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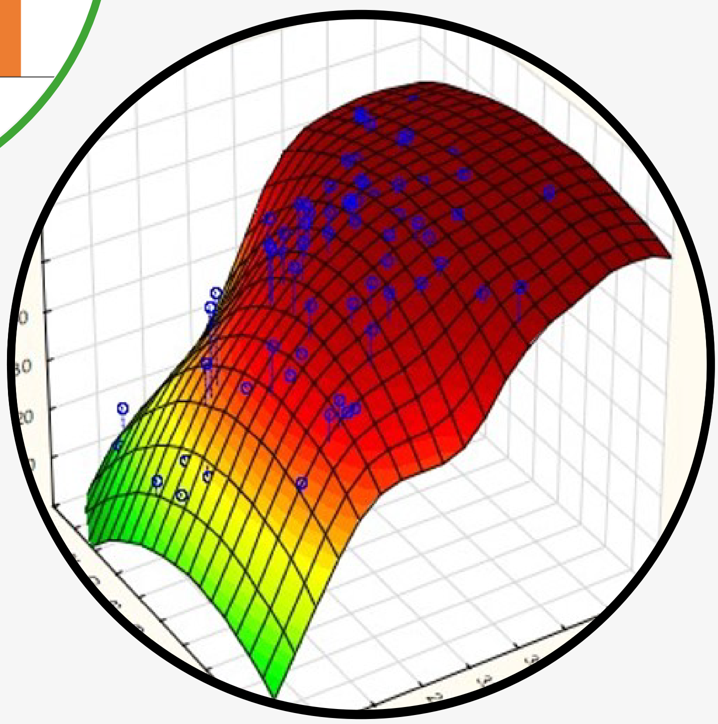

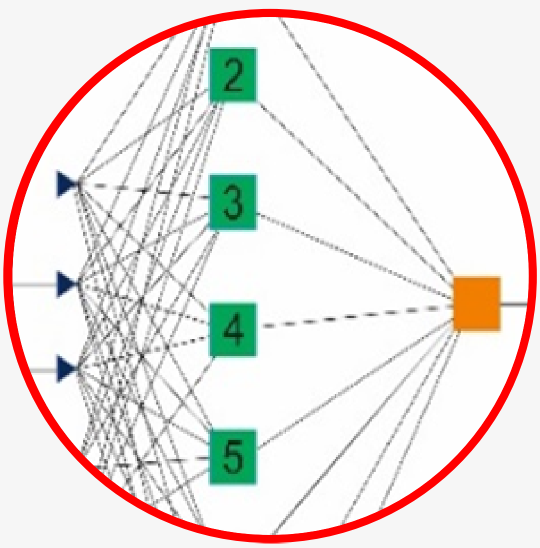

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Artificial Neural Networks as a Tool for Supporting a Moulding Sand Control System Based on the Dependency between Selected Moulding Sand Properties

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Abstract

The article presents the potential for using artificial neural networks to support decisions related to the rebonding of green moulding sand. The basic properties of the moulding sand tested in foundries are discussed, especially compactibility as it gives the most information about the quality of green moulding sand. First, the data that can predict the compactibility value without the need for testing are defined. Next, a method for constructing an artificial neural network is presented and the network model which produced the best results is analysed. Additionally, two applications were designed to allow the investigation results to be searchable by determining the range of values of the moulding sand parameters.

Keywords:

artificial neural network, decision support, green moulding sand, compactibility

1. INTRODUCTION

Moulding is a complex technological process characterized by numerous process parameters. Currently, the control of the moulding sand condition is performed by measuring properties such as compressive strength or permeability. These properties are important in terms of information about the suitability of the moulding sand for moulding and, because of the relatively short time which is needed to carry out these tests, they are the main source of information on the proper conduct of the rebonding of the moulding sand process. In order to obtain complete information about the moulds, additional tests of other properties, such as friability or fluidity, should also be performed.

From the perspective of the optimal properties of moulding sands, and in reference to their suitability for forming, there is parameter known as the moldability index which allows their usefulness to be determined [1, 2]. The compactibility of the sand is also measured. This parameter is very sensitive to changes in the composition of the moulding sand and its moisture content, and in terms of its physical properties it is similar to the moldability index. Compactibility also gives a good assessment in the case of the rebonding of moulding sands and can be a guideline for carrying out the rebonding process, also as a parameter used in controlling the systems of the rebonding of the moulding sand process.

It is possible to directly measure the values of the moldability index and compactibility, but not all foundries have facilities for the automatic and rapid measurement of these parameters. Most foundries evaluate them on selected properties of moulding sand, such as:

- compressive strength,
- permeability,
- apparent density.

These properties depend on the moisture of the moulding sand, which is regulated in the various stages of the circulation of sand in the foundry. Additionally, in order to obtain complete information on the amount of fresh ingredients needed to supplement the moulding sand used, the amount of active bentonite should be determined [3, 4].

As part of previous works in this field, attempts have already been made to implement systems based on artificial intelligence mechanisms supporting the determination of the parameters of this process [5, 6]. One solution was a system for determining sand core parameters based on the 3-point bending test, but it was not a solution that could be used in real-time production processes [7]. This disadvantage is also characteristic of other artificial intelligence approaches, such as those based on artificial neural network mechanisms implemented in a Matlab environment [8] or using genetic algorithm and particle swarm optimization [9]. Artificial intelligence methods such as the adaptive neuro-fuzzy interference system (ANFIS) have also been used to estimate the influence of chemical composition on the parameters of moulding sand [10, 11].

Due to the complexity of this process and its dependencies, a predictive model has been developed as a part of presented work which, on the basis of the artificial neural network and properties mentioned above, will determine sand quality control parameters, i.e. compactibility. A schematic diagram of the proposed model is shown in Figure 1.

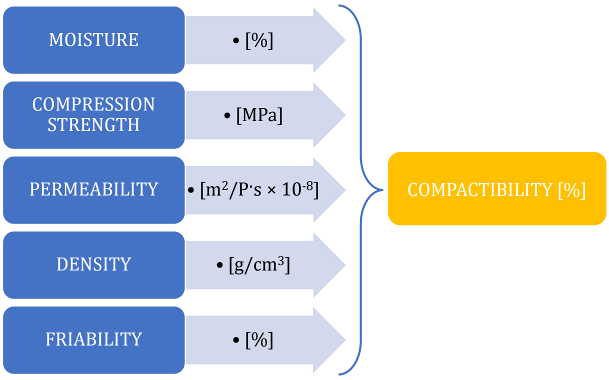

Fig. 1. Data schema

Despite the dependence of the moulding sand properties on moisture, it is important to introduce moisture as an input parameter in the model because it is not a linear dependence. Additionally, the values of this property depend on the content of other moulding sand components, such as the amount of bentonite or other additives (carbon forming additives). Constructing the model in such a way as to include moulding sand moisture will increase the quality of the model.

The selected parameters of compaction assessment are those that are easy to determine from the point of view of the foundries. The measurement of these parameters is based on standard cylindrical fittings. The parameters can be measured with the use of basic laboratory equipment for determining the properties of moulding sand, which are already basic equipment in foundry laboratories and, in most cases, not time-consuming. The ability to measure these properties in combination with the predictive model developed provides the opportunity to develop a control system for moulding sand in real time, which is presented in this paper.

2. SOURCE DATA ANALYSIS

The results of research concerning the effect selected parameters of green moulding sands on compactability, collected during many experiments, may constitute the basis for the development of the prediction model.

The data were obtained for moulding sands with different compositions by testing how changes in selected moulding sand properties depend on the moisture content (1.5–4.5%) and the amount of bentonite (4–12 parts by weight). The research was carried out for Zębiec Specjal bentonite. The wide range of applied moisture levels makes it possible to include extreme cases of drying or over-moistening of the moulding sand. These moulding sand properties can be used without any restriction, because the neural network is resistant to noise, i.e. values outside the accepted range. A fragment of the developed database that was available during this research is presented in Table 1. The global table contained 198 records.

The nature of the presented data are knowledge vectors consisting of input-output pairs (x_i, z_j). The compaction parameter (z_1) was adopted as the dependent variable. The following properties were input variables:

- moisture (x_1),
- compressive strength (x_2),
- permeability (x_3),
- flowability (x_4)
- and apparent density (x_5).

The grain composition of the matrix, determined by the grain size and homogeneity, which has a strong influence on the individual properties of the moulds, especially permeability, was omitted for the analysis.

In the system of dependencies of specific moulding sand properties on selected factors analysed, using historical data to create a model that allows the rapid verification of the mould condition, together with the swift and more precise correction of changes in sand composition towards the desired properties (in green moulding sands, this mainly concerns controlling the moisture content).

Table 1
Part of the data table

Moisture (x_1)	Compression strength (x_2)	Permeability (x_3)	Friability (x_4)	Density (x_5)	Compactibility (z_1)
1.4	0.07	333	55.54	1.57	29
1.71	0.07	353	37.07	1.54	49
2.22	0.06	360	23.7	1.53	62
2.51	0.06	330	16.46	1.56	64
2.91	0.05	300	13.19	1.58	65
3.15	0.05	288	11.54	1.59	64
3.82	0.04	260	6.09	1.62	64
1.21	0.06	317	62.43	1.58	27
1.68	0.05	350	34.69	1.57	57
1.74	0.05	353	31.65	1.57	60
2.41	0.04	317	22.16	1.58	62
...	...	...	...	...	...

3. ARTIFICAL NEURAL NETWORK PROJECT

When looking for appropriate forms for the design of the predictive model, due to the nature of the data and their quantity, the authors decided to use artificial neural networks (ANNs), which are perfect for situations where there is a need to model highly nonlinear phenomena and multidimensional functional dependencies, as is the case with the analysed process [12]. The presented knowledge vectors are a source of learning examples for artificial neural networks. The task of the network is to learn, as precisely as possible, a function that approximates the association of input (x_i) with output (z_i). It is a classic example of supervised network learning, also known as learning with a teacher.

The methods of teaching neural networks, widely described in the literature [13–15] rely on the cyclical update of network weights based on information about the target function gradient and the minimization direction determined at each step. Properly designed neural networks are able to independently formulate the dependencies between the parameters of the phenomenon during the learning process. The purpose of training a neural network is to select its topology and parameters in such a way as to minimize errors in determining the output value.

With the essence of the problem specified and the set of data to be analysed, the design of the neural network was initiated. Building a predictive model with the use of artificial neural networks based on the collected data was carried out in the stages presented in Figure 2.

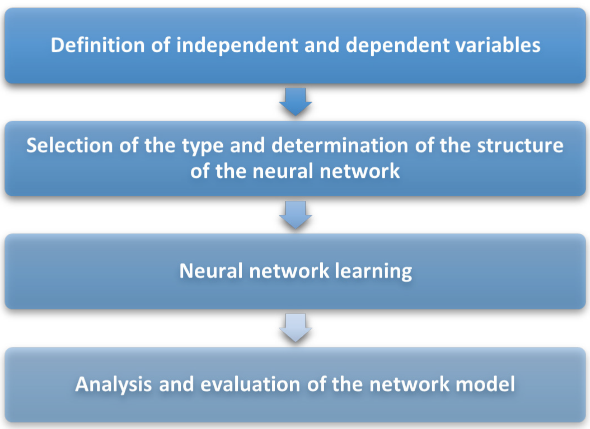

Fig. 2. Stages of neural network designing

3.1. Determination of independent and dependent variables

The neural network is meant to indicate the influence of individual factors on one of the parameters that controls the quality of the moulding sand, i.e. compactibility. Table 2 presents the independent variables (inputs of the neural network) and explained variables (output of the neural network) adopted in the model. Column (2) presents the adopted names of variables, column (3) presents units in which the variables are provided. Column (4) shows the ranges of the variability of the tested parameters. It should be noted that all of the operating variables in the model are numerical in nature.

Table 2
Characteristics of system variables

(1) No.	(2) Variable name	(3) unit	(4) Range	(5) Type
INPUT (independent variables)				
1	Compression strength	MPa	0.04–0.20	real
2.	Permeability	[m^2/Pa·s × 10^{-8}]	127–560	real
3.	Friability	[%]	1.41–93.21	real
4.	Density	[g/cm^3]	1.47–1.65	real
5.	Moisture	[%]	1.21–4.53	real
OUTPUT (dependent variables)				
6.	Compactibility	[%]	10–73	real

3.2. Selection of the type and determination of the structure of the neural network

To determine the optimal network architecture, the STATISTICA program and its Automatic Neural Network module were used. The set of data describing the modelled phenomenon (approx. 200 vectors of knowledge) was split into three sets:

- training set (70%) – these data include examples of inputs (x_i) and the corresponding output values (z_i), which are the basis for determining the connection weights between individual neurons of the network; the modification of the weight values continues until the approximation criterion is achieved in the training set (minimization of the approximation error) or the error in the validation set begins to grow;
- test (15%) – the validation set is used to control the course of the learning process by checking the degree of the training of neurons; in practice, learning involves two phases: selecting weights for the training set and testing weights on samples from the validation set;
- validation (15%) – data that has not been used in the learning process, on the basis of which the accuracy of learning the network is checked.

The artificial neural network was determined by defining:

- an artificial neuron model,
- network topology,
- and network learning rules.

In this work, several hundred network architectures with different numbers of hidden neurons and different activation functions in the hidden and output layers (linear, sigmoid, tangesoid and exponential) were tested with the use of the Automatic Neural Network module.

From among all networks generated by the program, the network with the lowest validation error was finally selected and given the name MLP 5-8-1. This error for the COMPACTIBILITY output variable was calculated at the level of 2.93%. The measure of the error was the mean squared error (MSE) of the predicted (by the model) and the real (observed) values, expressed by the Formula (1).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(y_i - \hat{y}_t\right)^2 \tag{1}$$

The structure of the selected network is shown in Figure 3. The network is an MLP (Multi-Layer-Perceptron) network consisting of one input layer (5 neurons), one hidden layer (8 neurons) and an output layer (1 neuron). The logistic (sigmoid) function was assumed as the activation functions in the hidden layer of neurons, while the exponential function was adopted for the layer of output neurons..

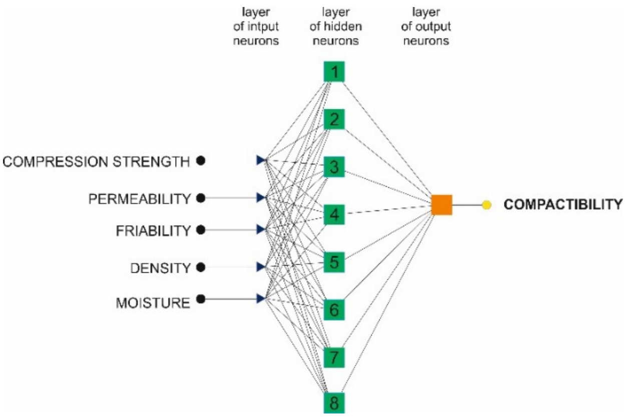

Fig. 3. Developed neural network architecture

A summary of the learning process of the selected neural networks for each output variables and their specific characteristics is given in Table 3.

Table 3
MLP 5-8-1 neural network parameters

Name of network	MLP 5-8-1
Error (training)	3.503
Error (validation)	1.760
Error (testing)	2.931
Quality (training)	0.985
Quality (validation)	0.992
Quality (testing)	0.993
Training algorithm	BFGS 57
Activation (hidden)	Logistic
Activation (output)	Exponential

In this network, the BFGS (Broyden–Fletcher–Goldfarb–Shanno) method was used for training. In the case of the selected MLP 5-8-1 network, the assumed minimal approximation error was not achieved; the training process was terminated in 57 epochs, when the validation error started to grow.

3.3. Analysis and evaluation of the network model

An additional measure of the quality of the network model was the Pearson's linear correlation coefficient (R), calculated in individual types of sets (training, validation and test sets) for the network response and set values. This coefficient is one of the basic measures of the quality of the model fitting. This coefficient is determined from Formula (2).

$$R^2 = \frac{\sum_{i=1}^{n}\left(\hat{y}_t - \overline{y}\right)^2}{\sum_{i=1}^{n}\left(y_t - \overline{y}\right)^2} \tag{2}$$

where:

- y_i – actual value of the variable y coming from the observation;
- $\hat{y}_i$ – theoretical value of the dependent variable determined on the basis of the model;
- $\overline{y}$ – arithmetic mean of empirical values of the dependent variable.

The correlation coefficient for the training sample was 0.98, for the validation sample 0.99, and for the test sample 0.99. Correlation graphs for individual sets are shown in Figure 4.

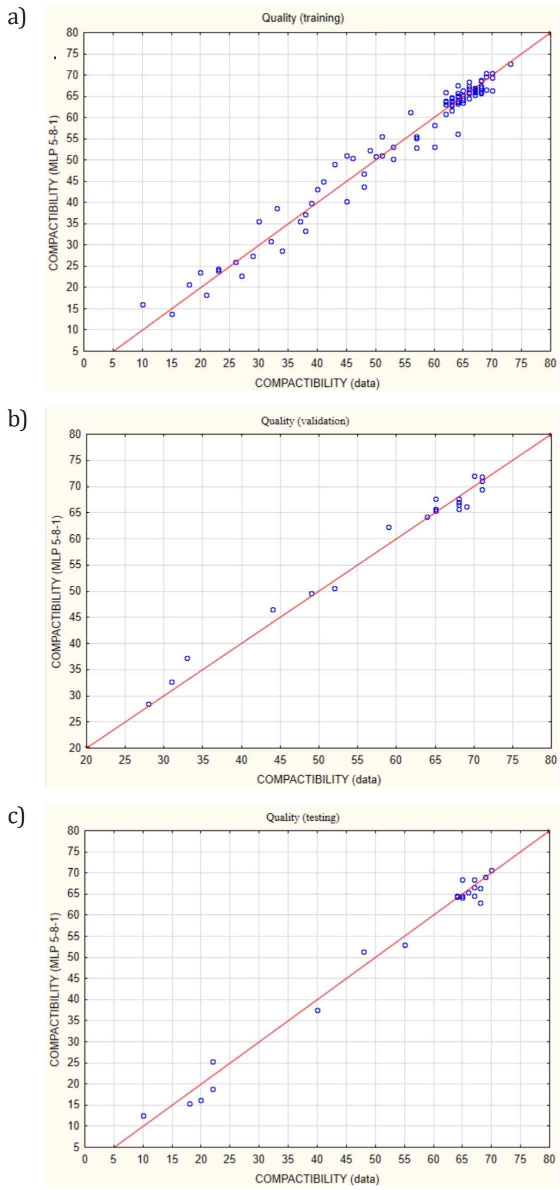

Fig. 4. Comparison of the distribution of data generated by the MLP 5-8-1 network with the experimental data for the sets: a) training; b) validation; c) testing

4. RESULTS AND DISCUSSION

4.1. ANN sensitivity analysis

The sensitivity analysis allowed us to distinguish important variables from those that are not important to the network result, and provided insight into the usefulness of the individual input variables. This analysis indicates variables that can be rejected without losing network quality and key variables that must never be rejected. The sensitivity analysis shows the loss incurred by rejecting a particular variable.

If a certain amount of data is rejected, an increase in the network error should be expected, therefore the basic measure of network sensitivity is the quotient of the error W (Eq. (3)) obtained at network start up for a data set without one variable and the error obtained with a set of variables.

$$W = \frac{Error_i}{Error} \tag{3}$$

The greater error after rejecting the variable is, in relation to the original error, the more sensitive the network is to the lack of this variable. If the error quotient is 1 or even lower, removing the variable has no effect on the network quality and even improves it. After performing a sensitivity analysis for all variables, the variables can be ranked in order of importance (Tab. 4).

Table 4
Sensitivity analysis

Friability	Moisture	Compression Strength	Density	Permeability
26.44	8.20	7.32	1.22	1.04

The obtained results of the global sensitivity analysis for the MLP 5-8-1 network, in the context of connections between moulding sand various properties and the sensitivity to changes in the moulding sand composition, from the point of view of an expert in the field of the subject, indicate the general correctness and validity of the adopted model (solution). Since the friability is close to linear in the range of applied moisture, its value can be clearly determined for the selected composition of the moulding sand. Moisture is important because its value determines the values of the moulding sand properties [16–18].

Figure 5 shows a graphic representation of selected analyses, developed on the basis of the results generated by the MLP-5-8-1 neural network. The charts show the influence of selected parameters of the moulding sand on compactibility. They confirm the general correctness of the adopted solution.

The first chart shows that moisture has a significant impact on compactibility, with a significant increase in compactibility occurring with greater moisture levels. Meanwhile, the compactibility value decreases with increasing density but at a much lower speed. The confirmation of the results of the sensitivity analysis can be seen here (Tab. 4), with the density parameter in fourth place in terms of significance. In this analysis, friability has the greatest impact on compactibility, while permeability has the lowest. These tendencies are confirmed by the second graph in Figure 5, which shows a very clear decrease in compactibility with increasing friability. There is also a noticeable increase in compactibility with increasing permeability, albeit with much less intensity.

a)

b)

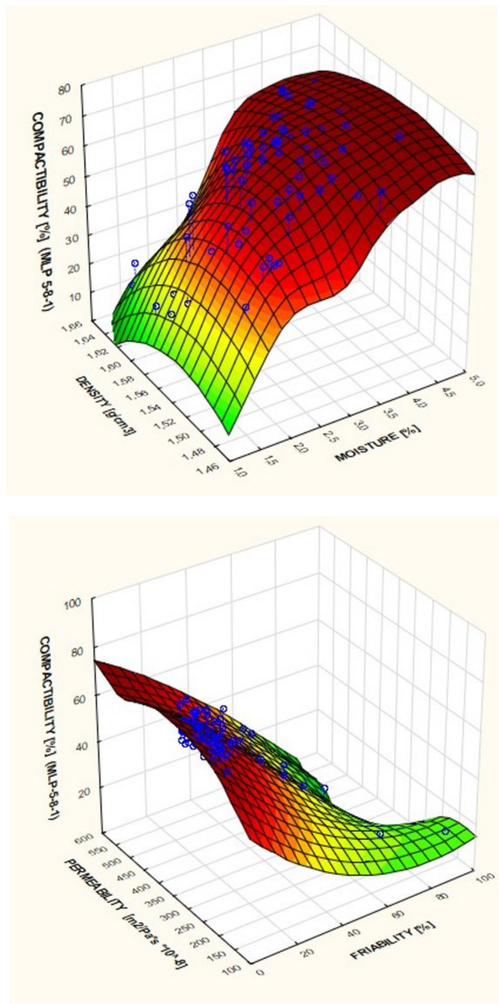

Fig. 5. Compactibility dependencies as a function of: a) density and moisture inputs; b) permeability and friability inputs

4.2. Network implementation

An application was created which allows the use of the developed network model to calculate the parameters of the casting process. The application is presented in Figure 6.

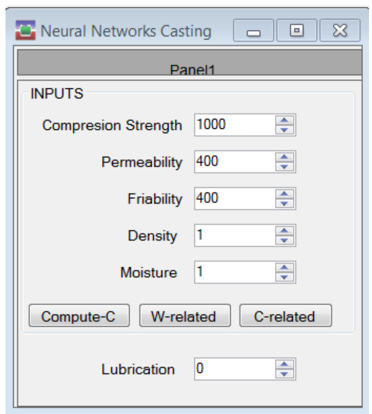

Fig. 6. Entering the values of the ranges of moulding sand properties

The main functionalities of the application are as follows:

- Adjustment of the dependent parameter ranges to the value of the moisture parameter. Due to the fact that the density, friability, permeability, compression strength parameters are directly dependent on the moisture parameter, the application at first stage of determining the parameters of the foundry process affords the opportunity to specify their ranges. The user selects the value of the moisture parameter, and the application narrows the selection of the values of the remaining input parameters of the process to those values that appear in relations with the given moisture value.
- The calculation of the initial value of the compactibility parameter. Based on process input parameters selected by the user (moisture, density, friability, permeability, compression strength) and the developed neural network model, the application calculates the value of the output parameter, namely compactibility.
- Determining the ranges of the input parameters for the selected value of the compactibility output parameter.
- An additional functionality of the application, developed using the experimental data on the basis of which the model of neural networks was created, is the possibility of returning the ranges of input parameters (moisture, density, friability, permeability, compression strength) for which the specific values of compactibility were obtained.

Based on the data used in the preparation of the system, an additional application was developed that can be useful during the process of the rebonding of moulding sand. This application allows the user to view and filter data in relation to individual process parameters (Fig. 7).

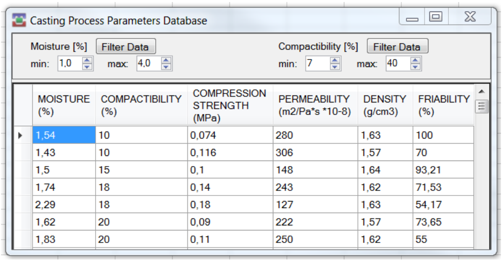

Fig. 7. The application that provides the process data

The application user is able to view data concerning the moulding sand preparation process. Additionally, it can sort the results according to specific process parameters. A separate functionality is the possibility of filtering data in terms of the value of the moisture and compactibility parameters, so that the application only returns data related to processes within the ranges selected by the user. Such an application could be used by technicians in mould production processes, as the data collected in the system would be helpful in the process of determining the moisture of the moulding sand in order to obtain the requisite sand compactibility.

5. SUMMARY

The presented application based on the developed artificial neural network allow us to view and filter data in relation to individual process parameters, and can be also very useful when choosing the correct technology and process parameters for moulding sand preparation. The presented tool facilitates checking how our moulding sands will react after changing their moisture in real-time, based on parameters that can be tested quickly during the production process. The system can also be used to predict how many fresh components should be added to moulding sand. This seems to be a crucial feature since the determination of the amount of active bentonite in moulding sand is very time consuming and rarely performed in foundries.

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An Analysis of the Prospects of the Use of Magnetic Water Treatment in Foundry Engineering

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Abstract

Scientists are currently focused on creating technologies that produce positive results without affecting the environment. One such technology is magnetic water treatment. In this paper, an analytical review of publications devoted to the application of magnetic treatment of water in various branches of engineering, agriculture, and medicine is carried out. Current views on the structure of water molecules, as well as the theories explaining the influence of the magnetic treatment of water on its properties, are reviewed. The results of studies of the influence of water treated by a magnetic field on the properties of molding sand are analyzed, including those in which the authors of the article took part. It is shown that the magnetic treatment of still water can increase the green strength of the molding sand containing this water from 0.035 to 0.052 MPa, and that of water in motion to 0.075 MPa. Thanks to this, the amount of binder in the molding sand can be reduced. It is concluded that the use of magnetically treated water in foundries is promising.

Keywords:

water, magnetic field, magnetic water treatment, molding sand, green strength

1. INTRODUCTION

G. Piccardi suggested in the 1930's that there was an interrelation between the geomagnetic field and water properties [1]. However, the first real interest among specialists in magnetic water treatment arose after 1945, when the Belgian engineer T. Vermeiren patented a simple and effective way to combat salt deposits in steam boilers [2]. Water containing hardness salts was passed through a magnetic field. In a fairly short period, studies on the effects of magnetic and electromagnetic water treatment in various industries were conducted (Fig. 1):

- in the power industry to reduce the formation of scales in heat exchangers [3–11];
- in the production of building materials [12–17];
- in agriculture to increase the yield of various crops [18–20];
- in the neutralization of wastewater [21];
- in medicine and biology [22];
- in foundry engineering for the preparation of molding sands [22–28].

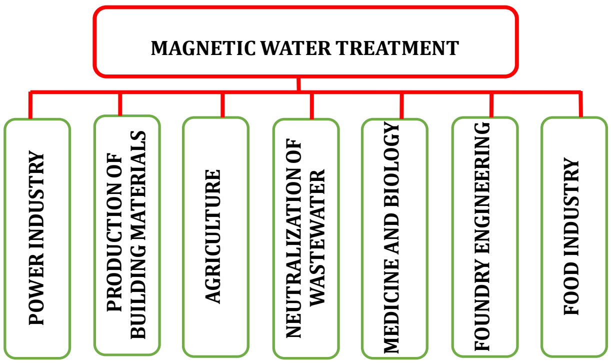

Fig. 1. Magnetic water treatment applications

In the majority of cases, the authors noted a positive effect of magnetic or electromagnetic water treatment. However, V. Ochkov [29] was skeptical about the data available in the literature. He explained the positive results of magnetic water treatment as a) accidental; b) a manifestation of the "human factor"; c) a marketing campaign by the manufacturers of special equipment.

The present review focuses on the analysis of the positive effect of electromagnetic water treatment on the properties of the molding sands in which it is used. Theories that have appeared in recent years are used to explain the available results.

2. STRUCTURE OF WATER AND HYPOTHESES EXPLAINING CHANGES IN ITS PROPERTIES UNDER MAGNETIC TREATMENT

In 1933, D.J. Bernal and R.H. Fowler [30] created the classical theory of water structure. They first showed that each water molecule is surrounded by four others. Due to the existence of directional intermolecular bonds, the arrangement of molecules resembles tetrahedral coordination.

W. Ramsay and J. Shields [31], W. Sutherland [32], G.W. Stewart [33], R. Mecke [34], M. Yel'yashevich [35], M. Magat [36], N. Bjerrum [37], L. Pauling [38], J. Lennard-Jones and J. Pople [39] made great contributions to the development of water structure theory. In recent years, the fundamental works of X.F. Pang [40, 41] have been published.

The predominant opinion is that "most hydrogen-bonded chains of water molecules can mutually unite and form some closed configurations by connecting the head and tail of the linear chains with hydrogen bonds. These closed configurations can include chains with hydrogen bonds containing 2 (dimer), 3, 4, 5, 6, or more water molecules" [40]. This view can be used to explain the magnetizability of water.

Numerous experiments have shown that water can be magnetized under the influence of a magnetic field, although the magnetization effect is small. Based on the analysis of a large amount of experimental data, the authors [21, 22, 41–44] showed that this changes its optical and electromagnetic properties, surface tension force, dielectric permittivity, viscosity, crystallization and boiling temperatures. For example, the authors [42] indicate that the surface tension of water after magnetic treatment decreased from 72.44 mN/m to 57.62 mN/m (1 T intensity field with treatment time for 13 min at 25°C). The authors [43] point out that the refractive index of magnetized water was increased by 0.1% from 1.333 to 1.335 under the influence of a magnetic field (10 T at 25°C). The authors [43] also observed a slightly increasing melting point (5.6 mK) of water after magnetic treatment as well as an increase in water's vaporization enthalpy after magnetic treatment (45–65 mT, 22°C) from 58.86 to 68.86 kJ/mol. The studies [41] also showed significant differences in infrared absorption spectra and Raman spectra of magnetized and ordinary water. Raman spectra peaks for the magnetized water are larger than that without magnetized water (the positions of these peaks do not change). The strengths of the 1500 cm^{-1} peak in the magnetized and pure waters are 148 and 124, respectively. The authors [41] explain this result by the intensification of "ring proton currents" in the closed chains of water molecules.

Hypotheses explaining the essence of the magnetic field effect on water and aqueous solutions can be divided into three groups.

The first group of hypotheses proceeds from the fact that water always contains impurities. According to the theories of this group, the spontaneous formation and decay of colloidal complexes of metal cations: Ca^{2+}, Mg^{2+}, Fe^{2+} and Fe^{3+}, occurs under the influence of a magnetic field in the treated water and fragments of their deca further form the centers of nucleation of inorganic salts. In the presence of Fe^{3+} cations and the smallest ferromagnetic Fe_2O_3 particles in water, the formation "of colloidal hydrophobic sols of Fe^{3+} cations with chlorine Cl^- anions and neutral H_2O molecules having the general formula $[xFe_2O_3{\cdot}yH_2O{\cdot}zFe^{3+}]{\cdot}3zCl^-$, which may cause the formation of nucleation centers whose surface adsorbs calcium Ca^{2+} and magnesium Mg^{2+} cations (forming the basis of the carbonate hardness of water)" [45]. It should be noted that the theories of this group satisfactorily explain the positive effect of magnetic treatment of water to prevent or reduce scale formation in pipes and heat exchangers.

Hypotheses of the second group explain the effect of a magnetic field on water by means of the polarization of dissolved ions and the deformation of their hydration shells under the action of the magnetic field [46]. In addition, it is assumed that the effect of the magnetic field on the Ca^{2+}, Mg^{2+}, Fe^{2+}, and Fe^{3+} ions dissolved in water may also be associated with the generation of a weak electric current in the moving water flow or with pressure pulsation [47].

Hypotheses of the third group postulate that the magnetic field directly affects the structure of water associates due to the dipole polarization of water molecules, which are formed from many H_2O molecules bonded to each other by low-energy intermolecular Van der Waals forces, dipole-dipole interactions and hydrogen bonds, which can cause the deformation of hydrogen bonds and their partial breakage, and the migration of mobile protons H^+ within associative elements of water and uniting of H_2O molecules into temporary associates – clusters [40, 48].

The above hypotheses do not fully cover all of the assumptions and views on the essence of phenomena occurring during the magnetic treatment of water. At the same time, a large number of experiments confirming changes occurring in water under the influence of a magnetic field eliminates doubts as to the validity of the observed phenomena.

3. THE USE OF MAGNETIC WATER TREATMENT IN FOUNDRY ENGINEERING

An essential reserve for improving the quality of casting into sand molds is to improve the properties of molding materials used for their production. An important point in this is the use of environmentally friendly technologies and materials.

The strength of green molding sands depends mainly on the properties (the adhesive properties and the contact angle) of the liquid and semi-liquid films covering the sand grains (water, moistened clay, etc.). Thus, by influencing these films, it is possible to influence the strength properties of the molding sands as a whole.

Boldin et al. [49] explain the formation of the strength properties of green molding sand by the polarity of the water molecule and the presence of an electric double electric charge on the micelles of the clay binder.

The authors [49–52] explain the formation of the strength of green molding sand by the fact that on the surface of solid particles (sand and clay), a double electric layer is formed by hydrogen ions and hydroxyl groups. There is a spontaneous, unipolar orientation of dipoles and liquid ions on the surface of sand and clay. The degree of orientation of the particles decreases with distance from the surface. At the same time, according to Boldin et al. [49], the disoriented particles have a "wedging" effect and prevent particle convergence.

It can be assumed that magnetically treated water will have dipoles with preferential orientation with respect to the surface of mineral particles (sand and clay). This will decrease the "wedging" effect and provide a better particle approach and, consequently, the greater strength of the sand.

In a number of studies [22–28], water, clay slurries, aqueous solutions of sols included in the molding sand, and the green molding sand were subjected to magnetic treatment. In addition, different starting materials were used, from which different compositions of molding sand were prepared. The action was carried out both by electromagnets and permanent magnets, and the mixing time of the components was different. Therefore, it is impossible to compare the quantitative indicators of the effect of magnetic treatment.

Let us analyze the results of individual works separately in order to identify general patterns.

V. Klassen [23] supplies data on the increase in the compressive strength of the green molding sand mixture (93.2% quartz sand, 4.8% clay, and 2.9% water) 2 times after magnetic treatment of water with a simultaneous increase in gas permeability.

In [27] the magnetic treatment of water allowed the strength of the sand-cement molding sand to be increased by 30%.

Yu. Vasin et al. [53] also conducted studies with sand and bentonite mixtures (100 wt. parts of quartz sand, 10 wt. parts of bentonite and 4.5 wt. parts of water). The application of magnetized water increased the strength from 40 to 52 kPa (1.3 times) (Fig. 2) and gas permeability from 287 to 313 units (1.44 times). It is remarkable that the effect of the magnetic treatment of water was retained for more than 1 hour.

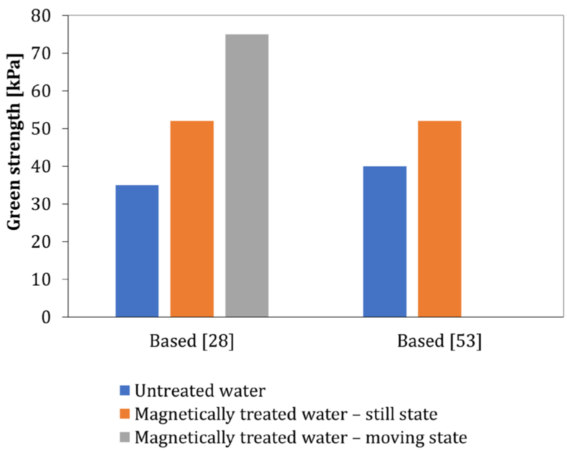

Fig. 2. Green strength of molding sands

The authors of the research [24–27] focused their attention on the study of the effect of movement velocity of sodium silicate, clay slurry, and an aqueous NaOH solution on the strength of different molding sands. The magnetic treatment of still sodium silicate made it possible to increase the strength of the molding sand (97 wt. parts of quartz sand, 3 wt. parts of molding clay, 1 wt. part of NaOH, 5 wt. parts of sodium silicate with a density of 1420 kg/m^3) by 1.6 times. The movement of sodium silicate through the electromagnet at a velocity of 1 g/s additionally increased the strength of the sand by 10% compared to the fixed sodium silicate treatment. It was found that the positive results of the magnetic treatment was retained after even 9 hours [25]. Moving 0.5% aqueous NaOH solution through the electromagnetic treatment apparatus at a speed of 0.6 m/s ensured an increase the strength of the molding sand (90% quartz sand, 1% clay and 3.5% aqueous NaOH solution) 1.35 times compared to the fixed solution treatment [24].

L. Dan et al. [28] conducted research on the effect of various factors on the green strength of the molding sand, which contained quartz sand (76.2%), molding clay from the Chasiv Yar deposit in the form of powder (19%) and water (4.8%). During the experiments, water was treated by electromagnet at still or by stirring in the vessel; the treatment time and the electric power supplied to the electromagnet were varied.

The study [28] showed that even the treatment of still water with an alternating magnetic field increased the green strength of the molding sand containing this water from 0.035 MPa to 0.052 MPa compared to the molding sand that contained untreated water (1.48 times). Stirring with a glass stirrer at ~1 revolution per second increased the green strength to 0.075 MPa (an additional 1.44 times) (Fig. 2).

To achieve maximum results for the green strength of the molding sand, it was sufficient to conduct magnetic water treatment for 2.5 minutes. As in the studies [25, 53], the effect of the magnetic treatment of water was maintained for a long period of time. Even after 120 hours, the green strength of the samples made from sand containing magnetically treated water was 1.3 times higher than that of the control samples.

Analysis of the use of magnetically treated water in foundry engineering has shown the following positive results: a) magnetic treatment of water and water binders indisputably increases the green strength of molding sand and improves its gas permeability; b) magnetic treatment of moving water is more effective compared to the magnetic treatment of still water; c) the positive effect of magnetic treatment of water on the properties of molding sand is maintained for a long time. At the same time, there is no consensus in the literature about the modes of magnetic water treatment required to achieve the best results.

4. CONCLUSIONS

Analysis of the literature on the magnetic treatment of water has shown the following:

- water changes its properties under the influence of a magnetic field: electro-physical, optical, surface tension, temperatures of phase transformations, infrared absorption spectra, Raman spectra, etc.;
- to date, there is no unified theory explaining changes in water properties under the action of a magnetic field;

- the application of water treated by a magnetic field to reduce scale formation in heat exchangers and pipes, in agriculture, in the manufacture of concrete products, in biology and medicine provides a positive effect;
- the use of water magnetization and aqueous binders in molding sands increases their green strength. Magnetic treatment of still water can increase the green strength of the molding sand containing this water from 0.035 to 0.052 MPa, and that of water in motion to 0.075 MPa. It can reduce the amount of binder used in the molding mixtures;
- long-term retention of improved properties of the molding sands opens up the prospect of using the magnetic treatment of water and aqueous binders in the industry;
- to make a final decision on the use of magnetic water treatment in foundry engineering, it is necessary to carry out comprehensive research aimed at establishing the optimal techniques and modes of such treatment.

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