APPLICATIONS OF ARTIFICIAL INTELLIGENCE TECHNIQUES IN METAL CASTING -A REVIEW

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Abstract

Process control and monitoring of product quality during metal casting operation(s) cannot be overemphasised. In addition, algorithms, models and optimisation techniques can be developed in metal casting processes to minimise casting defects through artificial intelligence. This review paper explores the applications of artificial intelligence (AI) in metal casting process. The evolution, fundamentals concepts of the AI methods/tools covering Fuzzy Logic (FL), Case Based Reasoning (CBR) and Artificial Neural Networks (ANN) are discussed accordingly. Furthermore, applications of these methods/tools in aspects of casting process optimisation, product quality monitoring/control of defects, intelligent design and materials selection are critically reviewed. The structure of this article provides clear understanding of the concept to foundry engineers, researchers and stakeholders in metal casting industry for enhancing net-shape casting with high reliability and integrity.

Keyword: Algorithm, Artificial Intelligence, Casting defects, Manufacturing, Metal Casting, Optimization; Soft Computing

1.0 INTRODUCTION

Metal casting is one of the oldest processes of manufacturing and it is assumed that it is as old as mankind. It is also known as net shape process. In the last three decades, a lot of advancements have been taken place in the field of metal casting. However, green sand casting remains one of the most versatile casting processes due to readily available and cheap raw materials; flexibility with respect to shape, size and composition; and the possibility of recycling the moulding sand (Singha and Singh, 2015). The sand casting process starts with preparation of mould, pouring molten metal into a sand mould, allowing the metal to solidify, and then breaking away the sand mould to remove a casting product. Out of the various steps involved in the casting process, moulding and melting processes (pouring of molten metal) are the most important stages. Improper control at these stages results in defective castings (Tiwari *et al.*, 2016). Casting is a process of pouring molten metal into the cavity of a mould and allowed to solidify into a required shape. Casting as a process involves a relationships of many parameters such as mould temperature, moisture content, permeability of sand, type of binders, pouring temperature and gating system. These parameters significantly have effect on the mechanical properties of the cast. In the past the foundry engineer has used the manual methods in producing cast products. This has led to defective cast and resulted in cast rejection (Lei and Su, 2019). In casting industry, the cast parts defects caused by solidification shrinkage, improper feeding, heat transfer mechanism between the cast and the mould and the sand mixture represent a major cause for casting defects and rejection. The defects can be minimised through artificial intelligence. Artificial intelligence (AI) is a fourth industrial revolution of computational analysis (Schwab, 2017; Pan, 2016), distinguished by the shift of agency and control from humans to technology, and thus transforms our previous understanding of human-technology relations. This revolution and its implications highlight new theoretical and empirical questions that need to be addressed by organizational researchers on workforce structures, designs, decisions and analysis (Brynjolfsson *et al.*, 2018; Danaher, 2017; Huang and Rust, 2018; Kaplan, 2015; Kellogg *et al.*, 2019; Pfeffer, 2018; Wirtz *et al*., 2018). However, this paper presents review of applications on artificial intelligence.

2.0 Artificial Intelligence

2.1 Development of the AI Algorithm and Models

Numerical analysis is constantly used in casting industry for a better understanding of both the critical aspects related to heat transfer and fluid flow phenomena. This relationship between metallographic structures and formation of microstructure defects in the cast parts has employed numerical analysis in the past decades (Das *et al.*, 2015). Some of the thermo physical properties necessary for obtaining very accurate results by using numerical analysis are very often totally missing in case of some alloys which have a very high commercial interest for casting industry. The casting technologies have many advantages as the flexibility of manufacturing some complex geometry. Furthermore, by controlling the casting process can be obtained, through a single processing operation, a cast part which corresponds to the imposed mechanical properties and quality level. Thus, the application of numerical analysis in casting is good while thinking towards application of AI in casting will act as programming of machine learning in controlling the precision parameters of casting process.

Due to computational time consumption during analysis in controlling parameters of casting process will require better algorithm that will speed up defects control in casting. The algorithms such as genetic algorithm (GA), ISRES (Improved Stochastic Ranking Evolutionary Strategy) and ESCH (Evolutionary Strategy with Cauchy Distribution) are samples of AI algorithms that is being applied engineering application. The latter is a meta-heuristic version of an Evolutionary Strategy (ES) workflow, using a Cauchy random number function to generate each individual, instead of the usual uniform distribution function available in almost all programming languages (Bertelli *et al.*, 2014).

In casting industry, the casting part defects caused by solidification shrinkage represent a major cause for rejection. Some researchers stated that pore formation is determined by the heat transfer mechanism between the cast and mould, shrinkage solidification or improper feeding of the mould. The type of mould used in metal casting depends heavily on the type of casting to be produced, the alloy involved and the complexity of the shape to be cast. Heat transfer between the solidifying casting and mould is critical for high quality casting. In addition, heat transfer between the casting and the mould is primarily controlled by conditions at the mould-metal interface. The quality of castings in a green sand mould are influenced significantly by its properties, such as green compression strength, permeability, mould hardness and others which depend on input parameters like sand grain size and shape, binder, water etc. Thus, applying AI into this moulding process will minimise defects.

Lee *et al.* (2018) stated that the prediction of internal defects of metal casting immediately after the casting process saves unnecessary time and money by reducing the amount of inputs into the next stage, such as the machining process, and enables flexible scheduling. This research is intended to look at Artificial Intelligence, which has proven to be one of the most important tools in decision making in Energy industry, with the industry increasingly becoming more digitalized, data generated, processed, and analysed are used for product design, planning, and production control. This makes the Energy industry more reliable, flexible and efficient in production processes. Artificial Intelligence has been a central focus for many researchers in the last 3 decades. Casting defects which occurred as a result of inaccurate process parameters, mould design, sand mixtures, and processes and procedures could be resolved with the aid of Artificial Intelligence. Hence, optimising the processes and procedures offers tremendous potential for the Energy industry via predictive production and maintenance. This will reduce defect in casting and cast rejection, thereby avoiding wastages in terms of cost, production time faster and energy consumption and can be used to study industrial scale Problems.

2.2 Applications of AI in Casting

Artificial Intelligence (AI) could be defined as the simulation of human intelligence in machines programmed to think like humans and mimic human's actions. This term may also be applied to a machine that exhibits traits associated with a human minds or brain such as learning and problem solving skills. In today's scenario of competition and precision, where we are talking about six sigma lots of efforts are being made by the foundry engineers to reduce rejection of defective castings. And very high cost and time is associated with analysis and prevention of defects in castings because previously they were dependent on the conventional trial and error methods that lead to huge losses. Therefore, use of computational intelligence methods in the field of sand mould design, defect identification, evaluation, analysis, and casting process planning with the objective casting quality assurance is increasing day by day (Rai and Ganguly, 2018).

2.3 Optimisation, monitoring and control of casting process parameters and defects

AI has been adopted in optimisation, defect monitoring and control, process parameters in casting base on different algorithm approach. The algorithm includes the prediction of internal defects of metal casting process (Lee *et al*., 2018). This saves unnecessary time and money by reducing the amount of inputs into the next stage, such as the machining process, and enables flexible scheduling. Bayesian inference algorithm was employed by Sata and Ravi (2016) in analysing investment-casting defect. Sata and Ravi (2016) proposed the process to predict and prevent various defects, based on the computation of posterior probabilities of process parameters using Bayesian inference methodology. The inference was based on AI. It overcomes the limitations of other approaches used so far for the purpose, including ANN and casting process simulation. Unlike an ANN model, which presents challenges in the selection of training model and requires a large amount of input data for the purpose, the proposed approach can be directly applied to existing data. In comparison with casting process simulation, which requires a 3D model of casting, thermo-physical property data for the casting alloy, accurate specification of the boundary conditions, followed by mesh generation, solver computation, post-processing, and interpretation of results, the proposed approach is much simpler to apply by foundry engineers.

Moreover, the proposed approach cannot only identify the cause of casting defects but also highlight the range of process parameters that should be avoided to minimize the occurrence of those defects. The relative ease and speed compared to other methods make this approach particularly useful for such industrial applications. Automatic localization of casting defects with convolutional neural networks was introduced in Ferguson, Lee & Law, (2017) identified several different convolutional neural network (CNN) architectures can be used to localize casting defects in X-ray images. The advantage of transfer learning is allowed to localized models to be trained on a relatively small dataset. In an alternative approach, a defect classification model on a series of defect images and then use a sliding classifier method to develop a simple localization model. This compares localization accuracy and computational performance of each technique. Promising results were shown for defect localization on the machine database of X-ray images called (GDXray) dataset and establish a benchmark for future studies on this dataset (Ferguson *et al.*, 2017).

Das *et al.*, (2015) brought about methodology for modelling and monitoring of centrifugal casting process. In this a study, a process monitoring strategy has been devised for a centrifugal casting process using data-based multivariate statistical technique, namely, partial least squares regression (PLSR). The practical implication of the study involves development of a software application with a back-end database which would be interfaced with a computer program based on PLSR algorithm for estimation of model parameters and the control limit for the monitoring chart. It would help in easy and real-time detection of faults. Based on a case study, the PLSR model constructed for this study seems to mimic the actual process quite well which is evident from the various performance criteria (predicted and analysis of variance results (Das *et al;* 2015).

2.4 Intelligent Design and Materials Selection

Decision support systems in the metal casting industry by Prasad and Ratna (2018); the study adopted a framework developed by Ngai *et al.,* (2009) on selection of material is a AI application of artificial intelligence techniques in metal casting. The necessary time needed for casting a large, intricate and geometric object can be significantly shortened by computer aided development methods. Optimising metal casting by means of artificial intelligence avoids costly changes as a result of casting defects and reduces post processing operations and the quality of cast product increased. Artificial Intelligence help the engineer to predict accurately the process parameters, mould design and sand mixtures required to produce a non- defective cast. It gives the engineer an insight into the kind of facilities they would use for prevention of defects in castings thereby avoiding the trial and error methods that leads to huge financial loss. Hence, Artificial Intelligence helps engineers in modelling a conservative design decisions when building a production platform. Overdesigned equipment essentially results in wastages in terms of money. For instance, one millimetre error in diameter of a casting can bring a lost on the scale of millions of dollars in capital investment. Hence, AI is a vital factor for cost reduction, wastages and competitiveness. This invariably helps in improving the productivity of the oil and gas industry via production concept, planning, design as well as quality of products.

2.5 Method for Steelmaking and Continuous Casting Production Process

The heuristic rescheduling method for steelmaking and continuous casting production process with multi refining modes developed by Yu *et al*., (2016) is effective rescheduling of casting process. This challenge and presents a comprehensive analysis of start-time delay disturbance, its consequences, and strategies to resolve conflicts. A heuristic rescheduling algorithm is then proposed to allow the system to remain alert to this type of disruption in real SCC production, and to quickly react it with an optimal rescheduling plan that has the minimum total waiting time. The proposed methodology and algorithm are applied to and illustrated through both a simulated prototypical SCC system and Shanghai Bao Steel plant, a real industrial setting. (Yu *et al.,* 2016). The inverse modelling of heat transfer is a useful tool in analysing contact heat transfer at the ingot surfaces during the casting process. The determination of the boundary conditions involves an experimental work consisting in the evaluation of the thermal history, generally at the casting surface, experimentally provided by infrared pyrometers. Additionally, numerical simulations, based on the solution of the 2D transient heat conduction equation, are performed in order to be inversely solved in response to the measured thermal data furnished by the sensor.

2.6 Challenges and Future Works

Numerical analysis is constantly used in casting industry for a better understanding of both the critical aspects related to heat transfer and fluid flow phenomena and the relations between them and the metallographic structures and the formation of microstructure defects in the cast parts. (Das et al., 2015). Some of the thermo physical properties necessary for obtaining very accurate results by using numerical simulation are very often totally missing in case of some alloys which have a very high commercial interest for casting industry. The casting technologies have many advantages as the flexibility of manufacturing some complex geometry. Furthermore, by controlling the casting process can be obtained, through a single processing operation, a cast part which corresponds to the imposed mechanical properties and quality level. This new concept near-net-shaping can be applied in casting by controlling the precision parameters of the process. The accuracy of data as well as the sheer volume is basic information required for evaluating data, recognizing patterns for analysis. AI is replacing the data and forming a databases using digital monitoring to optimize casting products. This will reduces casting defects and costs, as well as efficiency increment in casting.

4.0 CONCLUSION

In conclusion this review deals with the applications of artificial intelligence techniques in metal casting in a real factory setting. The artificial intelligence can help in simulations, manufacturing, advanced planning and scheduling casting systems. Subsequently, AI also help in machine learning algorithms such as decision tree, random forest, artificial neural network, and support vector machine which can be used for casting product quality prediction Finally, AI is feasible in performance model of casting through quality process, cost and time which is very important in casting manufacturing process.

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