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Sand Casting Process Optimization via Design of Experiments: A Review

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Abstract
Designing and optimizing of gating is an essential part of casting foundry as it contributes significantly to predict and minimize the flow turbulence resulting to casting defects like rough surface, sand inclusion, etc. An Optimization scheme for gating design parameters for casting was proposed with different past studies of the researches. Various designs were modeled and mould filling simulation rooted to minimize turbulence and macro defects are recommended in this review. Statistical software is introduced following the design of experiments (DOEs) practice, 'Taguchi Method' for optimizing designs. Results are analyzed through various mathematical methods showing the best combination of the parameters. Design of experiments for optimizing in gating systems is effective, easy to implement and bring out good quality casting.

Keywords: *Sand casting defects, gating designs, FEM, DOE, Taguchi method*

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INTRODUCTION

Now-a-days, in developing world, with the perception of the artificial intelligence, levels of automation are escalating with rapid rate. Casting are well recognized as the manufacturing method in which multifaceted shapes were transformed from molten metal in a mould at mass and quality production which also bears failure risk throughout the process. Major applications are in casting of automotive and spacecraft parts as well as industrial and domestic machineries. As we cannot predict the actual cause, casting defects are very receptive and need a deep study to relate various parameters to be altered significantly. The two consecutive stages in casting are the filling and solidification processes. In filling, defects may occur due to inappropriate design of ingate consisting of pouring basin, sprue, sprue-well, runner and ingate. In solidification, defects tend to shrinkage and location of hotspot can be altered with optimum riser design. Proper casting designs and its optimization to reduce production time and cost can pilot to defect free/quality casting. This technique is imperative for upgrading the productivity as well as lessens the manufacturing cost by minimizing the rejection rate.

LITERATURE REVIEW

B. Ravi, *et al.* 1992 [1], worked in applying simulation process for the gate and riser arrangement of a bearing block. Different modules were created by the team and designs were generated with the assist of CAD/CAM software within their foundry lab, Indian Institute of Science. Various gating and risers locations were simulated and analyzed on the root of different criterions clearly mentioned using C language and a PC-AT. As a result of the study they pointed out the advantages of unpressurized gating over the pressurized one with the help of optimal design for tooling.

Li Chagyun, *et al.* 2006 [2], have done study work on the filling characteristics with acryl glass mould to cast titanium alloy. As listed by the authors, four different factors as forward, backward, top and bottom filling process with three different levels were examined using hydraulic simulation modeling and conclusions were prepared in favor of optimizing the problem leading to less defective castings.

G.O. Verran, *et al.* 2008 [3], had a research work regarding the assessment of quality in a die casting module, a double cylinder cover of compressor engines made up of SAE-305 aluminium alloy. An automatic data acquisition system connected as CPU and other equipments were installed to optimize three parameters i.e. slow and fast shots and up-set pressure at three levels and a total 18 casting combinations were made for comparing density and porosity rating respectively. Analysis were done using analysis of variance (ANOVA) at 95% confidence level showing the turbulence in the molten metal for high and fast shots with air entrapment and porosity but high up-set pressure posses optimum casting density. Hence, best combination was mentioned and conclusions were in favor of DOE technique for the optimization problem.

Sudhir Kumar, *et al.* 2008 [4], were worked for optimizing the problem of casting aluminium alloy metal in an expandable pattern casting process. According to the study, four factors i.e. grain fineness number, time of vibration, degree of vacuum and pouring temperature at three respected levels were considered for L_9 orthogonal array experiment using Taguchi scheme to optimize the product's Tensile strength and percentage elongation. The results of above experiments were analyzed with ANOVA at 5% significant level and concluded the higher contributing factors for the response. As a result of this paper, optimum levels were pointed out for the best responses for the casting.

D.R. Gunasegaram, *et al.* 2009 [5], presented a paper regarding shrinkage porosity of aluminium factory of XYZ MOTOR COMPANY, Australia ltd. The main goal behind this effort was to pointing the significant parameters for defects involvement. Experiments were setup using aluminium. Alloy in a permanent moulds of steel and further discussing about the model of design of experiments (DOEs), responses, factors with their levels; they studied five factors with two levels for the optimization using $^1/_2$ factorial design technique. Finite difference technique based software was selected for simulating the problem and assumptions were based for heat transfer coefficient with initial temperature. Results were analyzed through normal probability chart and main effect plot. At the end, suggestions were made accordance with optimized process with reduced scrap rate through design of experiment.

B. Senthil Kumar, *et al.* 2009 [6], have done a study finding toward minimizing the pull-down defects (known as external shrinkage as mentioned) caused in iron casting in a green sand mould. Three factors namely the pouring time, carbon equivalent and riser related to gating with three different levels for each and an interface of factors were optimized using Taguchi L_9 orthogonal array techniques. Outcomes were analyzed with the support of ANOVA and Fisher's test at 0.1 confidence level and suggestions were obtained for the optimized levels. At the end, higher productivity was achieved and the numbers of pull-down defective casting were reduced by the process.

R. Ahmad, *et al.* 2011 [7], worked on a plate casting of Aluminium LM6 alloy to determine the optimal runner diameter. A vortex flow runner arrangement with three different diameters was made and experiments were conducted. Data were collected using universal testing appliance for the strength using three-point bending test. Results were studied with Weibull Distribution showing the higher strength at the location which is away from the in gate and at both end of those plates. Hence, as a conclusion, they stated that the runner diameter having a direct relation with the strength of material and optimized system was successfully installed.

C. M. Choudhari, *et al.* 2013 [8], has presented a research work which basically deals with the shrinkage defects in casting, to optimize the designs and to explore the riser for better sand casting. At first, design were made confirming that riser posses higher value of module than casting so that solidification takes much time in riser than in casting for the purpose of shifting the hot-spot from casting to riser followed by runner, In gate, etc. According to this paper, somewhat CAINEs scheme based on Chvorinov's Rule was introduced to design riser. Through the calculations, it shows that Yield Force of riser is somehow larger than that of casting hence giving optimum design for the experiment. Three diverse values of diameter for riser were taken and finite element software was used for the purpose of modeling and simulation. As the result of comparing simulations and actual experiments, riser with sleeve shows comparable result as that of only riser shows, concluding increased yield strength of casting goods with this method.

Manu Khare, *et al.* 2014 [9], worked for minimizing the casting percentage defects of a flywheel prepared of cast iron in a green sand casting process. Further listing three factors as most significant were green strength, clay content along with pouring temperature with two levels, author conducted a total of eight experiments and the results was obtained in term of percentage defects and analyzed with ANOVA approach. At the end, conclusions were noted referring the most significant factor as green strength of the mould with significantly minimized defects.

B. Vijaya Ramnath, *et al.* 2014 [10], were engaged to optimize and analyze the runner design for Alloy AD C12 casting material for the purpose of manufacturing commutator end brackets. In his related work, it is pointed that ratio of surface area and volume should be minimum for the given shaped runner. Various design parameters were listed linking to bracket, runner, die, etc. Various flow simulations were performed using a software package and velocity, temperature, porosity and solid fraction distributions were obtained in order of getting the results compared with flat gate and their optimized spoon fed gating design and validated with microstructure examinations. Conclusions were made that optimized design was applicable in reducing filling time and negative pressure enhancing the product acceptance.

K. Ch. Apparao, *et al.* 2016 [11], had done a research on an aluminium alloy square plate made by high pressure die casting apparatus in a small industry at Hyderabad. In their study, Taguchi Method was applied to optimize four parameters i.e. the pouring temperature, filling time, die temperature with injection pressure at three diverse levels to minimize the porosity. A total nine experiments and their S/N ratios were analyzed with ANOVA and conclusions were made indicating significant factors as injection pressure and pouring time. With the ending, authors concluded that optimum levels were contributed to minimum porosity with optimization and simulation.

K. Srinivasulu Reddy, *et al.* 2016 [12], had presented their work which deals with the collapsibility of mold material and the surface finish of the grey cast iron casting. Molds were made using no-bake binders with the silica sand and design of experiments was done using L_9 orthogonal array (Taguchi method) for three factors i.e. grain Fineness number, binder percentage and iron oxide percentage at nine different experiments. Data were obtained using statistical software along with ANOVA and regression analysis was done for smaller-the-batter S/N ratio. As a result, they found that contribution for binder percentage is very high in collapsibility whereas low in surface roughness. Hence, conclusions were made that increasing binder percentage, collapsibility increases, but increasing the grain fineness number, collapsibility of the mold decreases. Using above parameters, optimal collapsibility with surface roughness were judged as an optimal design for casting.

Rajkumar Ohdar, *et al.* 2016 [13], in the study focused to the optimization technique for getting optimal solution of mold properties (permeability and green compression strength) using four control factors i.e. mulling time, clay, moisture and coal dust content using multi-objective genetic algorithm. Further in the study, author mentioned the methods of genetic algorithm step by step and stated that the iterations made in the whole algorithm were known as generations. Moving from one solution to other, it shows gain in function whereas loss in other. Moulds were prepared in the laboratory and L_{27} orthogonal table was used for optimization and analyzed in the statistical software for permeability and green compression strength and numbers of non-dominated solutions with numbers of generations were obtained. At the end in the research, author concluded that anyone of the above combinations was accepted because none of them shows better property with other approving the technique.

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