Casting Design Optimization driven by Simulation

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The methods layout of a casting is an important activity in tooling development. It involves critical decisions regarding part orientation in mold, parting line, cores, cavity layout, feeders, feedaids and gating system. An improper layout leads to either poor quality or low yield, affecting manufacturing costs and productivity[1].

Computer simulation provides a clear insight regarding the location and extent of internal defects, ensuring castings are right first time and every time. It however, requires a 3D CAD model of the method layout (with mold cavities, cores, feeders, and gating channels), proper setting of boundary conditions for each virtual trial, and correct interpretation of results. AutoCAST software integrates and automates the above tasks, and provides an extremely easy-to-use graphical user interface suitable for even first-time computer users. The mold cavities, feeders and gating system are automatically optimized, driven by the criteria and constraints specified by user. This reduces the total time for methods design and simulation of a typical casting to less than one hour.

Methods design is usually carried out manually on 2D drawings of the cast part. Then tooling is fabricated, trial castings are produced in the foundry, and inspected. If sample castings contain defects (such as shrinkage or gas porosity), then the methods layout is modified and the process is repeated. Each such iteration can take up several days, affecting regular production. After a few iterations, the foundry may resort to a 'safe' methods design (implying low yield), or continue with high rejection rates (implying high scrap or repair cost). This is especially true in the case of large castings, where the cost of a trial or repair can be prohibitive.

Assuming a typical foundry develops 50 new castings every year, each casting requires at least 2 trials, and the average cost of each trial (tooling modification, melting & pouring, inspection, and effect on regular production) as Rs. 20,000, the economic loss works out to be two million (20 lakh) rupees per year per foundry.

Further, taking the average difference in the price of a saleable casting and scrap metal as Rs. 10/kg, and assuming average rejections in a foundry as 5%, the economic loss caused by defective castings works out to Rs. 500 per tonne of production (in reality this can be much higher, with transport, warranty, and failures during product life).

Casting simulation can overcome the above problems: virtual trials do not involve wastage of material, energy and labour, and do not hold up regular production. However, most of the simulation programs available today are not easy-to-use, take as much time as real trials, and their accuracy is affected by material properties and boundary conditions specified by users. The biggest problem is the preparation of 3D model of the mold cavity with cores, feeders and gating for every iteration, which requires CAD skills and takes considerable time for even simple parts. This also prevents early manufacturability evaluation and improvement by product designers, which can benefit several times more than tooling and process changes.

The AutoCAST software developed by Advanced Reasoning Technologies, Mumbai in collaboration with I.I.T. Bombay provides a single integrated user-friendly environment for casting methods design, solid modeling, and simulation[2]. It handles both ferrous and non-ferrous parts, and sand as well as metal molds. Release 10 incorporates multi-cavity mold layout, automatic modeling and optimization, and a costing model to compare various layouts (Fig.1).

Fig.1. Casting methods design and simulation software.

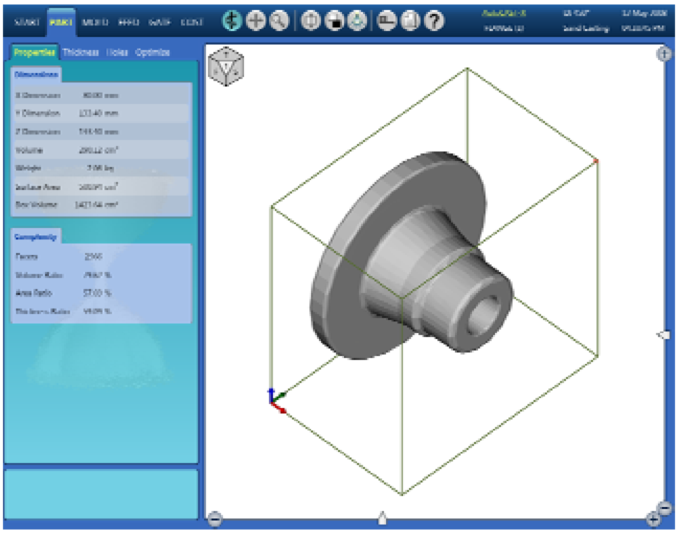

Fig.2. Part property computation.

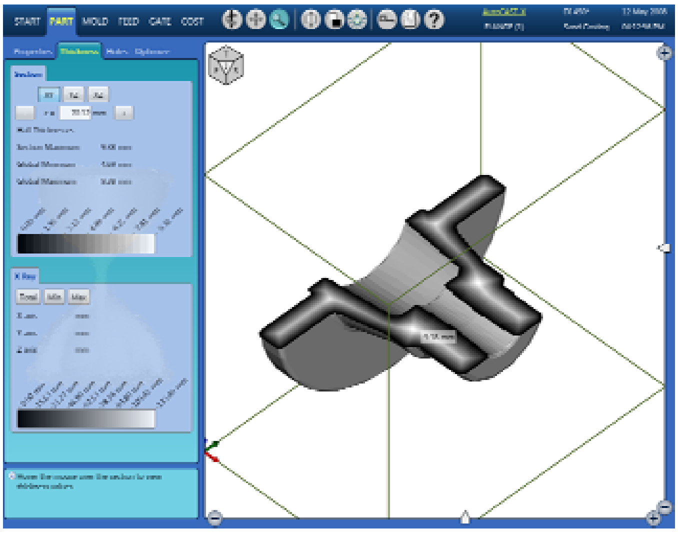

Fig.3. Part thickness distribution with sensor.

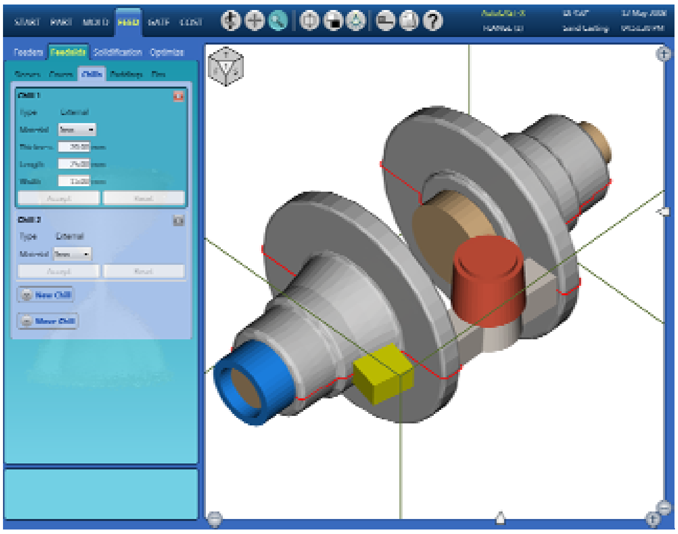

Fig.4. Methods design and its automatic modeling.

Computer-aided Methods Design

The main input is the 3D CAD model of an as-cast part: without drilled holes, and with draft, shrinkage and machining allowance (Fig.2). The model file can be obtained from the OEM firm, or created by a local CAD agency. Various display options such as pan, zoom, rotate, transparency and measure, are provided to view and understand the part model. The cast metal and process are selected from a database. Thickness map is generated. Part manufacturability (compatibility with the selected process) is computed and pictorially displayed (Fig.3).

Methods design involves cores, feeders and gating system. Holes in the part model are automatically identified for core design, or plugged if they are drilled. Even intricate holes can be identified by specifying their openings. The print length is computed based on core diameter and length (the user can change their values if required), and the entire core model is automatically created. The program suggests the number of cavities depending on the mold size (selected from a customizable library), considering both cavity-cavity and cavity-wall gaps. Then the part model is automatically duplicated in the correct locations as per the desired cavity layout (Fig.4).

To facilitate feeder location, a quick solidification analysis is carried out that identifies feeding zones. The user selects a suitable connection point close the hottest zone, and the size of the feeder is computed using modulus principle (solidification time of feeder slightly more than that of the feeding zone). Standard feeder shapes include cylindrical, oval, spherical-bottom, cruciform, etc. Other shapes can be imported. The feeder model is automatically created; the user can change its dimensions or apply feedaids such as insulating sleeves and exothermic covers. Chills, padding and fins can also be created. More feeders or feeders with multiple necks can be created by specifying their positions.

The gating channels are also created semi-automatically. First, the user indicates gate positions on the part or feeder model. Then the sprue position is decided, and connected to the gates through runners. Runner extensions are also automatically created. Either horizontal or vertical gating system can be designed and modified within minutes. The program suggests a suitable filling time (which can be changed by user), accordingly computes the dimensions of the gating channels, and creates their solid model.

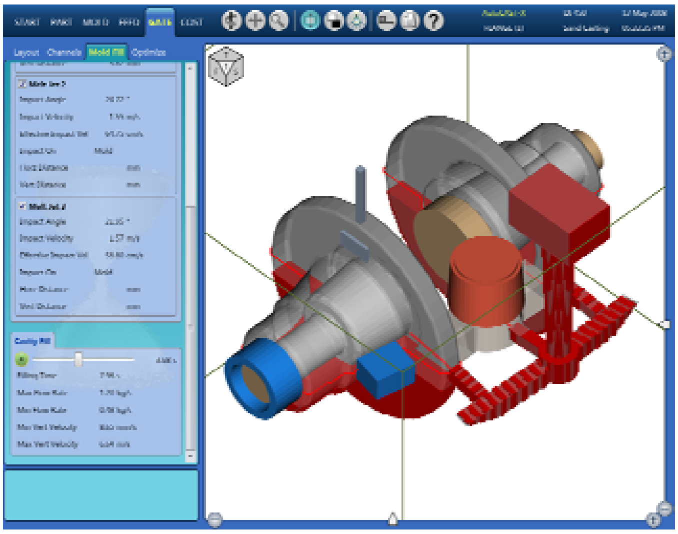

Fig.5. Melt jet path and mold filling.

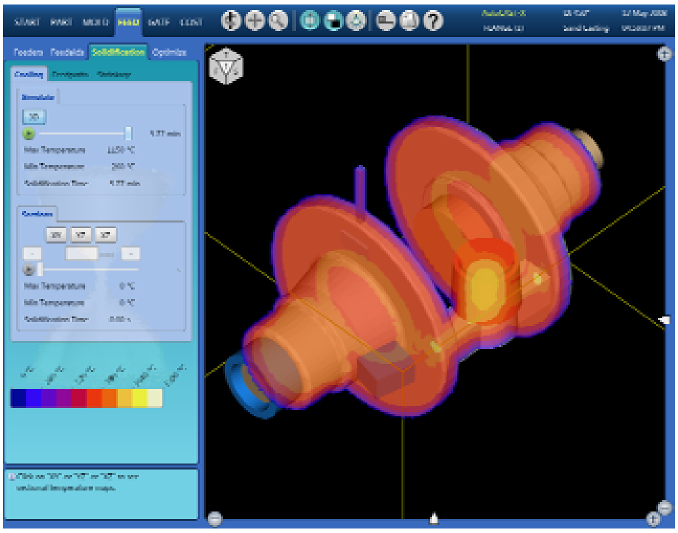

Fig.6. Casting solidification simulation.

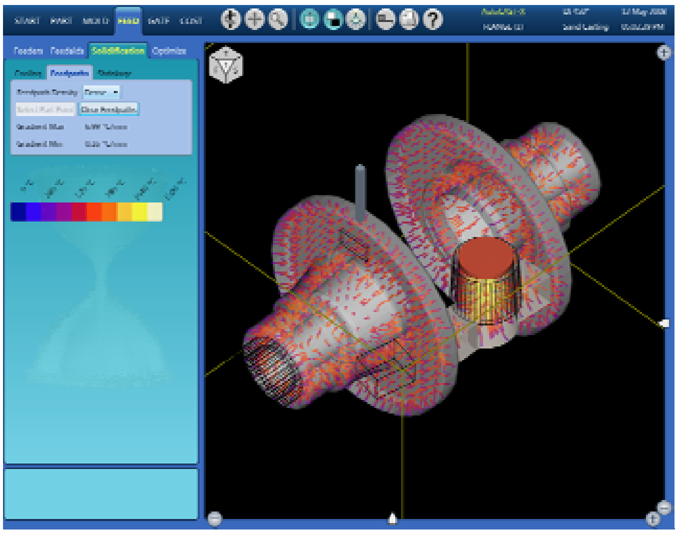

Fig.7. Feed metal paths (temperature gradients).

Automatic Optimization

The mold cavity layout, feeders, and gating models are automatically optimized within minutes based on quality requirements and other constraints[3]. For mold cavity layout, the primary criterion is the weight ratio of cast metal to mold material. A high ratio such as 1:2 (cavities too close to each other) can reduce the heat transfer rate and lead to shrinkage porosity defects. A low ratio such as 1:8 (cavities too far from each other) implies poor utilization of mold material and reduced productivity. The program tries out various combinations of mold sizes and number of cavities to find the combination that is closest to the desired value of metal to mold ratio.

The gating optimization is driven by the ideal mold filling time, which depends on cast metal, casting weight and minimum wall thickness. Fast filling leads to turbulence-related defects (mold erosion, air aspiration and inclusions). Slow filling may cause defects related to premature solidification (cold shuts and misruns). To optimize the gating design, mold filling is simulated and total fill time is computed (Fig.5). A layer-by-layer filling algorithm takes into account the instantaneous velocity through the gates (considering back pressure), and the local cross-section of the mold cavity. This gives a fairly accurate estimation of filling time, while being computationally fast. If the difference between the ideal and simulated filling time is more than a specified limit, the program automatically changes the gating design, creates its solid model, and verifies the filling by simulation.

The feeder optimization is driven by casting quality, defined as the percentage of casting volume free from shrinkage porosity. The user indicates a target quality. The program automatically changes the feeder dimensions, creates its solid model, carries out solidification simulation (Fig.6), and estimates the casting quality. The solidification simulation employs the Vector Element Method, which computes temperature gradients (feed metal paths) inside the casting, and follows them in reverse to identify the location and extent of shrinkage porosity (Fig.7). This has been found to be much faster than Finite Element or Volume Method, and usually more accurate too. Feeder design iterations are carried out until the desired quality is achieved, or the number of iterations exceeds a set limit. The user can accept the results, or can modify the feeder design interactively.

Fig.8. Cost analysis and methods report generation.

Finally, the cost of the casting is computed in terms of amortized tooling, cast metal, other materials (mold, core, etc.), energy, and labour. Various cost rates and parameters can be set by the user. This enables comparing different casting layouts in terms of tooling and manufacturing cost. A detailed methods design report along with an image of the entire casting is automatically generated, which can be printed or stored for future reference (Fig.8).

The metal database covers all major alloys (aluminum, copper, cast iron, ductile iron, steel, and precious metals) and processes (sand, shell, investment, die casting). It can be customized to any new metal-process combination.

The software has been developed for standard Windows XP computers, and performs well on even portable computers. The graphical interface is designed to minimize the learning and operation time, and the user is gently guided through forgotten or wrong steps. Even those without any prior exposure to computers are able to use the software after a single day of training. All steps starting from part model importing to mold, core, feeder and gating system design, simulation and optimization are completed within one hour for typical castings.

Direct benefits include at least 50% reduction in casting development time and porosity defects. Other benefits include yield improvement, faster quotation, handling more complex parts and knowledge reuse for future projects. Continuous interaction of the R&D team with local industry has made it possible to incorporate hundreds of useful improvements over the last 20 years.

Today AutoCAST is the most widely used casting software in India with 50 licenses (foundries, engineering and R&D institutes, and consultants) covering all major cast metals and processes. Many others have used the software for benchmarking. Simulation consultants are available across the country to provide local technical support, ensuring a smooth transition to computer-aided methoding.

Summary and Future

Casting simulation can minimize the wastage of resources required for trial production. In addition, the optimization of quality and yield implies higher value-addition and lower production cost, improving the margins. For widespread application, simulation programs must be fast, reliable, and easy to use. This has been achieved by integrating methods design, solid modeling, simulation and optimization in a single software program, and automating many tasks that otherwise require scientific knowledge and computational skills. In many benchmarking exercises and simulation clinics (Fig.9), the software has consistently proven its reliability in predicting internal defects (ex. shrinkage porosity) within minutes, often by senior engineers who are first time computer users. The simulation costs are a fraction of the costs of foundry trials, while providing better and faster insight for casting optimization. A network of local technical support centres and simulation consultants across the country ensures that even SME foundries in remote areas can now take advantage of the technology. The goal of castings right first time, every time, in the shortest time, is within the reach of every foundry.

Fig.9. Casting simulation training and clinic at Mumbai.

References

1. B Ravi, Metal Casting: *Computer-Aided Design and Analysis*, PHI India, New Delhi, 2005-2008, ISBN 81 203 2726 8.
2. Advanced Reasoning Technologies, *AutoCAST Software User Manual and Case Studies*, http://www.autocast.co.in, 2009.
3. B Ravi, "Casting Simulation and Optimisation: Benefits, Bottlenecks, and Best Practices," *Indian Foundry Journal*, 54 (1), Jan 2008.