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Review of Optimization Aspects for Casting Processes

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Abstract: ***In today's global competitive environment there is a need for the casting set ups and foundries to develop the components in short lead time. Defect free castings with minimum production cost have become the need of this indispensable industry. Rejection of casting is caused due to defective components. These defects depend on various process parameters which need to be improved using various methods in optimization. The IT industry with the help of manufacturing industry have developed various software packages which simulate the casting process which help to identify the parameters affecting the quality of castings. The simulated results can be used to predict the defects, optimize the factors and take corrective steps to minimise these defects. This paper provides comprehensive literature review about optimization aspects of casting process and shows shear necessity of investigation of the process parameters and process optimization.***

Keywords: Metal Casting, Virtual Process Simulation, Optimization, Taguchi Techniques, Design of Experiments (DOE).

1. Introduction

Castings are one of the foremost metal shaping techniques known to mankind. Many battles were fought in early times which were won using arrow heads, spears, shields and hot oil cauldrons, one of the earliest castings mankind developed. Castings range from the humble chunks or hunks of low grade pig iron like those used as earth moving machinery counterweights, to those with complex non-ferrous metallurgical alloys which are used directly as precision parts like in the automotive industry. There are hundreds of casting processes, for thousands of metals and alloys for millions of parts which can be produced through castings. Apart from it being a basic low cost methodology for mass production of complex shapes and sizes which is the basic purpose or intent, castings can be used as far as ones fertile imagination exists. Time has never marred the importance of castings nor ever will, but yes technology has played an important role in making Castings more versatile, quicker, accurate, energy efficient and greener for the environment. Now with sophisticated I.T. tools, analysis and simulation softwares there is a revolution which has been bought across for the turnaround time to develop a casting and also how the casting would look like or behave when put to intended use.

In the casting manufacturing process solid metal is melted, which is then poured into the cavity which can also be termed as mould. The mould holds the molten metal which then solidifies and forms the desired component. Thus designs and shapes of high intricacy and detail can be achieved in a single step using casting process. Hence a designer can design and make any desired shape he wishes using metal casting process.

Casting components can vary in size, right from smallest component which can resemble the size of an ant to large components weighing in tons. There are numerous advantages of casting for producing complex shapes, internal contours , irregular surface parts, long hollow sections, also for very large parts for which machining is difficult. Seeing all these advantages, casting is one of the most important manufacturing process.

Process Optimization is necessary to improve the performance as per the industry standards. These performance members include improving productivity and cost by minimizing rejections. In the pursuit to achieve these improvements various process parameters such as runner and gate locations, shot pressure, number of risers, runner and gate shape, mould material and temperature of molten metal are needed to be optimized by controlling them efficiently.

2. Literature Review

2.1 Review of Parameters Investigated:

C.C Tai and J.C Lin (1996) optimized the techniques used to design a runner in die casting process. The entire process was mathematically modelled using Abductive network technique. This helped them to optimize the runner design in the making stage by ruling out the various discrepancies in the system in the development stage itself. [1]

Ching-Chih Tai (1998) optimised the control of accuracy of the component which was made using metal die casting process. In order to locate the correct gate position of the design mould, a finite element method was used. On the bases of the results obtained from finite element analysis, an Abductive network was designed which could predict important process parameters such as the injection angle and sectional ratio of the runner and gate and injection positions. Optimizing these process parameters lead to more accurate components. [2]

B.H. Hu, K.K. Tong, X.P. Niu and I. Pinwill (1999) carried out optimization of the design for gating and runner systems of components used in the telecommunication industry using various numerical simulation methods. The components produced by die casting are mainly thin wall components made from magnesium. The numerical analysis was performed on a commercial software MAGMASoft, a Computer Aided Engineering (C.A.E.) package. The software helped to simulate the process virtually which helped to optimize the runner and gating systems for the thin walled magnesium parts produced by the hot chamber die casting process. Eventually two combinations of runner and gating systems were analysed performing these numerical simulations and the better of the two was considered. [3]

G.P.Syrcos (2001) optimized the Die casting process using Taguchi methods. He tried to achieve optimal setting of the die casing process performing Design of Experiments (DOE) and using Taguchi technique. Piston velocity, metal temperature and filling time were the factors chosen to be varied in the process. The results concluded that the selected parameters affect the density of the material effectively and hence the porosity defect can be gradually reduced. [4]

Mekonnen Liben Nekere and Ajit Pal Singh (2005) conducted a study on various optimization techniques used for Aluminium Blank Sand Casting Process. During their study they came across Design of Experiments (DOE) Taguchi's technique which helped them to find out major contributing factors in the die casting process. They carried out experimental runs on two batches of blanks of aluminium casting which indicated the major factors responsible such as grain size, clay content, moisture content, ramming, sprue size, riser size, and diameter to thickness (D/t) ratio of the blank. An orthogonal array was constructed for the seven factors identified, and performed eighteen sets of experiments to generated the required data. A statistical analysis of variance (ANOVA) was also performed to see which process parameters are statistically significant. They verified the readings by performing a verification experiment in which the new data proved to be promising and hence the sand casting process was enhanced by Taguchi robust design method. [5]

Rohallah Tavakoli and Parviz Davami (2007) carried out design optimization of an automatic feeder used in the steel casting process. The Design process of the feeder consisted of factors such as determination of the feeder-neck connection point on the casting surface, initial feeder design and optimization of feeder shape and feeder topology. Process optimization was eventually achieved by introducing an automatic feeding system to the existing process which helped in increasing productivity by reducing process time. [6]

Cavus Falamaki and Jamileh Veysizadeh (2007) studied optimization of centrifugal casting method used to manufacture one step alumina membrane supports using Taguchi's Design of Experimental (DOE) approach. The method of Taguchi was implemented where L9 array was taken under consideration. It was found that the first target function is the most suitable as far as the membrane characteristics of the sintered compact. With the help of this target function an optimum configuration for controlling the parameter levels were achieved. [7]

G.O. Verran, R.P.K. Mendes, L.V.O. Dalla Valentina (2008) studied the optimization of process parameters of aluminium alloy die casting using Design of Experiments (DOE). The study was carried out to analyse significant process parameters such as up-set pressure, slow shot and fast shot. The process parameters were further narrowed down by applying Design of Experiments (DOE) method which helped to further optimize these crucial parameters. The porosity in metal casting products was reduced thus improving the quality of the product by using various combinations of the process parameters of die casting. [8]

D.R. Gunasegaram, D.J. Farnsworth and T.T. Nguyen (2008) studied shrinkage porosity by identifying crucial factors using numerical simulative approach of Design of Experiments (DOE). Many critical process parameters that affect parameters such as size and location of a shrinkage pore were narrowed down using simulative approach which were then substituted in the mathematical model of Design of Experiments (DOE). The mathematical model helped to reduce the number of simulations performed, which lead to substantial savings in labour cost and the time invested to conclude on a solution. As this issue was a live one from the foundry, optimization lead to reduction of the scrap material by more than 13% which was well appreciated. [9]

Zhizhong Sun, Henry Hu and Xiang Chen (2008) studied the numerical methods used to optimize the parameters of a gating system for a magnesium alloy casting. They used Taguchi technique of Design of Experiments (DOE) to find out the effect of various parameters such as height and width of ingate and dimensions of the runner which are major process parameters which influence magnesium alloy casting. The mould filling and metal solidification process was simulated on commercial Computer Aided Engineering (CAE) package MAGMAsoft. The optimized process parameters resulted in improved filling velocity, reduced porosity and increased product yield of castings made from magnesium alloy. [10]

Radomir Radiša, Zvonko Gulišija and Srećko Manasijević (2009) worked on optimizing process design for die casting process to enhance the properties of the components. They performed virtual process simulation using commercial Computer Aided Engineering (CAE) package MAGMASoft which help them to predict the various defects in components as well as the process. The virtual simulation helped to point out the flaws such as metal freezing in feeding system at the entry which lead to a clog in the process which lead to partial filling of the die. Hence they optimised the process by virtually simulating the process which can be easily carried out using a process simulation tool. [11]

Y. Sun, J. Luo, G.F. Mi and X. Lin (2010) studied the castings of a rear truck axle made of nodular cast iron and eliminated the defects in them using numerical simulative methods. The three dimensional modelling of the rear axle was developed on a commercial Computer Aided Design (CAD) package Pro Engineering which was the first step to carry out the analysis. The modelled component was then simulated on a commercial simulation software Z- Cast which gave an insight in the solidification process which lead to formation of a numerical solidification model. On resolving the model the pouring system by ladle and casting cross sectional structure of the rear axle was optimised which lead to overall improvement of the casting process. [12]

Ingo Hahn and Jörg C. Sturm (2010) carried out optimization of designs for the casting process. The study was carried out using Design of Experiments (DOE) as a tool for optimizing various factors of the casting process. The study focused on significant factors such as faulty gating design and pouring conditions which lead to the various defects in casting process. The process simulation was carried out using commercial process simulation package MAGMASoft which helped to virtually perform the process and carry out the Design of Experiments (DOE). [13]

Mayur Sutaria, Vinesh H. Gada, Atul Sharma and B. Ravi (2012) studied the solidification process of casting using level set method. The feed paths of the casting process were computed using Eulerian technique for computational of capturing the moving boundaries and interfaces of the casting product. Their main aim for carrying out this computation was to numerically analyse the feed paths and hot spots by simultaneously performing the level set method and the mathematical model of the feed path. This experimental research gave the researchers insight in feed path calculations which were validated using level set method. [14]

Charnnarong Saikaew and Sermsak Wiengwiset (2012) improvised the quality of castings made by optimizing the moulding sand composition. The optimization was performed by formulating a dual mathematical problem by combining Response Surface Methodology and propagation error. They managed to improve the proportion of bentonite and water which was added to recycled sand of mould to minimise the waste caused by iron casting which was possible using the dual mathematical formulation. The research was concluded by citing that the optimal proportion of one time recycled mould sand was 93.3% mass and 5% mass of bentonite, also 1.7 mass% of water which had a green compression strength of 53,090 N/m^2. [15]

E. Angladaa, A. Meléndez, L.Maestro and I. Domiguez (2013) made adjustments in the problem of numerical simulation which were needed to optimize the investment casting process. The simulation of the investment casting process was carried out on a commercial package ESI Pro Cast which helped the researchers to make the Finite Element Model (FEM). This Finite Element Model (FEM) to predict the defects which surface in the component during and after the process of casting. The simulation was based on transient analysis which was combined with fluid dynamics also considering the latent heat which was emitted during solidification process of the component. [16]

Hassan Jafari, Mohd Hsbullah Idris and Amirreza Shayganpour (2013) studied the lost foam casting process where process parameters were taken into consideration for manufacturing Ai – Si – Cu alloy. The evaluation of these significant parameters was conducted using Design of Experiment (DOE) as the tool where a full factorial model of the system was formed. The properties of casting were affected due to significant manufacturing factors which indicated pouring temperature played an important role in the quality of the castings. The research concluded by stating that the higher pouring temperature results to better surface finish in the components made using casting process. [17]

Huijun Feng, Lingen Chen, Zhihui Xie, Zemin Ding and Fengrui Sun (2013) carried out a generalised study on the various optimization techniques used for solidification during heat transfer of continuous slab casting. Prior to the study it was observed that there was a lot of heat loss in this system due to which this problem was taken into consideration for further research. Numerical Simulation tools were used to calculate the optimal cooling rate of the continuous slab casting process which results in efficient solidification of the slab components. [18]

Uday A. Dabade and Rahul C. Bhedasgaonkar (2013) analysed the various defects in the process of metal casting process and optimized the performance of the system using Design of Experiments (DOE). The entire process of metal casting was simulated virtually using a commercial Computer Aided Engineering (CAE) package MAGMASoft. The virtual simulation helped to narrow down on defects such as hot tears and shrinkage porosity. The Design of Experiments (DOE) model was used to improve the feeding system design and gating locations which helped them to achieve a reduction in shrinkage porosity by 15% and improved yield strength by 5%. [19]

Swapnil A. Ambekar and Dr. S. B. Jaju (2014) reviewed optimization techniques used to improve the gating system of casting in order to achieve reduction in the defects caused during the process. They used Design of Experiments (DOE) as a tool for carrying out optimization of the shrinkages in the component which lead to heavy rejection in the foundry. The virtual filling simulation of the component was carried out on commercial Computer Aided Engineering (CAE) packages Ansys FLUENT and Z- Cast which helped them to understand the flow of metal during the casting process. The virtual simulation pointed out porosity as the most common defect which was caused due to improper riser design and gating design which lead to large rejections of casted products in the foundries. They developed a new riser and gating system which helped to reduce the shrinkage porosity reducing the rejection in the foundry. [20]

Harshil Bhatt, Rakesh Barot, Kamlesh Bhatt, Hardik Beravala and Jay Shah (2014) carried out the simulation of casting process to optimize the design of feeding systems. The process simulation was performed using commercial Computer Aided Engineering (CAE) package AUTO Cast X which showed them the various defect causing parameters. The Design of Experiments (DOE) model was used to get various combinations for the dimensions of the feeder to reduce the intensity of the hot spots. The research was concluded by optimizing the feeding system by reduction in the hotspots of the component. [21]

P. Shailesh, S.Sundarrajan and M.Komaraiah (2014) studied the centrifugal casing technique for Al-Si alloy and optimized its process parameters using Taguchi's method of Design of Experiments. It was observed that the mechanical properties of the components such as density and yield strength were enhanced by refining the process using Taguchi Design of Experiments (DOE) model. The results indicated that the reducing the pouring temperature and increasing the speed of the die leads to improved mechanical properties of the casted components. [22]

C. M. Choudhari, B. E. Narkhede and S. K. Mahajan (2014) reduced the defects caused in casting process by simulating the casting process. The process was simulated using Computer Aided Engineering (CAE) package Auto CAST X which pointed out major casting defects in the system. The defects such as shrinkage cavity, porosity and sink were identified in the simulation. A new feeder was designed to reduce the defects which were detected by AutoCAST X which was hen performed experimentally. The values attained from the experiment were similar to that simulated by the software hence validating the process improvement. [23]

Su-Ling Lu, Fu-Ren Xiao, Shuang-Jie Zhang, Yong-Wei Mao and Bo Liao (2014) carried out simulation of centrifugal casting process of a wet - type cylindrical liner. The virtual simulation was carried out using a Computer Aided Engineering (CAE) software Pro Cast. The main aim to simulate the component was to narrow down the casting defects that appear on the inside the liner of the wet – type cylinder. These defects mainly include coarse grain structure and shrinkage porosity which occur due to faulty designs of the feeder and gating systems. In order to resolve the defects in the liner of the wet type cylinder, a process model was made on Pro Cast software. The results derived from the simulation were further optimized to improve the process of casting. [24]

Zhang Jie, Zhang Dongqi, Wu Pengwei, Wang Gang, Li Feng and Dai Penglong (2014) studied TiB2/A356 aluminium base composite to be used for investment casting and carried out numerical simulation to optimize the process. The process simulation was performed using a commercial Computer Aided Engineering (CAE) casting package Pro Cast. The numerical simulations obtained from Pro Cast pointed out the week links in the process which were then optimized. The results indicate that the problems of shrinkage porosity defects have been resolved by increasing of pouring temperature and casting speed. Also by adding the insulation materials around the gate and riser the system has gained more stability. [25]

From above discussion and findings, it is clear that many researchers have contributed to the optimization procedure by investigating various aspects of the casting process. They have mainly worked towards improvement in casting and elimination of defects such as differential cooling solidification, shrinkages, gating design, riser design, pouring conditions, porosity, mould wear, cold shunts and blow holes.

3. Conclusion

We also need to acknowledge the formation of front end integration for casting Industries in the form of engineering workshops to machine castings and finally offer the finished product ready for assembly and use. This was more a necessity and need. Though with all the technology, men and machines the defect free casting though minimised cannot be wished away or ruled out. Now Castings are produced in one country and exported to many others which is a global norm, due to many reasons which is another topic all by itself. The castings undergo machining in conventional machining centres & also in high end CNC machining centres. Discovering a casting blowhole or a defect after machining leads to the whole casting getting rejected and more often than not, the machining process is more expensive than the basic casting itself. Hence all major casting manufacturers have forward integrated to value add by creating castings and machining them to finished specifications themselves to ensure that the perfect end product reaches the customer and there is zero rejection.

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