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Model Development and Simulation for Estimating the Moulding Behaviour of River Sand at Different Clay Contents

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Abstract: Foundry operatives have been conducting laboratory tests physically and characterizing silica sand of river bed for moulding purposes with a view to ascertaining their properties. This has made flexibility and speed of decision-making difficult during moulding practice. This study was aimed at developing a model and simulation for estimating the moulding behaviour of river Niger coarse sand at different clay contents. Physical tests were carried out on 90 samples of coarse sand/clay/water composition. Experimental data obtained from the physical tests were used to develop modeling equations. The equations were then used to develop the software for simulation. Statistical tests were used to validate the developed models. The GFN of the coarse sand was 42.42%. Grain distribution indicated a normal curve showing the different sizes of sand that aided sand mould compactability. The trend of the relationship properties and clay content indicated linearity in compactability (38-50), green hardness (55-82), green shear strength (0-160) and shatter index (38-55) while an inverse linearity was observed in permeability (150-125). However, green compression strength which maintained a steady positive relationship from 5-9% clay showed a fluctuating pattern up to 13% clay. 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 3.0 GB free hard disk with information on the installation, running and using the application software. This SSMPD has contributed to rapid determination of coarse sand properties for foundry mould practice.

Keywords: Coarse Sand, Model Equation and Simulation, Foundry Operations, SSMPD Software

1. Introduction

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 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. 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 [3-6].

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 3360µµm (6 mesh) to 53 µm (270 mesh) [5] while clay particles are 20µm 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 [5] 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 [7]. Srinivasan [5] gave typical values for permeability as 10-80g/cm^2 for cast iron, 20-35g/cm^2 for aluminum and 120-180g/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 [8]. This is about 10% for bentonite and about 20% for fireclays [5]. 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 [9] survey shows that there are 160 foundry companies in Nigeria. These foundries produce 80000 tonnes 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 [10, 11]. 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 [12-17].

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.

2. Materials and Methods

2.1. Sample Location

River Niger is located in western Africa, flowing primarily from west to east, through Guinea, Mali, Niger, Benin and Nigeria to the Gulf of Guinea. With a length of 4180km it is the third longest River in Africa, after the rivers Nile and Congo. The drainage basin covers an area of about 2,092,000km^2 and includes two Deltas----an inland Delta in central Mali and a coastal Delta along the Gulf of Guinea [18]. Idah town is located at the eastern part of the River Niger and lies on latitude 6° 43'North and longitude 6° 45 East [19].

Silica sand that constitute the bulk material of this synthetic moulding sand was obtained from the River Niger at Idah beach location. Clay binder (bentonite) was purchased from the local open market and it 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 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 15minutes for every 50g sand. Samples were taken for chemical analysis to reveal the composition of the sand.

2.2. Standard Specimen Preparation

Sand (157g) having 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13% bentonite and conditioned with water was prepared into standard specimen for sand control tests. A sample for sand test was prepared in a 5.1cm diameter tube set with pedestal in a sand ramming machine by dropping three successive times under gravity, a 6.4kg rammer from a 5.1cm height to compress the sand in the tube. Specimen was 5.1cm diameter X 5.1cm height.

2.3. 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.

2.4. Surface Hardness Test

Indentation or compact tester was pressed on the rammed mould and the value was read on the empirical scale, 0-100 units. The procedure was the same for green hardness test as well as dry hardness test. The exception was that one was a wet sample while the other a dried sample.

2.5. Permeability Test

With the standard rammed specimen retained in the tube, the tube was sat on the permeability tester and operated according to instructions. It operated by passing air (200 mL of air) through standard sample. The permeability values were obtained from the meter (scale) on the instrument.

2.6. Test for Green Compression Strength (GCS)

The standard specimen was striped from the tube and the flat faced compression heads were inserted on the universal sand strength machine. The rammed specimen was placed between the compression heads. The hand wheel was turned to load the specimen progressively. It was read on the scale marked green compression at the point of fracture (break load). The electronic version was used in this experiment. Dry compression test for dried sample followed the same procedure.

2.7. Test for Green Shear Strength (GSS)

The standard specimen was striped from the tube. The shear heads were inserted on the universal sand strength machine. 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 version was used in this experiment.

Shatter index test: The standard specimen was fixed at the top of the shatter tester which was projected and dropped from the height. On getting to the mesh sieve basin, it scattered into pieces. The indicated formula was used to calculate the shatter index.

2.8. Refractoriness

The temperature for the occurrence of burn-on sand around the casting was taken as the refractoriness of the sand. This was confirmed with the pyrometric cone test.

2.9. Model Development

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 so, the linear function was derived with mathematical expression according to Olaitan&Ndomi [20]. This implied that shatter index, mould surface hardness, compactability, permeability and strength were functions of clay content (binder) and moisture (temper). The change in property with respect to binder and temper of moulding sand varied directly with clay content.

2.10. Model 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 (SE) and correlation coefficient(r) analysis. 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. 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 correlation coefficient was used to measure the amount of association that existed between the experimental data and predicted data. Comparing experimentally generated data with model predicted data was done. The computation of the correlation coefficient, the variance, standard deviation, standard error and confidence interval at 95% level was done. Tests of significance (t) of the correlation coefficient with a view to accept or reject the null hypothesis was carried out. 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:

1) Exactly the same;
2) Closely the same;
3) Fairly the same.

Software Development: The model was implemented through software development for quick estimation of the investigated moulding properties of the locally formulated synthetic 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 the flowchart and algorithm for the software.

3. Results

Table 1 shows sieve analysis of River Niger sand traditionally used for block making. The sieve numbers involved were 1-13 and the grains distribution (Figure 1) shows normal curve, which is an indication of blend of all sizes required for foundry moulds. The grains fineness number obtained was 42.4 which indicated coarse sand that is suitable for mould making to receive poured liquid cast iron and steel.

Table 2 shows data generated from experiment as the sand/clay admixture was tested of mould properties. Nine admixtures of 5-13% clay with 6% water held constant constituted a sample in each admixture. A sample was 157g. Each test in an admixture required 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.

Table 3 is a comparative analysis of experimental (X) and predicted (Y) mouldingproperties for the coarse 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 to be noted that the significance tests and coefficient of correlation values were utilized for the said purpose. Further, model accuracy was determined by comparing model predicted values of responses with their corresponding target (that is, obtained through experiments) values.

The developed software simulated moulding action from the model of the explanatory and explained variables. The expected output was the prediction of properties of moulding sand from clay contents.

Table 1. *Sieve Analysis for coarse sand.*

Sieve No	Mesh Size	Sieve No. mm	Retained Sample (g) for 50g	Retained Percentage% for the 50g	Multiplier	Product
1	-------	1.6	1	1.82	3	5.46
2	6 mesh	1	4	7.27	5	36.35
3	12 mesh	0.710	4	7.27	10	72.7
4	20 mesh	0.630	3	5.45	20	109
5	30 mesh	0.4	11	20	30	600
6	40 mesh	0.315	9	16.36	40	654.4
7	50 mesh	0.200	14	25.45	50	1272.5
8	70 mesh	0.160	4	7.27	70	508.9
9	100 mesh	0.125	4	7.27	100	727
10	140 mesh	0.100	1	1.82	140	254.8
11	200 mesh	0.080	0	0	200	0
12	270 mesh	0.063	0	0	300	0
13		Pan	0	0		
	TOTAL		55	99.98		4241

$$\mathrm{GFN} = \frac{\mathrm{Product}}{\mathrm{Retained\%}} \text{ (source: [6])}$$

$$= \frac{4241}{99.98} = 42.42\%$$

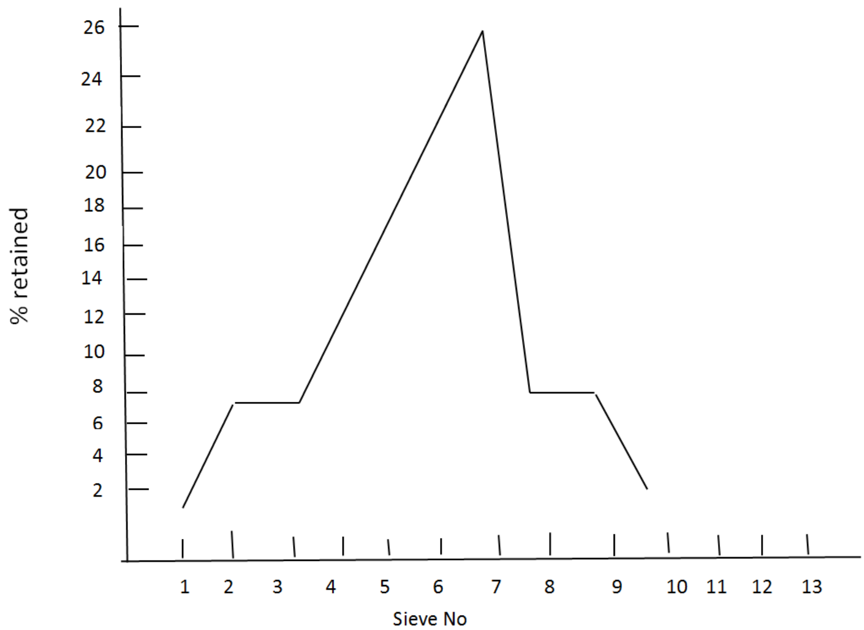

Figure 1. *Grains distribution curve for River Niger coarse sand.*

Table 2. *Data (Moulding Properties) Generation for Coarse Sand.*

Samples	Compactability %	GFN	Hardness (green)	Hardness (dry)	Permeability
5% clay /6% water (8g clay, 10g water, 139g sand)	38	42.42	55	93	150
6% clay /6% water (10g clay, 10g water, 137g)	38	42.42	70	93	140
7% clay /6% water (11g clay, 10g water, 136g sand)	41	42.42	72	92	130
8% clay /6% water (13g clay, 10g water 134g sand)	44	42.42	75	93	130
9% clay /6% water (14g clay, 10g water, 133g sand)	44	42.42	73	93	130
10% clay/6% water (16g clay, 10g water, 131g sand)	44	42.42	78	94	130
11% clay/6% water (18g clay, 10g water, 129g sand)	46	42.42	83	93	130
12%/6% water (19g clay, 10g water, 128g sand)	47	42.42	83	92	130
13% clay/6% water (21g clay, 10g water, 126 and)	50	42.42	82	92	125

Table 2. *Continued.*

Samples	Dry Compression strength N/m^2	Green comp. Strength N/m^2	Green Shear Strength N/m^2	Shatter index %	Refractoriness °C
5% clay /6% water (8g clay, 10g water, 139g sand)	1680	0	0	38	1700
6% clay /6% water (10g clay, 10g water, 137g)	2390	100	120	37	1700
7% clay /6% water (11g clay, 10g water, 136g sand)	2640	250	120	29	1700
8% clay /6% water (13g clay, 10g water 134g sand)	1270	100	160	39	1700
9% clay /6% water (14g clay, 10g water, 133g sand)	1470	610	160	43	1700
10% clay/6% water (16g clay, 10g water, 131g sand)	2030	560	200	50	1700
11% clay/6% water (18g clay, 10g water, 129g sand)	1780	300	240	50	1700
12%/6% water (19g clay, 10g water, 128g sand)	2490	250	200	53	1700
13% clay/6% water (21g clay, 10g water, 126 and)	1780	300	160	55	1700

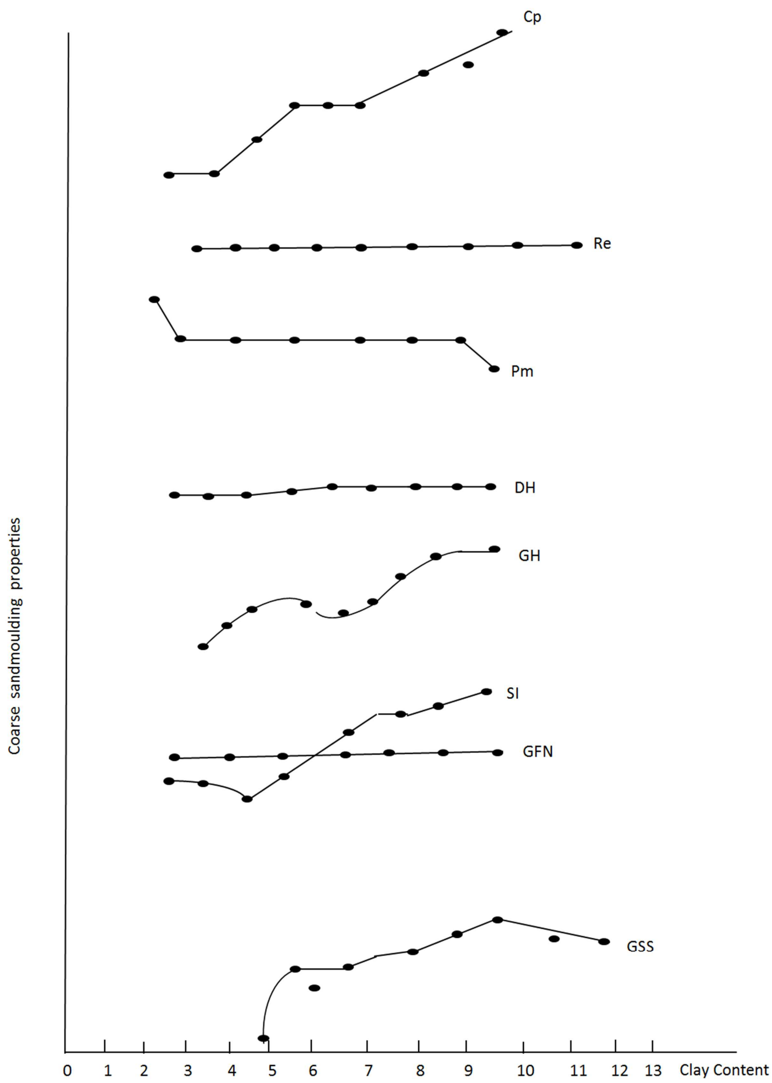

Figure 2. *Scatter graph of moulding properties versus clay content.*

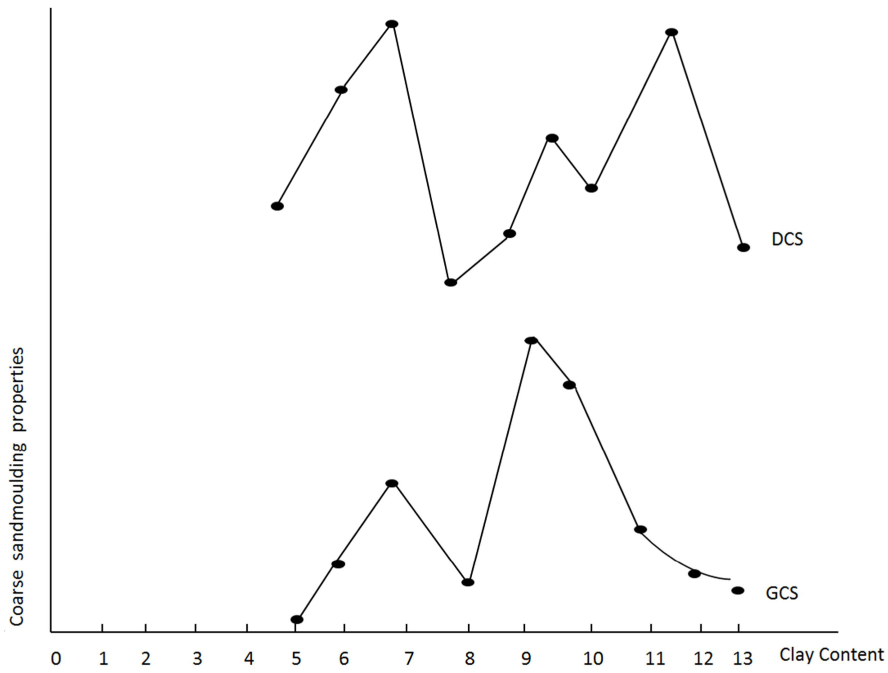

Figure 3. *Scatter graph of moulding properties versus clay content.*

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

In the plot (scatter graph) of moulding properties versus clay content (Figure 2), the following properties, compactability (Cp), green hardness (GH), Shatter index (SI), increased steadily with increase in clay content forcoarsesand. Permeability (Pm) decreased steadily with increase in clay content forcoarsesand (Figure 2). Green Shear Strength (GSS) increased steadily with increase in clay content for coarse sand (Figure 2). Green compression strength (GCS) and Dry Compression Strength (DCS) maintained steady increase from 5-9% clay before it presented fluctuating patternof results up to 13% clay (Figure 3).

3.1. Model Development

The properties variation with respect to the variable, clay content, was the basis of the model development. 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 will arise linear regression with a mathematical technique for finding the straight line that best fits the values of a linear function plotted on a scatter graph as data points. If a best fit line is found, it can be 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 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 showed that rate of sand properties was proportional to the clay content. The first step in the modeling was to write the equation denoting an unknown constant of proportionality by K , we have:

$$\frac{dP(c)}{dc} = KP(c) \tag{1}$$

See, Kreyszig (2004)

3.2. Model Equation for the Moulding Properties of River Niger Coarse Sand

If $P_{CP}(c)$ is the moulding property's compactability of the produced mould sample from coarse sand, then using the work of Kreyszig (2004) [21], equation (1) becomes:

$$\frac{dP_{CP}(c)}{dc} = KP_{CP}(c) \quad (2)$$

where,

$P_{CP}(c)$ is the mould property's compactability.

C is the clay content.

K is the constant of proportionality.

Solving equation (2) using the separation of variables method and integrate accordingly yields the following:

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

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

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

$$\Rightarrow \quad P_{CP}(c) = e^{Kc+a}$$

$$\Rightarrow \quad P_{CP}(c) = Ae^{Kc}$$

At $c = 5$, $P_{cp}(5) = 38$

Hence,

$$38 = Ae^{5k}$$

$$A = \frac{38}{e^{5k}}$$

$$\Rightarrow \quad P_{CP}(c) = \frac{38}{e^{5k}} e^{kc}$$

When $c = 7$, $P_{cp}(7) = 41$

$$41 = \frac{38}{e^{5k}} e^{7k}$$

$$\Rightarrow \quad 41 = 38e^{(7-5)k}$$

$$\Rightarrow \quad \frac{41}{38} = e^{2k}$$

Therefore,

$$k = \frac{1}{2}\ln(\frac{41}{38}) = 0.03799295329$$

Hence,

$$P_{CP}(c) = \frac{38}{e^{0.1899647655}} e^{0.03799295329c} = 31.43e^{0.03799295329c}$$

Following the same pattern of modelling the moulding property's compactability of the produced mould sample from coarse sand, other moulding properties can be modelled as follows:

For the moulding property, green hardness (GH), of the produced mould sample from coarse sand

At $c = 6$, $P_{GH}(6) = 70$

Hence,

$$70 = Ae^{6k}$$

$$\Rightarrow \quad A = \frac{70}{e^{6k}}$$

$$P_{GH}(c) = \frac{70}{e^{6k}} e^{kc}$$

When $c = 7$, $P_{GH}(7) = 72$

$$72 = \frac{70}{e^{6k}} e^{7k}$$

$$\Rightarrow \quad e^k = \frac{72}{70}$$

$$\Rightarrow \quad k = \ln\frac{72}{70} = 0.02817087738$$

Hence,

$$P_{GH}(c) = 59.11e^{0.02817087738c}$$

For the moulding property, dry hardness (DH), of the produced mould sample from coarse sand.

At $c = 7$, $P_{DH}(7) = 92$

Hence,

$$92 = Ae^{7k}$$

$$\Rightarrow \quad A = \frac{92}{e^{7k}}$$

$$P_{DH}(c) = \frac{92}{e^{7k}} e^{kc}$$

When $c = 8$, $P_{DH}(8) = 93$

$$93 = \frac{92}{e^{7k}} e^{8k}$$

$$\Rightarrow \quad e^k = \frac{93}{92}$$

$$\Rightarrow \quad k = \ln\frac{93}{92} = 0.01081091589$$

Hence,

$$P_{DH}(c) = 85.295e^{0.01081091589c}$$

For the moulding property, shatter index (SI) of the produced mould sample from coarse sand

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

Hence,

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

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

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

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

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

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

$$\Rightarrow \quad k = \frac{1}{3}\ln\frac{43}{37} = 0.05009406764$$

Hence,

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

For the moulding property, permeability (PM) of the produced mould sample from coarse sand

$$\text{At } c = 5, \quad P_{PM}(5) = 150$$

Hence,

$$150 = Ae^{5k}$$

$$\Rightarrow \quad A = \frac{150}{e^{5k}}$$

$$P_{PM}(c) = \frac{150}{e^{5k}}e^{kc}$$

When $c = 6$, $P_{PM}(6) = 140$

$$\therefore \quad 140 = \frac{150}{e^{5k}}e^{6k}$$

$$\Rightarrow \quad e^{k} = \frac{140}{150}$$

$$\Rightarrow \quad k = \ln\frac{140}{150} = -0.06899287152$$

Hence,

$$P_{PM}(c) = 211.79e^{-0.06899287152c}$$

For the moulding property, Green Shear Strength (GSS), of the produced mould sample from coarse sand

$$\text{At } c = 6, \quad P_{GSS}(6) = 120$$

Hence,

$$120 = Ae^{6k}$$

$$\Rightarrow \quad A = \frac{120}{e^{6k}}$$

$$P_{GSS}(c) = \frac{120}{e^{6k}}e^{kc}$$

When $c = 8$, $P_{GSS}(8) = 160$

$$\therefore \quad 160 = \frac{120}{e^{6k}}e^{8k}$$

$$\Rightarrow \quad e^{2k} = \frac{160}{120}$$

$$\Rightarrow \quad k = \frac{1}{2}\ln\frac{160}{120} = 0.1438410361$$

Hence,

$$P_{GSS}(c) = 50.63e^{0.1438410361c}$$

For the moulding property, Grain Fineness Number (GFN), of the produced mould sample from coarse sand

$$\text{At } c = 5, \quad P_{GFN}(5) = 42.42$$

Hence,

$$42.42 = Ae^{5k}$$

$$\Rightarrow \quad A = \frac{42.42}{e^{5k}}$$

$$P_{GFN}(c) = \frac{42.42}{e^{5k}}e^{kc}$$

When $c = 6$, $P_{GFN}(6) = 42.42$

$$\therefore \quad 42.42 = \frac{42.42}{e^{5k}} e^{6k}$$

$$\Rightarrow \quad e^k = \frac{42.42}{42.42} = 1$$

$$\Rightarrow \quad k = \ln 1 = 0$$

Hence,

$$P_{GFN}(c) = 42.42e^{0c} = 42.42$$

For the moulding property, Refractoriness (RE), of the produced mould sample from coarse sand

At $c = 5$, $P_{RE}(5) = 1700$

Hence,

$$1700 = Ae^{5k}$$

$$\Rightarrow \quad A = \frac{1700}{e^{5k}}$$

$$P_{RE}(c) = \frac{1700}{e^{5k}} e^{kc}$$

When $c = 6$, $P_{GFN}(6) = 1700$

$$\therefore \quad 1700 = \frac{1700}{e^{5k}} e^{6k}$$

$$\Rightarrow \quad e^k = \frac{1700}{1700} = 1$$

$$\Rightarrow \quad k = \ln 1 = 0$$

Hence,

$$P_{RE}(c) = 1700e^{0c} = 1700$$

For the moulding property, Dry Compression Strength (DCS), of the produced mould sample from coarse sand

At $c = 6$, $P_{DCS}(6) = 2390$

Hence,

$$2390 = Ae^{6k}$$

$$\Rightarrow \quad A = \frac{2390}{e^{6k}}$$

$$P_{DCS}(c) = \frac{2390}{e^{6k}} e^{kc}$$

When $c = 7$, $P_{DCS}(7) = 2640$

$$\therefore \quad 2640 = \frac{2390}{e^{6k}} e^{7k}$$

$$\Rightarrow \quad e^k = \frac{2640}{2390}$$

$$\Rightarrow \quad k = \ln \frac{2640}{2390} = 0.0994855508$$

Hence,

$$P_{DCS}(c) = 1315.715e^{0.0994855508c}$$

For the moulding property, Green Compression Strength (GCS) of the produced mould sample from coarse sand

At $c = 11$, $P_{GCS}(11) = 300$

Hence,

$$300 = Ae^{11k}$$

$$\Rightarrow \quad A = \frac{300}{e^{11k}}$$

$$P_{GCS}(c) = \frac{300}{e^{11k}} e^{kc}$$

When $c = 12$, $P_{GCS}(11) = 250$

$$\therefore \quad 250 = \frac{300}{e^{11k}} e^{12k}$$

$$\Rightarrow \quad e^k = \frac{250}{300}$$

$$\Rightarrow \quad k = \ln \frac{250}{300} = -0.1823215568$$

Hence,

$$P_{GCS}(c) = 2229.025e^{-0.1823215568c}$$

Modeling of River Niger sand properties for foundry moulds in metal casting is a viable follow-up to the results of the experiment. The following are the equations derived from experimental data:

For coarse sand:

$$P_{CP}(c) = 31.43e^{0.03799295329c}$$

$$P_{GH}(c) = 59.11e^{0.02817087738c}$$

$$P_{DH}(c) = 85.295e^{0.01081091589c}$$

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

$$P_{PM}(c) = 211.76e^{-0.06899287152c}$$

$$P_{GSS}(c) = 50.63e^{0.1438410361c}$$

$$P_{GFN}(c) = 42.42e^{0c}$$

$$P_{RE}(c) = 1700e^{0c}$$

$$P_{DCS}(c) = 1315.715e^{0.0994855508c}$$

$$P_{GCS}(c) = 2229.025e^{-0.1823215569c}$$

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.

Table 3. *Comparative Analysis of Experimental (X) and Predicted (Y) moulding properties for coarse sand.*

Mould Sand mix	(Cp) Compactability (%)		(GH) Green Hardness		(DH) Dry Hardness		(Pm) Permeability	
	X	Y	X	Y	X	Y	X	Y
5%clay6%water (8gclay, 10gwater, 139gsand)	38	38.01	55	68.95	93	90.03	150	150.00
6%clay6%water (10gclay, 10gwater, 137gsand)	38	39.48	70	70.00	93	91.01	140	140.00
7%clay6%water (11gclay, 10gwater, 136sand)	41	41.01	72	72.00	92	92.00	130	130.67
8%clay6%water (13gclay, 10gwater, 134gsand)	44	42.60	75	74.05	93	93.00	130	122.00
9%clay6%water (14gclay, 10gwater, 133gsand)	44	44.24	73	76.17	93	94.01	130	114.00
10%clay6%water (16gclay, 10gwater, 131gsand)	44	45.96	78	78.34	94	95.03	130	106.24
11%clay6%water (18gclay, 10gwater, 129gsand)	46	47.74	83	80.60	93	96.07	130	99.15
12%clay6%water (19gclay, 10gwater, 128gsand)	47	49.58	83	82.88	92	97.11	130	92.54
13%clay6%water (21gclay, 10gwater, 126gsand)	50	51.50	82	85.25	92	98.16	125	86.40
Statistical tests$\bar{d}$	0.9		1.82		1.27		-17.11	
R	0.96742		0.8813		-0.28		0.82	
Var. D	1.58		20.1		9.22		262	
Sd	0.42		1.50		1.01		5.4	
SE	0.14		0.50		0.34		1.8	
Var. ($\bar{d}$)	0.176		2.23		1.02		29	
Coefficient of variation	0.47		0.82		0.8		-0.32	
RSS	19.984		190.4		88.231		4730	
r^2	0.936		0.78		0.08		0.67	
Tc	2.15		1.22		1.255		-3.17	
Confidence. lnt. at 95%confidence level	1.28/0.524		2.56/1.68		0.79/0.75		-9.91/-24.3	

Mould Sand mix	(SI) Shatter Index (%)		(GSS) Green Shear Strength N/m^2		(GFN) Grain Fineness Number		(Re) Refractoriness °C	
	X	Y	X	Y	X	Y	X	Y
5%clay6%water (8gclay, 10gwater, 139gsand)	38	35.20	0	104.0	42.42	42.42	1700	1700
6%clay6%water (10gclay, 10gwater, 137gsand)	37	37.01	120	120.01	42.42	42.42	1700	1700
7%clay6%water (11gclay, 10gwater, 136sand)	29	38.91	120	138.58	42.42	42.42	1700	1700
8%clay6%water (13gclay, 10gwater, 134gsand)	39	40.91	160	160.02	42.42	42.42	1700	1700
9%clay6%water (14gclay, 10gwater, 133gsand)	43	43.01	160	184.77	42.42	42.42	1700	1700
10%clay6%water (16gclay, 10gwater, 131gsand)	50	45.22	200	213.35	42.42	42.42	1700	1700
11%clay6%water (18gclay, 10gwater, 129gsand)	50	47.54	240	246.36	42.42	42.42	1700	1700
12%clay6%water (19gclay, 10gwater, 128gsand)	53	50.00	200	284.47	42.42	42.42	1700	1700
13%clay6%water (21gclay, 10gwater, 126gsand)	55	52.55	160	328.48	42.42	42.42	1700	1700
Statistical tests$\bar{d}$	-0.406		46.67		0		0	
R	0.815		0.6		0		0	
Var. D	19		3489		0		0	
Sd	1.5		19.7		0		0	
SE	0.5		6.6		0		0	
Var. ($\bar{d}$)	2.1		388		0		0	
Coefficient of variation	-3.7		0.42		0		0	
RSS	338.34		47514.14		0		0	
r^2	0.664		0.36		0		0	
Tc	-0.3		2.37		0		0	
Confidence. lnt. at 95%confidence level	-0.4981/-0.314		66.17/ 27.17		0		0	

Mould Sand mix	(GCS) Green Compresion Strength N/m^2		(DCS) Dry compressionStrength N/m^2					
	X	Y	X	Y	X	Y	X	Y
5%clay6%water (8gclay, 10gwater, 139gsand)	0	896	1680	2163.68				
6%clay6%water (10gclay, 10gwater, 137gsand)	100	746.5	2390	2390.00				
7%clay6%water (11gclay, 10gwater, 136sand)	250	622.08	2640	2640.00				

Mould Sand mix	**(GCS) Green Compresion Strength N/m^2**		**(DCS) Dry compressionStrength N/m^2**					
	X	**Y**	**X**	**Y**	**X**	**Y**	**X**	**Y**
8%clay6%water (13gclay, 10gwater, 134gsand)	100	518.40	1270	2916.15				
9%clay6%water (14gclay, 10gwater, 133gsand)	610	432.0	1470	3221.19				
10%clay6%water (16gclay, 10gwater, 131gsand)	560	360.0	2030	3558.13				
11%clay6%water (18gclay, 10gwater, 129gsand)	300	300.0	1780	3930.32				
12%clay6%water (19gclay, 10gwater, 128gsand)	250	250.0	2490	2341.44				
13%clay6%water (21gclay, 10gwater, 126gsand)	300	208.3	1780	4795.57				
Statistical tests$\bar{d}$	207		1381					
R	-0.433		0.05					
Var. D	153503.32		3937019.505					
Sd	130.6		661.4					
SE	43.53		220.5					
Var. ($\bar{d}$)	17056		437447					
Coefficient of variation	0.631		0.48					
RSS	1613667.56		48653811.2					
r^2	0.2		0.0025					
Tc	1.585		2.1					
Confidence. lnt. at 95%confidence level	292.6/121.4		1957/805					

4. 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 *et al*., [22] remarked that green sand moulding process is traditional and common in 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 [23]. 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.

Regression analysis was used to establish relationship between two variables. The response variable Y was the dependent variable or variable of interest and the predictor variable X was the independent variable. An objective of regression analysis is to develop a regression model, relating y to X that can be used to predict values of the response variable. The regression equation is an algebraic representation of the regression line and was used to describe the relationship between the response and predictor variables.

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, i.e. high melting point metals are poured in coarse sand mould, while low melting point metals are poured in fine sand mould. Experience have shown that high melting point metals fuse the interfacing sand and fineness increases the susceptibility of such fusion, hence the use of coarse sand. 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. The coarse sandof River Niger at Idah location used for this study was subjected to sieve analysis. The result produced a normal curve which means the presence of varied sizes. The grains fineness number (GFN) for the coarse sand was 42.42. Grain fineness number (GFN) is measured in a scale of 0-100 units of coarse to fine.

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.

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

Forecasting is the estimation of the value of a dependent variable Y from the actual or projected value of independent variable X in a regression model. It is the estimation of the future value of the dependent variable of an equation.

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. To survive in the global market, It is important to keep pace with the changing technological trends. If this software is properly adopted, it 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.

4.1. 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 [6], 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 1MB RAM and 3.0GB free harddisk.

SSMPDCOARSE SAND SAMPLE properties that can be estimated by SSMPD 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).

4.2. 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

4.3. SSMPD Interface

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

Title InterfaceThe title interface welcomes the users of the software application. It contains the title of the application and the name(s) of the developers of the software application. The title interface is shown in Figure 1.

Figure 4. *SSMPD Title Interface.*

SSMPD Window Interface: Shown in Figure 2, the SSMPD window interface is the based interface for the software application and it loads immediately after the title interface. It indicates the Sand Properties on the toolbar. Clicking the Sand Properties menu reveals the Coarse Sand Properties Determination Tool. Users can click on any of the tools to perform analysis.

Figure 5. *SSMPD Window Interface.*

SSMPD Properties Determination Interface: The properties determination interface is made of three (3) interfaces, two of which are: the Sample Size Interface where the user is required to enter the silica sand sample size for coarse sand: the Coarse sand properties determination interface where the eleven (11) properties of the coarse sand sample is displayed after computation. Figures 4-5 shows the two interfaces that make up the properties determination interfaces.

Figure 6. *Sand Sample Interface.*

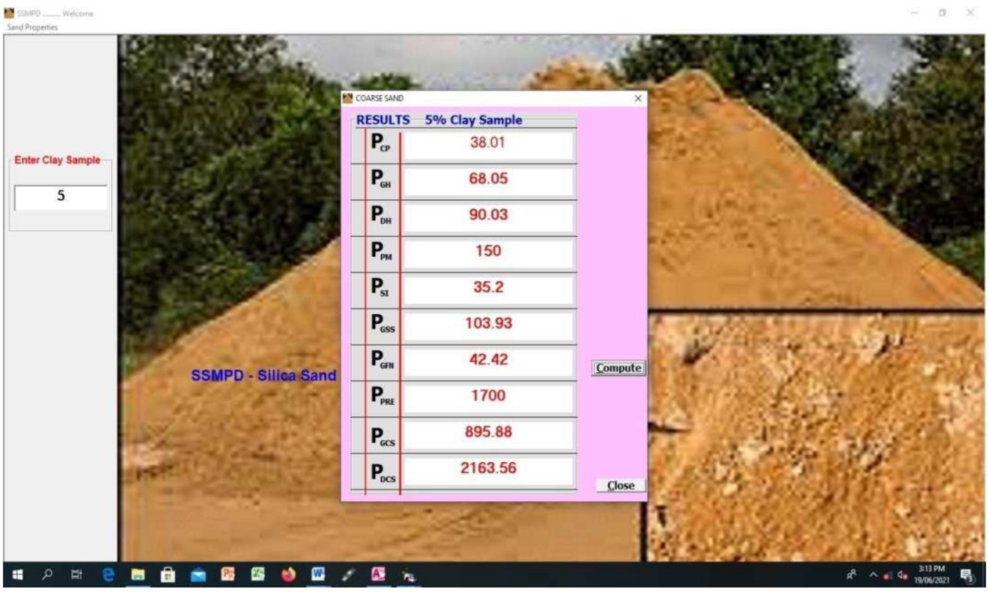

Figure 7. *Coarse Sand Properties Determination Interface.*

4.4. Install and Use SSMPD

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

1) Slot in the installation CD into the CD Drive of the computer (Laptop or Desktop) as the case may be.
2) Locate the SSMPD application folder inside the CD and double click on the folder.
3) Locate the exe file (SSMPD.exe) of the SSMPD and double click on it.
4) Follow the installation instructions/steps on your screen to complete installation.

5. 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, is clay with water held constant. Regression equations were derived for sand mould properties and expressed as a function of input variables. Experimental data were utilized for the said purpose. Relationships between the process variables and responses are presented graphically by utilizing surface plots. Most of the variables and their interactions had 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 (Cp, GFN, GH, DH, Pm, DCS, GCS, GSS, SI, Re) of River Niger 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.

6. Recommendations

The computer software programme is recommended for the following sectors:

a. 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.
b. Students in school shops undertaking mould practice.
c. Research institutes that are calibrating testing equipment.

Conflict of Interest

The authors declare that there is no conflict of interest.

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