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Forward and reverse mappings in green sand mould system using neural networks

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Abstract

The quality of castings in a green sand mould is influenced significantly by its properties, such as green compression strength, permeability, mould hardness, and others, which depend on input parameters. The relationships of these properties with the input parameters, like sand grain size and shape, binder, water, etc. are complex in nature. In the neural network based forward mapping, mould properties are expressed as the functions of input parameters, whereas attempts can also be made to determine an appropriate set of input parameters, to ensure a set of desired properties, in reverse mapping. In the present work, the problems related to both the forward as well as reverse mappings in green sand mould system were tackled by using a back-propagation neural network (BPNN) and a genetic-neural network (GA-NN). Batch mode of training had been provided to both the networks with the help of one thousand data, generated artificially from the regression equations obtained earlier by the authors. The performances of the developed models had been compared among themselves for 20 randomly generated test cases. The results show that GA-NN outperforms the BPNN and that both the NN approaches are able to carry out the reverse mapping effectively.

Keywords: Green sand mould system; Forward and reverse mappings; BPNN; GA-NN

1. Introduction

Green sand mould (the mould is named so, as it contains moisture during the pouring of molten metal) casting is the oldest and one of the most popular casting methods. The main aim of foundries is to produce good quality castings with a low cost. The moulding sand may be considered as a mixture of inert granular sand particles, bonding material and additive. The strength, permeability and thermal properties of the bonded sands are dependent on the constituents of the moulding sand [19]. The major source of defects in sand casting is the moulding sand mixture. The defects can be minimized by the proper control of moulding sand properties like green compression strength, permeability, hardness and bulk density, which, in turn, are dependent on the input parameters, such as sand grain fineness, amount of binder and moisture, etc. To investigate input–output relationships in a green sand mould system, both forward mapping (i.e., expressing mould properties as the functions of input variables) as well as reverse mapping (i.e., determining the set of input variables to obtain a set of mould properties) are to be carried out.

A lot of research was conducted on moulding sand and its properties during 1960's and 1970's around the world. Most of the research work during that period was based on experimental and theoretical approaches. Chang et al. [3] developed a model to evaluate the performance of green sand mould. They tried to establish relative difference in density as the index of flowability. However, their analysis was based on one-dimensional model and two empirical relations were obtained for relative compression strength and density as functions of moisture content. The main weakness of their model lies in the fact that the relative density might not be the only criterion to decide optimum level of water. Dietert et al. [6] established straight-line relationships for the water requirements of additives through experiments. The work also described the amount of water requirement for different additives. The experiments were conducted by keeping the mouldability index as a constant. While developing the equations, the amount of free water required for plasticizing the clay and water evaporations were not considered. With the change in mouldability index, the equation might not hold good.

Abbreviations: BPNN, back-propagation neural network; CCD, central composite design; DOE, design of experiments; GA, genetic Algorithm; GA-NN, genetic-neural network; NN, neural network

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Nomenclature

a	activation function constant
A	AFS grain fineness number
A_c	cross-sectional area of the specimen (cm^2)
b	activation function constant
B	% of bentonite clay
BD_{fact}	model predicted value of bulk density (g/cm^3)
c	activation function constant
C	clay to water ratio
CS_{ccd}	model predicted value of green compression strength (kPa)
D	number of strokes
h	height of specimen (cm)
H_{fact}	model predicted value of mould hardness
N	number of training scenarios
p	pressure of air (g/cm^2)
P	permeability number
P_{ccd}	model predicted permeability number
R	number of responses
T	time in minutes
V	volume of air (cm^3)
X	actual value of the variable
X_{max}	maximum value of the variable
X_{min}	minimum value of the variable
X_{norm}	normalized value of the variable

Greek symbols

α	momentum term
η	learning rate

Design of experiments (DOE) technique had been used by various investigators in the past to study the effect of different variables on the green sand mould properties. Rose et al. [18] used design of experiments technique to study the effect of amount of clay, geological origin of the base sand, degree of ramming and amount of water on green compression strength, rammed density, dry compression strength and dry shear strength. However, they did not develop the models to predict the responses and did not consider the important mould property like permeability, in their analysis. In another work carried out by Dhindaw and Chakraborthy [5], the statistical design of experiment technique was applied to study and control the properties of different sand systems. They extended the DOE application to resin-based sand systems in addition to green sand. In green sand system, they considered the bulk density of green sand along with green compression strength. However, the effect of silica sand grain size was not considered. The important mould property, such as permeability was also left out in their analysis. Moreover, they treated clay and water as independent variables and the levels of clay were selected in a narrow range of 4–6% of base sand. Parappagoudar et al. [14] developed linear models for green compression strength and permeability. But, the model was not found to be suitable for permeability prediction. In their experiments, mould hardness and bulk densities were not considered. An attempt was also made by Parappagoudar and Bhat [13], in the same direction but they did not consider the effect of degree of ramming (number of strokes) on mould properties. Neural network-based approaches were also developed as the forward mapping tool in clay-bonded moulding sand system [1,9].

In the present work, an attempt is made to develop soft computing-based models, such as back-propagation neural network (BPNN) and genetic-neural network (GA-NN) to model green sand mould system. The statistical models developed through DOE and regression analysis might be able to predict the responses accurately. However, the developed models are independent in the sense that each response is determined separately as a function of input variables. But, in actual practice, all the responses are measured for a particular set of input parameters. Moreover, to determine the set of input parameters, for a set of desired outputs might be an important practical requirement, particularly for on-line control of a process. Reverse mapping (i.e., to predict the inputs for a set of desired outputs) might be difficult to carry out by using response equations obtained through statistical analysis. As the models are developed independently, the interdependency of the output responses might be lost in statistical models. Hence, it is necessary to think for an alternative, which will consider all input parameters and responses as an integral system. In the present work, an attempt was made to carry out both the forward as well as reverse mappings in green sand mould system by using a back-propagation NN and a genetic algorithm (GA)-tuned NN. Training of an NN requires large amount of data. In practice, it is not feasible to conduct experiments to collect the huge amount of data required to train the neural network. In the present work, the training data have been generated at random by using the response equations derived through statistical analysis [12].

The back-propagation neural network (BPNN) trained by the generalized delta rule has been successfully used in many fields, especially for pattern recognition due to its learning ability. Its performance is influenced by many factors, such as the network structure (i.e., number of hidden layers and number of neurons in each layer) and learning parameters (i.e., learning rate, momentum constant and thresholds of system and pattern errors), which form components of the generalized delta rule [4]. In the present work, BPNN was developed to predict all four responses in one go. As the training data were collected off-line, a batch mode of training was used to optimize the neural network.

The back-propagation algorithm works based on gradient-based approach (i.e., steepest descent) and its solutions may get trapped into the local minima [10]. The generalized delta rule in BPNN may get the local optimum value and reduce the search space for the next iterations; thereby some good solutions are left out in the process. On the other hand, a genetic algorithm (GA) carries out its search in a huge space. Hence, the possibility of its solutions for being trapped into the local minima is less. Discontinuous functions could be handled easily by using a GA, whereas a back-propagation