COMPARATIVE ANALYSIS OF MONO-FACTORIAL EFFECTS ON COMPRESSIVE STRENGTH OF SANDCRETE BLOCK PRODUCED AT VARIOUS CURING AGE IN THE WARM HUMID CLIMATE OF NIGERIA

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ABSTRACT

Quality of a composite material like sandcrete block is basically a function of the basic properties of the constituent ingredients, mix ratio relationship, and production characteristics. This study therefore, investigates the effects of change in quantities of the constituent ingredients on compressive strength of sandcrete blocks produced at various curing ages in Owerri Metropolis. Field survey was conducted in the area to determine the production characteristics of the blocks marketed in the area. Based on the prevalent nominal mix ratio of the block, mix design on the constituent ingredients of the block based on box-wilson symmetric composite plan B_3 was adopted. Results of the strength from each experimental set of the design were used to form polynomial regression models of blocks cured at various ages. Findings show that the average compressive strengths of the 7-day, 14-day, and 28-day old cured blocks are 1.578 N/mm^2, 1.604N/mm^2, and 1.975N/mm^2. Mono-factorial analysis at the respective age of curing shows that cement and water factors has stronger effect on the strength of the block than sand factor. The nature of their influences is positive, and more linear than quadratic and mutual interaction relationships. The relationship of mutual interaction between the cement and water factors is seen only in the models of the 7-day and 28-day curing ages in the study. Since the strength of the block increases with increase in the age of curing, it therefore confirms the standard practice of 28-day curing age for improved quality of sandcrete block in the industry; as well as recommending mono-factorial analyses on the effects of the independent factors of the mix designed blocks cured age 28-day age, towards optimum composition of the sandcrete mix ingredients for desired quality of the blocks produced in the study area.

Key words: Sandcrete Block, Mix Design, Box-wilson Symmetric Composite Plan B_3, Model, Factorial Analysis, and Desired Quality.

INTRODUCTION

Sandcrete block is one of the basic construction materials widely used as walling units in Nigeria (Ikechukwu, 2015). It is composite in nature, a modern or conventional material of standard and marketable sizes usually applied in multiple and interrelated pattern in a building. Sandcrete block is obtained by mixing cementations materials, water, cement and sand in various proportions. The mixture when placed in standard forms, cured for a period of time will harden to form strong units of sandcrete block. The hardening process of the block is caused by chemical reaction between water and cement material, which continues for a long time and consequently makes the block stronger with the increasing age of curing until it optimizes. The quality of sandcrete blocks produced however differs from one manufacturer to the other because of noncompliance with the stipulated standard that regulates the quality of sandcrete block production (Ikechukwu, 2016 and Anosike et al, 2 012). As a walling unit, it can serve as load or non bearing wall. It helps to enclose and/or divide spaces in a building, as well transmits some dead loads to the foundation of the building where it functions as a load bearing wall. In general, apart from its ability to enclose spaces and helps in transmitting some loads, it should be able to withstand and moderate the external agents and the environment respectively, for the safety and comfort of the interiors and occupants respectively.

In view of these basic functional requirements of the block, the basic properties of the constituent ingredients, mix ratio relationship and the production characteristics becomes issue of concern for a desired quality. Mix design as the single most important factor for the quality assurance of composite materials according to Ikechukwu, et al (2016), counts on effect of change in the quantities of the constituent ingredients on the properties of the sandcrete block. The integrated results of every set of the mix design on the properties of the block formed into multiple regression model explain the relationship between the properties (objective function) as the dependent variable (Y_i), and the constituent ingredients (X_1, X_2, and X_3) of the block as the independent variables.

According to Anosike et al (2012), sandcrete blocks are manufactured in many parts of the country without any reference to suit local building requirements for good quality works for a long time. He said that in an attempt to enhance the best material and manufacturing practice, Standard Organization of Nigeria (SON) developed a reference document which prescribes the minimum requirements and uses of different kinds of sandcrete blocks as NIS 87: 2000 series. From 2004, the document however witnessed continuous review when NIS 87: 2004 took over as Nigeria Industrial Standard (NIS) for sandcrete block; and the last in 2007 from which NIS 87: 2007 standards emerged as the latest in Nigeria (Anosike et al, 2012). Other basic standards existing for the production of sandcrete blocks in Nigeria other than NIS 87: 2000, 2004, 2007 are BS 2028: 1975 and NBC: 2006.

These are meant to be used in controlling the quality of sandcrete blocks produced by manufacturers in Nigeria. After the introduction of the standards, variations still exist in the quality of blocks produced in Nigeria. This is primarily because the stipulated requirements contained in the reference document do not suit the local and climate conditions of Nigeria environment for effective block production in the study area (Ikechukwu, 2015). Both chance and assignable factors are known to cause variation in the quality of sandcrete block.

In the light of this ugly development, quality of sandcrete block remains very low until the standards in used consider the climatic and peculiar local factors prevalent in every unique environment. It is by so doing that standards in use become appropriate and relevant in producing good and suitable sandcrete blocks used in the study area and in Nigeria generally. This can only be done properly with the application of factorial design which form basis of most common design.

The idea is simple; having that the design is made up of all possible combinations of all chosen values of the predictive variables often called levels of all design variables for composite material/object. The design can be used both for quantitative and qualitative variables; and the effect of each variable (independent factor) on the objective function (independent factor) can be estimated independently in the model (Veh-Matti et al 2011). Normally, the optimality of such design is always dependent on the model. Hence, optimal designs are often used in selecting the best experimental point so that it enables optimality criterion about the model to be used (Veh-Matti et al, 2011).

Damirel et al (2013) in their work applied the central composite design (CCD) degree of surface methodology in designing experiments for the optimization of textile dye degradation by wet air oxidation to evaluate the interactive effects of the three most important operating variables. Results showed that the predicted values were in good agreement with the experimental values (R^2 = 0.9981 and Adj-R^2 = 0.9965). It defines the propriety of the model and the achievement of CCD in optimization of wet air oxidization process.

In another application of response surface methodology, Raju et al (2012) used it to determine optimal medium composition for gentamycin production by an indigenous micromonospora echinospora MTCC 708; with a view to reducing the number of experiments, and obtaining the mutual interactions between the input variables. In the experiments, the optimum values of the four independent variables were obtained, and the goodness of the fitness of the model was check by determination coefficient.

Wikipedia, (2014), another free encyclopedia reported an application of box-wilson experimental design method for the solar photo-catalytic degradation of textile dye staff. The effects of oxidant and catalyst dosages and flow rate in Fe (III)/H_2O/solar-UV advanced oxidation process were determined.

Nevertheless, this attention is most needed when the climatic condition is very severe and most challenging to the sustainability of the composite materials. The intensive downpour and high humid nature of the WHC zone in combination with other external agents/forces result more significant to compressive stress due to the usual functional position of the composite material in the building structures.

RESEARCH METHODOLOGY

The method adopted in this scientific investigation is based on the research designs of field survey and design of experiments. The basic information derivative of the design of the sandcrete mix is in the quantitative forms, which predicts properties of the blocks to establish relationship between the independent factors (cement - x_1, water - x_2, and sand - x_3) and the dependent factor (compressive strength) in the mix design experiment.

Data gathered from the field survey in the study area were used as basis for the design of sandcrete mixes using Box-wilson symmetric composite plan B_3 in the design experiments, as applied by okereke (2004). With the results of the experiment as objective functions which depend on the mix design effect of the independent factors (cement, water, and sand) in the study, the block productions with river sharp sand aggregates (2.36mm > Dia > 0.425mm) were formed into multiple regression models of different curing ages. Subsequently, Fisher's distribution test analyses were carried out on the models for adequacy (Okereke, 1991; and Raissi, 2009). The models that were confirmed adequate were consequently subjected to student't' test for test of significances of the constituent coefficients in the models.

Further analysis for the mono-factorial effect of the independent factors on the final models of the blocks of different curing age (7-day, 14-day and 28-day ages) were carried out to determine the degrees of effects of changes in the predictive factors of the respective model on the strength property, for optimized mix design of the block in the warm humid climate.

DATA PRESENTATION AND ANALYSES

Regression Models for the Compressive Strength of Manually Produced Sandcrete Blocks with Hard Sand Mix in the WHC

$R_{D7(hs)} = b_0 + b_1x_1 + b_2x_2 + b_{11}x_1^2 + b_{12}x_1x_2$

$= 1.578 + 0.075x_1 + 0.046x_2 + 0.061x_1^2 + 0.30x_1x_2$ …(1.0)

$R_{D14(hs)} = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}x_1^2 + b_{22}x_2^2$

$= 1.604 + 0.061x_1 + 0.047x_2 + 0.033x_3 + 0.079x_1^2 + 0.029x_2^2$ …(2.0)

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

$= 1.975 + 0.085x_1 + 0.054x_2 + 0.062x_1^2 + 0.034x_1x_2$ …(3.0)

Table 1.0. Results of the Factorial Analysis on Model (Equ. 1.0)
$R_{D7} = 1.578 + 0.075X_1 + 0.046X_2 + 0.061X_1^2 + 0.30X_1X_2$

S/N	FACTORS	LEVELS	X_{ij}	X_{ij}	X_{ij}	X_{ij}	REMARKS
1	X_1		X_2 , X_3	X_2 , X_3	X_2 , X_3	X_2 , X_3	
		-1	-1 , -1	-1 +1	+1 -1	+1 +1	
			0.286	0.286	-0.314	-0.314	
		+1	-1 , -1	-1 +1	+1 -1	+1 +1	
			-0.164	-0.164	0.436	0.436	
2	X_2		X_1 , X_3	X_1 , X_3	X_1 , X_3	X_1 , X_3	
		-1	-1 , -1	-1 +1	+1 -1	+1 +1	
			0.254	0.254	-0.346	-0.346	
		+1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			-0.254	-0.254	0.346	0.346	
3	X_3		X_1 , X_2	X_1 , X_2	X_1 , X_2	X_1 , X_2	
		-1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.00	0.00	0.00	0.00	
		+1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.00	0.00	0.00	0.00	

Legend: X_1 - Cement, X_2 - Water, X_3 - Sand

As seen in Table 1.0, change in the quantity of sand ingredient in the mix has no significant effect on the strength in the 7th day age of curing. Therefore, any change in the sand content without any change in any other constituent ingredient maintains the same magnitude of strength property in the experiment. Thus, the most influential on the property among cement and water factors is cement factor. The property is optimized at (1.578n/mm^2 + 0.436n/mm^2) in the experiment, when the cement factor is at maximum with water factor respectively. Hence, mutual interactive reaction exists between the cement and sand factors.

i. Effects of Cement (X_1) on Compressive Strength ($R_{7(hs)}$)

According to Fig.1a, Factor x_1 (cement) has positive and negative effects on the compressive strength of the sandcrete block produced with hard sand . Every increase in cement content results in increase in the strength, when water factor is at maximum level. The effect on the property is seen to be stronger when cement content is at average to maximum levels.

However, when water factor is at minimum level, increase in the cement content results to decrease in strength. Besides, the influence of change in the content of water in the mix is more significant when water is at maximum level in the experiment.

ii. Effects of Water (X_2) on Compressive Strength ($R_{7(hs)}$)

In Fig.1b, change in the content of water is directly proportional to its effect on compressive strength of the block when cement content is at maximum level in the mix while; the change in the water content is inversely proportional to its influence on the strength when cement content is at minimum level. Besides, the effect of change in water content on the property of the block is more significant when cement factor is at maximum level in the mix than at minimum level.

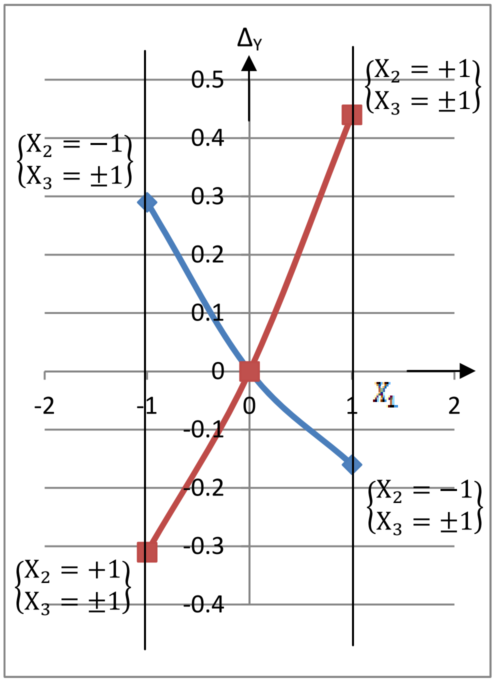

Fig. 1a. Effect of Cement (X_1) on ($R_{7(hs)}$)

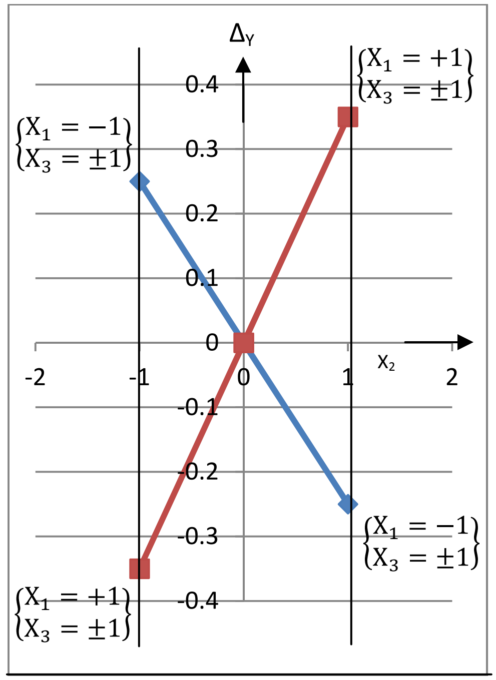

Fig. 1b. Effect of Water (X_2) on ($R_{7(hs)}$)

Table 2.0. Results of the Factorial Analysis on Model (Equ. 2.0)

$$R_{D14} = 1.604 + 0.061X_1 + 0.047X_2 + 0.033X_3 + 0.079X_1^2 + 0.029X_2^2$$

S/N	FACTORS	LEVELS	X_{ij}	X_{ij}	X_{ij}	X_{ij}	REMARKS
1	X_1		X_2 , X_3	X_2 , X_3	X_2 , X_3	X_2 , X_3	
		-1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.018	0.018	0.018	0.018	
		+1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.14	0.14	0.14	0.14	
2	X_2		X_1 , X_3	X_1 , X_3	X_1 , X_3	X_1 , X_3	
		-1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			-0.018	-0.018	-0.018	-0.018	
		+1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.076	0.076	0.076	0.076	
3	X_3		X_1 , X_2	X_1 , X_2	X_1 , X_2	X_1 , X_2	
		-1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			-0.033	-0.033	-0.033	-0.033	
		+1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.033	0.033	0.033	0.033	

Legend: X_1 - Cement, X_2 - Water, X_3 - Sand

Table 2.0 shows that the three independent factors when changed in their contents have no mutual interaction with one another in the 14-day age of curing. The strength property however increases when the respective factors are increased regardless of what change is going on in any other constituent ingredient in the mix. Besides, the water factor at this age is the most influential with increase of 0.076n/mm^2 in strength value when the factor is maximized in content.

Consequently, the average strength in the mix design experiment improve maximally by 0.140n/mm^2 when the best point of experiment is targeted at this curing age.

i. Effects of Cement (X_1) on Compressive Strength ($R_{14(hs)}$)

Cement factor (x_1) in Fig.2a has positive and negative effects on compressive strength of the block produced with hard sand at any given quantity of cement and water factors in the mix. The positive effect however, is stronger in the experiment than the negative effect. Increase in the cement content from minimum (-) to average (0) levels results to decrease in the strength. When the increase goes beyond average (0) level towards the maximum (+) level, the strength however increases at a higher rate.

ii. Effects of Water (X_2) on Compressive Strength ($R_{14(hs)}$)

At all levels of cement and sand factors in Fig.2b every increase in the water content from minimum to average levels leads to increment in strength value. As the increase in water content goes beyond the average level towards the maximum levels, the strength however increases proportionally at a higher rate.

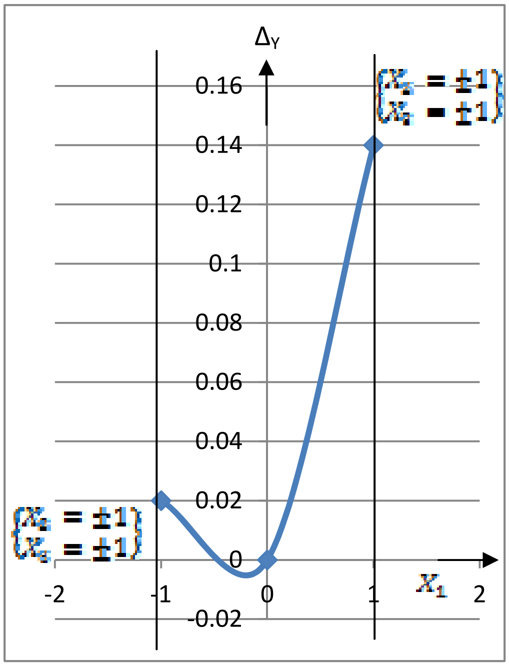

Fig. 2a. Effect of Cement (X_1) on ($R_{14(hs)}$)

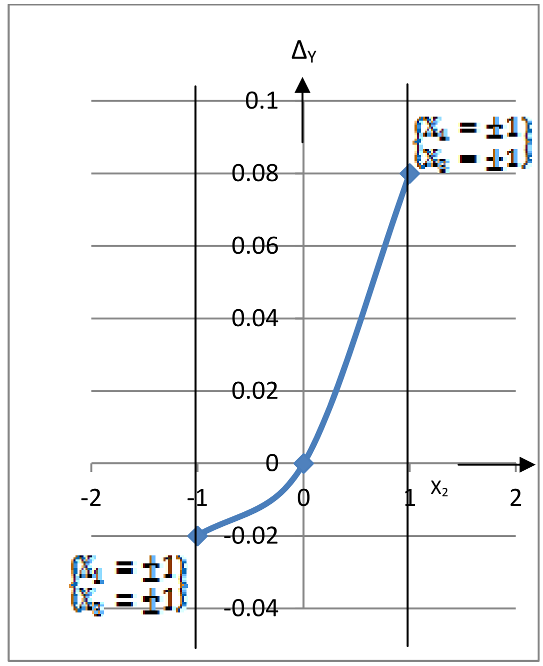

Fig. 2b. Effect of Water (X_2) on ($R_{14(hs)}$)

iii. Effects of Sand (X_3) on Compressive Strength ($R_{14(hs)}$)

In Fig.2c, Sand factor (X_3) has absolute positive effect on the compressive strength of the block. Any increase in sand content results to a corresponding increase in the strength. The effect on the property is constant at all levels of cement and water factors.

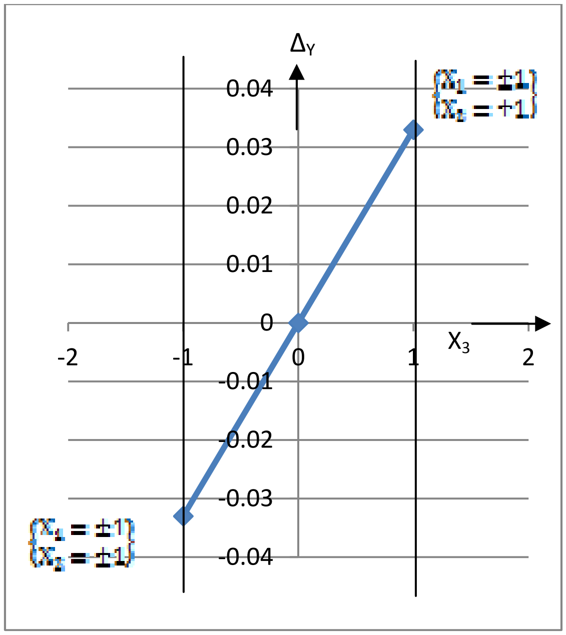

Fig. 2c. Effect of Sand (X_3) on ($R_{14(hs)}$)

Table 3.0. Results of the Factorial Analysis on Model (Equ. 1.0)

$$R_{D28} = 1.975 + 0.085X_1 + 0.054X_2 + 0.062X_1^2 + 0.034X_1X_2$$

S/N	FACTORS	LEVELS	X_{ij}	X_{ij}	X_{ij}	X_{ij}	REMARKS
1	X_1		X_2 , X_3	X_2 , X_3	X_2 , X_3	X_2 , X_3	
		-1	-1 , -1	-1 +1	+1 -1	+1 +1	
			0.011	0.011	-0.057	-0.057	
		+1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.113	0.113	0.181	0.181	
2	X_2		X_1 , X_3	X_1 , X_3	X_1 , X_3	X_1 , X_3	
		-1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			-0.020	-0.020	-0.088	-0.088	
		+1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.020	0.020	0.088	0.088	
3	X_3		X_1 , X_2	X_1 , X_2	X_1 , X_2	X_1 , X_2	
		-1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.00	0.00	0.00	0.00	
		+1	-1 , -1	-1 , +1	+1 , -1	+1 , +1	
			0.00	0.00	0.00	0.00	

Legend: X_1 - Cement, X_2 - Water, X_3 - Sand

Table 3.0 shows that change in quantity of sand ingredient in the mix has no significant effect on the strength in the 28-day age of curing; hence any change in the sand content without any change in any other constituent ingredient maintains the same strength property in the experiment. The most significant on the property among cement and water factors is cement. The property is optimized at (1.975n/mm^2 + 0.181n/mm^2), when the cement factor is at maximum with water factor respectively. Hence, mutual interactive reaction exists between the cement and sand factors at this age also.

At last, the maximum strength value of 14-day curing age at (1.604n/mm^2 + 0.140n/mm^2), and that of 7-day curing age are significantly exceeded by maximum strength value of 28-day age of curing at (1.975n/mm^2 + 0.181n/mm^2).

i. Effects of Cement (X_1) on Compressive Strength ($R_{28(hs)}$)

According to Fig.3a, cement factor (x_1) has positive and negative effects on compressive strength of the block produced with hard sand depending on the cement content and the content of water factor in the mix. The positive effect however, is stronger in the experiment than the negative effect. Increase in the cement content from minimum (-) to average (0) levels results to decrease in the strength when the water content in the mix is at minimum level. If the increase exceeds average level tending to maximum level, the strength however increases at a higher rate.

Nevertheless, when the water content in the mix is at maximum level, every increase in the cement content from minimum to average level leads to the increase in strength. As the increase in cement content goes beyond the average level towards the maximum levels, the strength however, increases at a higher rate.

ii. Effects of Water (X_2) on Compressive Strength ($R_{28(hs)}$)

Water factor (x_2) in Fig.3b has absolute positive effect on the compressive strength of the block. Any increase in water content results to a corresponding increase in the strength. The effect on the property due to changes in water content is more significant when the cement content in the mix is at maximum level than when at minimum level.

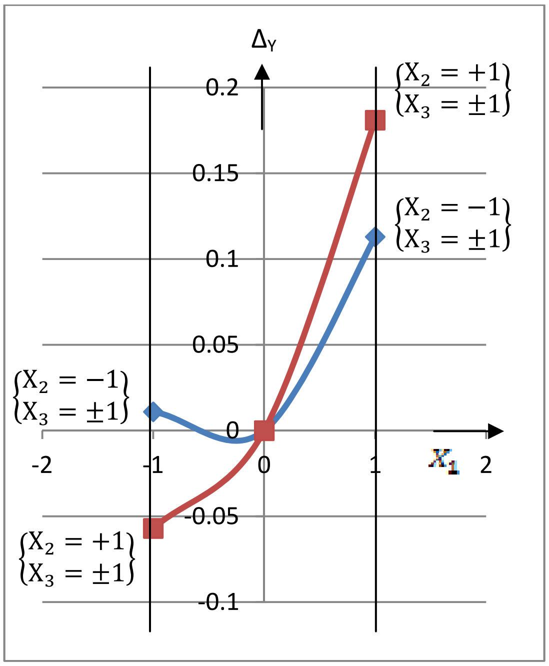

Fig. 3a. Effect of Cement (X_1) on ($R_{28(hs)}$)

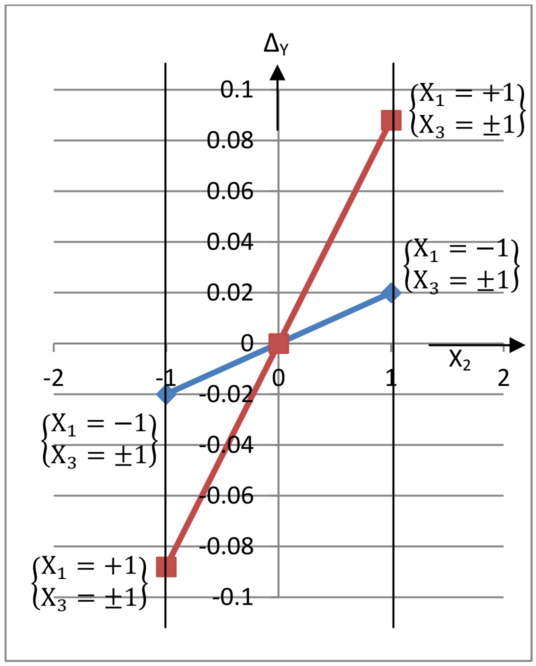

Fig. 3b. Effect of Water (X_2) on ($R_{28(hs)}$)

DISCUSSION OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

Models for all the respective curing ages in the study are mixed in nature, with regard to the characteristics of the constituent ingredients of the sandcrete mix. The models are characterized by combination of linear, quadratic and mutual interaction relationships of the respective ingredients.

Findings show that blocks designed and cured at 7-day, 14-day, and 28-day ages have compressive strength of 1.578 N/mm^2, 1.604N/mm^2, and 1.975N/mm^2 respectively at neutral values of the experiments in their respective models. The average strength at the 7-day age is the least while; the average strength at the 28-day age of curing is the highest in value.

Change in the quantity of cement factor is the most significant to the strength followed by change in water factor. Nevertheless, sand factor is the less significant in the experiments especially, in the 7-day and 28-day curing ages. Hence, significant mutual interaction relationships exist only between cement and water factors in the experiments. Changes in these two factors therefore have noticeable effects on the strength of the block especially, on the 7-day and 28-day cured blocks. Besides, the cement factor has influence of quadratic relationship in all the models of the mix designed experiments.

The mono- factorial analyses therefore, show how to improve on the compressive strength property of the block at the respective age of curing by optimum combination of the constituent ingredients in the mix. This ofcourse is base on the knowledge of the mono-factorial effects of the respective sandcrete ingredients on the strength in the study.

As a result of the mono-factorial analysis, the mix can be optimally designed to improve the average strength of the study at 1.578 N/mm^2, 1.604N/mm^2, and 1.975N/mm^2 to 2.014n/mm^2, 1.744n/mm^2, and 2.156n/mm^2 for the 7-day, 14-day, and 28-day ages of curing respectively in the experiment.

In conclusion, the study therefore provides the fore knowledge of the implication of change in the content of the constituent ingredients of the sandcrete mix on the strength of the block at the respective age of curing. It forms basis for choosing the appropriate mix design proportion for desired quality of sandcrete block in the study area. Thus, the optimized property can be achieved at all stages of curing with optimum combination of the constituent ingredients of the sandcrete mix in the experiment.

Although the 28-day curing age of sandcrete block as one of the standard production characteristics for improved block work in the industry is confirmed, factorial analysis on models of designed sandcrete mix forms basis for regulating and improving more on the properties of the block to meet up with desired qualities, as the case may be.

The study therefore recommends that sandcrete mix be designed with strong emphases on cement and water ingredients for optimum combinations of the ingredients towards realization of high quality blocks in the study area. To complement the mix design effort, blocks should always be cured up to 28 days for effective strength development in the industry.

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