Review Article

OPTIMIZATION IN GREEN SAND CASTING PROCESS FOR EFFICIENT, ECONOMICAL AND QUALITY CASTING

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ABSTRACT

Among the industrial activities sand casting process still remains as one of the most complex and indefinite activities. Due to the complex relationship between casting defects and green sand properties, it is imperative to control many green sand characteristics that influence casting quality. Traditional method of trial-and-error based on know-how and experience has many disadvantages such as being nonsystematic, time consuming, error-prone and requirement for long durations of experimentation. There is a necessity to replace this traditional approach to produce higher quality casting products within reasonable periods of time making better use of statistics, artificial intelligence knowledge acquisition neural networks and data mining tools. This paper extensively reviews published research on green sand casting process. The effects of riser design, gating system, moulding sand, oxidation and deformation of casting during heat treatment, machining allowance, etc., on the economical manufacture quality castings were reviewed. Determining the optimal process parameter setting will significantly improve the mould yield, output ratio of metal, shorten manufacturing period, save energy and resource, reduce pollution, and improve the competitiveness of enterprises.

KEYWORDS Green sand casting, gating system, riser, mould yield, casting yield.

1. INTRODUCTION

The term "Green sand casting" refers to an object solidified in green sand mould. Green sand moulds are prepared with mixtures of silica sand, bonding clay and water. Sand castings are produced in specialized factories called foundries. Over 70% of all metal castings are produced via a green sand casting process. Although there are many new advanced technologies for metal casting, green sand casting remains one of the most widely used casting processes today due to the low cost of raw materials, a wide variety of castings with respect to size and composition, and the possibility of recycling the molding sand. The sand casting process is one of the most versatile processes in manufacturing because it is used for most metals and alloys with high melting temperatures such as iron, copper, and nickel. The sand casting process consists of pouring molten metal into a sand mold, allowing the metal to solidify, and then breaking away the sand mold to remove a casting product. The casting product can then be machined to remove surface imperfections or to add new features by standard machining methods such as grinding, turning, milling, and polishing. The sand used in the sand casting process is typically bonded with bentonite and water to mold the sand. The used sand can be recycled many times by adding new material to the return sand during reconditioning.

With the fast development of the car and machine building industry the casting consuming areas called for steady higher productivity. The basic process stages of the mechanical molding and casting process are similar to the manual sand casting process. The technical and mental development however was so rapid and profound that the character of the sand casting process changed radically. The first mechanized molding lines consisted of sand slingers and/or jolt-squeeze devices that compacted the sand in the flasks. Subsequent mold handling was mechanical using cranes, hoists and straps. After core setting the copes and drags were coupled using guide pins and clamped for closer accuracy. The molds were manually pushed off on a roller conveyor for casting and cooling. The molding lines can achieve a molding rate of 90 to 100 sand molds per hour. In 1962, Dansk Industri Syndikat A/S invented a flask-less molding process by using vertically parted and poured molds. Today molding lines can achieve a molding rate of 550 sand molds per hour and requires only one monitoring operator. Maximum mismatch of two mold halves is 0.1 mm. Cores need to be set with a core mask as opposed to by hand and must hang in the mold as opposed to being set on parting surface.

Castings are high-tech products which are integration of materials, metallurgy, casting, heat treatment, welding, measurement, etc., Although some new casting technologies prosper, for example, lost foam casting and die casting, the green sand casting technology is still the most important and popularly used method for mass production of small and medium weight casting. While foundry engineers have access to an overwhelming amount of experimental work carried out over the last hundred years or more, many results contradict each other, and inapplicable to real-life casting Most foundries still take several weeks to develop a casting, rejection level are high and the yield are sub-optimal. Therefore realization of efficient and economical manufacture of casting is significant on the road to modernization.

2. MEASURES FOR EFFICIENT AND ECONOMICAL MANUFACTURE OF QUALITY CASTINGS

Prof. John Campbell's 'Casting rules" were developed over a lifetime of work in the foundry and later research at the University of Birmingham. Much of the research work focused on the effect of melt handling at the various stages on the number of defects created and the effect on the reliability of casting subsequently made [4].

The quality of castings is affected by the technologies used in every production step such as pattern design, pattern plate utilization, feeding and gating system, sand technology, core design and its placement, melting and pouring, heat treatment, repair welding, etc.

2.1. Optimal riser design

Risers are used for prevention of shrinkage defects (Figure 2). However, they decrease the usage rate of metal and extend the cooling time of castings after solidification as well. Therefore, proper riser size needs to be designed to satisfy feeding with the smallest volume. Traditionally Caine's method, Modulus method and Naval research laboratory methods were used for riser design. In production, traditional methods and computer- aided design and computer aided engineering are combined for riser design recently. But potential exists for further optimization of riser size.

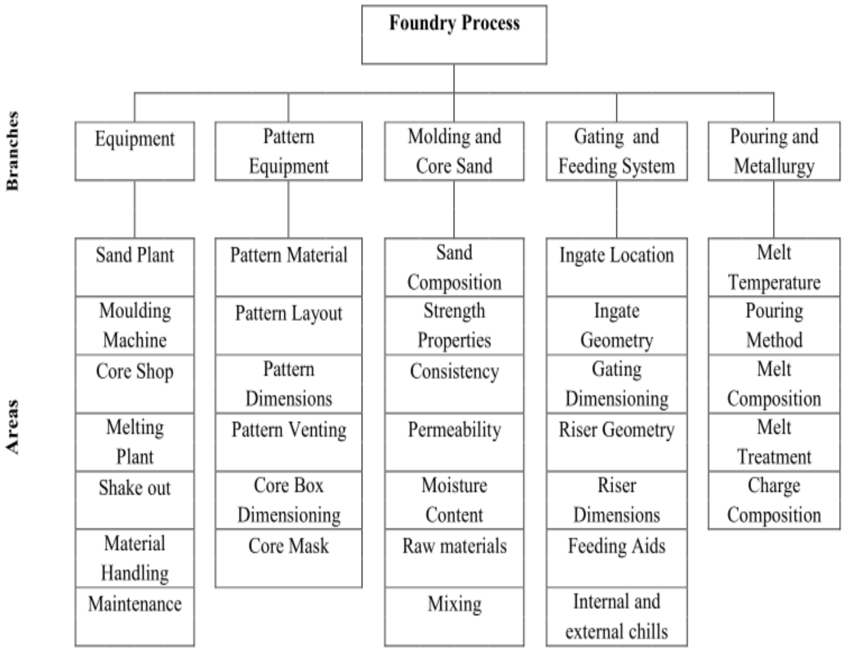

Figure1 shows the foundry process division into branches and areas of a modern foundry

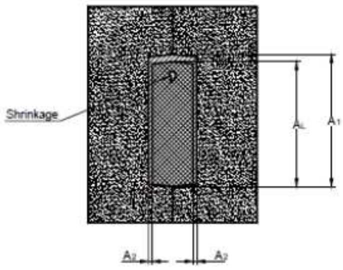

Figure 2. Shrinkage defect

Lots of researches on the optimality of riser design have been carried out for its significance.

Based on the finite element analysis of solidification heat transfer, a shape optimization technique for riser design was carried out by Zhang et al. [5] by using a global convergence method

Shen et al. [6] accomplished an automatic optimization system for riser without interference of human. The system could automatically find out the defects of casting part, establish riser's minimum size as the object function and the requirement of process as the constraint situation through analysis of results by casting simulation software, and use the numerical optimization algorithm based on temperature gradient to determine initial riser parameters, and then further optimize it till the best design of riser is obtained.

Li et al. [7] proposed a particle swarm algorithm to determine riser parameters, such as riser diameter, neck diameter and height, and the results showed that the riser volume decreased by 11.77% compared to that of modulus algorithms. These methods above are of the optimization approaches through multi-revision of the risers of known position and size.

Shouzhu et al. [8] proposed a new feeding distance rule using casting simulation base on a correlation between the Niyama criterion and radiographic casting soundness. The presented rules are shown to provide longer feeding distances in most casting situations.

Tavakoli el al. [9,10] proposed an optimization approach named the feeder growth method. The method is composed of three stages: determination of the riser neck connection point, construction of the riser neck and the riser growth. During the growth stage, the riser topology is improved gradually until satisfying some predefined criteria. Nowadays, its application is only limited to the cases where only one riser is required. Therefore, further extension to overcome this limitation can be considered as the outlook of future research .

Tavakoli et al. [11,12] also present a method named evolutionary topology optimization which is inversed to the growth method.

Mayur sutaria et al. (13) presented work to compute feed-paths and hot spots by combining level set method based sharp interface and feed path model. The model is based on the solution of energy and level set equation in solid and liquid with Stefan condition on the interface

In addition, for improvement of the holding temperature of riser before complete solidification, the surface coating materials on risers are also significant for riser design through strengthening the efficiencies of holding temperature and a highly exothermic riser is also applied in foundries.

2.2 Optimal gating design

The gating design and ingate position (Figure 3) plays an important role in the quality and cost of a metal casting. Due to the lack of theoretical procedure to follow, the design process is normally carried out on a trial and error basis. In production, traditional methods and computer- aided design and computer aided engineering are combined for gating design recently. But potential exists for further optimization of gating system.

Mcdavid et al [14] presented, a methodology for the optimal design of flow in foundry casting rigging systems. The methodology is based on a novel, fully analytical design sensitivity formulation for transient, turbulent, free-surface flows. The filling stage of the casting process is modeled by solving the time-averaged form of the Navier–Stokes equations *via* a turbulent mixing-length model, in conjunction with the volume-of-fluid (VOF) method for modeling the free surface.

Nesterova [15] presented a mathematical model of kinetics of filling the model during Casting by Gasified Models based on an analysis of thermal destruction of cellular polystryne.

Jeoan Kor et al. [16] casting design is formulated as a multi-objective optimization problem with conflicting objectives and a complex search space. An optimization method using multi-objective evolutionary algorithm (MOEA) is developed to overcome such complexities. A frame work for integrating the optimization procedure driven by data for the design evaluation is then presented. The proposed optimization framework is applied to the gating system of a sand casting. It is shown that the MOEA methods yield good results and provides more flexibility in decision making

Niels Skat Tiedje and Per Larsen [17] analyzed melt flow in four different gating systems designed for the production of brake disks experimentally and by numerical modeling. In the experiments, molds were fitted with glass fronts and melt flow was recorded on video. The video recordings were compared with the modeling of melt flow in the gating systems.

Fu-Yuan Hsu et al. [18] investigated the L-shaped junctions in running and gating systems used in aluminum gravity casting. Using computational modeling, a guideline for constructing two geometries of L-junctions was developed. The sequential filling profile of liquid metal along L-junction was confirmed by real-time X-ray video of an aluminum alloy sand casting

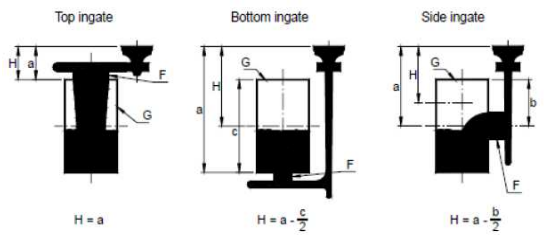

Figure3. Average Metallostatic height 'H' in three types of ingate position

2.3. Simulation of mould filling, solidification and casting defects

The defects such as shrinkage, crack and deformation were the key topics in castings production. Once the shrinkage deformation and the cracks appear in castings, it will cost much fees and time for repair welding. The casting might be discarded if these problems are severe. The stress is one of the main factors that cause deformation and cracks in castings during casting, heat treatment, machining, and service. Deformation, tendency to hot tearing, and residual stress in casting could be predicted by numerical simulation of the thermal and stress fields in casting during casting and heat treatment, which is helpful for optimizing the foundry technology, reducing the defects caused by stress-strain, ensuring the shape and size of casting, and improving the service life of casting.

Malcom blair et al [19] describes recent work to predict the occurrence and nature of defects in casting and determine their effect on performance.

Vijayaram et al. [20] presented a work on numerical simulation of casting solidification in permanent metallic molds

Sulaiman et al.[22,23], describes the simulation and experimental results of thermal analysis in sand casting process. Simulation model of 2-ingate mould and 3-ingate mould of sand casting are developed. They also presented a work on simulation of metal filling progress during the casting process.

Karunakar et al.[24] presented a work on prevention of defects in casting using back propagation neural networks.

Griffiths et al. [25] proposed a method for determining inclusion movement in steel castings by positron emission particle tracking (PEPT).

Ogorodnikova [26] simulated both the technology of low pressure permanent mold casting and the bending test. The shrinkage defects and residual stresses were predicted by computer methods.

An overview is presented on modeling of alloy casting solidification and heat treatment by Jianzheng et al. [27]

Abdullin. [28] presented a work on modeling a complex problem on the stress- strain state of a casting in the software ProCAST. It describe the main steps in the calculations, the initial data, and the results obtained from calculation of the filling of the mold, the crystallization of the alloy, and the stresses in the casting

Charles Monroe [29] presented a work on development on hot tear indicator based on the physics of solidification and deformation. This indicator is derived using available data from computer simulation of solidification and solid deformation.

Yinggan Tang et al. [30] proposed an effective segmentation method for the detection of typical internal defects in castings derived for an X-ray inspection system.

2.4. Optimizing process parameters of sand mold

Sand mold is one of the key factors that directly affect the production rate and product quality. Metal casting industries are actively involved to reduce the scrap rejection and rework during the manufacturing process of the components. To achieve this, the production concerns must follow the quality control procedures correctly and perfectly without any negligence. Timely implementation of the modified techniques based on the quality control research is a must to avoid defects in the products.

Y.Chang et al [31] investigated the properties of green molding sand and a new model is developed to evaluate the flowability of molding sand compact in this study experimental results are presented to show how the flowability of silica sand is affected by water content, bentonite and sea coal content.

Charnnarong Saikaew and Sermsak Wiengwisetto [32] optimize the proportion of bentonite and water added to a recycled sand mold for reducing iron casting waste using the following analysis techniques: a mixture experimental design, response surface methodology, and propagation of error. The effects of variation in bentonite and water added to a recycled sand mold on the properties of the molding sand were investigated. The iron castings were measured qualitatively using a stereo microscope and its surface hardness was also measured using a Rockwell hardness testing machine. The research concluded that the optimal proportion was 93.3 mass% of one-time recycled molding sand, 5 mass% of bentonite, and 1.7 mass% of water having a green compression strength of 53,090 N/m2 and a permeability of 30 A.F.S.

Parappagoudar et al. (33) utilized back-propagation neural network (BP-NN) and genetic-neural network (GA-NN) to model green sand mold system in forward mapping (to predict the responses from the known input parameters) as well as reverse mapping (to predict the set of input parameters for a set of desired outputs).

B. Surekha et al. (34) presented multi-objective optimization of green sand mould system using evolutionary algorithms, such as genetic algorithm (GA) and particle swarm optimization (PSO). In this study, non-linear regression equations developed between the control factors (process parameters) and responses like green compression strength, permeability, hardness and bulk density have been considered for optimization utilizing GA and PSO.

An optimization technique for process parameters of green sand casting based on the Taguchi parameter design approach is proposed by Guharaja et al. [35] and also by Sushil Kumar et al [36]. The process parameters considered are green strength, moisture content, pouring temperature, and mould hardness vertical and horizontal. An attempt has been made to obtain optimal level of the process parameters in order to yield the optimum quality characteristics of the casting.

Zhang [37] presented a work on optimizing casting parameters of steel ingot based on orthogonal method, The influence and signification of casting parameters on the solidification process of steel ingot were discussed based on the finite element method (FEM) results by orthogonal experiment method. The range analysis, analysis of variance (ANOVA) and optimization project were used to investigate the FEM results.

Noorul Haq et al. [38] demonstrated optimization of carbon dioxide casting process parameters by using Taguchi's design of experiment method .

Senthilkumara et al. [39] presented a work on Process factor optimization for controlling pull-down defects in iron casting. The identified factors were analyzed using 'Design of Experiments' approach. 'Signal-to-noise' ratio was estimated. Robust design factor values were estimated from the 'signal-to-noise' calculations. ANOVA analysis was done for robust design factor values.

2.5. Optimization of heat treatment

2.5.1. *Reduction of burns-off*

The metal materials will be oxidized at high temperature and oxidizing atmosphere during heat treatment. The material corrosion will result in addition of de-scaling process and deficiency in economic performance. The burning loss of materials during heat treatment is about 3%–4% of total casting mass at present. Decreasing the burning loss of materials is an efficient method for improvement of the output ratio of metal. The oxidation of steel during heat treatment is closely related to the furnace temperature, time in the furnace, and furnace atmosphere. [40]

2.5.2. *Deformation control*

The casting volume and shape will change, and even distort under the action of thermal stress and phase transformation during heat treatment. The final shape of casting is affected by thermal strain, elastic strain, traditional plastic strain, phase strain, and phase transformation- induced plastic strain. It is necessary to optimize heat treatment for controlling the deformation of casting, which will reduce or avoid the possible repair welding and shape correction work, and also decrease the machining layer thickness and time greatly affects the production cost and the casting quality in production. Large machining allowance will result in extension of machining period and cost [41].

2.6. Efficient cooling in the casting process

The production rate in the casting process is related to the solidification rate. The production period for sand casting is long enough, Therefore, it is critical to increase the cooling rate after solidification and shorten the cooling period in mold To realize efficient cooling some kind of methods were proposed.

Shi et al developed a method by using a fluidization plate and for improvement of the cooling rate of riser after solidification, a method mixed the mist cooling, and wind cooling was developed by Kang et al. [40]

In addition, the methods for increasing the cooling rate of casting still need to be developed for improvement of production efficiency, for example, rapping of sand mold, local shakeout, and increasing shakeout temperature [42]

3. CONCLUSIONS

Product and process design is the soul to realize efficient and economical manufacture of quality sand castings. There is great progress of green sand castings production, but it is still far away from optimal design. There is still huge potential for the improvement of casting design and process control technology. Computer science, artificial intelligence techniques and statistical process control methods have been utilized for solving various problems in manufacturing. Similar tools can be used to solve the problems in casting industry especially to reduce the defect percentages to reasonable levels.

The main area for optimization in green sand casting process for efficient and economical quality casting are:

- Optimizing and reducing riser mass
- Optimizing gating system
- Simulation of mould filling and solidification to avoid casting defects
- Optimizing process parameters of sand mold
- Optimizing pattern plate utilization
- Optimization of mould yield
- Optimum use of pads and chills
- Optimization of melt composition and temperature
- Efficient cooling during solidification
- Reducing oxidation and controlling deformation of casting in heat treatment
- Dimensional control and reducing machining allowance
- Efficient Shake out

- Efficient sand reclamation and recycling
- Foundry mechanization
- Data acquisition system and automatic control

The significance of optimization may be one or more of the followings:

- Quality casting
- Improving output ratio of metal
- Saving energy
- Saving resources
- Increasing manufacture rate
- Increasing enterprise benefit
- On-time delivery schedule
- Reducing pollution

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