Collaborative Design for Manufacture – Metal Casting Applications

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Abstract- **The importance of design for manufacture (DFM) and concurrent engineering – evolving a process compatible product design – is well established in industry. This is presently achieved using DFM guidelines available in handbooks or consulting manufacturing engineers before freezing the design. We present a 3D environment for DFM of cast products based on product modeling, process planning and simulation to predict and prevent manufacturability problems early in product lifecycle. A real-life DFM case study of a press cylinder casting is described. To facilitate collaborative DFM between product, tooling and foundry engineers separated by distance, a Web based Intelligent Collaborative Engineering (WebICE) framework is being developed, which is also described.**

Keywords: CAD/CAM, Collaborative engineering, Design for manufacture, Metal casting

I. INTRODUCTION

An increasing number of manufacturing firms are adapting concurrent engineering practices to continuously shorten their product development time, improve quality and reduce cost. This involves analysis of manufacturability and other lifecycle issues during the design phase. Design for manufacturability (DFM) involves predicting and preventing potential manufacturing problems by suitable design modifications. Such modifications are much less expensive in product design phase than at tooling or manufacturing phases. Existing DFM approaches include direct or rule-based approaches and indirect or plan-based approaches. The direct approaches evaluate manufacturability from guidelines illustrating design characteristics that improve or degrade manufacturability [1,2,3]. Indirect approaches involve planning, estimation and simulation of the manufacturing processes [4,5].

With increasing globalization, product design and manufacturing activities are getting dispersed all over the world. This leads to a need for collaboration between design and manufacturing engineers for designing easily manufacturable products. The collaboration can take place by face to face meetings or by using various means of communication (ex. telephone and email) to discuss potential manufacturing problems before freezing the design. However, it may be difficult or expensive to get the engineers in a single location for the meetings. Collaboration using telephone or email is not suitable for handling complex parts. Over the last few years, CAD/CAE/CAM tools are increasingly being used for creating, optimizing and manufacturing activities. A few DFM systems have been reported using web technology to support collaboration (essentially data exchange and communication) between design and manufacturing engineers in a distributed environment [6,7,8]. However, very little work is reported in integrated product design, process planning and manufacturability analysis (by process simulation) in a 3D environment, especially for cast products, which is the focus of our work.

Metal casting is one of the most important and widely used manufacturing processes, but involves a large number of inter-dependent parameters whose combined influence on casting quality is not very well understood, least by the design community. Designing process-friendly cast components that minimize total costs, defects and lead-time is a challenging task. This requires extensive knowledge of various casting processes including their capabilities and limitations. Product designers however, have little knowledge of various casting processes, essential to achieve benefits of DFM.

Several researchers have worked on the first step of DFM, that is, the selection of the most suitable casting process and product-process compatibility evaluation [9,10,11,12,13]. Ravi proposed feature based and simulation based approaches for early castability evaluation [14,15]. A knowledge management system has also been proposed for concurrent casting product process design [16]. There is however still a long way to go before intelligent CAD systems will be able to automatically critique a product design for compatibility with a specific manufacturing process and suggest directions for improvement. Until then, product designs will need to be verified by manufacturing experts before freezing and releasing the drawings for downstream activities. This requires methodologies for collaboration between design, manufacturing and other lifecycle engineers who may be located worldwide, an increasing trend with globalization.

This paper demonstrates how collaborative DFM by design and foundry engineers using 3D modeling, process planning and casting simulation helps in reducing costs and rejections. A real-life case study of a press cylinder improved for manufacturability using the proposed approach is presented. This required physical meetings between the product designer and foundry engineer. To eliminate the need for physical meetings, a web based collaboration facility called WebICE has also been developed and presented at the end.

II. DFM FOR CASTING: APPROACH

The proposed casting DFM approach essentially involves process planning, methoding (gating and feeding system design) and solidification simulation at product design stage. To motivate design engineers to adopt the DFM approach, the programs have been made automatic and efficient to the extent possible. The process plan and methoding are driven by product design and its requirements, and in turn provide inputs for solidification simulation, which enables prediction of internal defects (shrinkage porosity). The defects may be eliminated by adjusting the process plan, methoding and product design by mutual consultation among engineers.

A. Casting Process Planning

This involves decisions regarding steps, tooling type, process parameters (type of mold or core sand, pouring temperature, sand composition, etc.) and quality checks involved in manufacturing of castings. The casting process parameters determined in this phase act as an input for the methoding.

The process planning activity has been automated by developing a systematic methodology based on case based reasoning (CBR). It involves retrieving knowledge from the case base (previous casting projects), knowledge base containing if-then rules (fed by casting experts, tooling and foundry engineers) and library (standard methods and process parameters). The CBR methodology uses the nearest neighbor algorithm for identifying the nearest case from case base and applying the process planning knowledge of identified case to the new product [17]. For adaptation or in the absence of similar case in case base, the knowledge from library and if-then rules is processed and made available. The input for process planning involves product attributes related to material, geometry, quality and production.

B. Methoding

This deals with decisions related to tooling including gating and feeding systems. The location, shape and dimensions of these elements significantly affect the physics of the casting process, namely flow of molten metal in the mould and its solidification characteristics, which finally affect casting quality. The designs are carried out based on past experience or by using empirical equations that vary with material, geometry and process combination. The gating system comprising of sprue, runner and ingates is designed so that the mould is filled within a suitable range of time. The feeders are designed so that they solidify later than the connected portion of the casting containing an isolated hot spot, and thereby supply liquid metal need to compensate volumetric shrinkage during casting solidification. The methoding is carried out by a 3D casting design and analysis software AutoCAST developed through an industrial collaboration. The program automatically suggests the starting dimensions of the gating and feeding elements, and creates their solid models, which are then verified by simulation. The design is then modified, if necessary, followed by simulation until the desired quality is achieved.

C. Solidification Simulation

Solidification simulation enables predicting the location of internal shrinkage porosity. The results of simulation include the location of shrinkage porosity, progressive solidification through any section (cooling map) and directional solidification (feed paths). The AutoCAST also facilitates use of feed aids such as chills, insulation and exothermic pads to improve the solidification characteristics and yield.

III. INDUSTRIAL CASE STUDY

Here we present an industrial case study describing how the DFM approach enabled improving the manufacturability and quality of a real life casting. The DFM team comprised of the design engineer, foundry manager and consultant (second author). The exercise was initiated by the foundry, who agreed to share the details of casting methoding and process plan (necessary for solidification analysis) with other members of the DFM team. The OEM on its part, was open to design changes for improving the castability, which was essential for overcoming the given quality problem.

A. Background

The Heavy Foundry division of Mukand Limited located in Thane (near Mumbai), is one of India's leading casting manufacturers with ISO 9002 certification. They specialize in manufacturing heavy ferrous castings up to 100 tonnes in a single piece for OEMs (especially cement, power, steel and general heavy engineering industries). Siddharth Industries, Belgaum, is one of their major clients engaged in design and manufacture of heavy hydraulic presses used in metal extrusion, metal pressing and many other applications.

It was observed that a few of the extrusion press cylinders tended to leak after more than 5 years of continuous use at the projection shown in figure 1(a). Initially, assuming cyclic load in working condition (fatigue failure) as a cause leading to leakage, the cylinder was analyzed for stresses developed in working condition. However, it was observed that the projection (location of leakage) was subjected to low stresses and hence the failure because of fatigue was ruled out. The foundry on their part experimented with different methoding layouts, including use of local chill, feeder at the projection, and providing padding (taper on inside part of cylinder). The problem however, persisted.

B. Collaborative DFM of Casting

With the above background, the foundry approached our lab for help in solving the problem. Their inputs included current process plan, including all major process parameters. The OEM was invited to take part in the exercise, and they provided their input in the form of 3D model of the press cylinder.

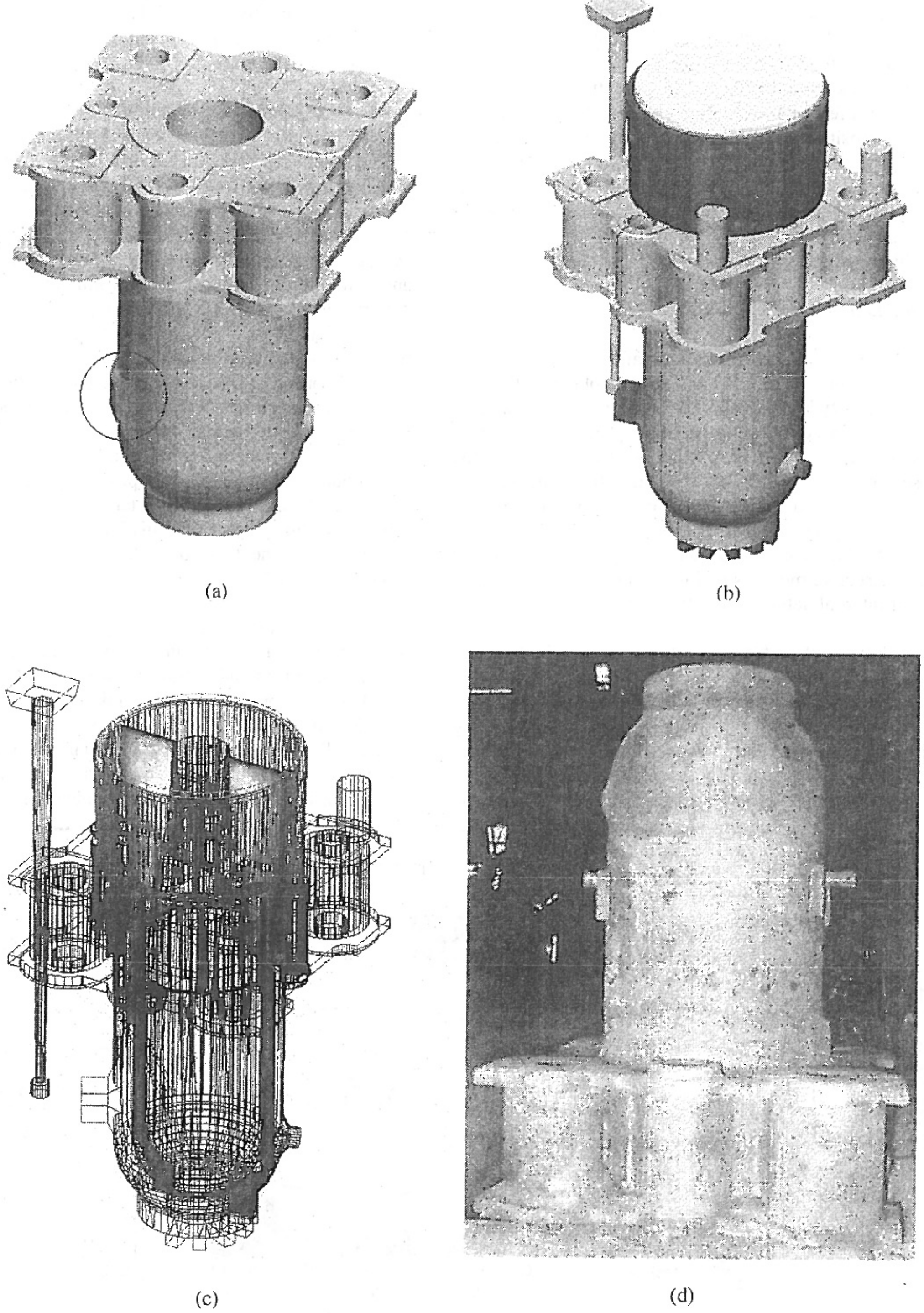

Figure 1: Industrial case study (a) press cylinder model (b) methoding - gating and feeding design
(c) solidification analysis shows micro porosity below junction (d) new casting with modified geometry

The part model, methoding and process plan data was used for simulating the casting. The results of analysis showed that the section connecting the feeder with the junction solidifies much before the projection, chocking the flow of feed metal and thereby leading to potential micro porosity under the projection. It was concluded that after a few years of service under fatigue load, these micro porosities get connected leading to leakage in few cases. Different solutions were modeled and simulated to alleviate the problem. This included use of padding (internal taper on the thin section to increase its thickness), but was discarded as it involved increased machining costs.

C. Solution

After several virtual tryouts and analysis it was concluded that it is difficult to completely eliminate micro porosity by methoding or process parameters alone. Therefore, in consultation with the product designer, it was decided to shift the projection to a new location closer to the feeder. This did not affect the product functionality, and solved the shrinkage porosity problem since the top feeder was now able to feed the junction area. The final casting was rigorously tested by various non-destructive methods and was found to be completely free of internal defects under the projection.

Such types of problems are quite common in the metal casting industry. Since product designers may have limited experience of casting processes, there is a need for communication and collaboration with casting engineers to predict and prevent potential manufacturing problems at the design stage itself. Traditional means of communication however, are inadequate to handle the time, distance and communication barriers that may exist between the design and casting engineers. These barriers can be overcome by web-based collaborative engineering of cast products. The next section presents a framework developed for this purpose.

IV. WEB BASED COLLABORATION

The WebICE (Web-based Intelligent Collaborative Engineering) framework has been developed to enable collaboration between team members who may be located apart. The XML-based CDML (Casting Data Markup Language) developed in an earlier investigation and continuously being updated, forms the backbone of the framework [18]. The CDML consists of two parts: tree and data blocks. The tree represents the hierarchical relationship between different types of information essential for collaboration between the product, tooling and foundry engineer, whereas the data blocks are used for storing the actual project data. The project information involves product details (3D model, quality and production requirement), process plan, methoding details, evaluation and other details. The team members can access the project information through a standard web browser. The functional diagram of the system is shown in figure 2.

The team members (tooling engineer, foundry engineer and consultant) interact with the system using different functions and utilities provided for collaboration. A 3D model compression and linking utility has been provided for product designers to upload the casting 3D model. All team members can manipulate (view, rotate, zoom) the casting model. In addition, an annotation facility has been provided for communication.

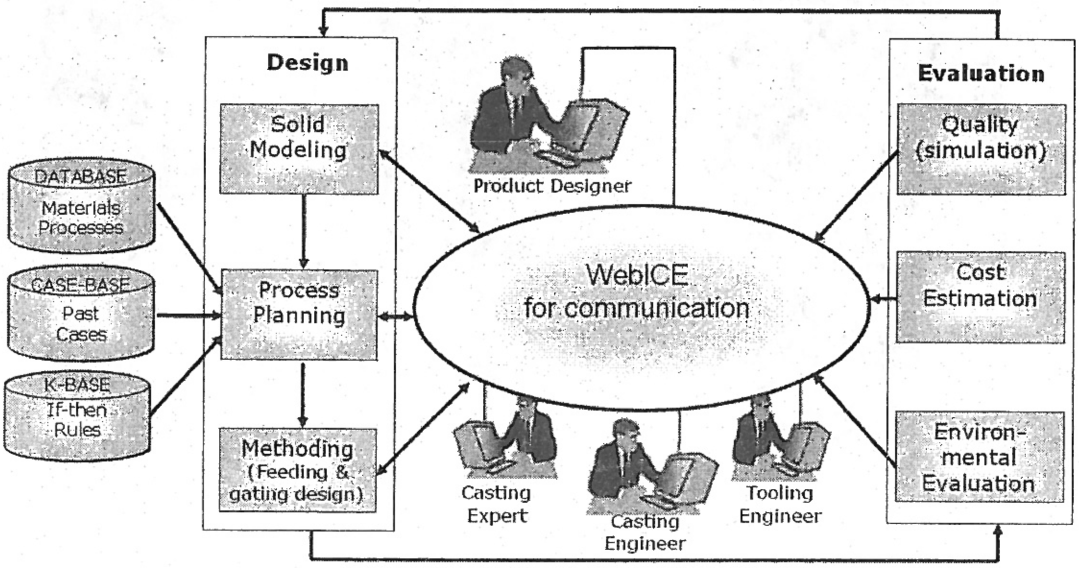

Figure 2: Collaborative casting DFM using WebICE

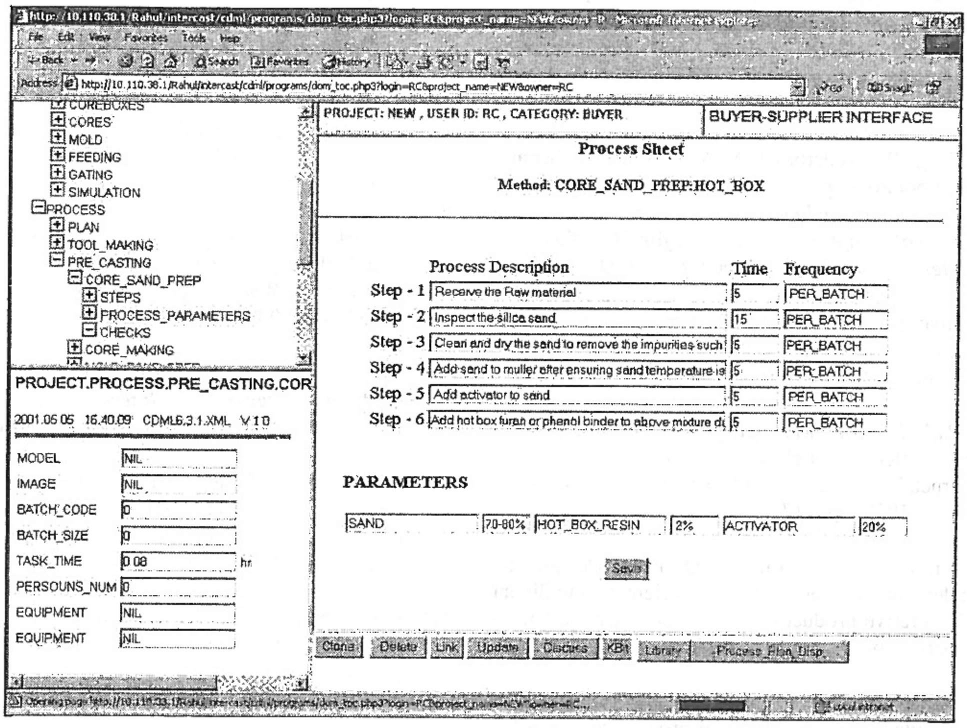

Figure 3: Casting process plan (partial)

The methoding and process plan can be uploaded to WebICE server so that team members can simultaneously view the plan and suggest modifications, if necessary (figure 3). Based on such inputs, the product, tooling and/or process plan can be modified and evaluated by process simulation, and the results can be uploaded to the WebICE server. All the team members can again view the results of analysis and discuss further improvements using the interface provided for collaboration. Functions to evaluate the product design and process plan in terms of cost and environmental aspects are currently being developed.

IV. CONCLUSION

The importance of Design for Manufacture (DFM) is now widely accepted in the engineering community. However, very few DFM tools are currently available to assist designers in quantitative evaluation of product manufacturability. There are no tools to integrate process planning and simulation in 3D collaborative design environment, especially for cast products. Our work fills this gap by presenting a collaborative DFM approach, which has been validated by an industrial case study. This involved improving the quality of a press cylinder casting while considering manufacturability, by slight modification in product geometry in collaboration with OEM and casting supplier. Further, a Web-based Intelligent Collaborative Engineering framework has been developed to enable project team members to overcome distance and communication barriers. Such an approach helps in predicting and preventing potential problems during the design phase itself. This will enable engineers to produce more quality-assured and cost-effective parts. It will also improve the level of communication between product, tooling and foundry engineers, leading to better and faster decision-making.

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