Comparative Reliability of Ultrasonic Pulse Velocity and Rebound Hammer Test Methods in Assessing Compressive Strength

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Abstract

This is an evaluation of the efficacy of the two most popular Non Destructive Testing (NDT) methods – Ultrasonic Pulse Velocity (UPV) and Rebound Hammer (RH) in assessing compressive strength of concrete. 150mmx150mmx150mm concrete cube samples were prepared, cured and subjected to UPV and RH tests at the end of : 1, 3, 7, 14, 21, 28, 56 and 90 days. The same samples were, then subjected to destructive (compressive strength) test. Correlation test, multiple regression analysis, graphs and visual inspection were used to analyze the data obtained. Results indicated increase in rebound hammer from 24 rebounds on the first day to 43 rebounds on the 90th day; while the result of UPV decreases from 43.10 Micro-Sec. on the first day, to 35.90 Micro-Sec. on the 90th day of curing. Regression Model which combines UPV with RH gave the following results: 10.93 N/mm^2, 13.99 N/mm^2, 25.23 N/mm^2 29.72 N/mm^2, 33.45 N/mm^2, 33.32 N/mm^2, 35.45 N/mm^2 and 36.75N/mm^2 for 1, 3, 14, 21, 28, 56 and 90 curing days, respectively. The conclusion drawn from the analysis, is that combination of rebound hammer and UPV methods is effective in assessing compressive strength of concrete. Hence it is recommended that for more accurate result, rebound hammer should be combined with UPV testing concrete, and that the following formula should be used = 45.80 + 0.88 X_1-1.31 X_2.

Keywords: *Concrete, Comparative study, **c**ompressive strength, rebound hammer**,** ultrasonic pulse velocity*

Introduction

Concrete constitutes between 50 to 70% of the total cost of building materials used to construct a building (Okekere, 2007). The quality of concrete in any building project, therefore , determines, to a large extent, the quality of the building, in terms of the performance of such structure, production cost and delivery time. Since, in practice, there is always a variance between the quality of materials after construction and that assumed during the design, such variation in properties should be kept as minimal as possible by constantly monitoring and controlling the properties of such material during the construction stage. This can be accomplished through material testing (Neville, 2007).

Ideally, such testing should be done without damaging the concrete. Non-Destructive Testing (NDT) is gaining ground as a technique which will assist in quality control of concrete. NDT may be applied to both existing structures and those under construction. According to Shetty (2010) NDT is now considered as a powerful method for evaluating existing concrete structures with regard to their strength and durability apart from assessment and control of quality of hardened concrete. NDT methods are relatively simple to perform. This, explain the reason why one of the recommendation made by Gambhir (2006), as a means of achieving significant improvement in concrete production, over the next quarter of a century, is making full use of non – destructive measurement and other technology advances to continuously monitor property performance and to maintain durability.

According to Carino (1994) and Opoola (2015), there has been reluctance in developing NDT test methods for concrete arising from the fact that they had evolved from the military research programme. According to Gambo (2017) NDT has a lot of advantages as a viable alternative for testing concrete structures. However, a major problem associated with it, is that it only assess not measure the quality of concrete. Thus, NDT rarely give a 'number' which can be unequivocally interpreted: engineering judgment is necessary (Neville, 2007). This is largely due to the inability of researchers to establish relation between the property measured by a given test and the compressive strength of test specimen.

This, undoubtedly is major drawback because it is only when inspection results are expressed in quantitative terms that such test method can be regarded as a measure of true quality.

That is why Shetty (2010) and Breysse, (2012) noted that the greatest challenge of adopting NDT methods for concrete is the fact that despite the relative simplicity of methods, the analysis and interpretation of the test result are not so easy. This agrees with the view Idrisoour (2006) who observed that the major drawback of NDT of concrete lies in the processing and interpretation of data. This, has led to one fundamental research question – on how to, not only develop new NDT methods but also improve the existing ones. UPV and RH are the two most popular NDT method used in the construction industry (Abdul-Salam, 1992; Ejeh & Dahiru, 1997; Arizioz *et al* (2009); Samarin & Meynink (1981) as cited in Alibado & AbdElmoaty, 2012) The non-destructive tests are usually used to give an approximate of the strength of concrete.

Materials and Methods

Materials

The materials used in the experiment are: Cement, fine aggregates, coarse aggregates and water. Details of the nature and quality of such materials are as follows:

Cement: The type of cement used for the study was the brand of Blended limestone cement. Tests were carried out in compliance with the Nigerian Industrial Standards, NIS, 11 (1974), NIS, 445 (2003), NIS 447 (2003), NIS 455 (2003) and British standards BS 12 (1996). The test includes the following;

a. Setting time test
b. Soundness and
c. Consistency test

These tests were undertaken in a concrete laboratory at Department of Civil Engineering, Ahmadu Bello University, Zaria. The tests results are presented in Table 2. Chemical analysis of the cement sample was carried out at the Centre for Energy Research and Training, CERT, Ahmadu Bello University, Zaria. Details of the results are presented in: Table .3.

Fine aggregates: Fine aggregates used in this research work were clean and air - dried river sand obtained from Bomo the outskirt of Zaria. It was sieved with a 5mm B5 112 (1971) sieve, so as to remove the impurities and larger aggregates. Before, the fine aggregates were used; they were subjected to sieve analysis. This was undertaken in accordance to the BS 933 Part 1 (1997). The result is presented in: Table 4.

Other properties of fine aggregates that were investigated include: Specific gravity on both oven dried basis, apparent specific gravity and water absorption. These tests were carried out in accordance with the following British Standards: BS 812 (1990), BS 882 (1992) and BS 933 (1997). Details of the results are presented in: Table .5.

Coarse Aggregates: The coarse aggregates used were crushed granite stones obtained from single quarry site along Zaria-Sokoto road, opposite Nigerian College of Aviation Technology, NCAT, Zaria. Sieve analysis was carried out on the coarse aggregates used in the experiment in accordance to BS 933 Part I (1997). The result of sieve analysis is presented in: Table 6

Other properties of coarse aggregate that were investigated include specific gravity on oven dried basis, apparent specific gravity and water absorption. These tests were undertaken in accordance to the following British standards: BS 812 (1990), BS 882 (1992) and BS 933 (1997). Details of the results are presented in: Table 7.

Water: Water used for mixing was clean, fresh, free from injurious oils, chemicals and vegetable matter or other impurities. It was portable water obtained directly from the tap.

Preparation of concrete samples

Mix Design

The final mix design entails the use of absolute volume batching with nominal mix of 1:2:4 and a water-cement ratio of 0.50 were chosen, based on the result of the trial mix. This was done in order to determine the proportion of each constituent to be used in the production of concrete samples. A mixing machine of horizontal rotary drum mixer with a revolution of 7turns/minutes and manual vibration method were used to produce the concrete cube.

The preparation of the samples and testing were carried out in accordance to the appropriate British standards such as BS 1881 (1986), BS 1881 (1988) BS 812 1990) and American Standard Testing Methods (ASTM).This was carried out at the Concrete Laboratory, Department of Civil Engineering , Ahmadu Bello University, Zaria. A total of 148 concrete cubes measuring 150mm x 150mm x 50mm were produced to cover all the various NDT tests.

Table 1: Quantity of Materials Required for a Batch of 12 Cubes

S/N	Types of Material	Quantity of Material required (Kg)
1.	Cement	14.17
2.	Sand	31
3.	Coarse Aggregate	60
4.	Water	6.5

Tests Undertaken

After calculating the required quantity of the individual ingredients needed as shown in Table 1, the concrete cubes produced, were subjected to the following tests, so as to assess the compressive strength of concrete, at the end of 1, 3, 7, 14, 21, 28, 56 and 90 days of curing. These tests include:

i. Ultrasonic pulse velocity test
ii. Rebound hammer test

Ultrasonic Pulse Velocity Test

At the end of each curing days, three (3) concrete cube samples were removed from curing tank and allowed to drain. They were, then, subjected to ultrasonic pulse velocity test in accordance to BS 1881: Part 203 (1986). The test was carried out at the concrete laboratory department of Civil Engineering, Ahmadu Bello University Zaria.

Rebound Hammer Test

Concrete cube samples were subjected to Rebound Hammer test at the end of each curing day. This was carried out in accordance to BS 1881: Part 202 (1986). A standard Schmidt hammer type N was used. For each set of tests, ten readings were recorded in order to make sure that the difference between the readings is not more than 4. The test was carried out in Department of Civil Engineering Ahmadu Bello University, Zaria.

Results and Discussions

Table 2: Physical Properties of Cement

Physical Properties	Determined as
Soundness	7mm
Setting time	
- Initial	133minutes
- Final	213minutes

Table 3: Chemical Composition of Blended Limestone Cement Brand

Oxide composition	Percentage oxide
SiO2	20.55
Al_2O_3	5.07
C_aO	64.51
Fe_2O_3	3.10
SO_3	2.53
MgO	1.53
K_2O	0.73
LOI	1.58

Table 4: Particle Size Distribution for Fine Aggregates

S/N	Sieve Sizes (mm)	Cumulative Passing (%)
1.	5	89.60
2.	2.36	79.10
3.	1.18	59.40
4.	600µm	32.40
5.	300µm	0.60
6.	150µm	0.25
7.	Pan	-

Table 5: Properties of Fine Aggregates

Parameters	Determined As
Specific gravity on oven dried basis	2.44
Specific gravity on saturated surface dried (SSD) basis	2.50
Apparent specific gravity	2.65
Water absorption (%)	3.20
% Silt con tent	1.90

Table 6: Particle Size Distribution for Coarse Aggregate

S/N	Sieve Sizes (mm)	Cumulative Passing (%)
1.	20	97.10
2.	10	55.88
3.	5	34.10
4.	2.36	28.00
5.	1.18	20.26
6.	600µm	11.10
7.	300µm	0.23
8.	150µm	0.083
9.	Pan	-

Tab le7: Properties of Coarse Aggregate

Parameters	
Specific gravity on oven dried basis	2.42
Specific gravity standard surface dried (SSD) basis	2.47
Apparent specific gravity	2.16
Water absorption	2.00
% silt content	0.85

Table 8: UPV Test Results and Compressive Strength of Crush Concrete Cube

Age (*Days*)	**Weight** (*kg*)	**UPV Readin g** (*Micro-second*)	**Compressive strength of Crushed Concrete Cube** (*N/mm²*)
1	8.28	43.10	8.94
3	8.25	41.50	16.65
7	8.30	37.60	27.13
14	8.20	35.40	29.41
21	8.15	35.90	30.60
28	8.15	36.90	32.59
56	8.20	36.10	37.31
90	8.10	35.90	38.40

Table 9: Result of RH and Compressive Strength of Concrete Cube

Age (*Days*)	**Average Rebound No** (*Rebounds*)	**Corresponding RH Compressive Strength From Table** (*N/mm²*)	**Compressive strength of Crushed Concrete Cube** (*N/mm²*)
1	25	16.30	8.94
3	26	20.16	16.65
7	33	34.15	27.13
14	34	38.22	29.41
21	39	48.88	30.60
28	40	50.13	32.59
56	42	55.85	37.31
90	43	58.40	38.40

Comparative Analysis of Compressive Strength, UPV and Rebound Hammer Tests Results

Furthermore, in order to compare the NDT test results (UPV and rebound hammer), with the destructive, compressive strength test result, another strength was calculated using the result of regression analysis of the NDT tests (UPV and rebound hammer tests) on one hand and destructive (compressive strength test) results, on the other hand. The strength determined is presented in Table 10.

Table 10: Comparison between Experimental and Theoretical Values of Concrete Cube Strength Determined Using the Combination of RH and UPV Test Results

Age	Experimental Values $45.8+0.88X_1-1.31X_2$ (N/mm^2)	Theoretical Values (*Regression Model*) (N/mm^2)	% Difference
1	8.94	10.93	22.25
3	16.85	13.99	-15.96
7	27.13	25.23	-7.00
14	29.41	29.72	1.10
21	30.66	33.45	9.10
28	32.59	33.32	2.24
56	37.31	35.47	-4.93
90	38.40	36.75	-4.30

As it can be observed from Table 10 the theoretical values determined from the multiple regression analysis slightly vary with the experimental values. Four of the theoretical values are marginally higher these are $10.93mm^2$, $29.72mm^2$, $35.45mm^2$ and $33.32mm^2$ as compared to the experimental values of: 8.94, 29.41, 30.66, 32.59, representing the following curing days: 1, 14, 21, and 28 while the remaining four are slightly less than the experimental values. These are $13.99N/mm^2$, $25.23N/mm^2$, $35.47N/mm^2$ and $36.75mm^2$, for 3, 7, 56 and 90 curing days respectively. However only three of the theoretical values are above or below +/ (-) 5.The mean of the percentage difference is 0.3%. Thus if the mean percentage difference is considered, then it can be inferred that there is no significant difference between the theoretical values and the experimental values, therefore, they are close.

This study also considers the combination of more than one method in evaluating the results. A comparison of the two tests results using graphs, was, first and foremost, carried out. The graphs are of two broad categories:

i. The graphs of test results using different methods, without converting the units of each test result to strength. This is in order to observe the shape of such graphs, by visual inspection, as the age of concrete sample appreciates.

ii. The graphs of test results obtained from various methods which were converted to strengths.

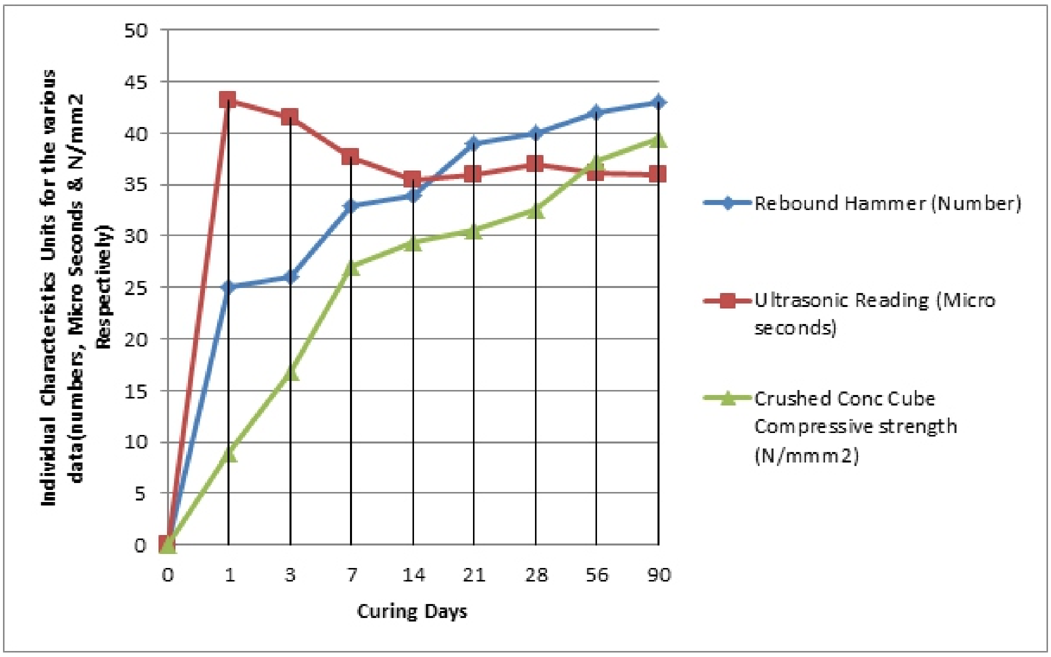

Figure 1: *Relationship between Crushed Concrete Cube Compressive strength, RH and UPV.*

From figure 1, it can be observed that the graph of RH readings has shape similar to the graph of compressive strength. There is rise in the values of the test results of these two test methods with increase in age. This means that RH test results, can give an idea of the compressive strength of the same structure.

On the other hand, the graph of UPV results showed a slight drop from left to right - meaning the value of UPV test results decrease with increase in curing days.

According to experts (e.g. RILEM Committee 43, 1993; Ferreira & Castro, 2000, Proverbio &Venturi, 2005, and Neville, 2007, Shetty, 2010), it is advantageous to use more than one NDT method at a time, most especially in situations where variation in properties of concrete affects the test results in opposite directions. For example, presence of moisture in concrete increases the UPV but decreases the rebound number. As such, accurate result may not be obtained if one of the aforementioned NDT methods is used in testing moist structure. Thus to get accurate result, from the study, multiple regression analysis was used to analyse the results of UPV, rebound hammer and compressive strength tests in order to establish a relation between the three results. This is to improve on ways and means of assessing the compressive strength of concrete (destructive test result) given the non-destructive test results. Summary of the result of the regression analysis is presented in Table 11.

Table 11: Results of Regression Analysis of Compressive Strength, RH and UPV Tests Results

Model A	**B**	**Level of Significance**
1. (Constant)	44.138	0.349
X_1	0.802	0.052
X_2	-1.183	0.225
Model B		
1. (Constant)	-26.560	0.657
X_1	0.957	0.025
X_2	0.597	0.689

Where: *X_1 X_2 are constant for the regression model*

Results of the analysis using the compressive strength results, UPV and rebound hammer tests for all the curing days (model A), showed that the level of significance of the intercept (constant), slopes - Pi and β_2 are 0.349, 0.052 and 0.225 respectively when these values are compared with 0.05 it can be seen that they are all greater as such, the result can be relied upon. Thus the equation obtained is as follows:

$$y = 44.138 + 0.802X_1 - 1.183X_2 \qquad 1$$

Where:

y = compressive strength (*N/mm²*)

X_1 = number of rebounds (*Number*)

X_2 = Ultrasonic pulse velocity (M*icro-seconds*)

Comparison of the Strengths obtained from UPV and RH Test Results and the concrete cube strength.

In order to arrive at a common and reliable base for comparative analysis, the UPV and rebound hammer test results were first of all, converted to strength. They were then, compared with the strength of concrete.

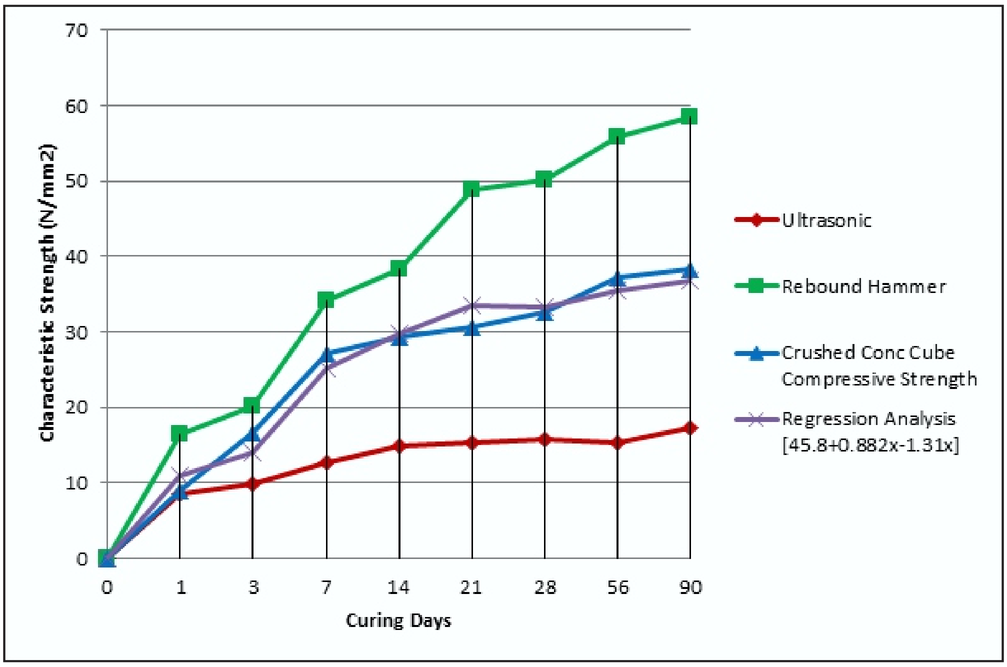

***Figure 2:** Graph of Strengths Obtained from UPV, Rebound Hammer and Compressive Strength of concrete cube*

This is shown in Figure 2. As it can be observed all the four graphs for ultrasonic test result, rebound hammer, the crush concrete cube strength and theoretical values obtained from regression model (45.8+0.882X-1.31X) rise from left to right meaning that there is direct relationship between the strength and age of concrete. These clearly show the actual pattern of strength development of concrete. Increase in compressive strength, with corresponding increase in age of the concrete. Although, the strength obtained from rebound hammer test result, is higher than the concrete cube strength determined from the destructive test (compressive strength test). On the other hand, the strength calculated from the UPV test result is comparatively lower than the strength of concrete cube determined from compressive strength test result.

However, one remarkable thing about this analysis is that the graph drawn using the multiple regression equation is very close to the concrete cube strength obtained from the compressive strength test. This means given the UPV and Rebound Hammer test results, the multiple regression equation derived from this study can be applied to determine the strength.

Table 12: Correlation of Compressive Strength against RH, UPV and Weight

	RH	UPV	Weight
Compressive Strength	0.914**	-0.929**	0.283

This means that it is only in one out five cases that such prediction can be accurate. As it can be observed from Table 12 result of correlation analysis shows that there is very high correlation (0.91) between compressive strength and rebound hammer – the higher the rebound hammer the higher the compressive strength, this is a very good linear relationship on the other hand there is corresponding inverse relationship between compressive strength and ultrasonic plus velocity this is very close to the maximum of (-1.00).

As it can be seen from Figure 2, the graph of UPV and Rebound hammer and that of rebound hammer only are closer to the graph of strength of concrete cube. This further confirms the earlier observation made - that the multiple regression analysis formula which combination UPV and RH. Results is reliable as values of obtained are very close to the values of concrete cube strength.

Table 13: Comparison between the Theoretical Models Determined from the Result of Analysis of NDT Results

S/N	NDT Method	Theoretical Model	Method of Analysis Used to determine the significance of the model			
			R^2 (%)	% difference of paired T Test Results	% difference between experimental and theoretical values	Ranking
1	Combination of RH& UPV	Regression Model $45.8 + 0.882X_1 + 1.31X_2$	96.1	-0.98	0.31	1st
2	Rebound Hammer	Regression model $-19.80 + 1.35X_1$	93	0.69	3.90	2nd
3	Ultrasonic Pulse Velocity	Regression Model *151 - 3.26*	87.4	1.55	3.4	3rd
4	Rebound Hammer	Graph $C = 0.6r$	-	-23.40	14.28	4th
5	Ultrasonic Pulse Velocity	Graph $C = 1378.56/T$	-	32.80	44.68	5th
6	Rebound Hammer	Conversion Table	-	-45.82	6.5	6th

Conclusion and Recommendations

Conclusions

The RH test method is more effective in predicting concrete cube compressive strength more than the UPV. The values obtained from the multiple regression analysis equation which relates UPV and rebound hammer test results with strength of concrete cube is very close to the actual compressive strength test result. Hence, more effective in assessing the strength of concrete.

Recommendation

Based on the result of the study, the following recommendations are made:

1. For more accurate result, RH should be combined with UPV in testing concrete,
2. Where RH and UPV are combined, the following formula should be used to determine the compressive strength.

$y = 45.80 + 0.88\ X]\text{-}1.31\ X_2$

Where:

y = Concrete cube strength (*N/mm*^{2}),

X_1 = Rebound hammer test result (*Number*)

X_2= UPV test result (*Micro-seconds*)

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