Relationship between Ultrasonic Pulse Velocity Test Result and Concrete Cube Strength

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Abstract

This paper presents the findings of a study on the relationship between Ultrasonic Pulse Velocity (UPV) and Concrete Cube Strength; in three distinct stages. First, a preliminary investigation of the various properties of the materials used for the production of concrete was undertaken. This was followed by trial mix using a nominal mix of 1:2:4, water – cement, W/C, ratios of 0.4, 0.5 and 0.6; along with two different consolidation methods – manual and machine vibrated. Based on the result of trial mix, W/C ratio of 0.5 was used to prepare and cure 150mm x 150mm x 150mm concrete cubes. The third stage subjected the samples to UPV and destructive tests at the end of the following curing days: 1, 3, 7, 14, 21, 28, 56 and 90 days. Ultrasonic Pulse Velocity test result showed an inverse relationship (of -0.935) with the crushed concrete compressive strength. Correlation test, multiple regression analysis, graphs and visual inspection were used to analyze the results. The conclusion drawn is that there exists a relationship between UPV test results and compressive strength. It is expressed as follows: $y = 151- 3.2x_1$; where y and x_1 are compressive strength and UPV test results respectively. Hence it is recommended that the above formula can be used in converting the UPV test results to compressive strength

Keywords: Concrete, cube strength, non-destructive test, relationship, 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 building production, 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.

The testson concrete can be broadly classified into mechanical test to destruction and non-destructive test. Non-Destructive Test (NDT) of concrete, however, unlike the application of NDT methods to materials such as metals, the use of NDT for quality control in concrete production is at its developing stage. According to 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. It was also noted that even when there were methods applicable to concrete, they were usually not available for civilian use or have been too sophiscated and expensive for practical use.

In recent years there are several NDT methods that were developed. It was, however noted that there are certain problems associated with the NDT of concrete. For instance, there is no standard for acceptance which defines the undesirable characteristics of non-conforming materials or structures. In other words it is when the capability of a non-destructive process is known in quantitative terms can the inspection results be considered a measure of true quality. Since, according to Gupta & Gupta (2006), Shetty (2010) and Neville & Brooks (2010), compressive strength is the property most valued by designers and quality control engineers as many of the desirable characteristics of concrete are quantitatively related to it; there is need to develop reliable predictive models to correctly evaluate compressive strength of concrete. This is especially important in case of Ultrasonic Pulse Velocity. UPV test method is one of the two most popular NDT methods used. There are efforts made by researchers in that respect. For example, Shariati, *et al* (2011) have undertaken an assessment of the strength of reinforced concrete structures using UPV and Schmidt Rebound Hammer Tests. Other research efforts include: Taginawa *et al* (1984), Bungey and Millard (1996), Dalrymple (2006), Aliabdo and Elmoaty (2012), Abdul'Azeez *et al* (2012), Lim and Cao (2013), Opoola (2015), etc. However, most of the researches were carried on existing structures. For the fact that designers, specifiers and producers and users of concrete made use of cube strength, in quality control, compliance and even secondary tests there is the high need to investigate the relationship between UPV, as the most accepted technique, among the popular NDT methods, and compressive strength. In view of the fact that compressive strength is regarded as the single most important quality index of concrete.

Methodology

The study entails laboratory investigation. Details of the materials and methods used are presented as follows:

Materials

The materials used in the experiment are: Cement, fine aggregates, coarse aggregates and water. Preliminary test were carried out on these materials so as to establish preliminary test results and obtain appropriate parameters. The various tests undertaken are as follows:

Cement

The type of cement used for the study was Ordinary Portland cement, OPC, manufactured and recently supplied by the Dangote Cement Company, Plc. various tests were undertaken so as to ensure that it complies with the relevant standards. These tests were carried out on the cement used in accordance to the Nigerian Industrial Standards, NIS, 11 (1974), NIS, 445 (2003), NIS 447 (2003), NIS 455 (2003) and British standards BS 12 (1996) and EN 197-1 (2000): Setting time test, Soundness and Consistency test. These tests were undertaken in a concrete laboratory at Department of Civil Engineering, Ahmadu Bello University, Zaria.

Fine aggregates:

Fine aggregates used in this research work were clean and air - dried river sand obtained from Samaru – Zaria. It was sieved with a 5mm B5 112 (1971) sieve, so as to remove the impurities and larger aggregates. Before the fine aggregate was used; it was subjected to sieve analysis. This was undertaken in accordance with BS 933 Part 1 (1997).

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

Coarse Aggregates:

The coarse aggregates used were crushed granite stones obtained from single quarry site along Zaria-Sokoto road. Sieve analysis was carried out on the coarse aggregates used in the experiment in accordance with BS 933 Part I (1997). 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 with following British standards: BS 812 (1990), BS 882 (1992) and BS 933 (1997)

Water

Water used for mixing was clean, fresh water, free from injurious oils, chemicals and vegetable matter or other impurities.

Equipment used

In the course of carrying out the various experiments certain equipment were used, details of the types of equipment used are presented in Table 1.

Table.1: Types of tests and description of equipment used

Types of test	Description of Equipment/Device Used
Ultrasonic Pulse Velocity	Portable Ultrasonic Non Destructive Digital Indicating Tester – Ultrasonic Machine Produced by Global Network Service Electronics Ltd, London England
Compressive Strength	Universal Compressive Testing Machine, Produced by SaniDesinon& Son Ltd Huns Let Foundry Leeds, U.K. England

Production and testing of concrete specimen

Trail mix

The experimental programme started with determination of the most suitable water-cement (W/C) ratio and compaction method. Preliminary mix was carried out using absolute volume method of batching with a nominal mix ratio of 1:2:4 and three (3) different W/C ratio of 0.4, 0.5 and 0.60.. The samples were tested to destruction after 7 days of curing in accordance with the relevant standards.

Final 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 to determine the proportion of each constituent to be used in the production of concrete samples, using mixing machine, a horizontal rotary drum mixer and manual compaction method.

Table 2: Quantity of materials required for a batch of 12 cubes

S/No.	Types of Material	Quantity of Material required (Kg)
1.	Cement	14.17
2.	Sand	31
3.	Coarse Aggregate	60
4.	Water	6.5

Ultrasonic Pulse Velocity Test

At the end of each curing day, 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 with BS 1881: Part 203 (1986) and AST C 597 (2002).The test was carried out at the concrete laboratory department of Civil Engineering, Ahmadu Bello University Zaria.

Results and Analysis

Result of Ultrasonic Pulse Velocity Test

The result of the ultrasonic pulse velocity test is presented in table 3.

Table 3: Ultrasonic Pulse Velocity test results and compressive strength of crushed concrete cube.

Age (*Days*)	Weight (*kg*)	UPV Reading (*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

See Appendix for details – A1

The UPV test results with the corresponding Ultrasonic Pulse Velocity test compressive strength results and the compressive strength of crushed cube arepresented as in Table 4.

Table 4: Ultrasonic Pulse Velocity test results, corresponding Ultrasonic Pulse Velocity test compressive strength result and compressive strength of crushed concrete cube.

Age (*Days*)	UPV Reading (*Micro-second*)	UPV Test Result Converted to Compressive Strength (*N/mm²*)	Compressive strength of Crushed Concrete Cube (*N/mm²*)
1	43.10	8.60	8.94
3	41.50	9.80	16.65
7	37.60	14.60	27.13
14	35.40	17.10	29.41
21	35.90	16.50	30.60
28	36.90	15.80	32.59
56	36.10	16.50	37.31
90	35.90	17.20	38.40

Ultrasonic Pulse Velocity (UPV)

Looking at the ultrasonic pulse velocity result in Tables 3 and 4, it would be noted that the UPV decreases with increase in the age of concrete this is also true when UPV is compared with the compressive strength. Result of correlation analysis shows that there is -0.929 correlations between UPV and the compressive strength. This is a very strong inverse relationship especially when compared with the maximum that is shown in figure 1. However, when UPV test results of first and third days of curing are examined, it will be observed that they are relatively high compared to the result of the remaining curing days.

Although the concrete cubes were allowed to drain as specified by the BS 1881 (1985), the wide difference between the first two curing days (1 and 3 curing days) in table 4 and the remaining test results, could be attributed to the fact that the concrete was at young age, during such test. The moisture content for such concrete sample is relatively higher than other samples of higher curing days. The UPV test results for 7 to 90 curing days are very close to the compressive strength test results. For instance, the compressive strength for the 21, 28, 56 and 90 days of curing are 16.50N/mm^2, 15.80N/mm^2, 16.50N/mm^2 and 17.20N/mm^2 respectively while the UPV test results for these days are 35.90mic.sec, 36.90 mic.sec, 36.10 mic.sec and 35.90 mic.sec. This represents difference of 5, 4.31, -1.21 and -2.50 when compressive strength values are subtracted from the results of UPV values. Viewed from another perspective, it can be observed that the 28 day cube strength, which 32.59N/mm^2 is representing 88.30% of the UPV test result for the same curing days. This still points an important observation made on test that there is no unique relationship between UPV and the strength. In view of the wide gap between the UPV test results for the 1 and 3 days of curing, another correlation analysis was carried out without this first two UPV test results, Result of such analysis shows that the correlation, is still inversely proportional but it dropped sharply from - 0,920 to - 0,400

These observations support one important fact - that there is a major shortcoming associated with the use of only UPV test method to assess concrete directly.

Comparison between UPV test results andcrushedcompressivestrength of concrete cube

A correlation analysis was used to compare the UPV test results with the concrete cube strength obtained from the destructive test (compressive strength test). Result of the analysis showed that there is inverse relationship of (- 0.935). The graph in figure 2 shows that the straight line moves from the bottom- right to left. This means the higher the value of UPV test result, the less the concrete cube strength. Regression analysis was also used to study the relationship between the UPV test results and the strength of concrete cube and to derive a formula for calculating the concrete cube strength, using the UPV test results. The regression equation is as follows:

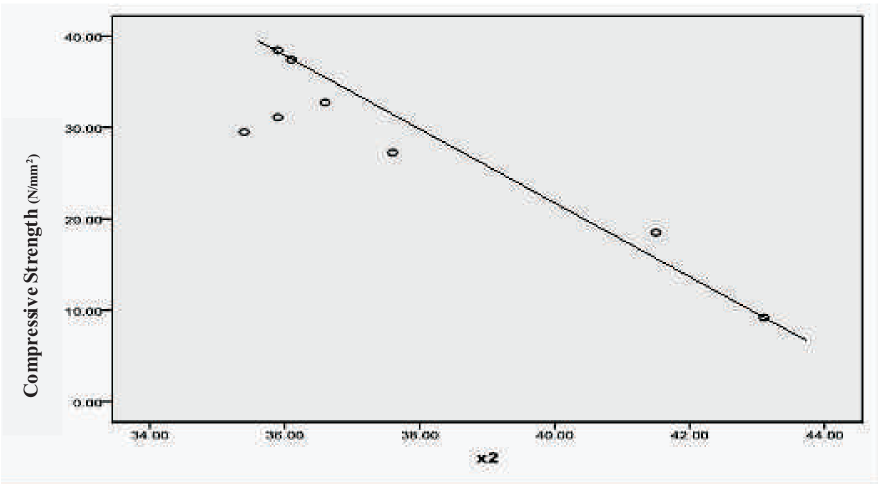

Figure 1: Result of Correlation Analysis of UPV and Compressive

Ultrasonic Plus Velocity *(Micro Seconds)*

$$y=151-3.26X \qquad (1)$$

Where:

y = Strength of concrete Cube (N/mm^2)

X_1=Average UPV test results (*Micro-seconds)*

Looking at the two important conditions used in assessing the goodness of fit of the regression equation - the R-Square and P - values, it would be noted that they are 87.4% and 0.001. When these values are compared with 100% and 0.005, the equation can be accepted.

Another comparative analysis of UPV test result with the strength of concrete cube was carried out by first plotting a graph of strength against the UPV test result, and then a formula for calculating the concrete cube strength from such a graph. Thus, the formula is as follows;

$$C = \frac{1378.56}{T} \qquad (2)$$

Where;

C = the strength of concrete cube (N/mm^2)

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

The strength obtained from these methods was compared with the actual strength determined from the destructive (compressive strength test).

Details of the UPV test converted to strength and the strength obtained from the destructive test is presented in Table 5.

Table 5: Comparison between Experimental and Theoretical values of concrete cube strength determined from Ultrasonic Pulse Velocity test results

Age (Days)	Experimental (Concrete cube strength) (N/mm^2)	Theoretical (Regression Model) [151 –3.26X$_1$] (N/mm^2)	% Difference	Theoretical (From graph) *[C=1378.56/T]* (N/mm^2)	% Difference
1	8.94	10.49	17.34	32.00	257.94
3	16.65	15.71	-5.64	33.22	99.52
7	27.13	28.42	4.75	36.67	35.16
14	29.41	35.60	21.04	38.94	32.40
21	30.66	33.97	10.79	38.40	25.24
28	32.59	31.68	-2.79	37.67	15.59
56	37.31	33.31	-10.72	38.20	23.85
90	38.40	35.57	-7.37	38.40	0.00

Looking at Table 5, it can be observed that the values of the experimental result are closer to the theoretical values obtained from regression analysis model than the ones obtained from the graph. For example, in 1st day the experimental is 8.94N/mm^2 while the theoretical is 10.44N/mm^2. At the 28 day of curing the experimental is 32.59N/mm^2 whereas the theoretical determined using the regression model, is 31.68N/mm^2 this represents a percentage difference of -2.79% (97.21% of the experimental).

Table 6: Comparison between Experimental and Theoretical values of concrete strength

	Regressive Model [151 -3.26X$_1$] (N/mm^2)	Theoretical(From graph) *[C=1378.56/T]* (N/mm^2)
Standard deviation	2.6	9.6
Standard Error	0.9	3.4
Variance	6.9	9.2

Result of comparative means: mean, shows that the standard deviation, standard error and variation of theoretical values obtained from regression model, are: 2.6, 0.9 and 6.9 as against the theoretical values determined from graph which has the following: 9.6, 3.4 and 9.2 as standard deviation, standard error and variation respectively. As such, if the average of percentage difference is considered the regression model has 3.42% while the theoretical values established from graph has average of 6.12% difference. According to Opoola (2015) "5 per cent (.05) is the border between small and not small". In other words since the difference is less than 5%, it can be regarded as very close to the experimental.

Additionally, in order to study the two methods used to convert the UPV test results to strength and establish the one that gives the best result, three graphs of strengths (determined using these methods) against curing days, were plotted. These graphs are:

I) The graph of the concrete cube strength obtained from the destructive test (compressive strength test).

ii) The graph of UPV test results converted to strength using the formula obtained in this research, using regression analysis. (y= 151-3.26X2).

iii) The graph that was plotted using the result of comparative analysis of concrete strength and UPV test results (C=1378.56/T); also obtained from this research.

These graphs of destructive (compressive strength) test and non-destructive (UPV) test results were plotted in order to compare and contrast between them so as to study the extent to which the graphs produced from the result of UPV test is close to that of the compressive strength test. Attempt was also made further to compare the aforementioned results with that of another researcher (Bungey *et al* 2006).

As it can be observed from figure 4.3, the graphs of strength obtained by converting UPV test results to strength using different formulas that were derived, are shown.

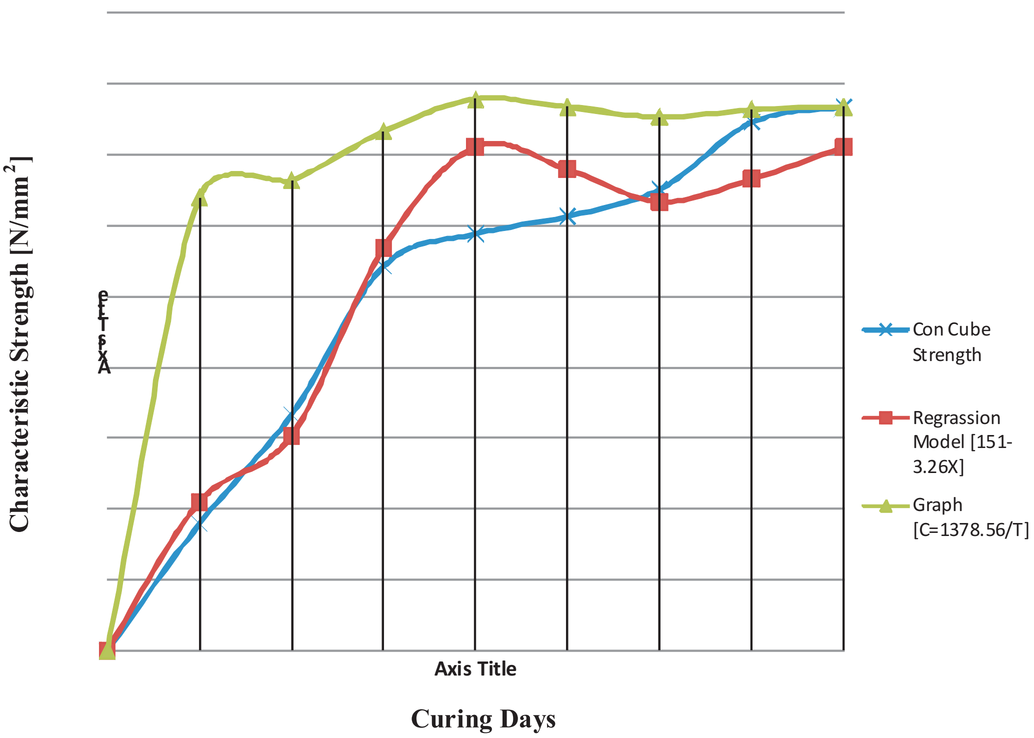

Figure 2: ***Concrete Cube strength and UPV test results converted to compressive strength using two formulas***

The graph of strength obtained from regression analysis is comparatively closer to the concrete cube strength obtained from compressive strength test. Except for the 14 days curing; this is relatively higher than the concrete cube strength. As for the 3, 7 and 28 days curing, the two results are very close. However, the other formula obtained from the result of comparative analysis of concrete strength and UPV test results (C=1378.56/T); is much higher. It is only the 56th and 90th day of curing that the two results seem to be in agreement. Thus this formula can be applied also to predict the concrete cube strength especially .at the 56 and 90 days. Looking at the graph plotted using the formula as outlined by Bungey*et al* (2006), it is higher; but one interesting thing about the graph is that it takes the shape of the strength of the concrete cube. That means it clearly depict the exact nature of strength development of concrete - increase in strength with age. However one important fact worth noting is that the difference is not much and hence this can be used to give a good idea of the strength; when the ultrasonic pulse velocity test result is known. There is no doubt that this result is by far, better than the current practice used in assessing the structural integrity of any concrete structure; in which a range of values of UPV test result is given so as to assess any structure - as good or bad. Thus, when the R square value, P value, the residual percentage difference and the shape of graphs of theoretical and experimental values are analysed, it can be inferred that the theoretical value obtained from the regression model (y= 151- 3.26X_1) is close to the experimental.

Conclusion and Recommendations

The research investigates the relationship between the UPV test result and compressive strength of concrete cube. It was found out that there is a decrease in the ultrasonic pulse velocity test results from 43.10 microseconds for the one (1) day old to 35.90 micro - seconds for the 90 days of curing. Also the UPV test result has an inverse relationship of (- 0.935) with the crushed concrete compressive strength. Based on the result of findings, it is concluded that the Ultrasonic pulse velocity test result has an inverse relationship with the compressive strength. Besides that,the use of only UPV test to measure strength may not give the exact value of concrete strength. Howeverit can give good idea of the compressive strength thus the study has determined the relationship between UPV test results and concrete cube compressive strength as follows:

y = l51-3.26Xi

Where:

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

X_1 = UPV test result (*Micro-seconds*)

Hence it is suggested that where UPV test is carried out, the aforementioned formula can be used to convert the test results to compressive strength. In addition, It is recommended that a study should be undertaken to assess the influence of concrete constituents – especially cement and aggregate, on the non-destructive test values of UPV.

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APPENDIX A1

Table A1: Ultrasonic Pulse Velocity Test Result

Side of Each Cube	Age (Days)	Distance (Length) (mm)	Time (Micro-seconds)	Velocity (m/s)	Average Velocity (m/s)	Velocity (Km/s)	Compressive Strength of Cube (N/mm^2)
01(a)	1	150	42.8	3505			
01(b)		150	43.4	3452	3497	3.5	8.6
02(a)	3	150	41.3	3632			
02(b)		150	41.7	3597	3585	3.6	9.8
03(a)	7	150	38.2	3927			
03(b)		150	37.0	4054	3991	4.0	14.6
04(a)	14	150	35.0	4286			
04(b)		150	35.0	4190	4238	4.2	17.2
05(a)	21	150	36.2	4144			
05(b)		150	35.6	5213	4179	4.2	17.2
06(a)	28	150	36.4	4121			
06(b)		150	36.8	4076	4099	4.1	15.8
07(a)	56	150	36.2	4144			
07(b)		150	36.0	4167	4156	4.2	17.2
08(a)	90	150	36.0	4167			
08(b)		150	35.8	4190	4179	4.2	17.2