WEST AFRICA BUILT ENVIRONMENT RESEARCH (WABER) CONFERENCE

24-26 July 2012
Abuja, Nigeria

PROCEEDINGS
(Volume 1)

Editors
Dr Samuel Laryea
Dr Sena A. Agyepong
Dr Roine Leiringer
Professor Will Hughes

RATIONAL DESIGN OF CONCRETE MIXES USING UNCRUSHED AGGREGATES

T. O. Alao[1]

Department of Building, Federal University of Technology, Minna, Nigeria

This paper presents the study carried out on naturally deposited gravel for use in the production of concrete mixes. Physical properties of the coarse aggregates was carried out and was found to satisfy specification requirements to produce normal grades of 20, 25 and 30 concrete with continuous grading, single size grading, natural deposit grading, gap grading(continuous) and gap grading (single size). Also, maximum aggregates of 10mm, 20mm and 40mm with low slump of 10 – 30mm and medium slump of 30 – 60mm were considered. The properties of the mixes both in the plastic and hardened states have been found to vary depending on the coarse aggregates grading used. Based on these results, the starting estimates for the compressive strength and approximate free-water cement requirements to give various levels of workability for uncrushed aggregates presented in the DOE design manual have been found to be invalid. The appropriate charts, tables and standard deviations for the revised relationship have been re-presented, which can be used directly in designing concrete mixes using the gravel as coarse aggregates.

Keywords: mix design, uncrushed aggregates, grading, specified strength

INTRODUCTION

Aggregates generally occupy 60 – 80 percent of the volume of normal weight concrete and hence, their characteristics influence the properties of concretes, Neville [1]. They are cheaper than cement and it is therefore economical to put into the mix as much of the aggregates. Coarse aggregates also confer a considerable advantage on the hardened concrete because it has a higher volume stability and better durability. It should be noted that the compressive strength of concrete cannot significantly exceed that of the major part of the aggregates contained therein. Hence, inadequate strength of coarse aggregates represents a limitation in achieving an increased strength due to premature fracture Alao, [2].

The uncrushed coarse aggregate of interest here is a quartz. It was sourced in and around Share/Tsaragi area of Kwara State, Nigeria. It is roundish in shape, which explains long transportation history by river and that visual observation within other deposit areas show little difference in physical appearance and that it is unlikely that physical and chemical property variation may exist, Ogunmola, [3]. It is extensive in deposit and has been used extensively in institutional building and road construction works.

[1] tatimalao@gmail.com

Alao, T.O. (2012) Rational design of concrete mixes using uncrushed aggregates *In:* Laryea, S., Agyepong, S.A., Leiringer, R. and Hughes, W. (Eds) *Procs 4th West Africa Built Environment Research (WABER) Conference,* 24-26 July 2012, Abuja, Nigeria, 251-261.

For this aggregates sample, the suitability and the validity of design tables and nomographs presented by the Department of the Environment (DOE) for the design of normal grade concrete mixes is investigated.

EXPERIMENTAL PROCEDURE

The physical properties of the uncrushed coarse aggregates like grading, unit weight, absorption capacity, moisture content and specific gravity were carried out. The properties were found to satisfy specification requirements of BS 812: Parts 1-4 (1975), BS 882 and 1201 Part 2 (1973).

The mix was designed using the procedure presented by the Department of the Environment (DOE) as presented by Teychenne et al [4]. Subsequently, constituent proportions of water, cement, fine and coarse aggregates were obtained for the specified slump and target mean strength criteria at 7 and 28 days respectively.

The limitation in the design for strength is the physical property of the coarse aggregates or aggregate type to be used. This is because the strength of the hardened concrete mixture cannot significantly exceed that of the coarse aggregates used. For this reason, only the design for normal grade concrete is considered: they are 20, 25 and 30N/mm^2 characteristic strengths suitable for reinforced concrete elements in buildings. Mild and moderate conditions of the concrete use were considered. For this reason, maximum expected slumps considered are 10 – 30mm and 30 – 60mm that are suitable for reinforced concretes.

While the code of practice CP110: 1972 recognizes four maximum coarse aggregates sizes namely: 10, 14, 20 and 40mm; the DOE method recognizes only 10, 20 and 40mm maximum and these are the maximum aggregate sizes considered here.

The fine and coarse aggregate contents were estimated based on saturated and surface dry conditions. Adjustments are generally required and carried out for the aggregate samples in their stockpile conditions.

Grading of the coarse aggregates.

This is a method for classifying the proportions of sizes of particles present in a deposit expressed as fractions or percentages of the total. Grading is done by sieve analysis. The gradings used here include:

Continuous Grading (CG): This is usually represented on the grading curve as a steep and continuous line/curve. It contains all size variations retained on 4.75mm to the maximum size of aggregate specified.

Gap Grading (GG): This is a grading in which one or more intermediate size fractions are omitted. In contrast to continuously graded aggregates on the grading curve, it is represented by a horizontal line over the range of sizes that are omitted.

Single Size Grading (SS): This consists of coarse aggregates with only one single size. When uniform single size grading is used, there is a much lower specific surface which suggests lower cement to coat the coarse aggregates.

Natural Deposit Grading (ND): This is the natural deposit of gravel containing the range of sizes from the smallest size in microns to the largest possible size. This may also be referred to as all-in aggregates. They are composed of both fine and coarse aggregates and without processing it produces low grade concrete, since some of the finer grades will contain silts and clays, Ogunmola, [3].

Neville [1] and Teychenne et al [4] suggested an alternative guide for continuous grading and gap grading, in which the coarse aggregate content can be subdivided if 10mm, 20mm and 40mm maximum aggregate sizes are combined depending on concrete usage, thus:

1 : 2 for combination of 10mm and 20mm material

1 : 1.5 : 3 for combination of 10mm, 20mm and 40mm material.

Variability of Concrete Strength

There are many factors, which affect the variability of concrete strengths. Teychenne et al [4] has listed those main factors influencing both the workability and strength of concrete that should be taken into account when designing a mix. It is probable that these factors will change during the progress of the job and should be accounted for. They can be made up of

variation in the quality of the materials

variation in the mix proportions due to the batching process and

variation due to sampling and testing.

Since concrete strengths follow normal distribution, it is expected that some proportion of the results may fall below specified values. For this reason, a measure of variability called standard deviation 's' is calculated as:

$$s = \sqrt{\frac{\sum (x-m)^2}{n-1}} \quad \ldots (1)$$

where x = an individual result, n = number of results, m = mean of the n results

Beal [5] suggested that for a set of three results, the term standard deviation is doubtful and it is better to talk of an average result. He suggested that average within-batch should be taken as $3\text{N/mm}^2 \pm 1.5\text{N/mm}^2$ from the mean and at a given level of control, the standard deviation increases as the characteristic strength increases up to a level, and above this level, it is independent.

It is a common practice now to adopt the characteristic strength concept for specifying strength development of concrete mixtures, below which a specified proportion of the test results called 'defectives' is expected to fall. It is on this basis of variability of results that a margin was introduced to have a mean strength greater than the specified characteristic strength. In other words, the designed strength should be greater than the design. In other words, further increase in cement content would not produce any appreciable increase in strength.

Slump

Slumps recorded are generally within the specified limits for continuously graded mix except for 20mm maximum aggregates sizes in which there occurs wide deviations. Mixes produced using these sizes have been recorded to be stiff thus requiring more mixing water. This is attributable to the large percentage proportion of aggregate sizes within 10mm and 20mm aperture sizes as evident in the sieve analysis. Conversely, slumps recorded for single size grading have been shown to exceed the expected slump values. This is attributable to the reduction in specific surface, since removal of intermediate sizes will reduce the specific surface thus requiring less water. For gap grading continuous and gap grading single size, slump values are also slightly exceeded. The results are presented in tables 1(a) – 1(c)

Table 1(a): Recorded Slumps against Expected for 10mm Maximum Aggregate Size.

Maximum Aggregate Size		10mm					
Characteristic Strength f_{cu} (N/mm^2)		20		25		30	
Free-water / Cement Ratio		0.55	0.55	0.53	0.53	0.48	0.48
Expected Slump (mm)		10-30	30-60	10-30	30-60	10-30	30-60
Recorded Strength (mm) for	CG	15	45	11	42	15	42
	SS	55	100	22	87	20	62
	ND	15	45	11	42	15	42

CG, SS, ND, GC and GS = Continuous grading, Single size grading, Natural *Deposit grading, Gap grading (continuos) and Gap grading (single site) respectively*

Table 1(b): Recorded Slumps against Expected for 20mm Maximum Aggregate Size.

Maximum Aggregate Size		20mm					
Characteristic Strength f_{cu} (N/mm^2)		20		25		30	
Free-water / Cement Ratio		0.55	0.55	0.53	0.53	0.48	0.48
Expected Slump (mm)		10-30	30-60	10-30	30-60	10-30	30-60
Recorded Slump (mm) for	CG	7	17	3	20	12	25
	SS	33	95	35	120	37	152
	ND	15	58	10	47	13	47
	GC	22	75	23	60	42	
	GS	24	75	25	68	22	63

CG, SS, ND, GC and GS = Continuous grading, Single size grading, Natural *Deposit grading, Gap grading (continuos) and Gap grading (single site) respectively*

Table 1(c): Recorded Slumps against Expected for 20mm Maximum Aggregate Size.

Maximum Aggregate Size		40mm					
Characteristic Strength f_{cu} (N/mm^2)		20		25		30	
Free-water / Cement Ratio		0.55	0.55	0.53	0.53	0.48	0.48
Expected Slump (mm)		10-30	30-60	10-30	30-60	10-30	30-60
Recorded Strength (mm) for	CG	12	40	10	38	12	45
	ND	15	18	12	45	12	45

CG, SS, ND, GC and GS = Continuous grading, Single size grading, Natural Deposit grading, Gap grading (continuos) and Gap grading (single site) respectively.

Compressive strengths

Compressive strength tests were carried out on specimen samples at 7 and 28 days respectively. The specimen samples prepared can attain as much as 80 percent of the 28 days strength. This obviously will allow stripping of formwork at an earlier age.

characteristic strength and that the mean strength is expected to be greater than the specified characteristic strength. Thus:

$$f_m = f_c + ks \qquad \ldots(2)$$

where: f_m = target mean strength, f_c = specified characteristic strength

s = standard deviation, k = a constant, ks = margin.

The value 'k' is derived from the mathematics of normal distributions and increases as the proportion of defective is increased. According to Beal, percentage defective is a chance variation as there is no guarantee that the expected defective batch will actually arrive on site. Conversely, it is also possible that 3 or 4 defective batches are also being supplied, therefore the chances/probability of occurrence of number of defectives can be calculated. The probability Pd of d defectives being delivered in T batches, if they are drawn from an infinite population with an overall proportion of P% defectives can be calculated by the formula as presented by Beal; thus:

$$Pd = \frac{T!\left(1-P\right)^{T-d} P^{d}}{d!\left(T-d\right)!} \quad \ldots \quad (3)$$

Compliance with Specified Requirements

The proportion of individual test results falling below the specified characteristic strength is most important according to the compliance criteria set out in the code of Practice CP 110. The limit of 5 percent has been set out. The mean strength obtained should always be greater than the characteristic strength. This implies that the limit is actually not on minimum strength. Beal [5] strongly criticized the replacement of 'minimum strength' by 'characteristic strength'. The new compliance acceptance provides that some defective materials will be supplied and that the limit of such material is not on minimum strength but on the maximum acceptable proportion of the defective material, which he termed to be inappropriate and vague. However, in a finished structure, the actual proportion of defectives is rather more important than the amount, which was expected.

The testing plans in the code of practice CP110 and BS 5328 both impose an absolute limit on minimum strength, yet the basic strength definition contains no such limit. Based on this definition, suppliers of concrete are neither bound by a minimum strength requirement nor even the limits of normal distribution provided he could show or expect less than 5 percent defectives.

DISCUSSION OF RESULTS

Measurements on the performance of the designed mixes were carried out both in the plastic and hardened states. Although the DOE mix design procedure specifies adjustments in mix proportions in order to produce the desired mix, which would have been an improvement on the properties exhibited by the first trial mix; this adjustment was however not carried out. This is because the aggregate source and characteristic properties will make further results obtained incompatible even with the revised

Table 2(a): Summary of the Cube Strengths for Grading Types for 10mm Maximum Aggregate Size.

Maximum Aggregate Size		10mm					
Free-water / cement rato		0.55	0.55	0.53	0.53	0.48	0.48
Expected Slump (mm)		10-30	30-60	10-30	30-60	10-30	30-60
Characteristic strength f_{cu} N/mm^2		20		25		30	
Recorded Strength (N/mm^2) for	CG	22.00	20.00	19.56	20.00	22.22	25.33
		25.33	25.33	26.22	26.37	35.70	35.70
	SS	21.33	20.89	19.11	20.44	25.33	22.62
		26.96	27.56	28.59	27.85	34.96	33.48
	ND	22.00	20.00	19.56	21.78	22.22	25.33
		25.33	25.33	26.22	26.37	35.70	35.70

The underlined quantities and the values not underlined are strength development at 7 and 28 days respectively. Each result is an average of three test results of 150x150x150 cubes

Table 2(b): Summary of the Cube Strengths for Grading Types for 20mm Maximum Aggregate Size.

Maximum Aggregate Size		20mm					
Free-water / cement rato		0.55	0.55	0.53	0.53	0.48	0.48
Expected Slump (mm)		10-30	30-60	10-30	30-60	10-30	30-60
Characteristic strength f_{cu} N/mm^2		20		25		30	
Recorded Strength (N/mm^2) for	CG	17.80	21.33	18.22	18.00	20.00	22.67
		22.67	25.78	24.45	25.19	26.96	26.45
	SS	18.22	18.22	22.22	18.67	22.22	21.33
		20.89	22.37	23.85	23.55	25.93	26.22
	ND	14.67	15.11	13.78	15.78	16.44	19.11
		20.44	22.22	21.78	22.22	29.78	32.00
	GC	21.78	23.56	21.78	23.56	29.78	25.33
	GS	20.00	19.56	20.00	20.44	25.78	25.33

The underlined quantities and the values not underlined are strength development at 7 and 28 days respectively. Each result is an average of three test results of 150x150x150 cubes

Table 2(c): Summary of the Cube Strengths for Grading Types for 40mm Maximum Aggregate Size.

Maximum Aggregate Size		40mm					
Free-water / cement rato		0.55	0.55	0.53	0.53	0.48	0.48
Expected Slump (mm)		10-30	30-60	10-30	30-60	10-30	30-60
Characteristic strength f_{cu} N/mm^2		20		25		30	
Recorded Strength (N/mm^2) for	CG	21.33	18.67	18.22	22.67	22.44	22.22
		24.31	23.34	24.00	25.56	31.55	31.26
	ND	14.44	14.89	17.11	15.56	19.78	19.11
		21.78	20.89	22.67	23.56	28.44	25.78

The underlined quantities and the values not underlined are strength development at 7 and 28 days respectively. Each result is an average of three test results of 150x150x150 cubes

The relationship

$$y = ax^b \qquad \ldots\ 4.1$$

is called a simple non-linear regression model with x as the independent variable and parameters *a* and *b* are the regression coefficients which can be solved explicitly by logarithmic transformation as:

$$\log y = \log a + b \log x \qquad \ldots\ 4.2$$

and the recovery of the coefficient and constant are obtained by taking the anti logarithm of the coefficient as:

$$a = anti\ \log(a) \qquad \ldots\ 4.3$$

The multiplicative model or multiple non-linear regression with two independent variables can similarly be written as

Average strengths recorded are generally above the specified characteristic strength values only in grade 20 concrete for all grading types and maximum aggregate sizes. Also, for grade 20 concrete, no individual test result falls below the specified characteristic strength. The standard deviations obtained were 1.57, 1.61 and 4.48 for grades 20, 25 and 30 concretes respectively. However, for grades 25 and 30 concrete, the average strengths recorded in some cases are below the specified characteristic strengths, which grossly violate acceptance criteria, since the margin '*ks*' cannot be negative. Only mixes with 10mm aggregates sizes do not exhibit aggregate breakages and strengths produced are well above the specified characteristic strengths. The foregoing discussion suggests that there is a higher reliability for mix designs in grade 20 concrete.

The high slumps recorded in single size grading may be partly responsible for the low strengths recorded. Aggregate breakages are also visible as a failure mode in single size grading and gap grading (single size). This suggests that the aggregates are weak.

It can further be concluded from the foregoing discussion that the uncrushed coarse aggregate samples can only be used to produce normal grade mixes up to $30N/mm^2$ but mix designs in grade 20 concrete is more reliable. The results are presented in tables 2(a) – 2(c)

Statistical Relationship between Strength Vs Water Cement Ratio and Free-water Vs Slump/Maximum Aggregate Size

If there exists some inherent relationship involving the set of variables from an underlying theory, then it is possible to arrive at the best estimate of the relationship between the variables. Where there seems to be lack of fit between a given data and regression equation then the problem can further be simplified by plotting the logarithm of the inputs on some graphs to reveal clearly the model fitting that best describes the results against the variable inputs. This however converts it to a linear sub-problem. This explicit method of solution forms the basis of the choice of the solution procedure adopted.

A relationship generally known to be non-linear can also be solved by fitting either a polynomial function, power function, exponential function or a reciprocal function, Walpole and Raymond, [6] and Draper and Smith, [7]. If there is no clear indication about the functional form of the regression of Y on X, it is often assumed that the underlying relationship is at least "well behaved" to the extent that it has a Taylor's series expansion and that the first terms of this expansion will yield a fairly good approximation and then fit a polynomial regression.

Regression Equation Formulation

The statistical technique adopted here is the method of least squares to estimate regression coefficients; which states that the sum of squares of the deviations between the observations and the mean is minimum Walpole and Raymond [6], Jerath and Kabani [8], Constantinides [9]. The following gives the minimization procedure for estimating the parameters and the constants.

Average strengths recorded are generally above the specified characteristic strength values only in grade 20 concrete for all grading types and maximum aggregate sizes. Also, for grade 20 concrete, no individual test result falls below the specified characteristic strength. The standard deviations obtained were 1.57, 1.61 and 4.48 for grades 20, 25 and 30 concretes respectively. However, for grades 25 and 30 concrete, the average strengths recorded in some cases are below the specified characteristic strengths, which grossly violate acceptance criteria, since the margin '*ks*' cannot be negative. Only mixes with 10mm aggregates sizes do not exhibit aggregate breakages and strengths produced are well above the specified characteristic strengths. The foregoing discussion suggests that there is a higher reliability for mix designs in grade 20 concrete.

The high slumps recorded in single size grading may be partly responsible for the low strengths recorded. Aggregate breakages are also visible as a failure mode in single size grading and gap grading (single size). This suggests that the aggregates are weak.

It can further be concluded from the foregoing discussion that the uncrushed coarse aggregate samples can only be used to produce normal grade mixes up to 30N/mm^2 but mix designs in grade 20 concrete is more reliable. The results are presented in tables 2(a) – 2(c)

Statistical Relationship between Strength Vs Water Cement Ratio and Free-water Vs Slump/Maximum Aggregate Size

If there exists some inherent relationship involving the set of variables from an underlying theory, then it is possible to arrive at the best estimate of the relationship between the variables. Where there seems to be lack of fit between a given data and regression equation then the problem can further be simplified by plotting the logarithm of the inputs on some graphs to reveal clearly the model fitting that best describes the results against the variable inputs. This however converts it to a linear sub-problem. This explicit method of solution forms the basis of the choice of the solution procedure adopted.

A relationship generally known to be non-linear can also be solved by fitting either a polynomial function, power function, exponential function or a reciprocal function, Walpole and Raymond, [6] and Draper and Smith, [7]. If there is no clear indication about the functional form of the regression of Y on X, it is often assumed that the underlying relationship is at least "well behaved" to the extent that it has a Taylor's series expansion and that the first terms of this expansion will yield a fairly good approximation and then fit a polynomial regression.

Regression Equation Formulation

The statistical technique adopted here is the method of least squares to estimate regression coefficients; which states that the sum of squares of the deviations between the observations and the mean is minimum Walpole and Raymond [6], Jerath and Kabani [8], Constantinides [9]. The following gives the minimization procedure for estimating the parameters and the constants.

$$y = ax_1^{\ b}\ x_2^{\ c} \qquad \text{... 4.4}$$

where *a*, *b*, and *c* are called the regression coefficients. Similar transformation to a multiple linear regression can be re-written as:

$$\log y = \log a + b \log x_1 + c \log x_2 \qquad \text{... 4.5}$$

and as before,

$$a = anti \log(a) \qquad \text{... 4.6}$$

Another model fitting involving transformation other than integer power is the exponential model of the type:

$$y = ab^x \qquad \text{... 4.7}$$

Whose solution is obtained by writing a set of simultaneous equation as:

$$\sum_{i=1}^{n} \log y_i = n \log a + \sum_{i=1}^{n} x_i \log b \qquad \text{... 4.8}$$

$$\sum_{i=1}^{n} x_i \log y_i = \sum_{i=1}^{n} \log a + \sum_{i=1}^{n} x_i^2 \log b \quad \text{... 4.9}$$

and the solution is:

$$a = \text{antilog}\,(a), \quad b = \text{antilog}\,(b)$$

The relationship between compressive strength and water/cement ratio were derived using Equations 4.1 and 4.2 while the relationship for free-water requirement as against expected slump and maximum aggregates size for both continuous and single size grading were executed using Equations 4.4 and 4.5. It also gives an inference on adequacy of the fitted model called the correlation coefficient R^2, which can range from 0 to 1, the larger the value of R^2 the better the model's fit.

Figures 1 and 2 give the relationship between compressive strength versus free-water/cement ratio for 7 and 28 days respectively. The relations for 28 days are as follows:

For continuously graded mix:

$$\text{Water content (kg/m}^3) = \frac{232.4952(\text{Slump})^{0.0714}}{(\text{Max. size})^{0.1742}} \quad (R^2 = 91\%) \ldots (4.10)$$

For single size graded mix:

$$\text{Water content (kg/m}^3) = \frac{219.60792(Slump)^{0.0918}}{(Max.\ size)^{0.2129}} \quad (R^2 = 89.6\%) \ldots (4.11)$$

2. For continuously graded mix:

$$f^1c\,(N/mm^2) = \frac{7.8936}{(w/c)^{1.8597}} \quad R^2 = 67\% \qquad \ldots (4.12)$$

For single size graded mix:

$$f^1\left(N/mm^2\right) = \frac{9.8629}{\left(w/c\right)^{1.5095}} \quad R^2 = 37\% \qquad \ldots(4.13)$$

The statistical relationship for free water requirements show a better correlation than for strengths.

Analysis of the results

Sufficient water is required for workability reasons and it should be noted that excessive quantity of water also reduces concrete strength. An acceptable mixing water to achieve the centre specification is therefore desired. For this purpose, a revised approximate free-water content (kg/m^3) required to give various levels of workability is suggested and presented in Table 3.0 for the uncrushed coarse aggregates considered. They are calculated from regression equations for continuous and single size gradings respectively. These values can now be used as a replacement for those suggested by the DOE mix design manual.

Also, in designing concrete mixes – using this uncrushed aggregates, the relationship between compressive strength versus free-water /cement ratio appropriate for this aggregate has been re-presented. They are derived essentially from regression analysis. Similarly, a revised approximate compressive strength (N/mm^2) of concrete made with a free – water cement ratio of 0.5 is also re-presented in Table 4. This table can be used to replace the one presented in the DOE mix design manual. It can be used directly as a starting design estimate and movement along the curve until it intercepts a horizontal line passing through the ordinate representing the target mean strength can be read easily. The corresponding value for the free – water / cement ratio is then read from the abscissa and used directly in further estimations for the proportion of concrete constituent materials. The regression equation was used to compute the graph of compressive strength- free water/cement ratio in figures 1 and 2

Table 3: Revised Approximate Free-water Contents (kg/m^2) Required to give Various levels of Workability.

Slump (mm)		0-10	10-30	30-60	60-180
V – B (s)		≥ 12	6 – 12	3 – 6	0 – 3
Max. size of aggregates (mm)	Type of aggregate				
10	Uncrushed	150 (175) <u>155</u>	180 (195) <u>175</u>	205 (210) <u>195</u>	225 (220) <u>210</u>
	Crushed	180	205	230	250
20	Uncrushed	135 (165) <u>135</u>	160 (180) <u>150</u>	180 (190) <u>165</u>	195 (205) <u>180</u>
	Crushed	170	190	210	225
40	Uncrushed	115 (140) -	140 (155) -	160 (165) -	175 (175) -
	Crushed	155	175	190	205

Values are to the nearest5 kg

Adapted from Manual on Design of Normal Concrete Mixes, DOE, HMSO, London. The values in parenthesis and those underlined are calculated from regression equation for continuous grading and single size grading respectively.

Table 4:Revised Approximate Compressive Strengths (N/mm2) of Concrete Mixes made with a Free-Water/Cement Ratio of 0.5

Type of Cement	Type of Coarse Aggregate	Compressive Strengths (N/mm^2) Age (days)			
Ordinary Portland Cement (OPC)	Uncrushed	18	27 (22) 22	40 (29) 28	48
Sulphate Resisting Cement (SPRC)	Crushed	23	23	47	55
Rapid Hardening Portland Cement (RHPC)	Uncrushed	25	34	46	53
	Crushed	30	40	53	60

Adapted from Manual on Design of Normal Concrete Mixes DOE, HMSO, London. The values in parenthesis and those underlined are calculated firm regression equations for continuous grading and for single size grading respectively.

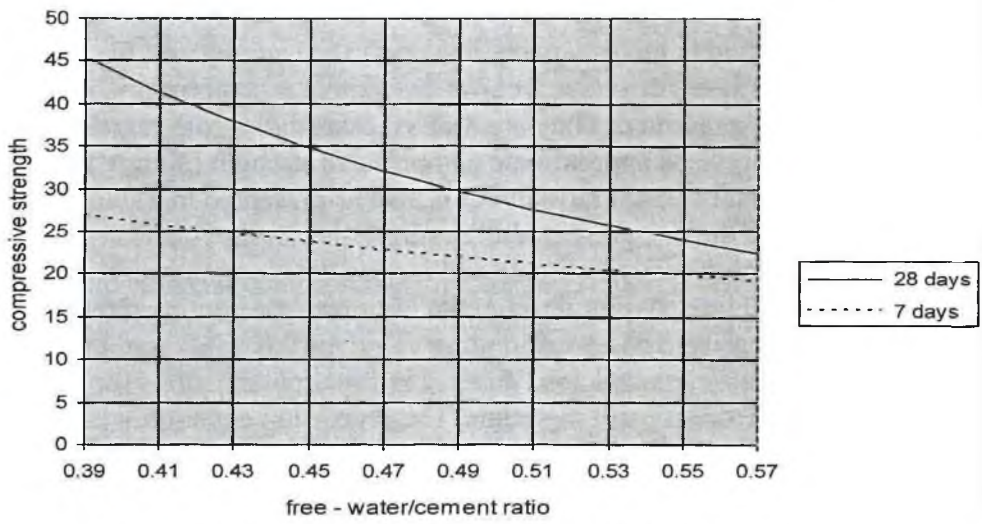

Fig. 1 compressive strength vs. free - water/cement ratio (continous grading)

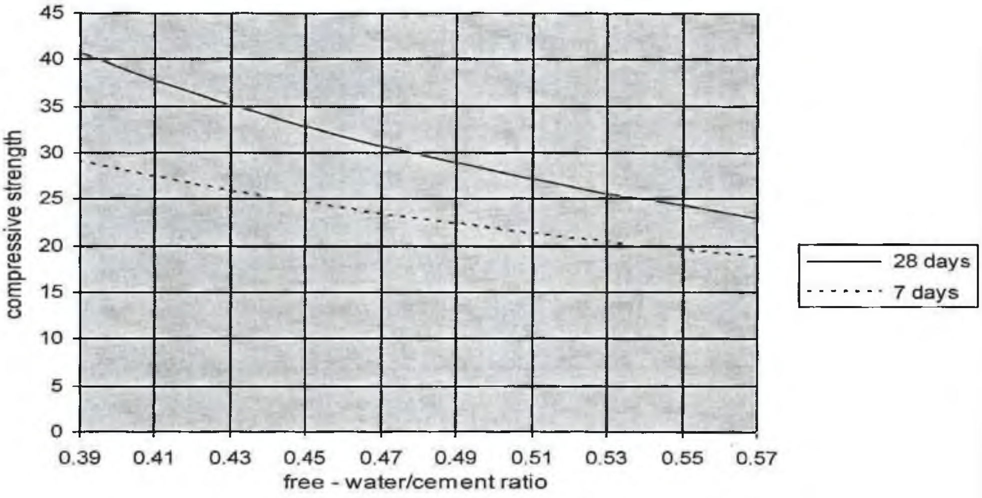

Fig. 2 compressive strength vs. free - water/cement ratio (single size grading)

CONCLUSION

Although the physical properties of the coarse aggregates satisfied specification requirements to produce normal grades concrete, premature fracture of the aggregate has made mix design strengths above 25N/mm^2 to be unreliable. From the study, the aggregates can be used economically if this limits are adhered to. The appropriate charts, tables and standard deviations for the revised relationship have been re-presented, which can be used directly in designing concrete mixes using the gravel as coarse aggregates.

REFERENCES

Neville, A. M. (1993). Properties of Concrete. Third Edition. Pitman Publishing Limited, London.

Alao, T.O (2006). Optimising the Design of Concrete Mixes Using the DOE Method for Uncrushed Aggregates. Journal of Research Information in Civil Engineering, University of Ilorin Science and Engineering Periodicals. Vol. 3. No. 1

Ogunmola, S.A (1991). A Study of the Suitability of Share Gravel as Concrete Aggregate. An Unpublished M. Eng. Thesis, Department of Civil Engineering,University of Ilorin.

Teychenne, D. C., R. E. Franklin, and H. Entroy (1975). Design of Normal Concrete Mixes. Department of the Environment, London, H.M.S.O.

Beal, A. N. (1981). Concrete Cube Strengths – What use Are Statistics?. Proceedings,Institution of Civil Engineers, December 1981, Part 2, Vol. 71: pp. 1037 – 1048.

Walpole, Ronald E. and Raymond. H. Myers (1972). Probability and Statistics for Engineers and Scientists. The Macmillan Company. New York. pp. 279 – 348.

Draper, N. and H. Smith (1966). Applied Regression Analysis. John Wiley and Sons Inc.New York. pp. 128 – 162, 263 – 301.

Sukvarsh Jerath and Isam. A. Kabani (1993). Computer – aided Concrete Mix

Proportining. Journal of the American Concrete Institute, proceedings, Vol. 80, No. 4, July – August, pp. 312 – 317

Constantinides, A (1983). Applied Numerical Methods with Personal Computers. McGraw-Hill Chemical Engineering Series, pp. 155 – 213.