PRELIMINARY EXPERIMENTAL ASSESSMENT OF A LOCAL SAND FOR POSSIBLE APPLICATION AS A STANDARD SAND IN CEMENT COMPREHENSIVE STRENGTH TEST

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ABSTRACT

Simplex Centroid Mixture Design was used to investigate the proportion of three fractions of local sand for possible application as standard sand in Comprehensive Strength (CS) test. The results show that the CS is largely dependent on the particle size of the sand. In general, increase in proportion of the fraction with relatively large fractions gives cement mortar with high CS while increase in fraction with finer particles decreases the CS of the mortar. Optimization analysis gave four different formulations of the local sand predicted to give cement mortars with compressive strengths that are largely the same as that of the standard sand. The composite sands have optimal proportion of the three bulk fractions of the local sand varying within 77.9 – 88.0 %, 9.3 – 12.7 % and 2.8 – 3.7 %, respectively. Validation results confirmed the predictions.

Keywords: Standard Sand, Cement, Comprehensive Strength Test

INTRODUCTION

Standard sand is a very important material not only in assessment of quality of cement and other building materials (e.g. lime & pozzalana), but also in the study of abrasive properties of building stones etc. [1]. In cement quality test, standard sand is used in Comprehensive Strength (CS) test which is usually done after 1, 2, 7 and 28 days curing of cement mortar under standard condition [2]. The test serves as direct measure of the load carrying capacity of the concrete prepared from the cement. It is a good guide to durability of cement and is often used as a cement classification parameter [3].

The compressive strength of concrete depends on the properties of the materials used, the proportion of the mix, the method of compaction, the presence of contaminants and their degree, and other controls during placing and curing [2,4]. Consequently, standard materials and conditions are employed for consistency and reproducibility. Thus, the test is mostly done with certain proportions of cement, water and sand. The kind and nature of sand used is particularly important as different sands are capable of giving concrete prepared from same batch of cement different compressive strength [5-7].

Although at the production plant of the Cement Company of Northern Nigeria (CCNN) Plc., Sokoto, Nigeria, 100 % of the raw materials are sourced locally, the company (like all others in the country) uses imported standard sand in preparation of mortar for cement compressive strength test. This is rather counterproductive with respect to foreign exchange savings (which could be significant at the long run) as well as creation of much needed jobs for the teeming youths in the country.

Therefore, this paper presents results of an investigation conducted on the suitability of a local sand from northern part of Nigeria for application in compressive strength test of Ordinary Portland Cement.

MATERIALS AND METHODS

Sampling and sample preparation

Sample of standard sand imported from the Netherlands and the cement used in the investigation were provided by Cement Company of Northern Nigeria (CCNN). Sample of local sand was collected from a local quarry at Talata-Mafara (12˚21'N, 6˚04'S) in Zamfara State, Nigeria. It was sun dried for two days, manually homogenized and then successively sieved through 2, 1.6, 1, 0.5, 0.2 and 0.08 mm standard mesh sieves with each fraction retained. Three bulk fractions (F1, F2 and F3) were then prepared from the retained fractions. The 1.6 and 1 mm fractions were combined to obtain F1 bulk fraction and the 0.2 and 0.08 mm fractions were combined to give F3 bulk fraction while 0.5 mm fraction was used as F2.

Experimental Design

The experiments were designed based on Simplex Centroid Mixture Design on MINITAB 15 platform. Each of the three components (bulk fractions F1, F2 and F3) was set to vary from a lower limit of 0 to an upper limit of 1350 g while the cumulative total was set at 1350 g per trial. Curing time (1 and 2 days) was used as process variable. Each experimental trial was done in duplicate to obtain a total of 40 completely randomized trials.

Preparation of Mortar and Compressive Strength Determination

The mortar and cubes for the compressive strength determination were prepared according to standard procedure of CCNN Plc. Quality Control Laboratory. For each trial, appropriate amounts of the bulk fractions, as obtained from the statistical design, were mixed and 450 g of cement was added followed by 225 cm^3 of distilled water. A slurry was formed from the mixture using an automatic mixer. This was transferred into a moulding prism to form cubes and then jolted for two minutes. After setting, the cubes were then incubated in water for 1 or 2 days in accordance with the experimental design. After the incubation period, each cube was divided into two and each half was crushed successively using a compressive strength machine and the compressive strength was recorded in N/mm^2. The compressive strength of each trial was taken as the average from the two halves of a cube. For comparison, five compressive strengths were obtained from mortar prepared using the standard sand. In all the trials same batches of the local sand and cement were used [8].

ANOVA as well as one-sample and two-sample *t*-tests on MINITAB 15 statistical software were used for regression and comparison of means at 95 % confidence level (i.e. $\alpha = 0.05$).

RESULTS AND DISCUSSION

Table 1 contains the statistical summary of the results obtained from CS tests using both local and standard sands. In general, irrespective of the curing time, the local sand displays wider range of values varying from as low as 0.59 to as high as 18.18 N/mm^2. As expected [9] the CS after 1 day curing appears to be significantly lower (0.59 to 12.45 N/mm^2) compared to that after 2 days (1.08 to 18.18 N/mm^2). The standard sand shows relatively less variability in CS (Standard deviation = 3.12 N/mm^2) obviously due to a more consistent composition.

Table 1. Summary of compressive strength tests results (in N/mm^2) obtained using the local and standard sands

Variable	N	Mean	StDev	Min	Max	Range
CSL	40	8.35	4.50	0.59	18.77	18.18
CSS	10	13.29	3.12	8.41	16.46	8.05
CSL_1	20	7.30	3.75	0.59	12.45	11.86
CSL_2	20	9.40	5.02	1.08	18.77	17.69
CSS_1	5	10.44	1.20	8.41	11.56	3.15
CSS_2	5	16.14	0.35	15.73	16.46	0.73

Key: CSL = Compressive strength of local sand; CSS = Compressive strength of standard sand; CSL_1 = Compressive strength of local sand after 1 day curing; CSS_1 = Compressive strength of standard sand after 1 day curing; CSL_2 = Compressive strength of local sand after 2 days curing; CSS_2 = Compressive strength of standard sand after 2 days curing.

Regression model analysis

Analysis of variance (at $\alpha = 0.05$) of the CS results generated a model that describes about 93 % of the variation in the experimental data. The analysis further shows that the linear regression model with respect to the components (bulk fractions) of the local sand is significant ($p < 0.0005$). There is also a significant interaction between component and time for both linear ($p = 0.023$) and quadratic (p < 0.0005) models. However, among the various two-way interactions, only that between F1 and time has a significant effect (p = 0.001) on the CS. Similarly, only the two three-way interactions involving F1 fraction (i.e. F1*F2*Time and F1*F3*Time) were found to have significant effect on the CS (Table 2).

Table 2. Results of Analysis of variance showing the significant terms and their respective coefficients in the regression model

Term	**Coef_A**	**Coef_P**	**SE Coef**	**T**	**P**
F1	1.08019×10^{-2}	14.583	0.5260	*	*
F2	7.18772×10^{-3}	9.703	0.5260	*	*
F3	5.64259×10^{-4}	0.762	0.5260	*	*
F1*Time	1.39043×10^{-3}	1.877	0.6840	2.74	0.010
F1*F2*Time	7.76197×10^{-6}	14.146	2.7247	5.19	0.000
F1*F3*Time	-4.69893×10^{-6}	–8.564	2.7247	–3.14	0.003

Key: Coef_A = Estimated regression coefficient for CS based on component amounts; Coef_P = Estimated regression coefficient for CS based on component proportions; T = Calculated student's *t*; P = the *p*-value.

Elimination of the statistically insignificant terms gives a less cumbersome model (equation 1, based on proportion of components) wits slightly lower correlation and predictive power (R^2= 90.15 to 89.96 % and Pred. R^2 = 86.23 to 87.77 %).

The robustness of the model is further observed from residual plots (Appendix) which shows that the residuals are approximately symmetrical and normally distributed with no discernable pattern.

$$CS = 14.583 * F1 + 9.703 * F2 + 0.762 * F3 + 1.877 * F1 * Time + 14.146 * F1 * F2 * Time - 8.564 * F1 * F2 * Time \quad ------1$$

Effect of Components

Fig. 1a shows the component effect plot after 1 day curing. The plot shows that as the proportion of the bulk fraction F1 increases relative to the reference blend, the CS increases almost linearly, and when it deceases, CS also decreases. On the other hand, as the proportion of the F2 fraction increases relative to the reference blend, the CS increases slowly and then more sharply at higher proportions. Decrease in proportion of F2, results in sharp increase in the CS (Fig. 1a). As proportion of F3 increases relative to the reference blend, there is sharp decrease in the CS. And decrease in the proportion of the fraction from the reference blend proportion does not seem to have significant effect on the CS. In general, higher CS is achieved by decreasing the proportion of F3 from the reference blend value of 33.33 % and increasing the proportions of F1 and F2, appropriately.

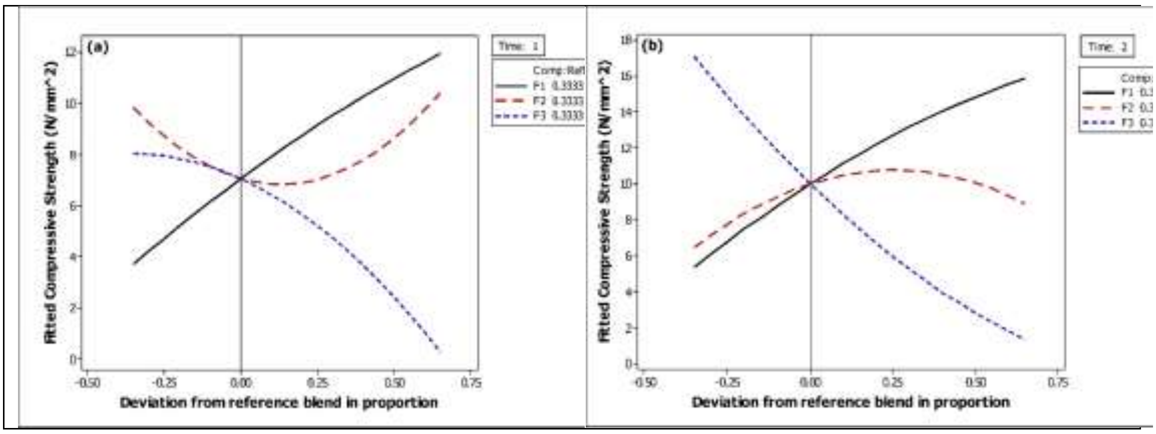

Fig. 1: Component effect plots showing how the relative proportion of the three components of the local sand affect CS relative to the reference blend after (a) 1 day curing and (b) 2 day curing.

Fig. 1b is the component effect plot of CS values obtained after 2 days curing. As observed for the 1 day curing, increase in the proportion of F1 component relative to the reference blend increases the CS and its decrease results in decrease in the CS. On the other hand, as F2 increases relative to the reference blend, CS remains nearly constant before it starts to decrease albeit slowly at relative deviations of about 40 %. Furthermore, CS decreases sharply and linearly as the proportion of F3 relative to the reference blend increases and increases with decrease in the proportion of F3. For 2 days curing, F2 appears to have optimal value at the reference blend value of 33.33 % while higher CS is obtained by increasing the proportion of F1 and concurrent decrease in F3 relative to the reference blend (Fig. 1b).

Fig. 2 shows the contour plot for CS both at 1 day and 2 days curing. Both plots further show that low CS values are obtained at high proportions of F3. In fact, quite low (<3 N/mm^2) are obtained even after 2 days curing when the proportion of F3 is high. CS values of 9 to 12 N/mm^2 (the range within which the CS of standard sand falls) are obtained when F3 is approaching 0 and F1 is high after 1 day curing. This is also true for the 2 day curing with CS values greater than 15 N/ mm^2 restricted to regions of high amounts of F1 and relatively low amounts of F2.

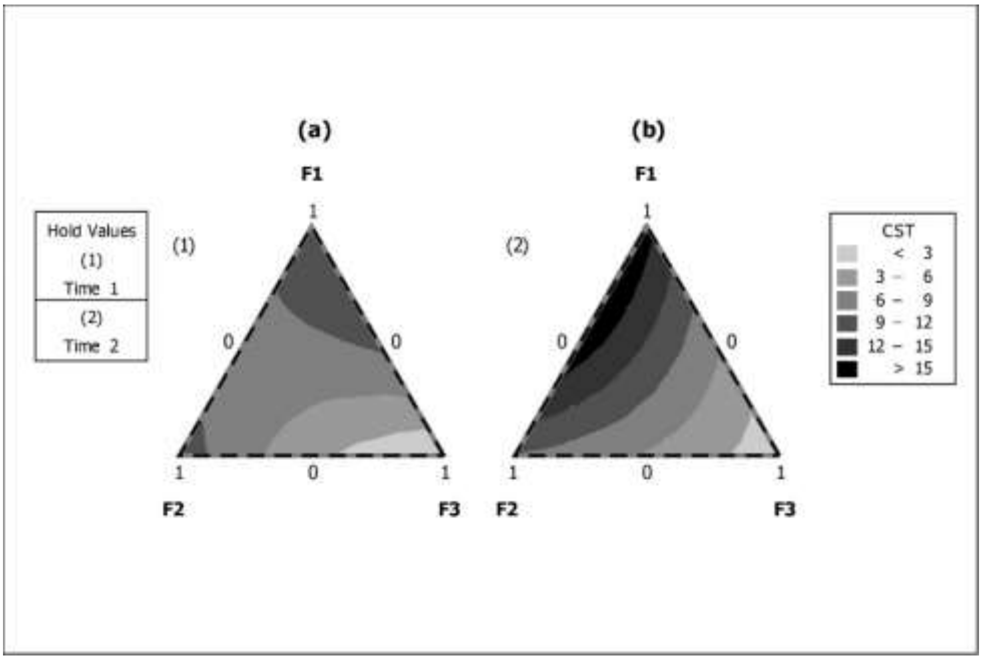

Figure 2: Contour plots showing how the relative proportion of the three components of the local sand affects CS after (a) 1 day curing and (b) 2 day curing.

Optimization and validation

Replicate determinations of CS on mortars prepared using standard sand give mean CS values of 10.44±1.20 and 16.14 N/mm^2 after 1 day and 2 days curing, respectively (Table 1). The region of the contour plot (Fig. 3) of CS of mortar prepared from the local sand which corresponds to the mean CS of the standard sand is shown in white. In other words, only those proportions of the F1, F2 and F3 that fall within the white region of the contour plot could give CS values that are statistically equivalent to those from the standard sand.

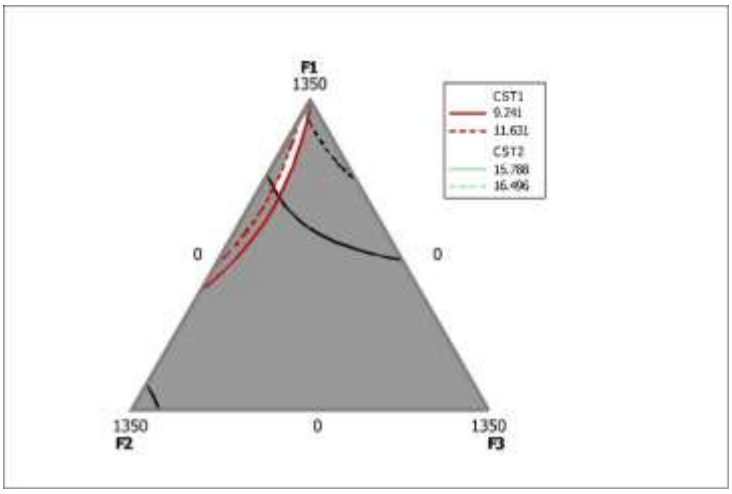

Figure 3: Superimposed contour plot showing the response surface based regression model and the region of the response surface that gives the desired CS values for both 1 day curing and 2 day curing periods.

Table 3: Results of optimization analysis showing the four predicted amounts (in g) of the three different bulk fractions of the local sand that simultaneously give the target CS for 1 day (10.43 N/mm^2) curing and 2 days curing (16.14 N/mm^2).

Solutions	F1	F2	F3	D1	D2	CD
LS1	1131.82	168.71	49.48	0.973	0.992	0.982
LS2	1128.36	171.61	50.03	0.994	1.000	0.997
LS3	1052.05	234.77	63.18	0.565	1.000	0.752
LS4	1187.72	125.11	37.17	0.642	1.000	0.801
GS	1131.82	168.71	49.48	0.973	0.992	0.982

Key: LS = local solution; GS = global solution; CS1 = predicted compressive strength after 1 day curing; CS2 = predicted compressive strength after 2 days curing; D1 = desirability of the predicted CS after 1 day curing; D2 = desirability of the predicted CS after 2 day curing; CD = the composite desirability.

Optimization conducted to obtain the relative amounts of the three bulk fractions of the local sand that simultaneously give the target mean CS of 10.43 and 16.14 N/mm^2 for 1 and 2 day curing, respectively gives four different solutions (Table 3). Most of the solutions have relatively high desirabilities with respect to the target CS and high composite desirabilities (>80 %). In agreement with previous observations, all the solutions consist of high (77.9 to 88.0 %) F1 fraction with particle size greater than 1.6 mm. This is followed by significant amounts (9.3 to 12.7 %) of F2 with medium particle size (0.5 mm). The finest fraction, F3 that has been observed to negatively affect CS is generally low (2.8 to 3.7 %) in all the solutions.

The optimizer predictions were experimentally validated by preparing composite local sand consisting of different proportions of the bulk fractions F1, F2 and F3 in the four predicted solutions (Table 3). The CS of the mortars were then compared to that of the standard sand. The results are presented in Table 4.

Table 4. Results of validation analysis comparing the experimentally obtained compressive strength to predicted compressive strength (in N/mm^2)

Solution	PCS1	ECS1	PCS2	ECS2
LS1/GS	10.469	9.000±0.071	16.139	15.550±0.212
LS2	10.443	9.390±0.028	16.142	15.200±0.141
LS3	9.917	9.450±0.071	16.142	16.350±0.212
LS4	10.863	8.600±0.141	16.142	15.550±0.212
STDS	-	10.436±1.195	-	16.142±0.354

Key: LS = Local solutions (see Table 2); GS = Global solution; STDS = Standard sand; PCS1 = Predicted compressive strength for 1 day curing; PCS2 = Predicted compressive strength for 2 day curing; ECS1 = Experimental compressive strength for 1 day curing; ECS2 = Experimental compressive strength for 2 day curing.

One-sample t-test (at $\alpha = 0.05$) was carried out to determine whether the experimental CS (ECS) are significantly different from the predicted CS (PCS). Results from mortar cured for 1 day show that with the exception of LS3, all other ECS are significantly different ($p < 0.05$) from the corresponding predicted CS. On the other hand, the experimental CS after 2 day curing are statistically equal to the corresponding predicted CS ($p > 0.05$) for all the four composite local sand mixtures. The disagreement observed at 1 day curing time is probably due to the fact that different batches of cement and sand were used in the model formulation and validation experiments. This is supported by the results from two-sample *t*-test used to determine whether there is any statistical difference between the experimental CS from standard sand and that from the local sand. All the results indicate that there is no significant difference ($p > 0.05$) between any of the sets for both 1 day and 2 days curing. The only exception is with respect to LS2 after 2 days incubation, the CS of which shows significant statistical difference ($p < 0.05$) from the standard sand.

However, *two-sample t-test* at $\alpha = 0.05$, comparing the empirical results to the corresponding CSs of using standard sand show that there is no significant difference between the formulated local sand and the later ($p > 0.05$). In fact the formulated sand gives more consistent and less variable CS results than the standard sand as illustrated in Fig. 4.

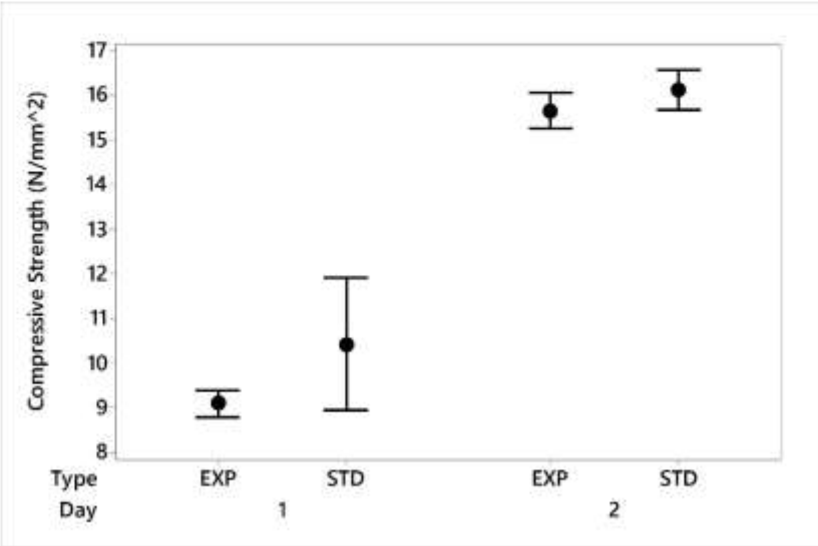

Figure 4: Interval plots comparing the compressive strengths of the formulated local sand (EXP) and standard sand (STD) after 1 and 2 days curing.

CONCLUSION

In this investigation, local sand, fractionated into three different particle size-based fractions, was investigated to determine the effect of the particle size on CS of Portland cement as well as determine the relative proportions of the fractions required to obtain a sand that could directly replace imported standard sand in CS test. The results revealed that the sand particle size significantly affect CS of Portland cement mortar and sand of relatively large particle size is need to adequately and directly replace the imported sand. Optimization results obtained predicted four different formulations of the local sand that should have similar CS as standard sand. Validation results show there was no significant difference between the formulated local sand and the standard sand after one and two days curing, respectively. In general, the sand shows convincing potentials for use to formulate a Nigerian standard sand for applications in cement quality control tests. Nevertheless, effect of longer curing time (one week and above) should also be investigated in order to come up with a final marketable product.

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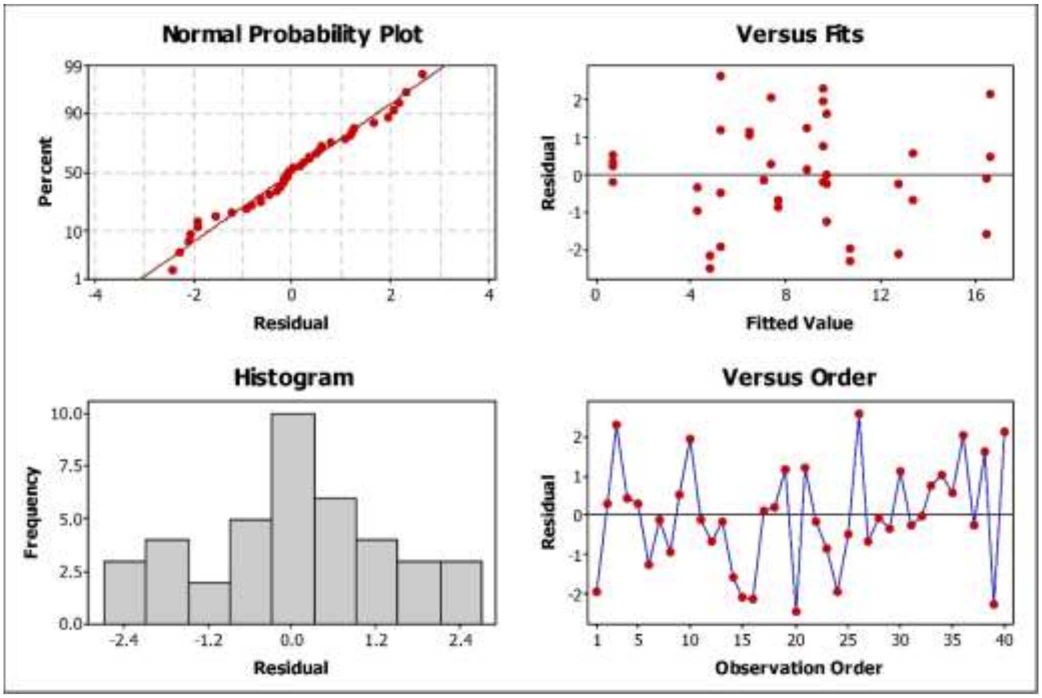
Appendix


Normal Probability Plot
Percent
Residual
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
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Observation Order