MAGMAsoft Helps Assure Quality in a Progressive Australian Iron Foundry

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Abstract

The use of MAGMAsoft, a computer code that simulates mould filling and solidification, has helped Toowoomba Foundry assure the quality of its iron castings with a higher degree of confidence, and reduce the cost of rejects. The effective use of this software package has resulted in major improvements being realised in the areas of controlling shrinkage porosity, inclusions and cold run defects. It has also contributed towards lowering the cost of methoding, productivity gains through reduced dressing, and safer fettling arrangements - all made possible by innovative methoding. An account of the different problems fixed in each of the above areas is provided using examples.

Introduction

Toowoomba Foundry (TF) is the market leader in Australia and New Zealand for wheel-related iron castings used by heavy vehicle manufacturers and their suppliers. Its Toowoomba Wheel Products (TWP) customers include Volvo Australia, Mack Australia, Iveco, Arvin Meritor and Colrain. The TWP range consists of hubs, brake drums, wheel spiders, and the recently launched disk brake rotors.

Other iron castings made at TF using its greensand mould casting process also enjoy a strong reputation for quality and performance. For instance, the high performance 'Iron Lightning' V8 cylinder heads manufactured at TF are highly regarded by the racing fraternity in the United States. The foundry also makes iron castings for other automotive customers such as Spicer Axles Australia, pump and irrigation equipment castings for Tyco, water fittings and custom-designed products for contract clients, and railway axleboxes for SKF and Koyo.

TF is already a quality accredited company. It is also the first iron foundry in Australia to be awarded the environmental management accreditation. In 2001, TF won an award at the voluntary Greenhouse Challenge programme.

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Established way back in 1871, TF has been continuously adapting itself to changing market needs in order to stay in business. While still relying on the skills of its tradespersons, it has now invested heavily in modern technology to propel itself forward towards achieving world class status.

In this paper, we shall describe how the use of a 'virtual reality' software simulation tool has enabled TF to transform from a foundry that consistently had to do several trials before getting a job right, into one which gets it right the first time almost all the time. In short, TF can now assure, as opposed to control, the quality of its products and processes with a higher degree of confidence.

Before launching into the main topic, a broad outline on modern technology available at TF is provided in the following Section in order that this paper is read in the proper context.

Modern Technology at TF

The use of virtual reality based on software tools enables TF to foresee problems before they happen and avoid them, and to conduct the manufacturing activities economically, and with a minimum of errors. Modern machinery controlled by software allow the foundry to operate at a higher level of productivity and a finer degree of consistency.

Quality at an affordable price is a major demand of the market. This obviously means a foundry has to provide a high quality casting, but should be able to manufacture it at a low cost.

An ever shortening product development lead time is another requirement of the day, as customers of the foundry scramble to be the first in the market with their products. In order to achieve this, the product, related tooling, and all relevant processes should be conceived and designed such that the product turns out right the first time, and every time.

To successfully meet the above two demands, TF has responded with investments in state-of-the-art technology. A finite element analysis package known as MSC PATRAN enables the engineers to carry out stress analyses on alternative casting shapes and arrive at the optimal shape for use in a given application. Another software package called MAGMAsoft, which simulates the flow and solidification of melt, is employed to determine the castability of a particular product so that it turns out right the first time, and is done so at the lowest possible cost. The 'right first time' capability also shortens product development lead time. A solid modelling package known as SolidWorks allows TF's engineers to model castings in 3-Dimensions and export the models into MAGMAsoft for simulation and into Computer Aided Manufacturing (CAM) cell machines for churning out patterns of the casting shape. The programmable CAM machines also use modern software such as Unigraphics and MasterCAM.

Often times, the customers want castings in a machined form to avoid capital investment of their own in this regard. TF has, over the years, invested in several Computer Numerically Controlled machinery to achieve higher productivity and process consistency. Recently, two high capacity robot cells that automatically machine hubs and brake drums were installed, and have helped TF serve the customer better with reduced delivery lead times.

There is also now the tendency in the vehicle manufacturing industry to procure items as a module. As a rudimentary example of this, instead of purchasing a brake drum and a hub separately and putting them together, the customer prefers to buy an assembly of these two items that is ready to go into a product being made at his or her facility. An automatic robot assembly cell that was installed recently helps TF carry out the assembly operation more efficiently. This cell also carries out balancing and roundness checking operations automatically.

Simulation as a Tool for Designing the Casting Process

It is beneficial to know, before making a casting, if it will turn out right. This will save time and money spent on trial and error. It is a bonus if one could come up with the cheapest method of making a particular casting.

Software simulation of the casting process helps TF achieve the above goals with remarkable consistency. It allows the optimal methoding to be arrived at within a matter of a few days, after considering several alternatives.

This increased confidence in methoding has allowed TF to introduce new products in a relatively short time. For instance, during the first half of 2001, a total of twelve TWP brake drums and a TWP hub were introduced for the New Zealand customers within a matter of 9 weeks. Further, a TWP disc brake assembly, the first of its kind for the foundry, was introduced in 6 weeks in August 2001 - days ahead of the original launch date.

Simulations are essentially mathematical calculations presented to the user in visual form using colours or lines or both. The software package encapsulates the physics (e.g. momentum, heat transfer) related to the processes involved in casting.

The user tells the software the shape of the casting and the runner/feeder system, what materials are used in the process, at what temperature the melt is poured and where it is poured into the mould. The software, as its output, gives the user the filling time, filling sequence, regions where inclusions which are washed in with the initial melt would end up, solidification time, the solidification pattern, regions which may suffer from shrinkage porosity problems, and metallurgical and mechanical properties of the finished casting.

To carry out the calculations, the software breaks down the entire casting process into several small time intervals, or steps, and solves relevant mathematical formulae at each of these time steps. When these time intervals are joined together and the results at each of these steps viewed in sequence, a continuously changing picture that imitates the actual casting process is obtained. Modern software tools have powerful visual capabilities which present this information in a manner that is easily understood.

The software package employed to carry out the simulation at TF is MAGMAsoft, which is the subject of the next Section.

A Brief Outline of MAGMAsoft

Key features of any software simulation tool include: (1) a good project recording environment where all "what if" design changes can be recorded, analysed sequentially and accessed at a later date; (2) a powerful automatic meshing capability that can import files from a CAD (i.e. Computer Aided Design) source and checks all contacting surface for boundary data input; (3) a comprehensive library of nonlinear material data; (4) fast but comprehensive solvers for filling and solidification; and (5) a comprehensive postprocessor to facilitate viewing the changing physics that follow any new "what if".

Correctly modelling the filling events is pivotal as this sets up the temperature ecology which drives solidification. For iron it is essential that the coupled heat transfer analysis is accurate as the metallurgy in spheroidal graphite iron is so sensitive to cooling rates. Also, correct prediction of the formation of solid phase growth sites and the micromodelling of phase formation must be possible as this will underpin the Finite Element Analysis of the part in service and the casting process must yield correct material properties (tensile strength, hardness etc.), and not just a sound casting.

As this software now maps a correct thermally dependent modulus of the casting and feeder arrangement, maximising yield is straight forward. Issues such as gas diffusion through the surrounding sand and venting not only allow for correct prediction of venting needs, but also shows up the influence trapped air pockets. These last to fill volumes diminish the cooling rate of a casting in localised spots and adversely affect the metallurgical characteristics, besides promoting microporosity in unexpected regions. Consideration of air pressure through the sand is also encoded in the solvers and aids correct simulation of feeding events during solidification.

Being able to run "what if" scenarios on different chemistry and inoculation practices is immensely helpful as each foundry is unique in this regard, with methods of inoculation, and furnace practices being influential in the outcome. So a package must be able to factor in the parameters that originate from these issues as they are practiced at each individual foundry. Really it is no longer good enough to just simulate solidification based on thermal changes. Inoculation, process setting, furnace practices, chemistry changes, shakeout all make a difference and typically the simulation only stops when below 700C when all solid phase transport has ceased.

As castings get thinner issues such as distortion due to residual stress and distortion that occurs post machining also may need to be taken into account. The ability to transfer results (e.g. residual stress, temperature maps, material properties) from the casting simulation to the finite element software is also needed to link this analysis effort into a real CAE (i.e. Computer Aided Engineering) cycle. Any break in this linkage diminishes the potential advantages that the technology offers. TF's selection of casting simulation software was based on these abilities of MAGMAsoft.

Examples of Successes Flowing from the Use of Simulations

Several jobs have profited from simulations. <u>For example, during the past financial year, which was only the second year of use of MAGMAsoft at TF, a total of 44 jobs were put through and benefits realised. Of these, 28 jobs were right the first time, shrinkage problems in 10 existing jobs were fixed, and productivity and process improvements effected in the balance 6.</u> Descriptions of the different problems solved are provided below under various categories.

Right First Time

One of the first jobs to be put through MAGMAsoft was the V8 cylinder head. This was completely new territory for the foundry back in 1999, as it had not cast an automotive cylinder head before. The customer wanted castings urgently, to be showcased at a Trade Show in the United States. TF was faced with a tight deadline. To make matters more difficult, the customer did not supply an engineering drawing, but handed only an existing casting with an altered shape. The port shape had been redesigned according to his laboratory tests to have an optimised flow for better engine performance. TF personnel had to measure the dimensions of this entire casting themselves, and create a solid model. This did not leave TF with enough time for carrying out several foundry trials to perfect the methoding.

Fig. 1: A machined V8 "Iron Lightning" cylinder head cast and machined at TF.

A simulation with a rough methoding was first carried out. This showed there was a potential for sinks to occur. It also highlighted a region with shrinkage porosity. Feeders were therefore added on, and a further simulation carried out. This time MAGMAsoft predicted a casting free of sinks and shrinkage. This methoding was therefore used for the foundry trials. The actual castings contained neither sinks nor shrinkage porosities. Also, due to the success, the castings made it to the Trade Show. Up to date, no cylinder head casting has been rejected at the foundry due to the above two reasons.

Shrinkage Problem Eliminated

Perhaps the best example for this category is the stub axle casting TF makes for one of its Australian customers. An entire batch of 39 spheroidal graphite castings made in September 1999 was rejected by this customer due to shrinkage porosity visible after machining at his facility. These castings were to go on cane harvesters that were being exported. Because the customer could not assemble the machines without castings, he was running the risk of holding up a ship bound for southern America.

TF carried out a simulation with MAGMAsoft, found out why the porosity occurred, fixed the problem electronically, did foundry trials, made a batch off 44 castings, dressed the castings, and dispatched them away - all within 6 working days of the news of the rejection of the original batch. It is debatable as to whether this swift turnaround could have been achieved without the simulation tool.

Inclusions Problem Fixed

One of the back plate castings TF had been making for years tended to suffer from severe sand inclusions every now and then. As the profit margins on this casting was relatively low, it was imperative TF made good castings every time.

A MAGMAsoft simulation was carried out with the existing runner system to understand the flow characteristics. The following were observed: (1) the curvature of the runner just prior to the ingates was such that any inclusions would have a good chance of entering the ingates, and (2) the high velocity with which the melt was emerging from the choke could be causing sand erosion from some parts of the runner. The runner system was completely redesigned such that the above problems were avoided. TF now makes good castings every time it pours this back plate job.

Process Improvement

Separating the feeders from the castings was an arduous task in some of the railway axlebox castings TF makes for bearing companies. This was because the feeder connections to the casting were so large, that they could not be mechanically knocked off using a wedge breaker that goes inbetween the casting and the feeder to split them apart. The feeders were therefore sawn off using a band saw. It was a relatively slow operation costing labour time, and a safety issue given that the operator was handling a heavy casting.

MAGMAsoft simulations were carried out to work out the smallest possible feeder connection that would be necessary to produce a sound casting. This allowed the use of the wedge breaker on many axlebox castings. Jobs other than axleboxes also have benefited from such optimisation.

Productivity Improvement

TF used to make 6 slingers in a mould box, but castings from one of these patterns suffered a 78% reject rate due to shrinkage porosity. Therefore a decision had been made to remove this pattern from the mould.

Fig. 2: A slinger casting.

After the purchase of MAGMAsoft, a simulation was carried out to determine why this particular mould cavity suffered most. Temperature profiles predicted by the software showed that, due to the design of the runner system, this cavity ended up being the hottest. The runner system was completely redesigned, and this 6th pattern reintroduced into the mould. As a result, a 20% improvement in moulding productivity was achieved.

Cost Reduction - Less Bought Out Materials and Less Machining

One of the TWP brake drums suffered a reasonably high level of shrinkage porosity due the shape of its cross section at a particular region. Because of this, a decision had been made to shift the casting from the cope half of the mould to the drag half. While this solved the shrinkage problem, due to the extra metallostatic pressure in the drag, the job suffered from severe metal penetration defect. Substantial time was therefore spent on dressing the surface. To counter this cost, the drum was again moved into the cope, but was cast this time with exothermic sleeves.

MAGMAsoft simulations were recently carried out during a minor redesign of the drum, not affecting the above region. At this point it was noticed that, if the runner system was suitably modified, there was no need for the exothermic sleeves. Today, perfect castings are obtained without the sleeves. Also, since there are no connections left behind where the feeders enclosed by the sleeves connected to the casting, productivity at the machine shop also is higher.

Conclusion

The use of MAGMAsoft at TF has enabled the foundry to progress towards getting castings right the first time, and cut the process development lead time significantly. This virtual reality simulation tool also allows TF to assure the quality of its products and processes with a higher degree of confidence due to its powerful predictive capabilities. Further, it has helped the foundry reduce the cost of rejects, and manufacture castings more economically.