Optimizing Casting Process Parameters by Using Design of Experiments and Machine Learning

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Abstract

High pressure die casting (HPDC) is a versatile but complex casting process. It is used extensively in the aluminium casting industry. Al-Si, Al-Si-Cu eutectic based alloys are most used in this process. Amount of casting scrap generated mainly depends upon design of mold and gating system, metallurgical quality of metal and process parameters. It is possible to improve the yield significantly by systematically optimizing process parameters. However, there are numerous metallurgical, design and process parameters, hence optimizing them becomes quite challenging. Finding most suitable operating conditions by trial and error is quite common in the industry. However, this method is expensive, not easy to do, error prone and operating parameters may not be the best with respect of productivity perspective. This paper presents a case study on systematically optimizing operating conditions for minimizing scrap generation and at the same time not compromising productivity. Design of experiment technique of Taguchi method and machine learning technique of Artificial Neural Network (ANN) was used. ANN is a software algorithm patterned after the operation of neurons in the human brain and is used extensively. Several HPDC aluminium casting runs were done for the purpose. Methodology was economical, efficient and solution found was optimum and robust. Solution was validated under actual casting conditions. Same approach can be used in other casting processes of the casthouse and in other areas of the smelter.

Keywords: Aluminium casting, High pressure pie casting, Taguchi methodology, Artificial neural networks, Design of experiments, Scrap reduction.

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1. Introduction- High Pressure Die Casting

High pressure die casting (HPDC) involves injecting molten metal into a die at high velocity and pressure. HPDC is widely used in the production of Aluminium automotive and many other components. HPDC is a versatile and efficient method for producing components requiring low surface roughness and high dimensional accuracy. However, improperly controlled operation can result in scrap generation. Scrap leads to increase in melting, casting, fettling, manpower, financing cost and it slows down the process significantly. And due to the fact that foundry has to process additional metal due to gating system and compensate for melt loss this effect gets amplified. Though the internal recycling as a percent may be small, on a long-term basis this can have significant adverse effect on profitability.

HPDC is a complex process consisting of over 150 process parameters. Due to this complexity and difficulty in properly configuring the operation results in many defects such as short fill, cold shut, cracks, blister, damage, bend, porosity and leak during pressure testing. However, the porosity is by far the most common defect. Porosity can be classified as gas porosity, shrinkage porosity, and flow porosity. First two are the most common in HPDC. It is not always possible to eliminate all defects completely as operating conditions have different effects on various types of defects. Sometimes, reduction in one type of defect can lead to increase of another type of defect. Process yield mainly depends on – 1) Design of mould and gating system, 2) Metallurgical quality of metal, and 3) Choice of process parameters. It is possible to improve the yield and productivity significantly by measuring and controlling metallurgical quality of metal and systematically optimizing process parameters. This paper is on optimizing process parameters.

2. Introduction to Experimentation Using DoE/TM and Machine Learning (ML)

Finding most suitable operating conditions by trial and error is quite common in the industry. Due to large number of HPDC process variables, process engineer is constrained to make educated guesses to decide on parameters. These are infrequently truly optimized parameters. One parameter/factor at a time experimentation is simply not practical. One cannot even know if one's "best" results are indeed the overall best that can be achieved, as vast areas of parameter space would have been missed. In many cases, productivity is compromised to keep scrap under control or vice versa.

In this study we use design of experiments (DoE), combined with machine-learning (ML) analysis, for screening and optimization. Several machine variables can be changed and investigated simultaneously as per appropriate statistical framework. This leads to much faster screening of experimental parameters and optimization. DoE approach enables sampling a large, multidimensional parameter space in a rational manner, which can then be coupled with machine learning to map the parameter space.

DoE is branch of applied statistics that deals with planning, conducting, analyzing, and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters. DoE is a powerful data collection and analysis tool-can be used many situations. It allows for multiple input factors to be manipulated, determining their effect on a desired output (response). By manipulating multiple inputs at the same time, DoE can identify important interactions that may be missed when experimenting with one factor at a time. Taguchi method (TM) is a type of DoE used extensively in engineering and technical applications. Reference [1] provides detailed information of TM. TM has been used extensively in manufacturing engineering for System design, Tolerance design and parameter design. Parameter design for optimizing HPDC operating variables is used in this paper.

Machine learning (ML) is a subfield of artificial intelligence, capability of machine to imitate human behavior. Machine learning is defined as: "A computer is able to learn by experience without explicitly being programmed – and improves performance as it learns". ML/AI have any algorithms - ANN, support vector machine (SPV), random forest (RF). Genetic algorithm (GA) is a ML software algorithm and is used extensively in optimization field. By applying machine-learning methods to the results of DoE, multidimensional maps are rendered. It is possible to see without bias, not only the areas or domains of "best" performance but also new areas that have not been previously considered. This approach can enable faster and higher fidelity exploration and optimization of new systems. This approach has several advantages - 1) less effort, much more insights 2) much faster and cheaper 3) can find important factors and their best levels 4) able to choose parameter levels keeping productivity in mind 5) findings have Statistical validity.

In the current work, experimentation is done using TM, predictive modeling and optimization are done using ANN and GA. Objective of the present work is to find most optimum operating conditions to minimize scrap generation. There are many case studies available in literature where models developed using ANN have been found to be consistently superior to ones developed using DoE alone.

8. References

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