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Optimization of Casting Process Parameters through Simulations

Tushar Rupnavar[1],Prof.B.R.Jadhav[2]

[1,2] Department of Mechanical Engineering, , Maharashtra, India

Abstract— *Foundry industry suffers from poor quality and productivity due to the large number of process parameters, combined with lower penetration of manufacturing automation and shortage of skilled workers compared to other industries. Global buyers demand defect-free castings and strict delivery schedule, which foundries are finding it very difficult to meet. Casting defects result in increased unit cost and lower morale of shop floor personnel. The defects need to be diagnosed correctly for appropriate remedial measures, otherwise new defects may be introduced. Unfortunately, this is not an easy task, since casting process involves complex interactions among various parameters and operations related to metal composition, methods design, molding, melting, pouring, shake-out, fettling and machining. For example, if shrinkage porosity is identified as gas porosity, and the pouring temperature is lowered to reduce the same, it may lead to another defect, namely cold shut.*

Keywords — Casting Design, Casting Defect, Simulation, Optimization, Analysis.

1. INTRODUCTION

Many foundries have experienced costly outbreaks of high reject rates due to metallurgical casting defects. A defect may arise from a single clearly defined cause or may be a result of a combination of factors, so that the necessary preventive measures are initially unclear. However, to prevent recurrence it is necessary to correctly diagnose the defect as well as to find the root cause of the defect.

Several approaches are being used in foundries to diagnose metallurgical casting defects. In most cases, a simple visual evaluation of the defect is conducted. Nevertheless, metallurgical casting defect analysis is also accomplished by chemical analysis, microscopic examination, destructive testing, and non-destructive testing. The logical classification of the origin of a casting defect presents great difficulty because of the wide range of inter-related molten metal and casting process contributing factors. In a broader classification, the metallurgical defects may be grouped under four generic origin sources: melting, moulding, pouring, and finishing. Casting defects are very often the result of these variables not being properly controlled.

The elimination of casting defects requires the collection and analysis of data. There are many statistical techniques to help us control process variables, correlate the effects of variables, analyze problems and establish priorities for problem solving. Perhaps the Pareto chart is the most common tool used to pinpoint major causes of scrap in a foundry. Still, all of these techniques are of little use if the defect is improperly diagnosed.

1.1Casting Defect Analysis

Casting defects analysis is process of finding the root cause of occurrence of defects in the rejection of casting and taking necessary steps to reduce the defects and to improve the casting yield. Techniques like cause-effect diagrams, design of experiments (DoE), casting simulation, if-then rules (expert systems) and artificial neural networks (ANN) are used by various researchers for analysis of casting defects. Casting defects result in increased unit cost and lower morale of shop floor personnel. The defects need to be diagnosed correctly for appropriate remedial measures; otherwise new defects may be introduced. Unfortunately, this is not an easy task, since casting process involves complex interactions among various parameters and operations related to metal composition, methods design, molding, melting, pouring, shake-out, fettling and machining. For example, if shrinkage porosity is identified as gas porosity, and the pouring temperature is lowered to reduce the same, it may lead to another defect, namely cold shut. So far, casting defect analysis has been carried out using techniques like cause-effect diagrams, casting simulation, design of experiments, if-then rules (expert systems), and artificial neural networks. Most of the previous work is focused on finding process-related causes for individual defects, and optimizing the parameter values to reduce the defects. This is not sufficient for completely eliminating the defects, since parameters related to part, tooling and methods design also affect casting quality, and these are not considered in conventional defect analysis approaches. In this work, we present a 3-step approach to casting defect identification, analysis and rectification. The defects are classified in terms of their appearance, size, location, consistency, discovery stage and inspection method. This helps in correct identification of the defects. For defect analysis, the possible causes are grouped into design, material and process parameters. The effect of suspected cause parameters on casting quality is ascertained through simulation. We trace the history of such approaches, starting from the Modulus Concentration Method in recent Gradient Vector Method in 2012, as well as their incorporation in software programs for casting design and simulation [1].

II. METHODOLOGY

In this proposed method of casting defect analysis, computer aided casting simulation technique is used for methoding, filling and solidification related defects such as shrinkage porosity, hot tears, etc. the DoE whereas (Taguchi method) is used for analysis of sand and mould related defects such as sand drop, bad mould, blow holes, cuts and washes, etc.

2.1 Casting Simulation for Casting Defects Analysis

The elimination of casting defects requires the collection and analysis of data. There are many statistical techniques to help us control process variables, correlate the effects of variables, analyse problems and establish priorities for problem solving. Perhaps the Pareto chart is the most common tool used to pinpoint major causes of scrap in a foundry. Still, all of these techniques are of little use if the defect is improperly diagnosed.It is a fact that the size and type of a foundry (i.e., large high-production foundry, medium, or jobbing foundry) as well as the cultural thinking of its management influence the methodology to diagnose casting defects, and the manner in which corrective actions are implemented. To correctly diagnose casting defects, it is imperative to fully document the defects by illustration, description, analysis, and accurate data. Attempting a corrective action without knowing exactly what is the problem may prove very expensive. Once a corrective action is found, it must be implemented. In jobbing foundries the corrective action usually takes place during the next production run, mainly because sampling will be cost prohibitive or because of production requirements. On the other hand, in the large high-production foundries the corrective action takes place almost immediately.

It has been known for two decades that the statistical approach to experimentation provides an orderly way to collect, analyze, and interpret significant effects of foundry process variables (1, 2, 3). One might initially think that full-scale DOE have been more widely used in foundry scrap reduction programmes. However, it appears not to be the case. In addition, most of the few published design of experiment methods in the foundry industry seem to be suited for the large highproduction foundries (4, 5, 6, 7). For design of experiments techniques to be successful on the foundry floor, senior foundry management has to commit adequate manpower and resources as well as to be actively involved in the process.

Computer simulation of casting process has emerged as a powerful tool for achieving quality assurance without time consuming trials. Software packages for simulating the solidification of molten metal in the mold enable predicting the location of shrinkage defects and optimizing the design of feeders to improve the yield; more advanced packages perform coupled simulation of mold filling and casting solidification. It has been reported that simulation studies can reduce casting defects, manufacturing costs and lead time by as much as 25%. Already, an estimated 1000 foundries (among 33,500 worldwide) are using simulation software to improve their performance and the number of simulation users is steadily increasing.

Methods design is usually carried out manually on the part to be cast. The tooling is then fabricated; trial castings are produced in the foundry in trial run in small batches, and inspected. If these castings contain defects, then the meth ding is modified and the process is repeated. Each such iteration can take up several days which delays delivery schedule is lead time and hence the customer is dissatisfied. After a few iterations, the foundry may find the best alternative for the meth ding which may help to solve the problems stated earlier. It may also help to increase yield, reduce the rejection rates This is especially true in the case of large castings, where the cost of a trial or repair can be prohibitive [2].

Casting simulation can overcome the above problems: virtual trials do not involve wastage of material, energy and labor, 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 casting along with mold, cores, feeders, gating, etc., which requires CAD skills and takes considerable time for even simple parts. Meth ding is an important task in casting production, directly affecting casting quality and yield. It involves several decisions, such as the size of mold box and number of cavities, orientation. Casting simulation is used to modify such method and to get best alternative of process.

2.2 Need of Optimization during Casting Process

Optimization is the process of finding the best way of using your resources, at the same time not violating any of the constraints that are imposed. By "best" we usually mean highest profit, or lowest cost. Even after spending significant resources (man-hours, materials, machine overheads and energy) for casting development, one of the following situations may arise during regular production.

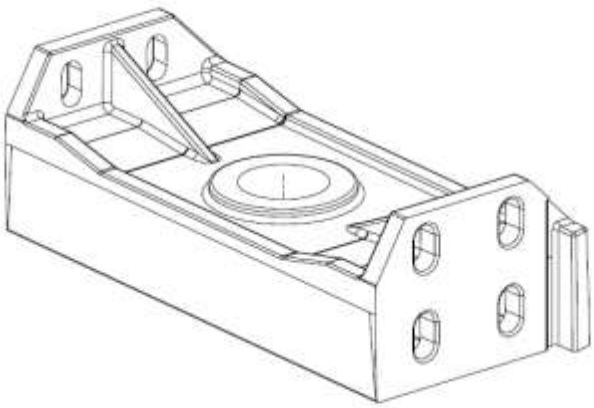

Fig.1: 2-D model of bracket chasis

2.3Optimization of Parameters by Casting Simulation Technique

A simulation model is, in general, used in order to study real life systems which do not currently exist. In particular, one is interested in quantifying the performance of a system under study for various values of its input parameters. Such quantified measures of performance can be very useful in the managerial decision process. The cost concerns of the metal casting company focus on the extra time and energy spent in changing the setup configurations in the manufacturing system. The need for changing the machine set-up is due to the various customer orders that vary in material type, make and dimension. The objective is to design the methoding system, optimize it with the help of simulation and minimize the cumulative total cost incurred in changing of machine set-up. The simulation model is built to assess the set-up cost of every possible combination of the orders. It is necessary to describe briefly the Computer Applications in Simulation of Metal Casting Process, AutoCAST software for simulation and its features and methoding for Green Sand Molded C. I. Casting for different components using simulation software.

2.4 Casting Simulation Programs

The casting simulation programs are used for analyzing:

i. Mould filling
ii. Casting solidification
iii. Internal stresses and distortion
iv. Microstructure and mechanical properties

The simulation programs are based on Finite Element Analysis of 3D models of castings and involve sophisticated functions for user interface, computation and display. The casting model (with feeders and gates) has to be created using a solid modeling system and imported into the simulation program. In addition, material properties (density, thermal conductivity, specific heat, latent heat, etc.) and process parameters (pouring time, pouring temperature, casting-to mold heat transfer coefficient) have to be provided by the user. The latter may require extensive experimentation to customize the software databases for a particular organization. After executing the simulation routine, the results can be post-processed to view color-coded temperature profile, velocity vectors or residual stresses. This enables predicting the probable location of defects. The results are reliable if the input data is complete and accurate. The casting design software developed at IITB named Auto CAST is getting popular because of the key features of it such as

i. Part volume, weight, surface area
ii. Part dimensions, as well as its height in cope and drag
iii. Wall thickness: minimum, average
iv. Significant modulus around a hot spot
v. Casting orientation in the mold
vi. Suitable position of the parting line
vii. Suitable location of feeder and gates.

Fig.2 shows input for the AutoCAST which is 3-D geometric model of bracket chasis created in the CATIA software. This model is imported in the AutoCAST as the .stl format [4].

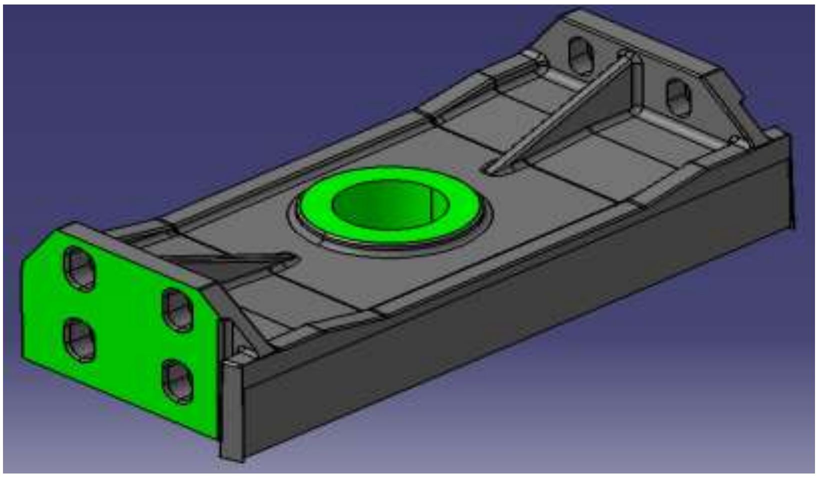

Fig.2: 3-D model of bracket chasis

III. NECESSITY OF OPTIMISATION USING SIMULATION

Richard W Heine and Carl R Loper et al. investigated that simulation model is used in order to study reallife systems which do not currently exist. In particular, one is interested in quantifying the performance of a system understudy for various values of its input parameters. Such quantified measures of performance can be very useful inthe managerial decision process. The cost concerns of the metal casting company focus on the extra time and energy spent in changing the setup configurations in the manufacturing system. The need for changing the machine set-up is due to the various customer orders that vary in material type, make and dimension. The objective is to design the methoding system, optimize it with the help of simulation and minimize the cumulative total cost incurred in changing of machine set-up. The simulation model is built to assess the set-up cost of every possible combination of the orders. It is necessary to describe briefly the computer applications in simulation of metal casting process, AutoCAST software for simulation and its features and methoding for Green Sand Molded C. I. Casting for different components using simulation software.

3.1 Necessity of Simulation

Computer simulation of casting process has emerged as a powerful tool for achieving quality assurance without time consuming trials. Software packages for simulating the solidification of molten metal in the mold enable predicting the location of shrinkage defects and optimizing the design of feeders to improve the yield; more advanced packages perform coupled simulation of mold filling and casting solidification. It has been reported that simulation studies can reduce casting defects, manufacturing costs and lead time by as much as 25%. Already, an estimated 1000 foundries(among 33,500 worldwide) are using simulation software to improve their performance and the number of simulation users is steadily increasing [6].

B. Ravi and R. C. Creese et al. investigated that casting simulation should be used when it can be economically justified for at least one of the following three reasons:

Foundries try to reduce rejections by experimenting with process parameters (like alloy composition, mold coating, and pouring temperature). When these measures are ineffective, then methods design (gating and feeding) is modified. When even this is not effective, then tooling design (part orientation, parting line, cores and cavity layout) is modified. The effect of any change in tooling, methods or process parameters is ascertained by pouring and inspecting test castings. Our studies show that replacing shop-floor trials by computer simulation saves time, provides a better insight, and helps in reducing the rejections by half – froman average 8.6% before to 4.3% after, as per a survey of nearly 200 foundries carried out by IIT Bombay (Fig. 1) [1]. This is however, still very high compared to the expectations of OEM customers. They are now beginning to share the responsibility for casting quality, by working closely with their suppliers, with the aim of reducing the rejections to near-zero level

• Manufacturability improvement by part re-design in consultation with OEM
• Methods knowledge management by re-using simulation projects
• Brand image enhancement by using the simulation facility as a marketing tool

High capacity foundries (over 5,000 tonnes/year) with a large number of jobbing orders (more than 100 per year) require in-house casting simulation facilities, preferably one for each foundry unit. Two or more medium capacity foundries, who have fewer jobbing orders, can share common facilities. Small foundries with less than ten new projects per year should set up co-operative simulation centers in their cluster, or approach casting simulation consultants. There are different types of users associated with casting simulation which are shown in fig.3 [7].

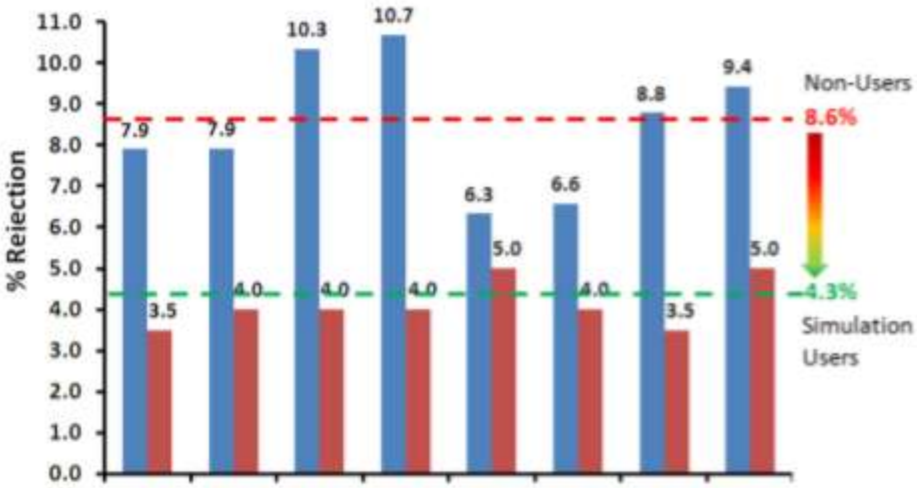

Fig.3: Types of Casting Simulation Users Based on Various Factors

IV. CONCLUSION

From literature it is seen that, now a days in the foundries majority of the casting rejection takes place due to shrinkage porosity defect also shrinkage porosity is the method related defect of casting process

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