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MATHEMATICAL MODEL ANALYSIS OF QUALITY OF CONCRETE PRODUCED IN THE WARM-HUMID CLIMATIC ZONE OF SOUTH EAST, NIGERIA

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ABSTRACT

In construction industries, noncompliance to existing standards has been one of the major causes of substandard material production and to an extent poor housing development. It has therefore degenerated to the inability of dictating standards with the performances of building materials in the industry. The threat of this ugly situation grows higher when materials of composite natures are involved. In this era of innovation in the construction technology generally, the study focuses onproviding a more reliable and faster means to producing cement concrete cubes and sancrete blocks of desired properties starting with Warm Humid Climatic (WHC) zone of Nigeria. In the beginning, field survey method was adopted to obtain information on a prior knowledge of the common nominal mix ratio used in producing cement concrete cubes andsandcrete blocks in the area. The information was used as a basis for designing the cement concrete cubes and sandcrete mixes using Box-Wilson symmetric Composite Plan B_m.Laboratory experimental tests were carried out on the blocks produced with the various mix designs to obtain values on their density and compressive strength properties. Polynomial regression models were therefore developed, and subsequently tested to certify their fitness considering only the independent variables (cement, water, and sand aggregates) that are significant for the respective properties. Mono-factorial effects of the variables were investigated on the properties to ascertain the degree of their influence on the respective properties. Progressively, optimal equations of the final regression models were therefore developed having optimized the respective significant variables in the models, using the quadratic equation for blocks of optimum and desired performances. To this end, nomograms were therefore constructed with the optimal values derived from the optimal equations to reflect various optimum compositions of the constituent ingredients (variables) for certain desired properties of the blocks, depending on the functional requirements or purposes of use. In the light of this rare development, speedy decisions productions of the blocks of desired properties will be possible and accurate. Production of the targeted properties of the blocks would therefore, not be hindered by the limited quantity of any of the ingredients, since there are possibilities of other optimum compositions that would accommodate the limitation in quantity of the said ingredient.

KEYWORDS: Sandcrete Blocks, Mix Designs, Box-Wilson Symmetric Composite Plan B_m, Nomograms, Optimum Compositions and Desired Properties.

1. INTRODUCTION

Building construction materials are various substances or items that form the basic component of various element of a building. From the beginning to the end of the building construction process, materials that are primarily used on site are cement, sand aggregates, water, steel, and timber. These are referred to as star materials (Ikechukwu, 2012). Most of them are naturally occurring, some are artificially processed while others are usually mixed together to give different components and elements found in erection of any building structure. Although the constituent ingredients found in the composite materials satisfy some set standard, the ratio of their compositions to one another is a notable factor that influences the quality of composite construction materials like, sandcrete blocks. The composition of the constituent ingredients of the blocks produced in WHC of Nigeria influences to a great extent the choice and quality of sancrete blocks used in the area. Each of the three major ingredients (cement, water and sand) of sandcrete blockhas factorial effects on the major properties of the block (Ikechukwu, 2015); giving the reason any one of them could be optimized in the mix for optimal values of the properties respectively, within the boundary limits of the design.

A nominal (conventional) mix ratio of the block does not take into account the mono-factorial effects of the respective ingredients in a certain locality (Okereke, 2002). The mix therefore, could not be optimized for improved performance of the component for lack of appropriate basis hence; the production of the desired quality may not be feasible in the end. Even though the use of nominal mix ratio has been a measure in the quality control process, it leaves no room for desired properties let alone the possibility of various optimum compositions of the constituent ingredients for the same desired property (Ezeokonkwo, 2015).

2. Method of Experiment and Analysis

Designed experimental method was adopted to clearly study empirically the role of the various factors on the quality of sandcrete blocks produced in Owerri Metropolis as a representative of the warm humid climatic zone of Nigeria for the purpose of construction works. Results from these experiments were meant to pave way for establishing appropriate standards for sandcrete block production in the area. For this purpose, data from the designed experiments were transformed into regression models.

The regression models were obtained, and according to Okereke (1991) and Raissi (2009), it involves the following stages:

i. Obtaining Regression Models:Two Regression models of the second degree for each of the parameters of interest (density, and strength) at the 28-day age are obtained in the form:

$y_i = b_0 + b_1x_1 + b_2x_2 + \ldots + b_nx_n + b_{12}x_1x_2 + \ldots +$

$b_{ij}x_{ij} + b_{11}x_1^2 + b_{22}x_2^2 + \ldots + b_{ii}x_i^2$(1)

Or

$y_i= b_0 + b_i\sum X_i + b_{ij}\sum x_ix_j + b_{ii}\sum x_i^2$.(2)

Where, b_i are the regression coefficient and x_i – the independent variables (I = 1, 2 and 3).

ii. Carrying out Regression Analysis – This is the stage of checking for adequacy (fitness) of the models using the Fisher statistics with the criteria, $F_{cal} \leq F_t$ for adequacy (fitness).

iii. Carrying out Factorial Analysis – Investigating the effects of the variables x_i as well as their mutual effects – x_ix_j. For this purpose, a quasi-mono factorial analysis is carried for each of the dependent variables (factors), at coded values of +1 and – 1.

iv. Carrying out Optimization Analysis – This is the process of searching for optimal values atwhich the parameters will assume the desired (optimal) values. According to Okereke (2004), these optimal values were used in the construction of nomograms. It is a graphic method for speedy determination of the respective quantities of the ingredients of the sandcrete mix for a given value of any of the parameters (objective functions), such as compressive strength and density properties. A total of 2 regression models for the strenght and density properties of the sandcrete mixes were obtained at the 28-day curing age, respectively. These models for the blocks in the experiments are presented in the following forms, respectively.

3. Regression Models for the Properties of Sandcrete Blocks Manually Produced in the WHC

i. For Mixes on Compressive Strength Property

$R_{D28(hs)} = b_0 + b_1x_1 + b_2x_2 + b_{11}x_1^2 + b_{12}x_1x_2$

$= 1.975 + 0.085x_1 + 0.054x_2 + 0.062x_1^2 + 0.034x_1x_2$(3)

ii. For Mixes on Density Property:

$\rho_{hs28} = b_0 + b_1x_1 + b_2x_2 + b_{22}x_2^2 + b_{33}x_3^2$

$= 1926 + 6.20x_1 + 14.40x_2 - 6.78xx_2^2 - 5.28x_3^2$. (4)

Factorial Analysis of Eqs. (1 and 2)

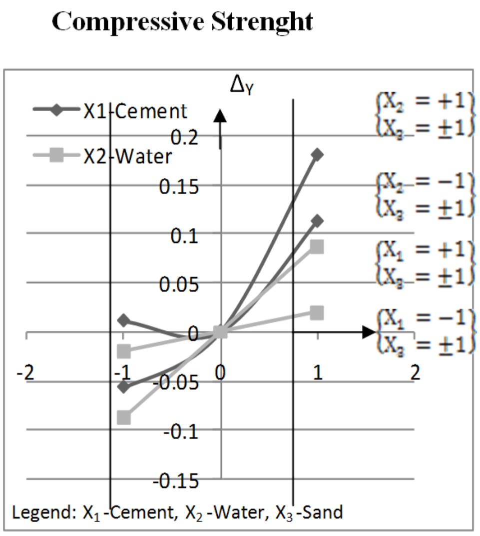

Figure 1: Combined Effect of X_1 and X_2 on the Strenght ($R_{28(hs)}$).

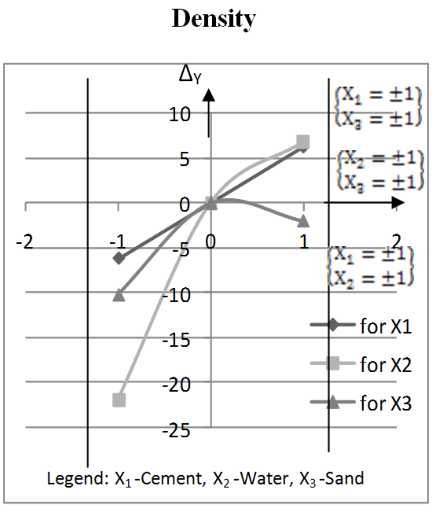

Figure 2: Combined Effect of X_1, X_2 and X_3 on Density ($\rho_{28(hs)}$).

4. Optimization of the Composition of the Sandcrete Mix Produced Manually Optimal values of the composition (ingredients) of the mix were used to substitute the compromised values of the significant variable (x_1 and x_2) in the derived models (Eqs. 3 and 4). As in Veh-matti

(2011); polynomial equations were obtained as optimal equations of the model in Eqs.3 and 4 respectively. The optimal equations (Y_{opt}) derived are as shown in Eq. (5) and (6) below.

$R_{28(hs)}(opt) = 1.97 + 0.11x_1 - 0.004x_2 - 0.004x_1x_2 = 0.005x_2^2$ (5)

$\rho_{28(hs)}\ (opt) = 1903.25 + 3.47x_2 + 3.39x_3 + 0.58x_2x_3$ (6)

Nomograms were therefore constructed from Eq. (5) and (6) by substituting the optimal values of the independent variables (x_1, x_2 and x_3)in the respective equations. The nomograms for the desired compressive strength and density properties in the WHC are shown in Figure (3) and (4) respectively.

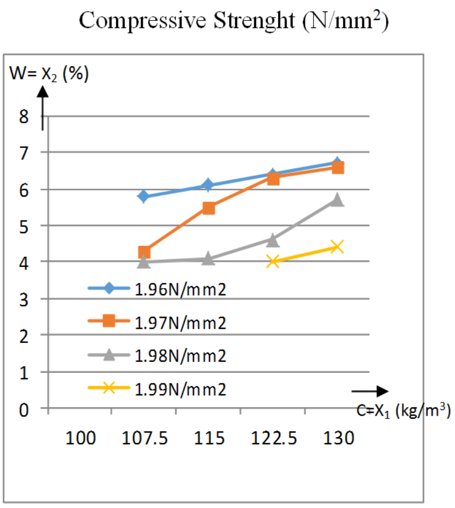

Figure 3: Nomograms for the Desired Compressive Strength.

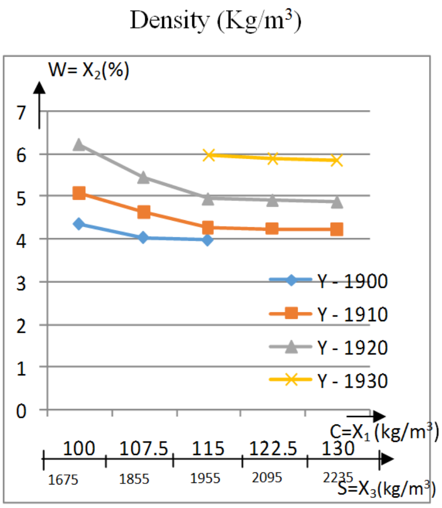

Figure 4: Density Properties in the Warm Humid Climate.

Nomograms for Manually Produced Sandcrete Blocks with range (1.96 - 1.99 N/mm^2) for Compressive Strenght(Figure 3) and with range (1900 - 1930 Kg/m^3) for Density(Figure 4), respectively.

With these nomograms, it is possible to produce sandcrete blocks using hand mould to obtain the desired compressive strength with a range of 1.96to 1.99 N/mm^2,and the desired density of 1900 to 1930 kg/m^3, with corresponding cement, water and sand contents in the WHC respectively, (Figure 3 and 4).

5. Summary of Findings

Regression analysis based on the Box-wilson symmetric composite plan B_3 (Box et al, 1951), was used to establish the relationships between each set of the mix designs and the properties (objective functions). This approach is not only cost effective, because of the few number of experimental points used, but also resulted in fundamental experimental data which were used to develop multi-factorial regression models, validated with appropriate regression analyses for each of the models.

These optimized mixes, with their corresponding optimal compositions were presented diagrammatically in the form of Nomograms in the study. The Nomograms serve as guides in designing sandcrete blocks with the desired level of the respective properties, as well as forming standard for quality control of suitable sandcrete blocks produced in the WHC zone of Nigeria thus, laying the foundation for establishing appropriate standards for quality control regulation of this common but important building material.

Through this feat, the following ranges of compressive strength and density properties are ($1.96 \leq R_{28} \leq 1.99/mm^2$), and ($1900 \leq \rho_{28} \leq 1930kg/m^3$) respectively, for speedy determination of the mix compositions of the sandcrete blocks.

Examples of mix designs using the density nomogram are given below.

The mix composition for desired density of 1900kg/m^3 in the study can be obtained with some optimum composition as follows (Figure 4):

Cement (x_1) = 100 kg/m^3, Water (x_2) = 4.38%

Cement (x_1) = 107.5kg/m^3, Water (x_2) = 4.06%

Cement (x_1) = 115 kg/m^3, Water (x_2) = 4.00%

6. CONCLUSION

The notable achievements of this study is the optimization of sandcrete mixes, using the established optimal values from the optimization analysis of the regression models of the studied properties of sandcrete blocks when produced in the warm humid climatic zone of Nigeria.

Through optimization of sandcrete mixes, it has become feasible to produce blocks with pre-determined properties, with known quantities of materials to be used. The factorial analysis on the constituent ingredients (independent variables) in the study has therefore, proven the fact that the composition of various levels of the respective ingredient is a significant factor in influencing the quality of the sandcrete block. The benefit derivable from this is that prospective builders can order blocks with known properties, once they can afford to pay the cost. It will no longer be a matter of buying blocks which quality is a suspect or unknown.

With the developed nomograms, it is possible to speedily design sandcrete mixes that will be used to produce blocks that will have any desired properties such as strength and density, in any part of the WHC. They serve as guides in designing sandcrete blocks with the desired level of the respective properties, as well as forming standard for quality control of suitable sandcrete blocks produced in the area. This would therefore, lay the foundation for establishing appropriate standards for quality control regulation of this common but important building material in Nigeria.

The findings made in this study therefore, are very significant in the construction industry especially in the building sub-sector. They would opened up a vista of hope for the development of appropriate standards for some construction materials in Nigerian building sub-sector, where realistic standards appropriate to peculiar environments are lacking.

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