Co-operative Virtual Foundry for Cost-Effective Casting Simulation

B. Ravi, Associate Professor
Mechanical Engineering Department,
Indian Institute of Technology, Bombay
bravi@me.iitb.ac.in

G.L. Datta, Professor,
Mechanical Engineering Department,
Indian Institute of Technology, Kharagpur
gld@mech.iitkgp.ernet.in

ABSTRACT

Virtual casting trials ensure that real castings are right first time and every time, in the shortest possible time. This involves computer-aided modelling, pattern design, methoding, simulation and optimisation. Casting simulation technology has been proven for all major cast metals and processes, giving reliable results for even complex castings. It is however, unaffordable and inaccessible to the majority of our SME foundries. We propose a collaborative national initiative to create a virtual foundry that can be reached through the Internet, and where virtual casting trials can be performed to optimise the tooling, methoding and process parameters. The virtual trials will consume a fraction of the resources required for real trials, and provide better insight to meet the desired quality requirements. The virtual foundry will be backed by a well trained team of casting engineers to guide the users and provide necessary technical support. The architecture, functions, and mechanism of the virtual foundry are designed so that even small foundries in remote areas are able to easily use and benefit from the technologies.

Keywords: Computer-aided Design, Casting Simulation, Foundry, Internet.

1. INTRODUCTION

Computer-aided casting development comprises three major phases primarily carried out in the OEM firm, tool-maker and foundry, respectively (Figure 1). The first phase involves shape design and optimisation of a cast part to meet the stated functional requirements. The second phase involves tooling development and methoding (or rigging), and its optimisation to achieve the required quality at the lowest cost, through shop-floor trials or process simulation. The third phase involves casting process planning (deciding the steps, parameters and checks in various activities), material requirements planning and scheduling, to produce the castings within the target dates.
The following benefits are reported by the users of computer-aided casting development technologies.

**Cost savings in casting trials:** The costs associated with tooling modification (feeders and gating), cast metal (wasted during melting, pouring, fettling), indirect materials (mould and core sand), energy (for melting, fettling, machining), labour (shop-floor and supervisors), and loss of regular production, are eliminated or significantly reduced.

**Cost savings during regular production:** This includes improved yield (in turn leading to lower energy cost, and more saleable castings), and significantly lower rejections during casting, machining and service.

**Cost savings by design improvements:** Computer-aided casting development in collaboration with OEM firms leads to reduced tooling complexity (therefore lower tooling cost), and robust product design (implying consistent quality in spite of minor variations in process parameters).

**Benefits by value-addition:** Better insight and confidence implies that more difficult (higher value) casting orders can be taken up. The foundries can also establish a documented scientific basis for quality certification, and use the system as a marketing tool, especially for export orders.

**Other long-term benefits:** Computer-aided systems ensure better working environment, rational decisions, faster training, and higher productivity. These factors directly help in attracting and retaining young engineers. The systems also help in preserving in-house experience even if key employees retire or leave, useful for troubleshooting old projects, and rapidly developing new casting projects.
The above benefits are driving increasing acceptance of IT applications in industry, as seen from a recent survey of over 100 foundries from all over India, covering all major metals and processes [1]. Internet-based applications (such as e-mail) had the highest growth in the last five years, followed by CAD/CAM and planning software programs. Casting simulation programs have the least penetration: about 15% in the sample group, and an estimated less than 3% overall in the country. Interestingly, most of the participants agree that casting simulation helps in faster development, lower rejections, higher yield, cost reduction and customer satisfaction (Figure 2). They are however, unwilling to acquire simulation software because of three major problems: (1) high initial cost, (2) difficulty in getting sufficiently qualified manpower, and (3) poor long-term technical support from software vendors. These problems are further magnified for SME foundries located in remote areas.

![Figure 2. Benefits and concerns of computer-aided casting software.](image)

In other words, computer-aided casting development technologies have significant proven benefits, and are essential for competitive success in the global casting market. However, most of our SME foundries can not take advantage of the technologies owing to problems related to high cost, qualified manpower and technical support. For widespread usage, two conditions need to be satisfied: (1) the benefits of virtual casting trials must be shown to be significantly higher than those of real trials, and (2) the cost and difficulty of virtual trials must be significantly lower than those of real trials. While the first condition is generally satisfied by most casting simulation programs available today (illustrated through industrial case studies), the second condition has become a major bottleneck, especially for SME foundries.

The above problem can be solved by creating a virtual foundry for rapid casting development. It can be used for virtual casting trials at a fraction of the time and cost of shop-floor trials, for optimising the methoding and process parameters. The virtual foundry can be reached through the Internet, so that even SME foundries in remote areas can use and benefit from casting simulation technology. It will be backed by a team of qualified and well-trained engineers, guided by experts, to assist the foundry users in initial stages and for difficult cases.
2. TECHNOLOGY DEVELOPMENT

Two critical technologies are required for implementing the virtual foundry system: (1) automated methoding and casting simulation, and (2) web-based casting project management. These technologies have already been developed, validated and refined over the last few years. The methodologies and results have been published in leading national and international journals and conference proceedings, receiving favourable review from peer researchers and experts. The underlying know-how and know-why have also been shared with the casting community through several continuing education programmes, in turn gaining valuable feedback and new ideas for the virtual foundry project. The related work and progress are briefly described here.

The technologies for automated methoding and casting simulation have been developed under the name AutoCAST [2]. The first step in automated methoding involves determining the best orientation of the casting to minimise undercuts, and the mould parting line to minimise draw and draft [3]. This is followed by feeder location (near the largest hot spot), and gating location (side feeder, if available, or a thick section with the least obstructions and free fall of metal). The design of the feeder and gating channels is also automatic. The feeder dimensions are computed based on the geometric modulus of the nearest hot spot region. Gating channel dimensions are computed after determining the ideal filling time (function of casting weight, section thickness and fluidity), followed by choke velocity (metallostatic head), and choke area, using the gating ratio [4].

The mould filling is simulated to determine the actual filling time (to check the gating design for the ideal filling time), identify metal impingement location and velocity (possibility of mould erosion/sand inclusions), and visualise blow hole formation, if any. The thermal gradients set up during mould filling, coupled with other important boundary conditions (mould and core materials, and feedaids such as chills and insulation) affect casting solidification. This is simulated using the vector element method which traces the feed metal paths in reverse to accurately pinpoint the location and extent of shrinkage defects such as cavity, porosity and centreline shrinkage [5].

The casting methoding and simulation program has been successfully validated by troubleshooting and optimising over one hundred different industrial castings of ferrous and non-ferrous alloys, produced in sand as well as metal moulds. In addition, an estimated 2000-3000 virtual castings have been produced in 40+ foundries where the technology has been implemented over the last few years, without any major discrepancy between predicted and actual observed results (shrinkage porosity).

A few case studies using the above technology, and leading to improved quality, yield and value, are shown in figures 3-5. The first case is an aluminium-alloy switchgear tank produced by gravity die casting (courtesy, Crompton Greaves Ltd., Mumbai). The casting is about 280 mm in size, and weighed 6.1 kg. It was found to leak during pressure-test, and rejections were as high as 35%. The methoding was modelled as produced in the foundry, and simulated to locate two regions of shrinkage locations leading to leakage. The methoding was improved by placing a chill in the cores and insulation on feeders, and verified by simulation. The rejection level immediately reduced to less than 6%.
Figure 3. Aluminium-alloy circuit breaker tank by gravity die casting

Figure 4. Ductile iron railway insert casting by Disamatic process

Figure 5. Steel press cylinder by green sand casting process
The second case is a ductile iron railway insert casting produced by Disamatic process (courtesy, Tulsi Foundries Ltd., Sangli). The casting is 176 mm long, weighing 1.4 kg (Figure 4). The initial methoding comprised a top feeder, leading to almost 100% rejection of sample castings. This layout was modelled and simulated to find the cause: the feeder was small and too far to feed the hot spot region. The modified layout comprised a bigger side feeder connected to two castings, which not only eliminated the shrinkage cavity, but also improved the yield from 66% to 67%.

The third case is a steel press cylinder casting produced by green sand process (courtesy, Mukand Ltd., Thane). The casting is about 3100 mm high, and weighed 22,923 kg (Figure 5). It was found to crack near a square-like projection on the side after 3-5 years of service, whereas the customer desired at least 10 years of service life. Casting simulation showed poor feeding and micro-porosity under the projection, leading to the conclusion that the porosity opened up into a crack due to repetitive loading after a few years of service. Since the methoding could not be improved further, the final solution was to move the projection closer to the feeder, and also provide a slight taper (padding to the central hole) to ensure progressive directional solidification [6]. The new casting was produced, rigorously inspected, and has successfully completed two years of service.

The second major R&D area relates to web-based technologies, which were explored for metal casting applications. The first task was to develop a web-friendly language for capturing and storing all information related to a casting project. This was achieved by creating a casting markup language (CastML), based on the XML (eXtended markup language) format, to store various groups of information related to project (admin),

![Web-based integrated casting engineering (WebICE) system](image-url)
product, tooling, process, material and quality in a hierarchical structure [7]. The next task was to create a client-server system to facilitate web-based casting project management and collaborative engineering among foundry and OEM engineers. A few functions such as casting alloy selection, process planning [8] and cost estimation [9], that did not require a solid model of the casting, were developed and provided in the system. The system, called WebICE (web-based integrated casting engineering), was implemented at www.metalcastingworld.com and a few virtual foundries were created [10] to test the concept. This provided valuable feedback from test users, as well as experience in developing and managing such systems.

In addition, advanced concepts such as Holonic Manufacturing System (HMS) were also explored to provide a higher level of automation and intelligence to the virtual foundry. A holon is essentially an autonomous and cooperative building block of a process for transforming, transporting, storing and or validating information and objects. A HMS comprising of holons representing various sub-systems of a foundry lends itself to analysis for comparison of process indices like productivity, lead time, cycle time, total transport work involved, shop floor area and human-hours [11].

The virtual foundry project is based on the technologies and experience described above. Its detailed architecture, major functions and working mechanism are described next, followed by the plan for its implementation and technical support.

3. VIRTUAL FOUNDRY

The virtual foundry will be a replica of a real foundry, with separate departments or sections for part design, tooling design, methoding, casting trial, and planning functions. Each real foundry that is a member of the community will have its own replica in the virtual foundry zone (Figure 7). Each virtual foundry (VF-A, VF-B, etc.) will be defined by its profile (cast alloys, process, equipment, etc.), and capabilities (range of casting
weight, complexity, quality, sample lead-time, etc.). Its customers (OEM-X, OEM-Y, etc.) will be able to send their enquiries (part model, order quantity, quality requirements, etc.) to the virtual foundry. The foundry will develop the casting, perform virtual casting trials until the desired quality is achieved, and plan actual production (material requirement, process plan and cost estimation). Upon confirmation of the order, the foundry will download all details of the optimised virtual casting, produce a sample casting for verification, and then initiate regular production.

The virtual foundries and casting software programs will be maintained in a set of powerful computers linked to the Internet through a virtual foundry server. The member users will access various sections of a virtual foundry after passing through three security gates as follows (Figure 8).

**Gate 1: Virtual foundry zone.** Only member foundries and OEM firms will be able to enter after providing their login id and password. After entering, they will see the names of virtual foundries located in the zone, and select a particular virtual foundry to enter.

**Gate 2: Particular virtual foundry.** Only the authorised engineers of a foundry and its customers (OEMs) will be able to enter the virtual foundry, after providing a specific login id and password. After entering, the foundry engineers will see the names of various casting projects under development. The OEM engineers will be able to see only their own projects. A particular project can be selected for entering.

**Gate 3: Particular casting project.** Only the authorised engineers of a foundry and its OEM customer placing the corresponding enquiry/order will be able to enter a particular casting project, after providing a specific login id and password. After entering, the engineers will be able to select different sections and functions of the virtual foundry (depending on the category of the user), to carry out casting development tasks.

The virtual foundry will have five major sections with the following functions (Figure 9):

**Part section:** This will have functions for sending and viewing a part model, selecting an alloy, calculating geometric properties (volume, weight, thickness, etc.), selecting the casting process and checking part manufacturability by the selected process.
**Figure 9. Major sections and functions of the virtual foundry**

**Tooling section:** This will have functions for selecting the casting orientation and mould parting, pattern design (applying draft and other allowances), and core design (print or supports, and allowances).

**Methoding section:** This will have functions for deciding the location, shape and dimensions of feeder(s) and gating elements, as well as number of cavities in the mould and their layout.

**Casting section:** This is the most important section, where simulation of mould filling and casting solidification will be carried out to predict related defects, if any. An additional useful function will be the least cost furnace charge mix calculation.

**Planning section:** This will enable casting process planning (steps, parameters and checks in mould-making, core-making, melting, pouring and fettling operations), material requirements planning, and casting cost estimation.

The working mechanism of the virtual foundry comprises two phases: (a) initial creation of a virtual foundry, and (2) using a particular virtual foundry to develop new castings. These are briefly described here.

A new virtual foundry is created by copying from a standard template and modifying its features to mimic the real foundry. Standard templates are based on metal-process combinations; for example: grey iron sand casting foundry, ductile iron shell moulding foundry, steel investment casting foundry, aluminium gravity die casting foundry, etc. The equipment specifications and foundry capability parameters may be changed, as described earlier. The location of the virtual foundry in the VF zone is decided, and an image of the foundry along with its name (same as the real foundry) is generated, so that it is visible to the visitors of the virtual foundry zone. Finally, the login id and password are set for the virtual foundry gate, to allow only authorised persons to enter the same. The password may be changed from time to time for enhanced security.

After a virtual foundry is created, the casting development projects can be initiated. This starts with the foundry receiving an enquiry from an OEM customer. The casting project
is initiated by selecting the particular cast alloy, and the casting process (type of mould, core, parting, etc.). The 3D model of the cast part is uploaded into the project. The functions in the part section of the virtual foundry are executed to compute part properties, and carry out initial manufacturability checks (minimum hole diameter, wall thickness, etc.). Then the part is taken through other sections of the virtual foundry for tooling design, methoding, casting trial (simulation) and finally process planning and costing. At any point, the OEM customer may visit the virtual foundry to check the progress of the project, and offer suggestions or assistance for improvements, if any. After optimising the casting to achieve the desired quality at the least cost (highest yield), the project details are downloaded for actual trial and regular production.

4. IMPLEMENTATION

The virtual foundry will enable a new casting project to be initiated and several virtual casting trials to be performed within a single day, ensuring that the first real sample casting meets the desired quality requirements at the least possible cost.

A combination of the latest software and web development tools have been tested to implement the virtual foundry project. The HTML (hyper text markup language) coupled with JSP (Java server pages) and a database system (such as MySQL) were found to be the best suited to create the virtual foundry zone along with security features. The data about individual virtual foundries and casting development projects will be stored using XML (eXtended markup language), which enables intelligent matching and analysis functions to be linked. The various functions of different sections of VF will be developed using C/C++ for high response speed and efficient memory management.

The virtual foundry will be developed in three phases to make it available at the earliest to potential users, while ensuring that later developments are compatible with the initial foundation. The first phase will involve creating the virtual foundry zone, and templates or databases for individual foundries, casting projects, casting alloys and processes. Simple database-driven functions (such as casting alloy selection), and those related to the planning section (process planning, materials planning and cost estimation), which do not need a solid model of the casting, will be added in the first phase.

The second phase will involve solid model based functions, related to tooling design and methoding. Virtual casting (simulation) functions will also be added, but these will be performed off-line by technical support engineers, and uploaded to the virtual foundry for viewing by the project team members. In the last phase, the casting simulation functions will be made available on-line so that the users can perform virtual casting trials themselves, assisted if necessary, by support engineers.

Two teams of engineers are required to develop and manage the virtual foundry project. The first team comprises software engineers to design, implement, and improve the entire system. The second team comprising technical support engineers, with prior experience of casting development, is equally critical for managing the system. They will develop and customise various databases (materials, processes, etc.), and provide round the clock assistance to the users in developing their casting projects.
Preliminary estimates indicate that the project will require about 5000 human-days of effort by software engineers for the initial implementation, followed by about 1000 human-days of effort per year to maintain and continuously improve the system. With a team of ten good software engineers, each phase of the project can be implemented within 12-15 months, and the system can be made fully operational within 4 years. In addition, about 2 human-days of support service will be required for every casting development project (assuming an average of 5 virtual casting trials per project). This will imply about 2000 human-days of effort by support engineers for a targeted 1000 casting projects per year. Assuming about 300 working days per person, we will need at least 7-8 qualified and well-trained technical support engineers.

The virtual foundry will function as a cooperative society, ensuring that its services are offered at the minimum costs, and the returns are invested for further development of the system and improvement of services. With an initial grant from the Government to implement the virtual foundry, and annual memberships towards maintaining the system, it will be possible to simulate an average (medium-complexity) casting for less than Rs.1000 (rupees one thousand only) in the virtual foundry.

5. CONCLUSION

A vision for improved competitiveness of our foundry industry has been presented, driven by a mission to offer cost-effective casting simulation services to even SME foundries in remote areas through a virtual foundry that can be reached through the Internet. The virtual foundry is an ambitious project, and will require all round support of the Government, professional bodies, researchers, consultants, user foundries, and their OEM customers. This paper is meant to elicit the feedback about the extent of usefulness of the system, and to invite participation from all interested parties towards an early implementation and deployment of the entire system.

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