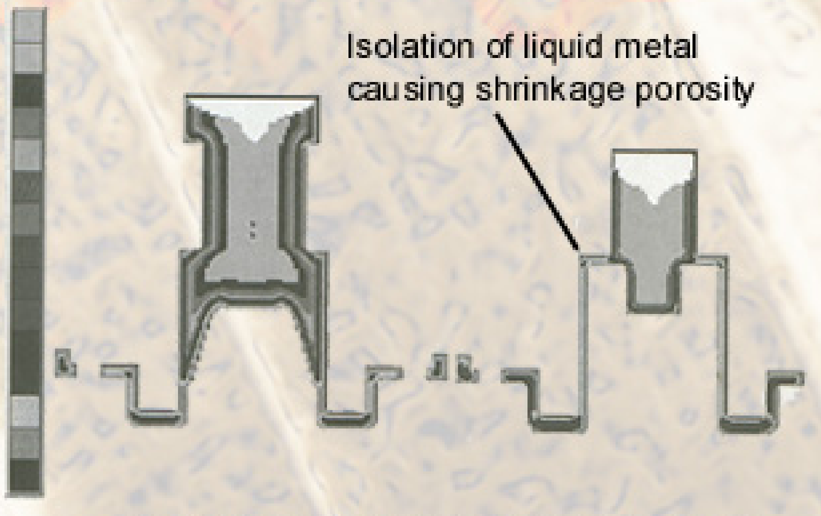

Fig 6. Macrofreezing patterns for modified component design (left) showing directional freezing towards the feeder and original design (right) showing hot-spots in critical area.

Modelling time for initial design - 45 minutes

Modelling time for modifications - 30 minutes

Simulation time (per method) 30 minutes

Original scrap rate - 15%

Current scrap rate - <2%

Numerical simulations

The MAVIS finite difference numerical analysis enhances the predictive capabilities of the software package. For example the solidification modelling of diecasting processes (cyclic) necessarily requires the analysis of the die temperature distribution to be carried out prior to the simulation of solidification. Account must be taken of the internal and external die shape and cooling systems if present. When cyclic processes are simulated using the MAVIS finite difference simulator the average steady state die temperature distribution is first calculated (fig.7) before proceeding to the simulation of solidification. Different cooling systems and die profiles can be simulated to examine the influence of the die temperatures on the quality of the casting and to establish the optimum die design.

Numerical simulations also predict the solidification time for every location within the casting. Figure 8 shows the solidification times for a gravity diecast 60/40 brass valve body which predicts an isolation of liquid metal which resulted in a surface sink. These times can also be particularly useful for estimating die cycling times and likely production rates. Solidification times can be determined for any critical fraction solid (the solidified fraction through which the alloy cannot feed) set by the user. Other results files which can be obtained include Niyama coefficients which can be used to determine the locations of macro and centreline shrinkage in steel castings and also dendrite arm spacings for aluminium alloys.

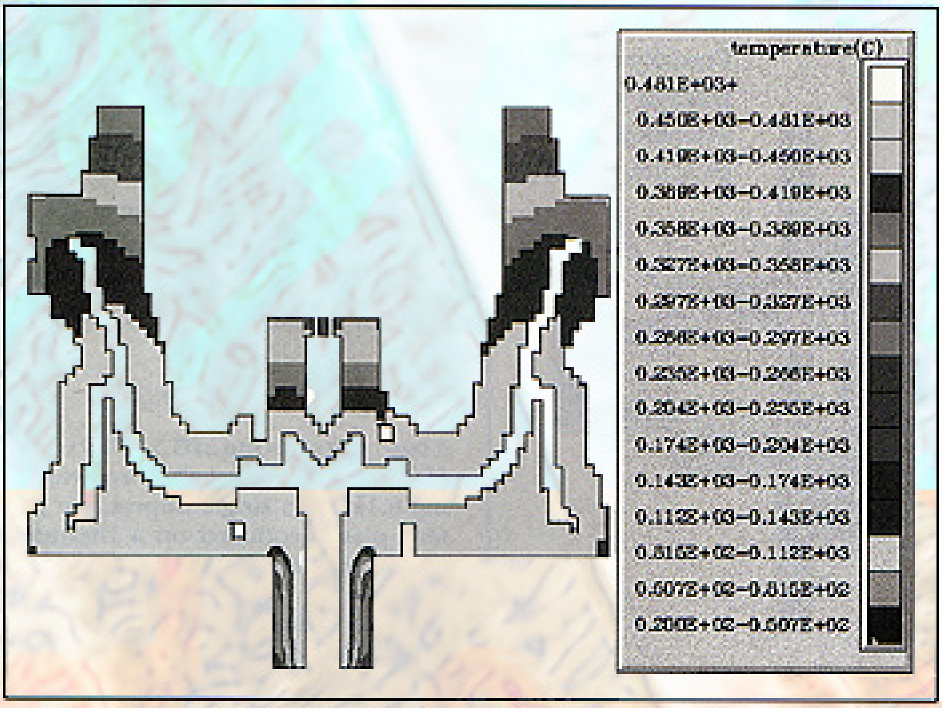

Fig 7. Average steady state die temperature distribution for a low pressure die cast road wheel

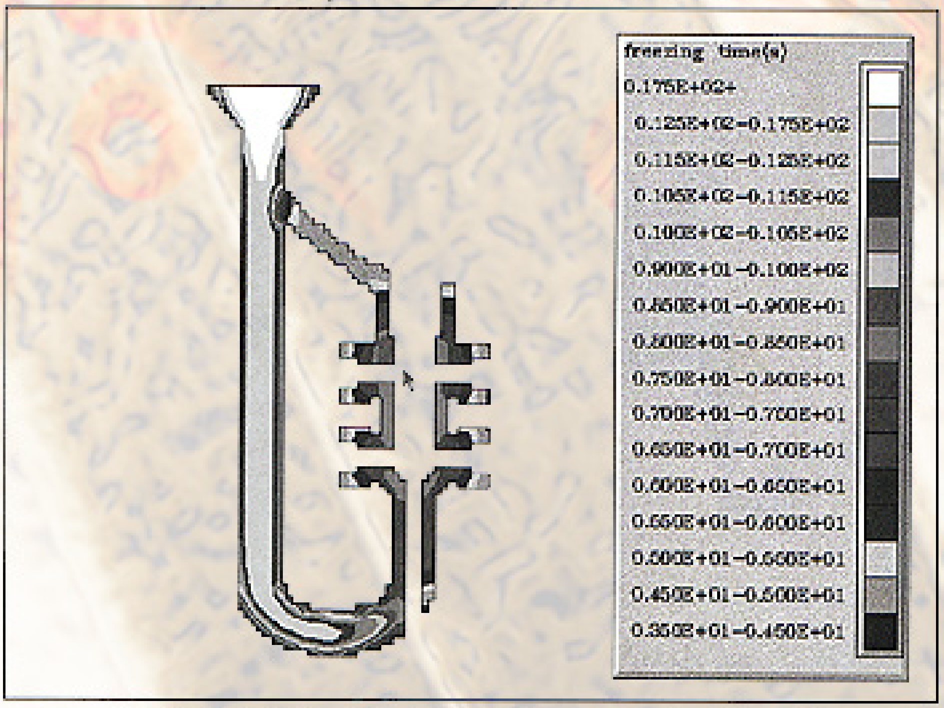

Fig 8. Solidification times for a gravity diecast valve body showing a surface sink defect

Summary

The MAVIS software has proved to be a very successful practical tool for solving typical shrinkage problems found in most foundries. The system enables the consistent design of economic methoding systems producing high quality right-first-time castings. The package combines all of the advantages of rapid simulation models with the additional benefits of a finite difference numerical model. The MAVIS software offers a unique combination of high specification and low cost which is further enhanced by a free update service included with the technical support.

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