Slump Test as an Indirect Indicator of the Characteristic Strength of Laterised Concrete

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This paper presents the possibility of using workability test (slump test) to predict the 28-day characteristic strength of laterised concrete. Three mix proportions: 1:1 1/2:3 (cement: laterite: granite chips), 1:2:4 and 1:3:6 were considered. The water cement ratios varied with each mix. For 1:1 1/2:3 from 0.52 - 1.12, 1:2:4 from 0.65 - 1.35 and for 1:3:6 from 0.90 - 1.80. Regression equations were used to fit the curve of the slump versus water/cement ratio and characteristic strength versus water/cement ratio. The equations were formulated for the descending portion of the characteristic strength curve where slump test is sensitive to change in workability taking the optimum water/cement ratio as the starting point. The ascending portion of the characteristic strength curve has initial zero slump and increases to optimum water/cement ratio. Generally, the results show good agreement between the experimentally observed quantities and the predicted values. The results further indicated that workability increases as water/cement ratios increase. At water/cement ratio lower than optimum, increase in water/cement ratios causes increase in strength but further increase after optimum water/cement ratio results in decreased strength values in all the mix proportions.

1. Introduction

Lateric soils are tropical in origin, they are readily available in many less developed countries where they can be available adjacent to the construction sites. Results of investigations on the properties of the soils (1 - 5) showed that concrete made with them are comparable in strength properties with those of normal concrete.

In engineering offices, design of concrete structures is usually based on specified characteristic strength of concrete, which is the strength expected to be accomplished on construction sites to ensure that the structures do not reach their limit states in service. Design methods use the concept of characteristic strength, that is, the value of compressive strength below which the strength of not more than 5% of the test material may be expected to fall. On big projects, efforts are made to ensure compliance with the specifications particularly the characteristic strength of concrete via quality control on sites. Cubes are usually made and cured in water and tested on the 28-day. The time lag between the casting of concrete and determination of the strength on the 28-day is such that if the strength falls short of specified, large amount of money is required to pull down the structure and rebuild it. In small construction projects, such a test is not carried out because the cost of the compression-testing machine is high, far beyond the purchasing power of most construction companies. The few laboratories that have the necessary equipment, apart from being far from most construction sites, charge colossal amount to carry out the test. Some investigations had been conducted on laterised concrete. It was reported by Lasisi and Ogunjimi (6) that

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source and mix proportions affected the characteristic strength of laterised concrete. In a related research, Falade (7) noted that the sources of laterite affect strength but according to him, the differences in strength values were statistically insignificant at 5% level. Schiessi and Schmidt (8) studied the bleeding characteristics of fresh concrete. The test method predicts the tendency of concrete mixtures to bleed and the effectiveness of preventive measures within the suitability tests. Popovics (9) in his study concluded that the available formulas for the prediction of the water requirement of concrete are not reliable enough and have limits of validity too narrow for practical purposes. He, however, noted that promising improvements existed as presented in his paper both in general and in particular forms.

Slump is the loss of plasticity or workability of fresh concrete and it measures the consistency of plastic concrete. Workability is an important factor of freshly mixed concrete as it determines the placeability and compactibility of the concrete. Placeability and compactibility of the mix also affect the compressive strength. Properly placed and compacted concrete will have higher strength than a poorly placed and compacted one. Numerous attempts have been made to correlate workability with some easily determinable physical measurement but none of these is truly satisfactory although they may provide useful information within a range of variation in workability. Some tests used for determining workability are slump test, compacting factor test, flow test, remoulding and vebe consistometer tests. Slump test is the most commonly used method for measuring the consistency or wetness of concrete. Powers (10) described the slump test as significant on the basis of its sensitivity to consistency. It is important to note that there is a limit to the class of consistency for which slump is valid. The test is not suitable for very stiff consistency (very dry mix) and flowing consistency (very wet mix). The slump test is sensitive to intermediate consistency. Neville (11) specified medium slump (50 - 100mm) for normal reinforced concrete, manually compacted and heavily reinforced sections with vibration. The slump characteristics of laterised concrete have not been given adequate attention possibly because of the charges that the slump of normal concrete for which laterised concrete is to be a substitute is insensitive and its results are unreproducible (Scholer, 12). However, it was reported by Popovics (13, 14, 15) that the slump is proportional to the tenth power of the water/cement ratio. He further noted that there was a good correlation between the K-procedure (a reliable method for measuring workability) and slump for values between 30 mm and 180 mm. It is therefore possible that the so-called poor reproducibility of the slump test is as a result of its high sensitivity. The advantages of slump test are:

(a) The apparatus consists mainly of a simple and relatively small cone, easy to handle either on site or in the laboratory,

(b) It does not require any skill,

(c) It is non-electricity dependent and,

(d) It can be used conveniently as a control test and gives indication of the uniformity of concrete from batch to batch.

In order to ensure that the specified strength of laterised concrete is satisfied on site, certain quality control measures are required. The use of slump test provides one of such methods by which the compressive strength of concrete can be assessed before casting the structural units.

The objectives of this study are to:

(i) Develop relationships between water/cement ratio, slump and strength in order to enable the prediction of 28-day characteristic strength indirectly from slump values,

(ii) Compare the experimentally determined quantities with those results obtained from the derived equations and

(iii) Investigate the effects of water/cement ratio and aggregate/cement ratio on strength values.

2. Methodology

Some of the factors that affect workability and compressive strength of concrete are:

- Water/cement ratio
- Quality of aggregate
- Specific surface area of aggregate
- Type and fineness of cement and aggregate
- Method of preparation
- Curing age
- Entrained air

Among these factors, for a specified aggregate size, and type and cement, the workability and compressive strength will be more affected by variation in water/cement ratios.

2.1 Preparation of Specimens

In order to test the hypothesis of the regression equations defining relationship between the water/cement ratio, slump and 28-day characteristic strength, test cubes were made for different mix proportions at varying water/cement ratios. The particle size ranges of lateritic soil used are those passing sieve size 2.36 mm but retained on sieve with aperture 0.30 mm opening. The coarse aggregate is from crushed granite. The particle sizes varied from 10 mm - 19 mm. **Figure 1** shows the grain size distribution for both the fine and coarse aggregate. Ordinary Portland cement whose properties conform to BS 12 (16) was used. Three mix proportions were considered, namely 1:1 1/2:3 (cement: laterite: granite chips), 1:2:4 and 1:3:6 representing rich, medium and lean mixes that are commonly used on construction sites. Batching was by weight. The water cement ratios varied with each mix. For 1:1 1/2:3 from 0.52 - 1.12, 1:2:4 from 0.65 - 1.35 and for 1:3:6 from 0.90 - 1.80. 100 mm cubes were used. The mixture of cement, lateritic soil and granite chips were mixed mechanically in a mobile rotating drum mixer. When the constituents had been thoroughly mixed, the required mixing water was added gradually. The workability (using slump test) of the fresh concrete was determined immediately after the final mixing. The cubes were cast in three layers in accordance with BS 1881 (17). Each layer was rodded 25 times. The blows were uniformly distributed over the surface of the mould. As the moulds were tapped, they were intermittently shaken to ensure the dislodgment of trapped air so that a densified and non-entrained air concrete could be obtained. The moulds with the cast specimens were stored for 24 ± 1 1/2 hours with polythene cover before demoulding. Subsequently, the cubes were demoulded and transferred into the curing tank that contained clean water. The average temperature of the curing water was 21 ± 2°C.

2.2 Testing of Specimens

Three specimens were tested at 28-day curing age for each water/cement ratio. The compressive strength of each cube was determined in accordance with BS 1881 (18) using a loading rate of 120 MN/min on a 600 KN Avery Denison Universal Testing Machine. The compressive strength was determined from relationship.

$$f = P/A \qquad (1)$$

and the characteristic strength was found from

$$f_{cu} = f_m - 1.64\,S \qquad (2)$$

where,

f	=	compressive strength
p	=	failure load
A	=	surface area of cube
f_{cu}	=	characteristic strength
f_m	=	arithmetic mean of the test results
S	=	standard deviation

3. Results and Discussion

3.1 Results

The moisture content test showed that the natural moisture content of the soil is 4.61% while the result of Atterberg limit tests indicated that the soil has liquid and plastic limits of 43.8% and 32.08% respectively. The sedimentation test showed that the fine particles in the lateritic soil sample is 3.45%. **Figure 1** shows the grain size distribution of the component of the laterised concrete. **Figure 2** shows the curves of experimental and the predicted slump and 28-day strength values for 1:2:4 mix proportion. **Table 1** presents the experimental results and those obtained from the regression equations for all the mix proportions considered in this study.

3.2 Discussion

Table 1 shows that with increase in aggregate/cement ratio, the water requirement for a mix to maintain the same level of workability increased. For each mix proportion, there exists optimum water/cement ratio. At water/cement ratio lower than optimum increase in water/cement ratio resulted in increased workability and strength. But at water/cement ratio higher than optimum value, increase in water/cement ratio led to increase in workability but decrease in strength. The increase in workability can be attributed to excess water in the mix while the decrease in strength is due to increase in quantity of water entrained in the hardened cube. This results in the development of internal pore pressure as the external load is applied which reduces the strength of the cube specimens. The curves for the slump have two distinct zones: linear and non-llinear. This assisted the formulation of linear and non-linear regression equations for the data collected for slump values in the laboratory.

The slump values at the boundary between the two zones are 60 mm for 1:1 1/2:3, 70 mm for 1:2:4 and 93 mm for 1:3:6. They occur at water/cement ratios of 0.92, 1.15 and 1.60 respectively. Imperical relationships were derived using regression analysis for each mix proportion to enable the prediction of slump and strength at any given water/cement ratio for each mix. The regression equations are formulated for the descending portion of the curve of the strength starting from the experimentally determined

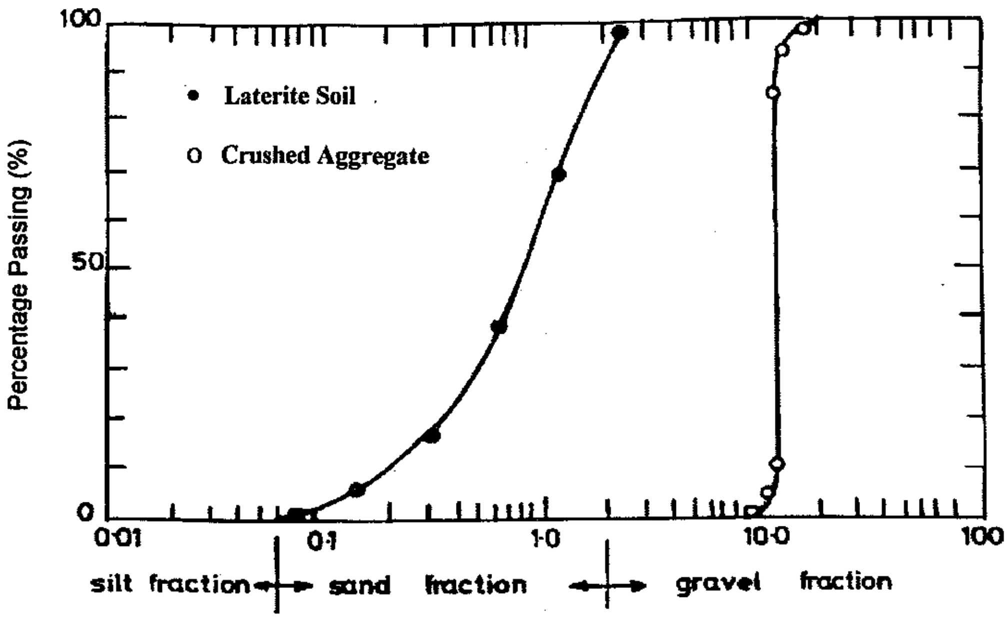

FIGURE 1: *The Results of Sieve Analysis of the Laterite Soil Sample and Crushed Aggregates*

optimum water/cement ratios, which give the maximum strength values. The ascending portions of the curve were not considered because of the insensitivity of slump test to measure the consistency of stiff mix. For the slump, the derived relationships between slump values and water/cement ratios are:

Zone 1 (lower portion of the curve)

Mix	Equation
1:1 1/2:3	$Y = 138.88\,X^{9.76}$ ....(3)
1:2:4	$Y = 20.47\,X^{9.36}$ ....(4)
1:3:6	$Y = 0.69\,X^{10.78}$ ....(5)

Zone 2 (upper portion of the curve)

Mix	Equation
1:1 1/2:3	$Y = 615\,X - 505.97$ ....(6)
1:2:4	$Y = 572.5\,X - 587.79$ ....(7)
1:3:6	$Y = 460\,X - 642.3$ ....(8)

Where,

Y = Slump
X = Water/cement ratio

For the 28-day characteristic strength and water/cement ratio, the relationships are:

Mix	Equation
1:1 1/2:3	$F_{28} = \dfrac{47.23}{4.83^{x}}$ ....(9)
1:2:4	$F_{28} = \dfrac{37.46}{3.65^{x}}$ ....(10)
1:3:6	$F_{28} = \dfrac{23.6}{2.98^{x}}$ ....(11)

where,

F_{28} = 28-day characteristic strength
X = water/cement ratio

In equations 3 - 11, to evaluate the values of slump and strength, the only unknown quantity is water/cement ratio, which makes the computation of slump and characteristic strength to be less cumbersome. The equations give good agreement with the experimentally determined quantities. At this point, it should be mentioned that a wide range of variables affects the workability and characteristic strength of concrete. Therefore, evaluating the parameters of equations to fit one series of experimental results may not

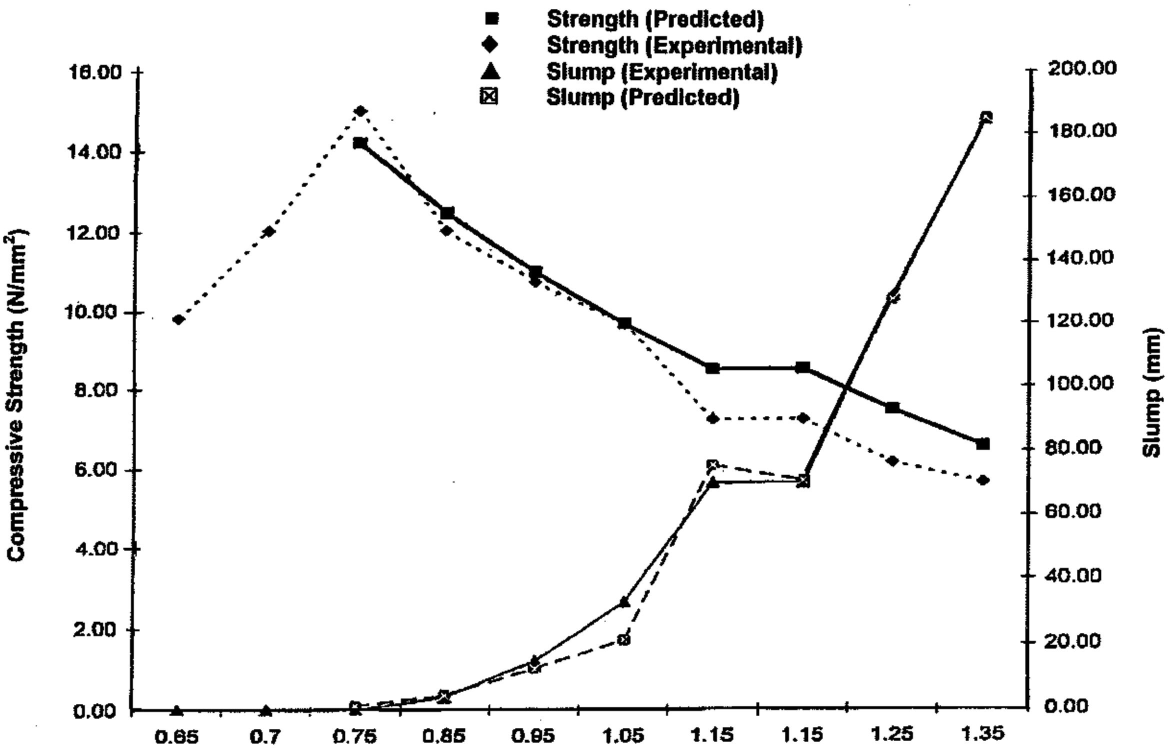

FIGURE 2: *Variation of Compressive Strength and Workability with Water/Cement Ratios*

assume the same degree of accuracy for another series tested under different conditions. A better and more logical way of incorporating the effect of the various factors is to evaluate the parameters of the equations on the basis of the average data collected for specimens with different concrete characteristics and tested under different conditions.

4. Conclusions

From the results of this study, the following conclusions can be made:

(1) For a specified aggregate size, type and cement, the characteristic strength and slump value of laterised concrete can be predicted at a given water/cement ratio.

(2) For each mix, below the optimum water/cement ratio, increase in water/cement ratio resulted in increased workability and strength but above the optimum value, further increase in water/cement ratio resulted in increased workability but decreased strength.

(3) When aggregate/cement ratio was increased, the water requirement to maintain the same level of workability increased for each mix proportion.

5. Acknowledgement

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TABLE 1: *Experimental and Predicted Values of Workability and Characteristic Strength*

Mix Proportion	Water/Cement Ratio	Slump (mm) Experimental Values	Slump (mm) Predicted Values	28-Day Strength (N/mm^2) Experimental Values	28-Day Strength (N/mm^2) Predicted Values
1 : 1 1/2 : 3	0.52	0.00	-	11.00	-
	0.57	0.00	-	12.43	-
	0.62*	0.00	1.31	17.40	17.79
	0.72	5.50	5.63	15.60	15.20
	0.82	21.00	20.02	13.90	12.98
	0.92	60.00	61.55	11.80	11.09
	0.92	60.00	59.83	11.80	11.09
	1.02	121.00	121.33	9.80	9.48
	1.12	183.00	182.83	7.90	8.09
1 : 2 : 4	0.65	0.00	-	9.80	-
	0.70	0.00	-	12.02	-
	0.75*	0.00	1.39	15.00	14.19
	0.85	4.00	4.50	12.00	12.46
	0.95	15.00	12.67	10.70	10.95
	1.05	33.00	21.55	9.60	9.62
	1.15	70.00	75.62	7.20	8.45
	1.15	70.00	70.59	7.20	8.45
	1.25	129.00	127.84	6.10	7.43
	1.35	184.50	185.09	5.60	6.52
1 : 3 : 6	0.90	0.00	-	5.90	-
	0.95	0.00	-	6.10	-
	1.00*	0.00	0.69	8.70	7.91
	1.10	1.50	1.93	7.70	7.09
	1.20	6.00	4.93	6.30	6.36
	1.30	13.50	11.67	5.80	5.70
	1.40	30.00	25.95	5.30	5.11
	1.50	54.00	54.51	4.60	4.58
	1.60	93.00	109.46	4.30	4.11
	1.60	93.00	93.00	4.30	4.11
	1.70	141.00	139.70	4.00	3.68
	1.80	185.00	135.70	3.70	3.30

* Optimum water/cement ratio

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