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Review Article

Review of Casting Process Improvement through ANN

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Abstract

Casting process is the most widely used process in manufacturing industries especially in automobile products. Systematic analysis and identification of sources of product defects are essential for successful manufacturing. Since the quality of casting parts are mostly influenced by process conditions, how to determine the optimum process condition becomes the key to improving part quality. The industry generally tries to eliminate the defects by trial and error method, which is an expensive and error-prone process. This paper presents review on a use of Artificial neural network (ANN) for the casting processes better than the other techniques such as design of experiment (DOE), inspection method, casting simulation, cause-effect diagram, genetic algorithm, fuzzy logic. ANN has challenges in the eve of prediction, optimization, control, monitor, identification, classification, modeling and so on particularly in the field of manufacturing. We discuss number of key issues, which must be addressed when applying neural network to practical problems, and steps followed for the development of such models are outlined. Artificial neural network also found that, the trained network has great forecast ability. Furthermore, the trained neural network is employed as an objective function to optimize the processes.

Keywords: *Artificial Neural Network (ANN), Casting Process, Optimization, Product defects*

1. Introduction

Metal casting has been a primary manufacturing process for several centuries during BC and is so even today in the 21st century. Today, its applications include automotive components, spacecraft components and many industrial and domestic components. The principle of manufacturing a casting involves, creating a hollow shape of the metallic components are to be make inside the sand mould and then pouring the liquid metal directly into the sand-shaped mould. Casting is a very versatile process capable of being use in mass production items for very large shaped pieces, with intricate designs and having properties unobtainable by any other methods. The major activities involved in making a casting are moulding, melting, pouring, solidification, fettling, cleaning, inspection and elimination of defective castings (D. Benny Karunakar, *et al*, 2008).

Major applications in both ferrous and non-ferrous casting material such as, casting engine block, valves, pump, aerospace and so on. Moulding, melting followed by pouring, fettling, inspection and elimination were the major steps followed in casting process. Control during each stage in casting process plays a vital role else it may lead to casting defects like rat-tails, scabs, cracks, blow holes, misrun, shrinkage, porosity, cold shut, scar, hot tears, cracks and so on. In past few decades, neural networks were use to tackle production related problems, controlling the process by reducing casting defects, lead times, scrap rate, production cost and to avoid trial and error method, expert dependent advices in optimizing the process (Manjunath Patel G C and Prasad Krishna, 2010). Metal casting is one of the direct methods of manufacturing the desired geometry of component. More than 60% of the automotive components are manufacture by metal casting process. Foundry industry suffers from poor quality and productivity due to the large number of the process parameters. Out of different casting methods, green sand casting is the commonly used method for producing automotive components. The quality of a green sand casting is the result of a great number of parameters, which works at different levels and influence the casting defects. Fig. 1 shows the steps involved in casting process (D. Benny Karunakar, *et al*, 2008).

The first step in making a casting is to make a hallow cavity inside sand mould such that the shape of the hallow cavity inside the sand mould would be similar to that of the component which is going to be manufactured. This process is called as ‘moulding’.

The second step is ‘melting’, which involves melting the solid charge metal inside a furnace and making the liquid metal free from slag and any dissolved gases. The third step is ‘pouring’, which involves pouring the molten metal inside the sand mould and allowing the liquid metal

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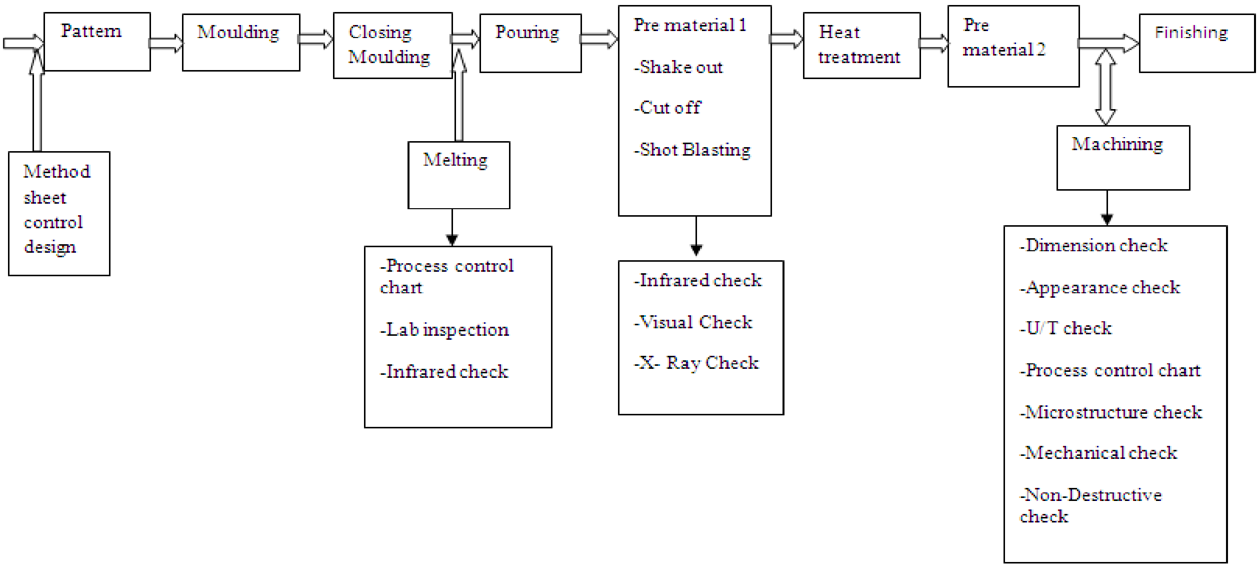

Fig.1 Step involved in making a casting

to solidify inside the mould, thus making the metal to take the shape of the mould cavity. The fourth step is the 'fettling' process, in which the sand mould is broken (after solidification of the casting) and after that, the solidified castings are taken out. Then the castings are clean with water, pressurized air, etc. The fifth step is 'inspection' that includes identification of defective castings through different techniques and ensuring quality control. The sixth step is 'elimination/dispatch', which includes recycling of defective castings for re-melting and passing on the sound castings for shipping.

Out of the several stages involved in the casting process, 'moulding' and 'melting' processes constitute the most important stages, as the parameters of these two processes mostly determine the quality of the casting. The moulding parameters like moisture percent, permeability, green compression strength (GCS), green shear strength (GSS) affect the quality of the finished casting. Similarly, melting parameters like liquid metal temperature, carbon percent in liquid metal (C), manganese percent in liquid metal (Mn), silicon percent in liquid metal (Si), sulfur percent in liquid metal (S), phosphorus percent in liquid metal (P) and chromium percent in liquid metal (Cr) also determine the quality of the finished casting. Improper control of moulding and melting parameters results in defective castings, which substantially reduces the productivity of a foundry industry (D. Benny Karunakar, *et al*, 2008).

2. Casting quality improvement techniques

A strong competition upon the market results in the fact that quality is the main advantages in winning new sales market. Any negligence at the successive stages of production affects the quality of final products. Casting quality improvement is the process of finding the root cause of occurrence of defects in the rejection of casting and taking necessary steps to reduce the defects and to improve the casting quality. A strong emphasis should be put on the control of the whole process, beginning with the control of the input of raw materials, through the control of the material melting, up to the control of the finishing processing of casted parts. Various casting quality improvement techniques such as; (i) Inspection method, (ii) Design of experiment, (iii) Casting simulation, (iv) Cause-effect diagram, (v) If then rules, (vi) Genetic algorithm, (vii) Fuzzy logic, (viii) Artificial neural network.

2.1 Inspection method

Inspection and testing of casting divide in five main categories such as casting finishing, dimensional accuracy, mechanical properties, chemical composition and casting soundness.

2.1.1 Casting finishing

The type of pattern or moulding sand, mould coating and method of cleaning can influence the surface finish of metal casting. So far, instrumentation for measuring surface roughness has not provided a useful evaluation, so it is perform largely through simple visual comparison using a series of test panels with increasing surface roughness.

2.1.2 Dimensional accuracy

Variation in the dimension of casting can be the result of mould cavity expansion caused by the heat and head pressure of molten metal, the contraction of the metal as it cools and heat treatment. The patternmaker who will compensate for the variations in the pattern's design predicts these expansions and contractions. For large volumes of castings, casting facilities may measure the critical dimensions of the castings more often to check for possible drift, particularly drift due to pattern wear. If a casting requires tight tolerances that are critical to the part's application, the customer should specify those tolerances. Casting customers should check how their casting supplier would verify the dimensions of the parts they produce. The accuracy of the measuring tools is just an important as the dimensional accuracy of the castings. In many instances, the customer supplies the gauges or fixtures needs to check routinely, dimension to the casting facility. Expecting exact dimensions over the course of a production run will result in frustration. The dimensions of each casting will vary slightly, so castings are specify by setting the range of values that the dimensions can fall within specified range. The range between the lower tolerance limit and upper tolerance limit can be set by the supplier, but the narrower the range, the more difficult to produce and test.

2.1.3 Mechanical properties

Mechanical testing gives an evaluation of the metal and the casting to determine whether the properties comply with the specified mechanical requirements. Following are common mechanical tests used in metal casting facilities such as hardness testing, tensile and impact testing, service load testing.

2.1.4 Chemical composition

The chemical composition of an alloy has a significant bearing on its performance properties. Minor alloying elements added to the material can further affect chemical composition. Casting alloys are typically specified accorded to ASTM, SAE and AMS alloy specifications. Depending on how susceptible an alloy is to variation of its chemical composition. Chemical analysis may be required to verify the proper composition is present to achieve a certain set of properties. Chemical analysis often involves a sample of molten metal poured in to a special mould and evaluated by spectrographic atomic absorption or x-ray fluorescence analysis. Many metal casting facilities check the chemical composition of the alloys they are pouring throughout the course of a day, so melt shop personnel can make required adjustments to the alloy composition as needed.

2.1.5 Casting soundness

Internal and surface defects that cannot detect through the regular course of visual inspection can notably affect performance of metal components. Several non-destructive methods can be employing to inspect castings for these "invisible" flaws. Non-destructive tests determine the integrity of a casting without causing physical damage, so once it passes the tests; it can be use for its intended application. Such nondestructive tests are visual inspection, dimensional inspection, fluorescent powder testing, magnetic particle inspection, ultrasonic testing and radiographic inspection.

2.2 Design of experiment

Design of experiments (DoE) is a best statistical technique introduced by Fisher to study the effect of various parameters simultaneously. Presently, DoE technique is follow according to Taguchi approach, which is very efficient procedure for economic satisfaction and product or process design projects. Learning and applying this technique from engineers and researchers can significantly reduce the time required for experimental investigations. DoE is highly effective and efficient technique while optimizing product and process designs. Study influence of individual process parameter on the performance and determine which parameter has more impact, which ones have less. We can find out which parameter should have tighter tolerance and which tolerance should be relaxed. The information from the experiment will tell you how to allocate quality assurance resources based on the objective data. This will analyze whether a supplier's part causes problems or not and how to combine different factors in their proper settings to get the best results. Benefits of DoE using Taguchi approach is to improve quality, which is the consistency of performance and it is achieved when variation is reduced. Moving the mean performance to the target as well as reducing variations around the target achieves consistency. The main aspect behind the DoE using Taguchi approach is to achieve reduced variation. Therefore, this technique focused to attain the desired quality objectives in all steps (Wimalin Sukthomya and James Tannock, 2005).

2.3 Casting simulation

Simulation is the powerful tool uses a set of mathematical equations implemented in a computer program, which uses generally different methods like FEM and vector element method etc. Vector element method used in Auto-CAST-X software which is very important simulation software used for mould filling and solidification analysis. In casting simulation, a mould filling and solidification analysis is carry out using an algorithm or program based on finite volume method, to identify the hot spots. Hence, defects like shrinkage porosities, hot tears, cracks, etc**.** The simulation programs are based on finite element analysis of 3D models of castings and involve simple functions for user interface, computation and display. The casting model has to be create using solid modelling software like CATIA, UG-NX etc and imported into the simulation program for further procedure. Simulation and method optimization of castings already in regular production leads to improvement in their quality or yield and sometimes both. The method of most castings is incorrectly design, under-designed, or over-designed. This can be clearly visualized using simulation and verified through matching simulated and actual observations. Often, only minor or major changes to the method are required: such as improvement in gating system takes place, which is very important aspect in method of casting. Even a small improvement in yield can give significant saving of resources, higher productivity over a period. The cost of poor quality (machining, transportation, repair, replacement) is becoming substantial, which can be considerably reduced using simulation and optimization technique (Dr. B. Ravi, 2005).

2.4 Genetic algorithm

Genetic algorithms are computerized search and optimization methods that work identical to the principles of natural evolution. Based on Darwin's theory of survival for fittest principles, GA (Genetic algorithm) finds the best and fittest design solutions, which is difficult to find using other techniques. GA is very useful for engineering design and applications because they are easy to use and they are likely to find the globally best design or solution, which is superior to any other design or solution. There are wide applications of GA, which include mechanical component design, process design, planning, job shop scheduling, control system, pattern recognition and operations research. Genetic Algorithm works with a coding of variables. The advantage of working with a coding of variable space is that coding discretizes the search space even though the function may be continuous. Genetic algorithm is very different from most of the traditional optimization methods (Shen Changyu, *et al*, 2007), (A. Krimpenis, *et al*, 2007).

2.5 Fuzzy logic

Fuzzy logic (FL) is very important part of artificial intelligence that is acquiring popularity and applications in control systems and pattern recognition. It is based on the observation that people make decisions based on imprecise and numerical data. Fuzzy models represent unclear and imprecise information, hence the term fuzzy. These models have the capability of recognizing, representing, manipulating, interpreting, and utilizing data and information that are unclear and lack of certainty takes place.

Fuzzy logic techniques used for decision making in conceptual design phase, to select casting process. The fuzzy logic techniques quite useful in selection methodology for casting process because the capability of each process different from foundry to another (Kasim M., *et al*, 2008).

3. Artificial neural network

Neural networks, which are simplified models of the biological neuron system, is a processing system made up of highly interconnected neural computing elements that have the ability to learn and acquire knowledge and make it available for use which massively distributed in parallel (S. Rajasekaran and G. Vijayalakshmi Pai, 2008). In human brain, the most basic element is neuron. The beauty of human brain is its ability to think, remember and apply past experiences to our future actions. Our human brain comprises about 100billion neurons, each neuron connects up to 200000 neurons and approximately 1000-10,000 interconnections are available. The neurons are arranged in such a way that, they form a layer and the connection pattern formed within and between the respective layers through weights referred as network architecture (Manjunath Patel G C and Prasad Krishna, 2010).

There is mainly three basic network architecture such as;

1) Single layer feed forward network
2) Multilayer feed forward network
3) Recurrent network

McCullock and Pitts introduced the first neural network (NN) as long as 1943; it was not until the 1980s. There are about 30 different NN architectures currently used in research. According to Krycha and Wagner, the four commonly used, basic network types are (Wimalin Sukthomya and James Tannock, 2005):

i. Adaptive resonance theory models (ART)
ii. Multilayer perceptron (MLP)
iii. Recurrent associative network
iv. Self organizing maps (SOM)

The neural network could predict cracks, misruns and air-locks accurately in most of the cases. The neural network could also predict other defects successfully. ANN is used to model a real world system, by tuning a set of parameters called weights, to learn the relationship between given inputs and their related outputs. These weights are associated with the connections between the neurons within the network; this weight alteration process is called as training. Training can be supervised or unsupervised (self-organizing). The supervised training, in which the user or researcher, and this training data set select examples of input-output pairs, is provided to the NN. The NN weights adjust automatically, in order to minimize the error between the output from the network and the desired output. The selected learning algorithm controls the weight adjustment process. When the error is sufficiently reduced, the network is considered to be successfully trained. Further data, previously 'unseen' by the network, may now be used to test or validate its performance. Various different learning algorithms are available to train MLP networks, including the back-propagation algorithm, conjugate gradient algorithms, Newton's method and Levenberg-Marquardt method. The back propagation algorithm is the most extensively adopted learning algorithm and was the algorithm used in many researches. There are also several sub-variants of the back-propagation algorithm, developed to resolve problems with the standard algorithm (Wimalin Sukthomya and James Tannock, 2005).

ANN is widely accepted as a technology offering an alternative way to simulate complex and ill-defined problems. They have been used in diverse applications in control, robotics, pattern recognition, forecasting, power systems, manufacturing, optimization, signal processing, etc., and they are particularly useful in system modeling. A neural network is a computational structure, consisting of a number of highly interconnected processing units called neurons. The neurons sum weighted inputs and then applies a linear or non-linear function to the resulting sum to determine the output and the neurons are arranged in layers and are combined through excessive connectivity (Shen Changyu, *et al*, 2007).

Identification and control are the two fundamental tasks of solving a problem. The identification and control of nonlinear systems are still challenging tasks. Recently, considerable effort has been invested in the use of artificial neural networks (ANN) for nonlinear control and identification. Both practical and theoretical results establish the use of neural control as one of the most promising areas of neural network applications. Neural networks have the ability to learn from their environment and adapt to it in an interactive manner similar to their biological counterparts. A very important feature of these networks is their adaptive nature, where 'learning by example' replaces 'programming' in solving the problems. This feature makes such computational models very appealing in application domains where one has little or an incomplete understanding of the problem to be solved, but where training data are readily available. Neuro-computing can play an important role in solving certain problems in science and engineering that would otherwise be difficult to solve, problems such as pattern recognition, optimization, event classification, control and identification of nonlinear systems, and statistical analysis, etc. In addition to neural network's usefulness in solving complex nonlinear problems, they are attractive in view of their high execution speed and their relatively modest computer hardware requirements (D. Benny Karunakar, *et al*, 2008).

The main aim of the optimization is achieving the optimal process parameters values and reduce the major defects occurs in casting process. Generally ANN is suitable technique for optimize the casting process parameters. These optimize parameters used for the casting process for reduces casting defects. When the defects are reduces then casting quality automatically improves.

Conclusions

The ANN technique is an effective method to model the complex relationship between the process condition and the quality index of casted parts. ANN can be employed for casting process starting from moulding to final inspection method. ANN appeared to be successful in indentifying possible sources of casting defects made in whole process. They are also to be useful in finding the actual causes of defects in products where the defects are influenced by large number of randomly changing production parameters. ANN has also used for the control, identification, modeling and especially for optimization. Casting process parameters are optimize by using ANN and achieve optimal process parameter values. ANN is the most efficient and accurate method for the analysis of casting defects. ANN improves the quality and yield of the casting in shortest possible time.

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