MAK HILL Publications Journal of Engineering and Applied Sciences

Research Article
doi: 10.59218/jeas.2023.1.14

Modelling Equations and Simulation for Predicting the Properties of Sand to Improve the Quality and Speed of Moulding Practice

[1]E.E Mukoro, [2]J.A. Bakare and [2]T.C. Ogbuanya

[1]*Department of Foundry, The Federal Polytechnic Idah, Nigeria*

[2]*Department of Industrial Technical Education, University of Nigeria, Nsukka, Nigeria*

ABSTRACT

In the foundry industry samples of moulding sand and core sand are sent to the testing laboratory on a periodic basis. The results are returned to process control laboratory and are plotted on control charts. Trends are noted and corrections made when necessary. This study was aimed at developing modelling equations and simulation for predicting the moulding behaviour of river Niger fine sand at different clay contents thereby bypassing laboratory tests. Physical tests were carried out on 90 samples of sand/clay/water admixture. Moisture content was held constant at 6% at optimum plasticity. Clay content was varied thus: 5, 6, 7, 8, 9, 10, 11, 12 and 13% and balance sand to conform to 157 g standard sample. Results obtained indicated that mould sand properties of compactability (40-46), green hardness (40.25-48.09), green shear strength (0-720) and shatter index (38-55) exhibited linearity while inverse linearity was observed in permeability (135-120). Refractoriness and dry hardness did not increase in value with increase in clay content. However, green compression strength, shear strength and dry compression strength which maintained a steady positive relationship from 5-7% clay showed a fluctuating pattern up to 13%. The GFN of the fine sand was 56.13%. The properties variation with respect to clay content was the basis of the model equations development. The model equations predicted the output close to the experimental results using Silica Sand Mould Properties Determination (SSMPD) software. The software was developed using VISUAL BASIC programming language. It is user friendly and runs on window computer of at least 1 MB RAM and 3.0GB free hard disk with information on the installation, running and using the application software. This SSMPD has contributed to rapid determination of fine sand properties and quality foundry mould practice. Statistical tests were used to validate the developed models. The correlation coefficient was used to measure the amount of association existing between the experimental data and predicted data. The computation of the correlation coefficient, the variance, standard deviation, standard error and confidence interval at 95% confidence interval at 95% confidence level was done. The t-test was used to check the extent of relation of the paired data, ie: exactly the same, closely the same and fairly the same.

OPEN ACCESS

Key Words
Fine sand, model equation and simulation, foundry operations, SSMPD software

Corresponding Author
E.E Mukoro,
Department of Foundry, The Federal Polytechnic Idah, Nigeria

Received: 20 December 2022
Accepted: 5 January 2023
Published: 2 February 2023

Citation: E.E Mukoro, J.A. Bakare and T.C. Ogbuanya, 2023. Modelling Equations and Simulation for Predicting the Properties of Sand to Improve the Quality and Speed of Moulding Practice. J. Eng. Applied Sci., 18: 1-14, doi: 10.59218/jeas.2023.1.14

INTRODUCTION

The purpose of sand control tests is simply to predict the behaviour of a sand mixture during moulding and casting[1]. Therefore, they are designed to duplicate foundry practice. As more foundries strive to eliminate the causes of casting defects, sand control the lack of which is responsible for numerous casting defects, has grown in importance. The acceptance of a moulding sand mixture is based on the fulfillment of certain property requirements[2]. These properties are determined by standard tests on standard samples that are representative of the whole sand. Moulding sand properties that are often tested are: green strength, dry strength, hot strength, shear strength, permeability, compactability, hardness, shatter index, refractoriness, fineness, flowability, cohesiveness[3,4].

The most common casting process used in the foundry industry is the sand casting system. Typically, about one ton of foundry sand is required for each ton of iron or steel casting produced. Foundry sand is used to provide bulk, strength and other properties to mould construction. Sand grain sizes range from 3360 m (6 mesh) to 53 µm (270 mesh) while clay particles are 20 µm or less in diameter. Sand that does not produce good flowability will require much more effort when packing the sand around the pattern to form the mould. In extreme cases, lack of flowability may result in moulds that are soft rammed, or of too low a rammed density. This is particularly so where the moulding machine has a predetermined cycle of automatic functions for producing the moulds. If the green strength of the moulding sand is insufficient, the mould may get distorted under its own weight when the pattern is withdrawn, and it is also prone to damage and distortion prior to and during final assembly of the mould itself. Further, such sand may contribute to dimensionally inaccurate and an unsound casting due to dilation caused by the pressure of the liquid metal when being cast. This is particularly so with cast iron, which has a peculiar phenomenon of expansion when solidifying. Insufficient dry strength will result in friability and premature break down of the mould surface, which in turn results in dirty and rough castings. Typical ranges of values of green compression strength and dry compression strength given by Srinivasan are 34-70KN/m^2 and 136-1050KN/m^2, respectively. Shear strength values are lower. If the sand mould does not have requisite permeability, then the steam and gases generated by the heat of the molten metal and from the metal itself will be unable to escape from the mould cavities and will tend to remain in the solidifying metal to form cavities in the casting known as "blowholes". From this, it is apparent that the amount of moisture present (typically 5-10%) and the gas evolution from the mould material have a strong influence on the tendency to form blowholes and necessitate different degrees of permeability[5]. Srinivasan gave typical values for permeability as 10-80 g/cm^2 for cast iron, 20-35 g/cm^2 for aluminum and 120-180 g/cm^2 for steel. Wet moulds require higher permeability than dry moulds while thicker and bigger casting require higher permeability than smaller and lighter casting. Most moulding sands are formulated with the minimum amount of clay required to achieve maximum strength attainable[6]. This is about 10% for bentonite and about 20% for fireclays. Angular sand grains packed together with less pore space is compared to round grains. Large grains allowed small ones to occupy their interstices or pore. All these reduce permeability and increase strength. The presence of moisture gives the mould sand mix the necessary plasticity.

Mukoro[7] survey shows that there are 160 foundry companies in Nigeria. These foundries produce 80000 t of castings annually. All government research foundries and government production foundries have quality control facilities for moulding sand and metal tests. Forty percent (40%) of private sector foundries do not have quality control outfits at all, specifically sand and metal tests. With the exception of Nigeria Foundries Ilupeju/Ota, Aqua-Agro Foundry Isolo, T. Sanyaolu Foundry Ota and Bamford Foundry Jos, all other private sector foundries have scanty quality control facilities. Quality control, the basis for producing quality castings and effective competition with imports is grossly lacking in the private sector foundries. Although, there is prohibitive cost associated with procurement of instruments and machines for sand/clay test, nevertheless, product scrapping and poor quality translates to non-sales and high cost of repetitive production. Therefore, the problem of this study is that jobbing and captive foundry industries set up with low capital base lack access to quality control testing equipment for the determination of mould sand properties.

The advantage of synthetic mould sand over natural sand is the possibility to control the composition of the mix in synthetic mould sand. Natural mould sand is already mixed for you by nature which may not satisfy your need or requirement. The standard international best practice is to formulate your mould sand mix to suit your foundry workshop specification[8,9]. Modeling the resulting properties of locally formulated synthetic mould sand mix will not only reduce the frequent entering into laboratories for quantitative and qualitative analysis, but also simulate the process for quick estimation of properties[10-13].

Foundry practice in small and medium enterprises in Nigeria cannot stagnate with the use of natural sand due to lack of capacity to control the properties of locally formulated synthetic mould sand mix. The purpose of this study was to develop a model for quick estimation and predicting the properties of synthetic sand at different clay contents for casting process.

MATERIALS AND METHODS

Silica sand that constitute the bulk material of this synthetic moulding sand was obtained from the River Niger at Idah beach location. Idah town is located onthe eastern part of the River Niger and lies on latitude 6°43' North and longitude 6°45' East. Clay binder (bentonite) was purchased from the local open market and was mixed with the silica sand in a ratio of 81-89 parts sand to 5-13 parts bentonite. Samples were prepared from the large heap of the silica sand after sorting to remove unwanted materials of vegetation and stones, then blended for uniform distribution of sand particles and then dried. The sand was screened in a sieve shaker (ENDECOTTS EFLI MK3 and SMETCO) holding thirteen meshes whose sizes (in mm) were 1.60, 1.00, 0.710, 0.630, 0.400, 0.315, 0.200, 0.160, 0.125, 0.100, 0.063, pan. The shaking time was 15 min for every 50 g sand. Samples were taken for chemical analysis to reveal the composition of the sand.

Standard specimen preparation: Known weight of sand (157 g) weighed with digital weighing balance of ATMA Technologies having 5, 6, 7, 8, 9, 10, 11, 12 and 13% bentonite and conditioned with water was prepared into standard specimen for sand control tests. A sample for sand test was prepared in a 5.1 cm diameter tube set with pedestal in a standard sand ramming machine (KELSONS and +GF+PRP type) by dropping three successive times under gravity with a 6.4 kg rammer from a 5.1 cm height to compress the sand in the tube. Specimen was 5.1 cm diameter×5.1 cm height and where otherwise the procedure was repeated using another weight. Ninety samples were produced and used for this study.

Compactability test: The moulding sand was loosely filled into the specimen tube. The sand was struck level with the top of the tube and then rammed with the standard three ramming blows in the ramming machine. The distance from the top of the tube to the level of the rammed sand was read as the percent compactability by dividing the decrease in the height by the initial height.

Surface hardness test: Indentation or compact tester (SMETCO) was pressed on the rammed mould. The value on the empirical scale, 0-100 units, was read. This procedure was the same for green (moist) and dry samples.

Permeability test: With the standard rammed specimen retained in the tube, the tube was sat on the electric permeability meter (SMETCO) and operated according to the instruction manual. It operated by passing air through standard sample. The permeability values were read from the meter (scale) on the instrument.

Test for green compression strength (GCS): The standard specimen was stripped from the tube and the flat faced compression heads were inserted on the analog universal sand strength machine (SMETCO). The rammed specimen was placed between the compression heads and the hand wheel was turned to load the specimen progressively. The scale marked green compression was read at the point of fracture (breakload). The electronic digital versions (SMETCO and KELSONS) were also used for this research. This procedure was the same for green (moist) samples as well as dry samples.

Test for green shear strength (GSS): The standard specimen was stripped from the tube and the shear heads were inserted on the universal sand strength machine, then the rammed specimen was placed between the shear heads. The hand wheel was turned to load the specimen progressively. The scale marked green shear strength was read at the point of fracture. The electronic digital version (SMETCO and KELSONS) were also used for this research.

Shatter index test: Shatter index of the core or moulding sands is determined by the use of shatter index equipment. This equipment is about 3 m above the base with the pulling lever attached 0.25 m from the upper end. To test for the shatter index of the sand 150 g of sand is weighed and poured into the sleeve. The weighed sand in the sleeve is rammed 3 times with the ramming machine. The sample is put on the shatter index equipment and the lever is pulled such that the sand is removed from the sleeve on top unto the receiving sleeve placed directly below the equipment. Then lumps of the sand on the sieve is collected and weighed. The weight obtained is divided by 150 and multiply by 100 to get shatter index value.

Refractoriness: The temperature at which burn-on sand was observed around the casting was the refractoriness. This was confirmed with a pyrometric cone test.

Model equations derivation: The properties variation (independent variables) with respect to dependent variable (clay content) was the basis of the model development. The properties variation of the locally formulated synthetic sand with the clay content and moisture tempered was expected to be linear and so, the linear function was derived with mathematical expression according to Olaitan and Ndomi. This implied that shatter index, mould surface hardness, compactability, permeability and strength are functions of clay content (binder). The change in property of moulding sand varied directly with clay content.

A linear function was expected whereby a mathematical equation in which no independent variable is raised to a power greater than one. A simple linear function with only one independent variable traces a straight line when plotted on a graph, also called linear equation. On that equation was the linear regression with a mathematical technique for finding the straight line that best fitted the values of a linear function plotted on a scatter graph as data points. The best fit line was used as the basis for estimating the future values of the function by extending it while maintaining its slope.

However, data generated in this study traced the non-linear regression- a form of mathematical model that reflected the results in a curve between two variables (x and y) rather than a straight line relationship as in the case of linear regression, which are usually simpler with expression such as y = a+bx. The main characteristic of a non-linear regression is that the prediction equation does not linearly depend on the unknown parameters. This type of regression uses functions such as trigonometry, logarithm and exponential.

As illustrated by the moulding problem, the physical information is that the experiment show that rate of change of the sand properties is proportional to the clay content. The first step in the modeling is to write the equation denoting an unknown constant of proportionality by k, we have[14]:

$$\frac{dp(c)}{dc} = kP(c) \tag{1}$$

The second step to arrive at a general solution is the separation of variables, integration and taking exponentials.

Model equation for the moulding properties of river Niger Fine S and: Let $P_{CP}(c)$ be the moulding property, compactability, of the produced mould sample from fine sand. Hence, using equation (1), we have:

$$\frac{dp_{CP}(c)}{dc} = kP_{CP}(c) \tag{2}$$

Where:

$P_{CP}(c)$ = Mould property, compactability
C = Clay content
k = Constant of proportionality

Thus, on separating the variables of equation (2) and integrating accordingly, we have:

$$\frac{dp_{CP}(c)}{Pcp(c)} = kdc$$

Which implies:

$$\int \frac{dP_{CP}(c)}{P_{CP}(c)} = \int kdc$$

$$\Rightarrow \ln P_{CP}(c) = kc + a$$

Hence:

$$P_{CP}(c) = Ae^{kc}, A = e^{a}$$

At c = 9, $P_{CP}(9) = 44$

$$\Rightarrow 44 = Ae^{9k}$$

$$\Rightarrow A = \frac{44}{e^{9k}}$$

Hence:

$$P_{CP}(c) = \frac{44}{e^{9k}}e^{kc}$$

When: c = 11, $P_{CP}(11) = 46$:

$$\Rightarrow 46 = \frac{44}{e^{9k}}e^{11k}$$

$$\Rightarrow 46 = 44e^{(11-9)k} = 44e^{2k}$$

Therefore:

$$k = \frac{1}{2}\ln\frac{46}{44} = 0.02222588107$$

Hence:

$$P_{CP}(c) = 36.02e^{0.02222588107c}$$

For the moulding property, Green Hardness (GH), of the produced mould sample from fine sand:

At c = 8, $P_{GH}(8) = 80$

$$\Rightarrow 80 = Ae^{8k}$$

$$\Rightarrow A = \frac{80}{e^{8k}}$$

Hence:

$$P_{GH}(c) = \frac{80}{e^{8k}}e^{kc}$$

When: $c = 9$, $P_{GH}(9) = 82$:

$$\Rightarrow\ 82 = \frac{80}{e^{8k}}e^{9k}$$

$$\Rightarrow 82 = 80e^{k}$$

Therefore:

$$k = \mathrm{In}\frac{82}{80} = 0.02469261259$$

Hence:

$$P_{GH}(c) = 65.66e^{0.02469261259c}$$

For the moulding property, Dry Hardness (DH), of the produced mould sample from fine sand:

$$\text{At } c = 7,\ P_{DH}(7) = 93$$

$$\Rightarrow 93 = Ae^{7k}$$

$$\Rightarrow\ A = \frac{93}{e^{7k}}$$

Hence:

$$P_{DH}(c) = \frac{93}{e^{7k}}e^{kc}$$

When: $c = 11$, $P_{DH}(11) = 94$

$$\Rightarrow\ 94 = \frac{93}{e^{7k}}e^{11k}$$

$$\Rightarrow 94 = 93e^{4k}$$

Therefore:

$$k = \frac{1}{4}\mathrm{In}\frac{94}{93} = 0.002673822238$$

Hence:

$$P_{DH}(c) = 91.17e^{0.002673822238c}$$

For the moulding property, Shatter Index (SI), of the produced mould sample from fine sand:

$$\text{At } c = 6, P_{SI}(6) = 37$$

$$\Rightarrow 37 = Ae^{6k}$$

$$\Rightarrow\ A = \frac{37}{e^{6k}}$$

Hence:

$$P_{SI}(c) = \frac{37}{e^{6k}}e^{kc}$$

When: $c = 9$, $P_{SI}(9) = 43$:

$$\Rightarrow\ 43 = \frac{37}{e^{6k}}e^{9k}$$

$$\Rightarrow 43 = 37e^{3k}$$

Therefore:

$$k = \frac{1}{3}\mathrm{In}\frac{43}{37} = 0.05009406764$$

Hence:

$$P_{SI}(c) = 27.40e^{0.05009406764c}$$

For the moulding property, Permeability (PM), of the produced mould sample from fine sand:

$$\text{At } c = 5,\ P_{PM}(5) = 135$$

$$\Rightarrow 135 = Ae^{5k}$$

$$\Rightarrow\ A = \frac{135}{e^{5k}}$$

Hence:

$$P_{PM}(c) = \frac{135}{e^{5k}}e^{kc}$$

When: $c = 6$, $P_{PM}(6) = 130$

$$\Rightarrow\ 130 = \frac{135}{e^{5k}}e^{6c}$$

$$\Rightarrow 130 = 135e^{k}$$

Therefore:

$$k = \mathrm{In}\frac{130}{135} = 0\ 0.03774032794$$

Hence:

$$P_{PM}(c) = 163.04e^{-0.03774032794c}$$

For the moulding property, green shear strength (GSS), of the produced mould sample from fine sand:

$$\text{At } c = 7,\ P_{GSS}(7) = 360$$

$$\Rightarrow 360 = Ae^{7k}$$

$$\Rightarrow\ A = \frac{360}{e^{7k}}$$

Hence:

$$P_{GSS}(c) @ \frac{360}{e^{7k}} e^{kc}$$

When: C = 9, $P_{GSS}(9) = 440$

$$\text{Ë} \;\; 440 @ \frac{360}{e^{7k}} e^{9k}$$

$$\Rightarrow 440 = 360e^{2k}$$

Therefore:

$$k @ \frac{1}{2} \text{In} \frac{440}{360} @ 0.1003353477$$

Hence:

$$P_{GSS}(c) = 178.35e^{0.1003353477c}$$

For the moulding property, grain fineness number (GFN), of the produced mould sample from fine sand:

$$\text{At } c = 5,\ P_{GFN}(5) = 56$$

$$\Rightarrow 56 = Ae^{5k}$$

$$\text{Ë} \;\; A = \frac{56}{e^{5k}}$$

Hence:

$$P_{GFN}(c) @ \frac{56}{e^{5k}} e^{kc}$$

When: c = 6, $P_{GFN}(6) = 56$

$$\text{Ë} \;\; 56 = \frac{56}{e^{5k}} e^{6k}$$

$$\Rightarrow 56 = 56e^{k}$$

Therefore:

$$k = \text{In } 1 = 0$$

Hence:

$$P_{GFN}(c) = 56e^{0c}$$

For the moulding property, refractoriness (RE), of the produced mould sample from fine sand:

$$\text{At } c = 5,\ P_{RE}(5) = 1400$$

$$\Rightarrow 1400 = Ae^{5k}$$

$$\text{Ë} \;\; A @ \frac{1400}{e^{5k}}$$

Hence:

$$P_{RE}(c) @ \frac{1400}{e^{5k}} e^{kc}$$

When: c = 6, $P_{RE}(6) = 1400$

$$\text{Ë} \;\; 1400 = \frac{1400}{e^{5k}} e^{6k}$$

$$\Rightarrow 1400 = 1400e^{k}$$

Therefore:

$$k = \text{In}1 = 0$$

Hence:

$$P_{RE}(c) = 1400e^{0c}$$

For the moulding property, green compression strength (GCS), of the produced mould sample from fine sand:

$$\text{At } c = 8,\ P_{GCS}(8) = 150$$

$$\Rightarrow 150 = Ae^{8k}$$

$$\text{Ë} \;\; A @ \frac{150}{e^{8k}}$$

Hence:

$$P_{GCS}(c) @ \frac{150}{e^{8k}} e^{kc}$$

When: c = 10, $P_{GCS}(10) = 250$:

$$\text{Ë} \;\; 250 @ \frac{150}{e^{8k}} e^{10c}$$

$$\Rightarrow 250 = 150e^{2k}$$

Therefore:

$$k @ \frac{1}{2} \text{In} \frac{250}{150} @ 0.255412812$$

Hence:

$$P_{GCS}(c) = 19.44e^{0.255412812c}$$

For the moulding property, dry compression strength (DCS), of the produced mould sample from fine sand:

$$\text{At } c = 5,\ P_{DCS}(8) = 1060$$

$$\Rightarrow 1060 = Ae^{5k}$$

$$\text{Ë} \;\; A @ \frac{1060}{e^{5k}}$$

Hence:

$$P_{DCS}(c) = \frac{1060}{e^{5k}} e^{kc}$$

When: c= 6, $P_{DCS}(6) = 1200$

$$\Rightarrow 1200 = \frac{1060}{e^{5k}} e^{6k}$$

$$\Rightarrow 1200 = 1060e^{k}$$

Therefore:

$$k = \ln \frac{1200}{1060} = 0.1240526489$$

Hence:

$$P_{DCS}(c) = 570.007e^{0.1240526489c}$$

Model equations validation: Statistical tests were used to validate the developed models. The experimental and theoretical data of each property was subjected to statistical tests (paired test, standard error and correlation coefficient) analyses. The correlation coefficient was used to measure the amount of association existing between the experimental data and predicted data. Comparing experimentally generated data with model predicted data was done. Data were accepted at 95% confidence level.

Tests of significance (t) of the correlation coefficient with a view to accept or reject the null hypothesis was carried out. The computation of the correlation coefficient, the variance, standard deviation, standard error and confidence interval at 95% level was done.

Software development: The model was implemented through software development for quick estimation of the investigated moulding properties of the locally formulated synthetic fine sand of River Niger. The software was developed using visual basic package. The derived mathematical model equations for sand-clay content moisture tempered was used to develop a flowchart and algorithm for the software.

RESULTS

Table 1 shows sieve analysis of River Niger fine sand traditionally used for plastering in building construction. The sieve numbers involved were 1-13 and the grains distribution (Fig. 1) shows normal curve, which is an indication of blend of all sizes required for foundry moulds. The grain fineness number obtained is 56.13 which indicates fine sand that is suitable for mould making to receive poured liquid cast non-ferrous metals.

The fine sand of River Niger at Idah location used for this study was subjected to sieve analysis as mentioned above. The result produced a normal curve which means the presence of varied sizes. The grains fineness number (GFN) for the fine sand being 56.13 is measured in a scale of 0-100 units of coarse to fine.

Table 2 shows data generated from experiment as the sand/clay admixture is tested of mould properties. Nine admixtures of 5-13% clay with 6% water held constant constitute a sample in each admixture. A sample is 157 g. Each test in an admixture requires a sample for the following properties: Compactability, Green hardness, Permeability, Green Compression strength, Collapsibility (Shatter index), Dry compression strength, Grain fineness number, Refractoriness, Dry hardness .

Figure 2 shows the trend pattern (linear or non-linear) for each property as the clay content increases. It was on the basis of this trend i.e., properties variation with respect to the variable, clay content, that the model equations were developed.

In the plot (scatter graph) of moulding properties versus clay content, the following properties: compactability (Cp), green hardness (GH), Shatter index (SI), increased steadily with increase in clay content for fine sands. Permeability (Pm) decreased steadily with increase in clay content for fine sand. Green Shear Strength (GSS) increase for fine sand was undulating. Green compression strength (GCS) and

Table 1: Sieve analysis for fine sand

Sieve no.	Mesh size	Sieve no. mm	Retained sample (g) for 50 g	Retained Percentage for the 50 g	Multiplier	Product
1	------	1.6	0		-----	
2	6 mesh	1	½	0.90	3	2.7
3	12 mesh	0.710	1	1.80	5	9.0
4	20 mesh	0.630	1	1.80	10	18.0
5	30 mesh	0.40	2.5	4.46	20	89.2
6	40 mesh	0.315	3	5.36	30	160.8
7	50 mesh	0.200	20	35.71	40	1428.4
8	70 mesh	0.160	12.5	22.32	50	1116.0
9	100 mesh	0.125	10	17.86	70	1250.2
10	140 mesh	0.100	2.5	4.46	100	446.0
11	200 mesh	0.080	1.5	2.68	140	375.2
12	270 mesh	0.63	½	0.90	200	180.0
13		Pan	1	1.80	300	540.0
	Total		56	100.05		5615.5

Fig. 1: Grains distribution curve for River Niger fine sand

Dry Compression Strength (DCS) maintained steady increase from 5-7% clay before it presented fluctuating pattern of results up to 13% clay.

These results of moulding sand properties are not just naturally expected but they followed and conform to standard results as reported in literature[5,8].

Table 3 is a comparative analysis of experimental (X) and predicted (Y) moulding properties for the fine silica sand. Statistical analysis was made for each of the regression models to confirm the statistical adequacy, type of relation and significance of variables. It is noted that the significance tests and coefficient of correlation values are utilized for the purpose. Further, model accuracy is determined by comparing model predicted values of responses with their corresponding target (that is, obtained through experiments) values[5]:

$$\text{GFN} @ \frac{\text{Product}}{\text{Retained (\%)}}$$

$$@ \frac{5615.5}{99.98}$$

$$= 56.13\%$$

Scale:

Compactability (Cp) --------------------------------- 1cm: 20
Grain fineness number (GFN) -------------------- 1cm:10
Green hardness (GH) ------------------------------ 1cm:10
Dry hardness (DH) --------------------------------- 1cm:10
Permeability (Pm) --------------------------------- 1cm:10
Dry compression strength (DCS) ---------------- 1cm:200
Green compression strength (GCS) -------------- 1cm:100
Green shear strength (GSS) --------------------- 1cm:100
Shatter index (SI) ---------------------------------- 1cm:10
Refractoriness (Re) -------------------------------- 1cm:200

The following are the model equations derived from experimental data for the fine beach sand:

$P_{Cp} = 36.02e^{0.02222588107c}$

$P_{GH} = 65.66e^{0.0246921259c}$

$P_{DH} = 91.27e^{0.002673822238c}$

$P_{SI} = 27.40e^{0.05009406764c}$

$P_{Pm} = 163.04e^{-0.03774032794c}$

$P_{GSS} = 178.35e^{0.1003353477c}$

$P_{GFN} = 56e^{0c}$

$_{Pre} = 1400e^{0c}$

$P_{GCS} = 19.44e^{0.255412812c}$

$P_{DCS} = 570.007e^{0.1240526489c}$

Table 3: Comparative analysis of experimental (X) and predicted (Y) moulding properties for Fine sand

	(Cp) compactabilty (%)		(GH) green hardness		(DH) dry hardness		(Pm) permeability	
Mould sand mix	X	Y	X	Y	X	Y	X	Y
5%clay 6%water (8 g clay, 10 g water, 139 g sand)	40	40.25	70	74.29	93	92.50	135	135.00
6%clay6%water (10 g clay, 10 g water, 137 g sand)	44	41.16	73	76.15	93	92.75	130	130.00
7%clay6%water (11 g clay, 10 g water, 136s and)	44	42.08	77	78.05	93	93.00	130	125.19
8%clay6%water (13 g clay, 10 g water, 134 g sand)	44	43.03	80	80.00	93	93.24	130	120.55
9%clay6%water (14 g clay, 10 g water, 133 g sand)	44	44.00	82	82.00	95	93.49	130	116.09
10%clay6%water(16 g clay, 10 g water,131 g sand)	47	45.00	83	84.05	94	93.74	130	111.79
11%clay6%water(18 g clay, 10 g water, 129 g sand)	46	46.00	83	86.15	94	94.00	130	107.65
12%clay6%water(19 g clay, 10 g water, 128 g sand)	47	47.03	85	88.31	93	94.25	130	103.66
13%clay6%water(21 g clay, 1 0 g water, 126 g sand)	46	48.09	85	90.51	93	94.50	120	100.00
Statistical tests $\bar{d}$	-0.62		2.40		0.052		-12.90	
R	0.83		0.94		0.391		0.69	
Var. d	2.2		3.80		0.8		95.00	
Sd	0.50.24		0.65		0.3		3.25	
SE	0.17		0.22		0.12		1.08	
Var. $(\bar{d})$	-0.81		0.42		0.09		10.55	
Coefficient of variation	21.0644		0.271		5.77		0.26	
RSS	0.691.24		81.76		6.531		2230.84	
r^2	0.69		0.88		0.153		0.476	
tc	1.24		3.70		0.173		-3.97	
Confidence. Int. at 95% confidence level	-0.368/-0.872		2.5/1.4		0.076/0.028		-7.5/-18.3	

	(SI) shatter index (%)		(GSS) green shear strength N/m^2		(GFN) grain fineness number		(Re) Refractoriness°C	
Mould sand mix	X	Y	X	Y	X	Y	X	Y
5% clay 6% water (8 g clay, 10 g water, 139 g sand)	38	35.20	0	294.54	56	56	1400	1400
6% clay 6% water (10 g clay, 10 g water, 137 g sand)	37	37.01	100	325.63	56	56	1400	1400
7% clay 6% water (11 g clay, 10 g water, 136 g sand)	29	38.91	360	360.00	56	56	1400	1400
8% clay 6% water (13 g clay, 10 g water, 134 g sand)	39	40.91	120	398.00	56	56	1400	1400
9% clay 6% water (14 g clay, 10 g water, 133 g sand)	43	43.01	440	444.00	56	56	1400	1400
10% clay 6% water (16 g clay, 10 g water, 131 g sand)	50	45.22	120	486.43	56	56	1400	1400
11% clay 6% water (18 g clay, 10 g water, 129 g sand)	50	47.54	480	537.77	56	56	1400	1400
12% clay 6% water (19 g clay, 10 g water, 128 g sand)	53	50.00	320	594.53	56	56	1400	1400
13% clay 6% water (21 g clay, 10 g water, 126 g sand)	55	52.55	720	657.28	56	56	1400	1400
Statistical tests $\bar{d}$	-0.406		159.36		0		0	
R	0.815		0.82		0		0	
Var. d	19		25415		0		0	
Sd	1.5		53		0		0	
SE	0.5		17.7		0		0	
Var. $(\bar{d})$	2.1		2824		0		0	
Coefficient of variation	-3.7		0.333		0		0	
RSS	338.34		431867.7		0		0	
r^2	0.664		0.67		0		0	
Tc	-0.3		3.0		0		0	
Confidence. Int. at 95% confidence level	0.498/0.314		226.2/92.5		0		0	

	(GCS) green compression strength N/m^2		(DCS) dry compression					
Mould sand mix	X	Y	X	Y	X	Y	X	Y
5% clay 6% water (8 g clay, 10 g water, 139 g sand)	0	69.71	1060	1059.88				
6% clay 6% water (10 g clay, 10 g water, 137 g sand)	100	90.00	12000	1199.87				
7% clay 6% water (11 g clay, 10 g water, 136 g sand)	610	116.19	1680	1358.34				
8% clay 6% water (13 g clay, 10 g water, 134 g sand)	150	250.00	1980	1537.74				
9% clay 6% water (14 g clay, 10 g water, 133 g sand)	250	193.65	1630	1740.08				
10% clay 6% water (16 g clay, 10 g water, 131 g sand)	250	250.00	1060	1970.76				
11% clay 6% water (18 g clay, 10 g water, 129 g sand)	200	322.75	1730	2231.05				
12% clay 6% water (19 g clay, 10 g water, 128 g sand)	350	416.67	1120	2525.72				
13% clay 6% water (21 g clay, 10 g water, 126 g sand)	610	538.00	2190	2859.30				
Statistical tests $\bar{d}$	36		315					
R	0.56		0.37					
Var. d	32765.55		365503					
Sd	60.34		201.5					
SE	20.1		67.2					
Var. $(\bar{d})$	3640.62		40611.4					
Coefficient of variation	1.68		0.64					
RSS	273732.40.314		3815788.32					
r^2	0.314		0.137					
tc	0.6		1.56					
Confidence. Int. at 95% confidence level	49/23		445/185					

Fig. 2(a-b): Scatter graph of moulding properties versus clay content

While laboratory physical tests produced the experimental results (X) the above model equations were used to produce the predicted results (Y) as shown in Table 3.

DISCUSSION

Silica sand is an extremely good material for casting moulds because it has the ability to withstand the temperature of the molten metal and can absorb and transmit heat and has sufficient permeability to allow gases generated during casting to pass between the particles without causing casting defects. Karunakaran[15] remarked that green sand moulding process is a traditional and common practice of manufacturing castings. Sand casting, also known as sand moulded casting is a metal casting process characterized by using sand as the mould material. The term “Sand Casting” can also refer to an object produced via the sand casting process. Sand castings are produced in specialized factories called foundries. Over 70% of all metal castings are produced via a sand casting process[16]. Sand casting is the most important and mostly used casting technique. To perform sand casting, we have to form a pattern (a full sized replica of the part), enlarged to account for shrinkage and machining allowances in the final casting.

The flow of River Niger causes the sand in the river bed to arrange in strata of coarse and fine sand layers with the fine in front. In civil construction, the coarse sand is used for blockmaking while the fine sand is used for plastering. In foundry manufacturing each grade of sand is sieved to reveal its grains sizes and shapes to foster interlocking and densification; second, the type of metal being cast influence the choice of sand grade to be used for moulding, ie., high melting point metals are poured in coarse sand mould, while low melting point metals are poured in fine sand mould. Experience has shown that high melting point metals fuse the interfacing sand and fineness increases the susceptibility of such fusion. Thirdly, the size of casting influence the choice of grade of sand to be used for moulding. That is big castings are made in coarse grade sand moulds, whilst small castings are made in fine grade sand moulds.

In preparing sand mould for foundry purposes, the sand is mixed with a binder to hold sand grains together and water is added to enable plasticity or mouldability. This is maintained at a critical amount that will retain the optimal bonding action of the binder. Additives are sometimes added for special effects but this addition is excluded in this study to avoid influence. Binders to the moulding sands should be added in minimum required quantity as it reduces permeability. Increasing binder content to a limit increases green compression strength, after which this strength remains practically unchanged with increase in binder content.

Modeling of River Niger sand properties for foundry moulds in metal casting is a viable follow-up to the results of the experiment as it added value in terms of speed, accuracy and reliability to casting mass production.

The forecasting power of a model can be tested using the t-distribution. In this modeling study it is the extent of relation of the paired data that was checked, which means:

- Exactly the same
- Closely the same
- Fairly the same

Forecasting of properties of sand mould is the estimation of the value of the dependent variable Y from the actual or projected value of the clay content which is the independent variable X in the regression model. It is the estimation of the future value of the dependent variable, properties of silica beach sand, with the model equations derived in this study. This forecasting is also reversible by using known values of the properties of beach sand to estimate the content of clay binder required.

Silica sand mould properties determination (SSMPD): SSMPD is a software application developed for quick and automatic determination of silica sand mould properties in Foundry Engineering Technology. The developed application is based on the models designed and formulated in Mukoro, for silica sand mould properties estimation.

The software package was developed using VISUAL BASIC programming language. It is a very user friendly application that runs on a windows computer of at least 1 MB RAM and 3.0GB free hard disk.

SSMPD is divided into two parts: Coarse sand sample and fine sand sample and the sand properties that can be estimated by SSMPD for both Coarse sand and Fine sand are Compactability (Cp), Grain Fineness Number (GFN), Green Hardness (GH), Dry Hardness (DH), Permeability (Pm), Dry Compression Strength (DCS), Green Compression Strength (GCS), Green Shear Strength (GSS), Shatter Index (SI) and Refractoriness (Re).

The importance of software applications in foundry engineering processes cannot be overemphasized. In recent years, many key developments have taken place in computer-aided design, simulation, rapid tooling, intelligent advisory systems and internet based engineering and most foundries are presently caught between change and survival. This is especially true in the case of foundries operating in the developing countries. However, to survive in the global market, they will have to keep pace with the changing technological trends. If properly adopted, these can lead to both immediate tangible benefits in terms of shorter lead time, higher productivity, lower rejections and long term intangible gains, in terms of better company image, higher confidence, stronger partnerships and improved marketing. Some of the factors hindering the foundries in their full adaptation are price competition, manpower availability and higher cost of trained technical manpower, lack of technical support and perception.

Running the app:

- Put ON laptop
- Right click ON
- Click RUN to bring SSMPD programme
- Click OK
- Type clay (%)
- Click sand properties
- Click coarse sand or fine sand
- Click compute
- Click close

SSMPD interfaces: SSMPD includes the following interfaces; Title Interface, SSMPD Window Interface, Properties Determination Interface.

Title interface: The title interface welcomes the users of the software application. It contains the title of the application and the names of the developers of the software application. The title interface is shown in Fig. 4.

SSMPD Window Interface: Shown in Fig. 5, the SSMPD window interface is the based interface for the software application and it loads immediately after the

Fig. 4: SSMPD title interface

Fig. 5: SSMPD window interface

title interface. It indicates the Sand Properties on the toolbar. Clicking the Sand Properties menu reveals the Coarse Sand Properties Determination Tool and the Fine Sand Properties Determination Tool. Users can click on any of the tool to perform analysis.

SSMPD properties determination interface: The properties determination interface is made of 3 interfaces. The Sample Size Interface where the user is required to enter the silica sand sample size for either coarse sand or fine sand. The Coarse sand properties determination interface where the 11 properties of the coarse sand sample is displayed after computation and finally the Fine Sand properties interface that displays the 10 properties of the fine sand sample. Figure 4-7 shows the four interfaces that makes up the properties determination interface.

Install and Use SSMPD: The following steps are to be taken to install and use SSMPD application on a computer running windows operating system:

- Slot in the installation CD into the CD Drive of the computer (Laptop or Desktop) as the case may be
- Locate the SSMPD application folder inside the CD and double click on the folder

Fig. 6: Sand sample interface

Fig. 7: Fine sand properties determination interface

- Locate the exe file (SSMPD.exe) of the SSMPD and double click on it
- Follow the installation instructions/steps on your screen to complete installation

CONCLUSION

A systematic study was conducted to model the clay-bonded moulding sand system. The output (that is, responses) of the system included, mould properties, namely compactability, permeability, hardness, refractoriness, strength, collapsibility, fineness. The process variable, that is input, was clay with water held constant. Regression equations were derived for sand mould properties and expressed as a function of input variables. The experimental data were utilized for the purpose of model equation development. Relationships between the process variables and responses were presented graphically by utilizing surface plots. Most of the variables and their interactions had a non linear relation with responses. The regression models were tested for their statistical adequacy and ability to make prediction by utilizing t-test and nine test cases, respectively. All the regression models were statistically adequate with the close fit of the function to true response. The model is useful for predicting the effects of clay addition on the moulding properties of beach sand.

The software package is users friendly and runs on the computers with visual basic package of at least IMB RAM and 3.0GB free hard disk. The algorithm analyse the properties of sand better than human operation. Relying on practical experiments and analytical tools will be costly, time-consuming and tedious.

RECOMMENDATIONS

The computer software programme is recommended for the following sectors: Jobbing and captive foundry industries set up with low capital base and lack access to quality control testing equipment for the determination of mould sand properties. Students in school shops undertaking mould practice. Research institutes that are calibrating testing equipment.

ACKNOWLEDGMENT

The following organizations made available their facilities for quality control: The Federal Polytechnic Idah departments of Foundry and Metallurgy. The Nigeria Foundries Ota-Ogun State and a tour of PRODA Enugu. I thank Mr Thomas Ayogu for providing the guidance for the development of the computer application software. I thank Dr. Michael Ukwuru for providing the guidance in research communication. My sincere thanks to Elo and Rume Mukoro for typesetting the entire work.

REFERENCES

1. Agbo A.O, N.E. Nwankwo and E.E. Nnuka, 2017. Efficacy of moisture content on the moulding properties of river Niger Onitsha beach sand using Ukpor clay as a binder. Int. J. Multidiscip., Res. Dev., 4: 16-20.
2. Aweda, J.O. and Y.A. Jimoh, 2009. Assessment of properties of natural moulding sands in Ilorin and Ilesha, Nigeria. J. Res. Inf. Civil Eng., 6: 68-77.
3. Adikwanduaba, S., 2005. Technology of Foundry Practice. Owerri: Bulfed Nig. Ltd.,, https://www.sciencepublishinggroup.com/journal/paperinfo?journalid=220&doi=10.11648/j.ijmea.20221005.11
4. Mukoro, E.E ., 2017. Characterization of locally formulated synthetic sand of Idah in Kogi state of Nigeria for large scale foundry practice. J. Manage. Technol., 14: 34-40.
5. Jain, P.L., 2003. Principles of Foundry Technology. Revised Edn., McGraw-Hill Education, ISBN-25: 0070447608, 9780070447608, Pages: 401
6. Edoziuno, F.O., 2017. Variation of moisture content with the properties of synthetic moulding sand produced from River Niger sand (Onitsha deposit) and Ukpor clay. Int. J. Res. Adv. Eng. Technol., 3: 102-106.
7. Mukoro, E.E., 2009. A survey of the foundry industry in Nigeria., https://studylib.net/doc/18315820/design-of-a-50-kilogram-capacity-cast-iron-crucible-furna.
8. Abolarin, M.S., Lawal, S.A. and A.A. Salawu, 2010. Effect of moisture content on the moulding properties of river Niger sand using Tudun-Wada clay as a binder. AU.J.T ., 13: 170-174.
9. Baba, G., N. Igu and M.I. Oseni, 2015. Characterization of River Niger (Idah Deposit), Ochadamu and Uwowo sands for foundry mould production. J. Emerging Trends Eng. Applied Sci., 6: 295-296.
10. Lilly, M.T., 2001. Computer applications and the Nigerian manufacturer. NSE Tech. Trans., Vol. 36.
11. Ajayi, J.A. and L. Oluwole, 2008. Modelling and simulation: A critical research and development (R&D) tool for re-engineering foundry industry. Niger. Metall. Soc., Vol. 25.
12. Holtzer, M., R. Dańko and A. Kmita, 2015. Influence of a reclaimed sand addition to moulding sand with furan resin on its impact on the environment. Water, Air, Soil Pollut., Vol. 227. 10.1007/s11270-015-2707-9.
13. Chate, G.R., G.C.M. Patel, S.N.B. Bhushan, M.B. Parappagoudar and A.S. Deshpande, 2019. Comprehensive modelling, analysis and optimization of furan resin-based moulding sand system with sawdust as an additive. J. Braz. Soc. Mech. Sci. Eng., Vol. 41 .10.1007/s40430-019-1684-0.
14. Kreyszig, E., 1998. Advanced Engineering Mathematics. 8th Edn., John Wiley & Sons, ISBN-14: 978-0471154969, Pages: 1288.
15. Karunakaran, P. and C. Jegadheesan, 2012. Investigation of the properties of moulding sand with waste powder from steel industry. Eur. J. Sci. Res., 77: 5-13.
16. Mishra, R., E.N. Gupta, D. Joshi, 2016. Prediction of moulding sand properties using multiple regression methodology. J. Adv. Comp. Commun. Technol., Vol. 4.