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A COMPARATIVE ANALYSIS OF THE REBOUND HAMMER AND ULTRASONIC PULSE VELOCITY IN TESTING CONCRETE

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Abstract

This work presents a study on the comparison between some non-destructive testing techniques (Rebound Hammer and Ultrasonic Pulse Velocity). Tests were performed to compare the accuracy between the rebound hammer and the ultrasonic pulse velocity method in estimating the strength of concrete. Eighty samples (cubes of 150 × 150 × 150) were prepared using two mix designs of 1:2:4 and 1:3:6 with a constant w/c ratio of 0.45 and were tested at 7, 14, 21 and 28 days. The slump test was between 62 – 78mm. The results obtained from the non-destructive testing methods were correlated with the compressive strength results which showed that a higher correlation existed between the Rebound Hammer and the compressive strength than the Ultrasonic Pulse Velocity. The rebound hammer readings had a correlation coefficient of 0.794 while the ultrasonic pulse velocity had a correlation coefficient of 0.790 for the 1:2:4 mix and the rebound hammer readings for 1:3:6 was 0.783 and that for the ultrasonic pulse velocity was 0.777. Statistical analysis of the results obtained showed that there was no significant difference between the means of the two methods for both mix at a 0.05 level of significance.

Keywords: concrete, non-destructive testing, compressive strength, rebound hammer, ultrasonic pulse velocity

1. Introduction

Concrete is susceptible to a variety of environmental degrading factors which tend to limit its service life. This therefore has brought about the need for test methods to measure the in-place properties of concrete for quality assurance and for evaluation of existing conditions. Since such test are expected not to impair the function of the structure and allow for re-testing at the same location to evaluate the changes in property at some other point in time, these methods should be non-destructive.

Non destructive tests as applied to concrete are those tests that do not alter the concrete quality. Non - Destructive Testing (NDT) as the name implies refers to a test that does not impair the intended performance of the element, member or structure under investigation.

At present the test used mainly as a basis of quality control is compression testing of cubes and it represents the potential strength of the concrete used. The main parameters determining the quality of concrete are its composition, compaction and curing. At the most it can be ensured that the composition of concrete going into the cubes and that going into the structure is the same. However, the methods of compaction and curing usually are different for the cubes and the structural members and as such the results obtained on cubes may not truly represent the quality of concrete in the structure. Hence the need for Non-Destructive Testing (NDT).

NDT of concrete is of great scientific and practical importance especially the need for quality characterization of damaged constructions made of concrete. Its importance can also be seen in the desire for a proposed change of usage or extension of a structure, acceptability of a structure for purchase or insurance, assessment of the quality or integrity of the repairs, monitoring of strength development in relation to formwork stripping, curing, pre-stressing or load application.

This research therefore seeks to compare the most common non-destructive techniques, the rebound hammer and the ultrasonic pulse velocity methods so as to see which method has a superior capability in the sense that it is capable of providing more information on concrete properties. This will aid in quality control on site as well as help in monitoring concrete strength development so as to hasten construction rate, facilitate possible correction of defects in structures, predict future performance and allow minor repairs.

1.1. Ultrasonic pulse velocity method

The ultrasonic pulse velocity is a stress wave propagation method that involves measuring the travel time, over a known path length of a pulse of ultrasonic waves. The pulses are introduced into the concrete by a piezoelectric transducer and a similar transducer acting as a receiver. A timing circuit is used to measure the time it takes for the pulse to travel from the transmitting to the receiving transducers. In 1945, Long undertook further investigations along these lines and reported on the instrument and technique that resulted from their work which led to the development of the Soniscope [1].

In 1951, Whitehurst used this Soniscope to carry out some investigations and thus, published a tentative classification for using pulse velocity as an indicator of quality. This is as shown in the Table below [2].

Currently, ultrasonic testing is extensively employed to estimate defects in concrete structures. It combines an easy test procedure and accuracy, at a relatively low cost [3]. This technique can detect areas of internal cracking, internal delamination, and relative strength parameters [4,5].

Table 1: Concrete quality and pulse velocity.

General conditions	Pulse velocity (m/s)
Excellent	Above 4570
Good	3660 – 4570
Questionable	3050 – 3660
Poor	2130 – 3050
Very poor	Below 2130

The instrument used in this technique consists of a transmitter and a receiver (two probes). The time of travel for the wave to pass from the transmitter to the receiver when kept opposite to each other is recorded in the ultrasonic instrument. This is referred to as the direct method. The semi-direct and indirect methods are made use of when access to the opposite face of the test specimen cannot be achieved. The direct method gives a void detect ability of 100% while the indirect method gives an accuracy of 66 – 99% percent void detect ability [6]. The accuracy of this method has been investigated. Slabs with fabricated voids at known location were used. The results obtained were then compared with the known location. It was observed that depth of void could be detected better with an accuracy ranging from 51.81 – 99.62% from day 3 – 28 respectively [7]. Its correlation has been investigated and it was found that a relationship could be established but depending on factors such as curing conditions, moisture content etc. [8-11].

In the test, the time taken by the pulse to travel through concrete is recorded and the velocity calculated as:

$$v = \frac{l}{t} \tag{1}$$

Where, v = pulse velocity (m/s), l = length (m), t = time (s).

The pulse velocity, v of longitudinal waves in a concrete mass is related to its elastic properties and density according to the following relationship:

$$E_d = v^2 \rho \frac{(1+\mu)(1-2\mu)}{1-\mu} \tag{2}$$

Where E_d = Dynamic modulus of elasticity, v = Velocity, ρ = Density of concrete, μ = Poisson ratio.

1.2. Rebound Hammer method

In 1958, Kolek noted that when concrete is struck by a hammer, a degree of rebound is an

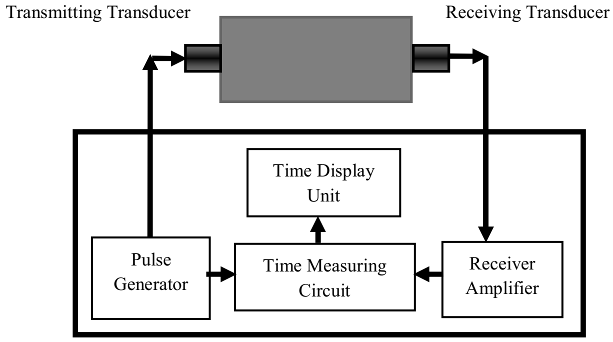

Figure 1: Left: UPV tester. Right: Schematic of UPV apparatus.

indicator of the hardness of the concrete. This was standardized by Ernst Schmidt, a Swiss Engineer. In 1948, he developed a device for testing concrete based upon the rebound principle [12]. This he did by developing a spring loaded hammer and devising a method to measure the rebound of the hammer.

In order to relate this rebound number to strength of the concrete, researches have been carried out and curves established [13]. A general correlation between compressive strength of concrete and the hammer rebound number has been reported [12,14]. Also good correlation between the flexural strength of concrete and the hammer rebound number has been established [11].

The only known instrument to make use of the rebound principle for concrete testing is the Schmidt hammer and is suitable for both laboratory and field work. Its essential parts are the outer body, the hammer, the plunger, the spring and the slide indicator. It was constructed and tested extensively at the Swiss Federal Materials Testing and Experimental Institute in Zurich [15]. Each hammer is furnished with correlation curves developed by the manufacturer using standard cube specimens. However, the use of these curves is not recommended since material testing conditions may not be similar to those in effect when the calibration of the instrument was performed [15].

The Rebound Hammer test is basically a surface hardness test and is used only on concrete where the surface has not been carbonated as the results tend to be very high and unrealistic on a carbonated surface. Hence it should be used for younger concrete than for older one. The test can be conducted horizontally, vertically upward or downward or at any intermediate angle. Due to different effects of gravity on the rebound as the test angle is changed, the rebound number will be different for the same concrete and require separate calibration or correlation charts [12].

Due to its simplicity and low cost, the Schmidt rebound hammer is by far, the most widely used non destructive test device for concrete. While the test appears simple, there is no simple relationship between the rebound number and strength of concrete [12].

Although the rebound hammer provides a quick, inexpensive means of checking the uniformity of concrete, it has serious limitations that must be recognized and taken into account when using the hammer. Estimation of strength of concrete by the rebound hammer within an accuracy of +15 to +20% may be possible only for specimens cast cured and tested under conditions similar to those from which the correlation curves are established. The results are affected by factors such as smoothness of the test surface, size, shape and rigidity of specimen, age of test specimen, surface and internal moisture condition of the concrete, type of cement and coarse aggregate, and extent of carbonation of concrete surface [12].

2. Materials and Methods

Materials used for this investigation were ordinary Portland cement, fine and coarse aggregates. Various tests were carried out as well to classify

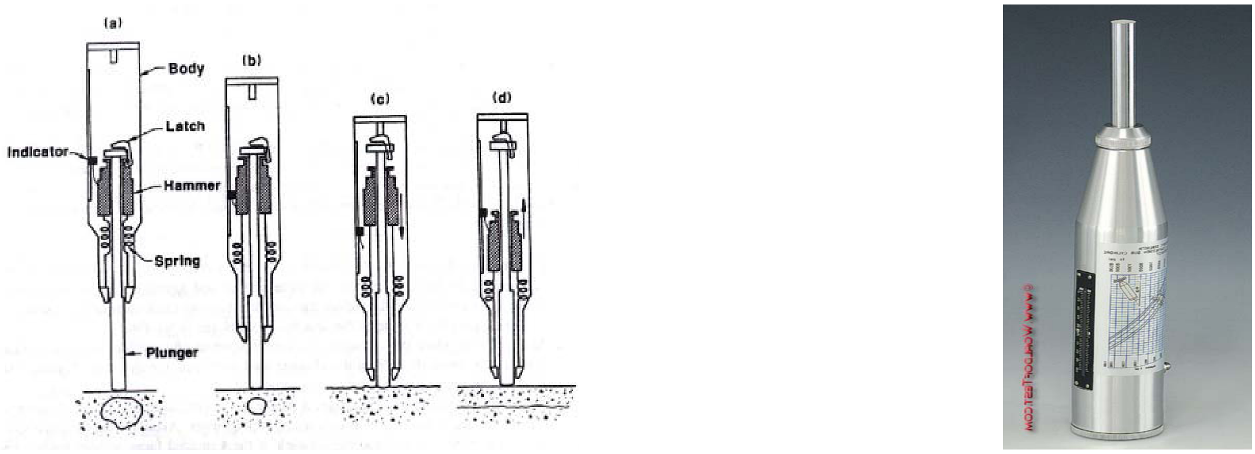

Figure 2: Left: Schematic of the Schmidt Rebound Hammer. Right: Rebound Hammer.

these aggregates. The non-destructive methods used in this research include the rebound hammer test, and the ultrasonic pulse velocity test.

2.1. Sample preparation

For the purpose of this research, cubes of dimension 150 × 150 × 150mm were cast. The two mix design for the cubes cast was one part of cement to two parts of fine aggregates to four parts of coarse aggregate (1:2:4) as well as one part of cement to three parts of fine aggregates to six parts of coarse aggregates (1:3:6). The constituents were properly mixed to ensure uniformity. Water was added using a water-cement ratio of 0.45 and mixed thoroughly. After placing of concrete in the moulds, compaction of concrete was carried out manually. The cubes were allowed to stay for 24 hours, the moulds dismantled and the cubes transferred to a curing tank. Testing was carried out after 7, 14, 21 and 28 days. A total of eighty cubes were moulded.

2.2. Tests on hardened concrete

The tests carried out on the hardened concrete were the Ultrasonic Pulse Velocity test, the Rebound Hammer test and the cube compressive test. Before the compressive tests were carried out, the cubes were subjected to testing using the Ultrasonic Pulse Velocity Tester using the direct method. The rebound hammer was then used on the same specimen. A total of 10 readings was taken on each test surface as recommended by ASTM C805 and the average rebound number was then obtained. Each cube was then placed in the testing machine in between two metal plates. Having properly positioned each cube, load was gradually applied without shock until the cube failed and the loads at failure were recorded for each sample. The load at failure was then divided by the effective area of the cube in square millimeters to obtain the compressive strength of the cube.

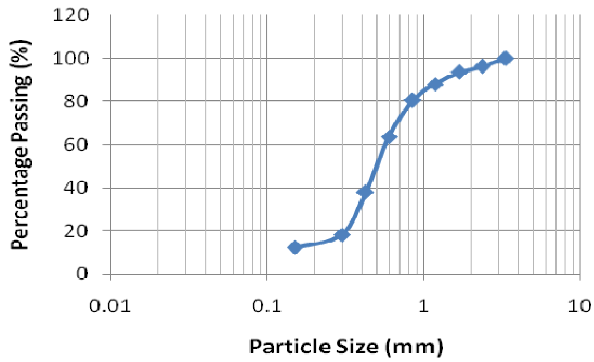

Figure 3: PSD for Sand.

3. Results and Discussion

From the analysis carried out on the constituents of the samples, sand had a specific gravity of 2.65 and a bulk density of 1334 kg/m^3.The coarse aggregate had a specific gravity of 2.67 and a bulk density of 1690 kg/m^3. The cement used for this work had a specific gravity of 3.15. Regression analysis was computed on the data obtained was using 'MS Excel' software. The re-

Table 2: Analysis of results obtained from tests.

Item	N	Range	Minimum Value	Maximum Value	Mean	Standard Deviation	Variance
R.H	80	16.80	8.00	24.8	14.13	3.89	15.15
UPV	80	1.183	3.363	4.546	3.93	0.29	0.085

Table 3: Statistical analysis of strength results at 28 days.

Cubes	N	Mean	Standard deviation	Variance	Df	Standard error	t_{cal}	t_{tab}
UPV	20	20.64	3.28	10.74	38	0.80	0.36	1.686
RH	20	20.23	3.89	15.16				

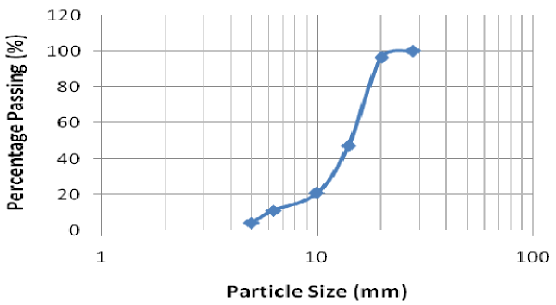

Figure 4: PSD for Gravel.

bound hammer readings had a correlation coefficient of 0.794 while the ultrasonic pulse velocity had a correlation coefficient of 0.790 for the 1:2:4 mix and the rebound hammer readings for 1:3:6 was 0.783 and that for the ultrasonic pulse velocity was 0.777. This is not different from the results obtained by Nash't et al where the rebound hammer correlation coefficient was 0.77 and that of the ultrasonic pulse velocity was 0.59 [16]. Domingo [11] also obtained a higher correlation coefficient for the rebound hammer than the ultrasonic pulse velocity where the rebound hammer had a correlation of 0.94 and the ultrasonic had a correlation coefficient of 0.84 [11]. This shows that a better correlation with compressive strength can be obtained using the rebound hammer than the ultrasonic pulse velocity. The linear relationship gave the best correlation between the two variables and hence was used.

The regression equations for the rebound hammer method for both 1:2:4 and 1:3:6 mix designs were:

$$s = 1.012r + 1.218$$

$$s = 1.339r - 4.878$$

while that of the ultrasonic pulse velocity method for both 1:2:4 and 1:3:6 mix designs were:

$$s = 15.05v - 43.27$$

$$s = 14.43v - 43.05$$

where s is the strength, r is rebound number, v is the ultrasonic pulse velocity.

From Figures 4.5 and 4.6 it can be seen that although the concrete had the same strength, the rebound hammer readings were higher than that of the ultrasonic pulse velocity at the early age of day 7 and went below that of the ultrasonic pulse velocity test as the age increased and that the ultrasonic pulse velocity testing method can assess concrete strength better with stronger concrete. This could be due to the fact that the rate of gain of surface hardness of concrete is rapid up to the age of 7 days, following which there is little or no gain in the surface hardness.

From the results, statistical analysis show that at a 0.05 level of significance, there was no significant difference between the mean of the two methods for both mix.

4. Conclusion and Recommendations

Test results for hardened concrete show a reasonable correlation of compressive strength with the rebound hammer and Ultrasonic Pulse Velocity. The sensitivity of the pulse velocity test in measuring strength is affected by the concrete age, as the concrete matures, the sensitivity of the Ultrasonic Pulse Velocity to strength gain or achieved by the concrete increases. The rebound hammer shows less sensitivity as the concrete matures since it is a surface hardness test and for age

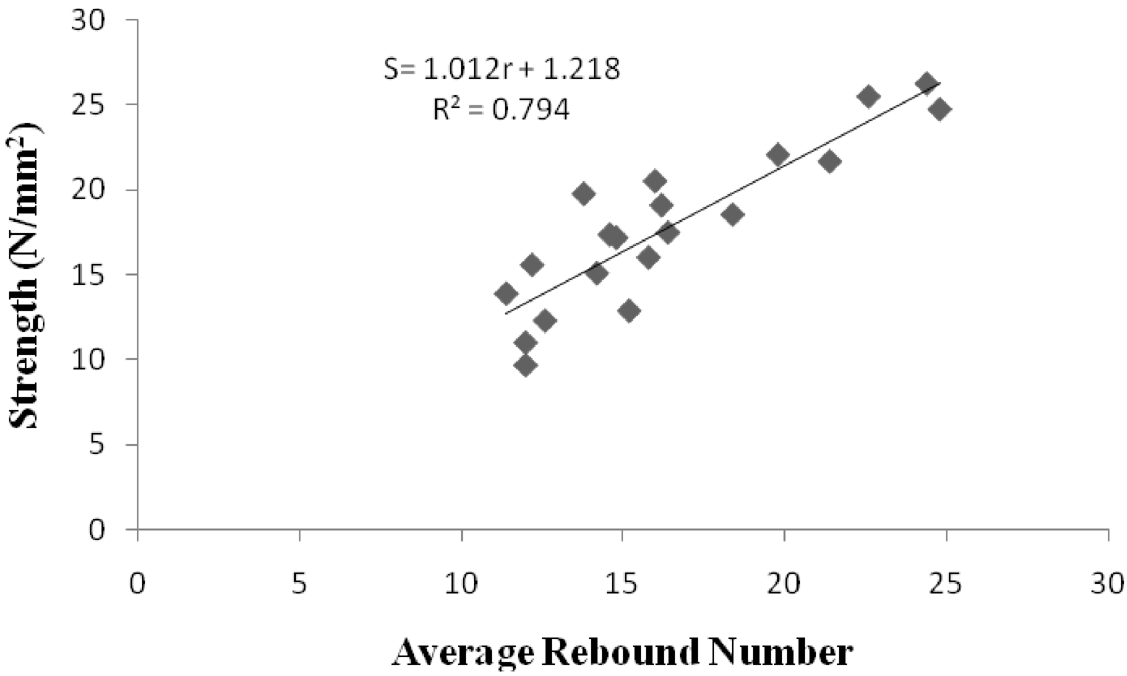

Figure 5: Correlation Chart for Rebound Hammer Number for 1:2:4 mix.

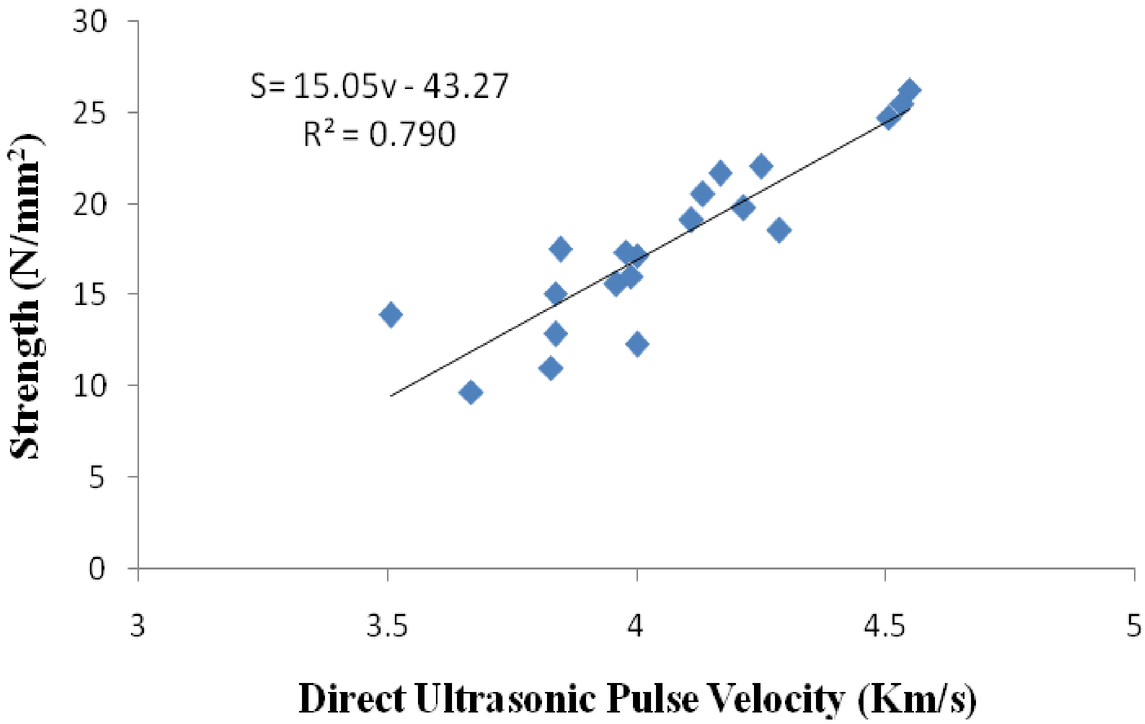

Figure 6: Correlation Chart for UPV for 1:2:4 mix.

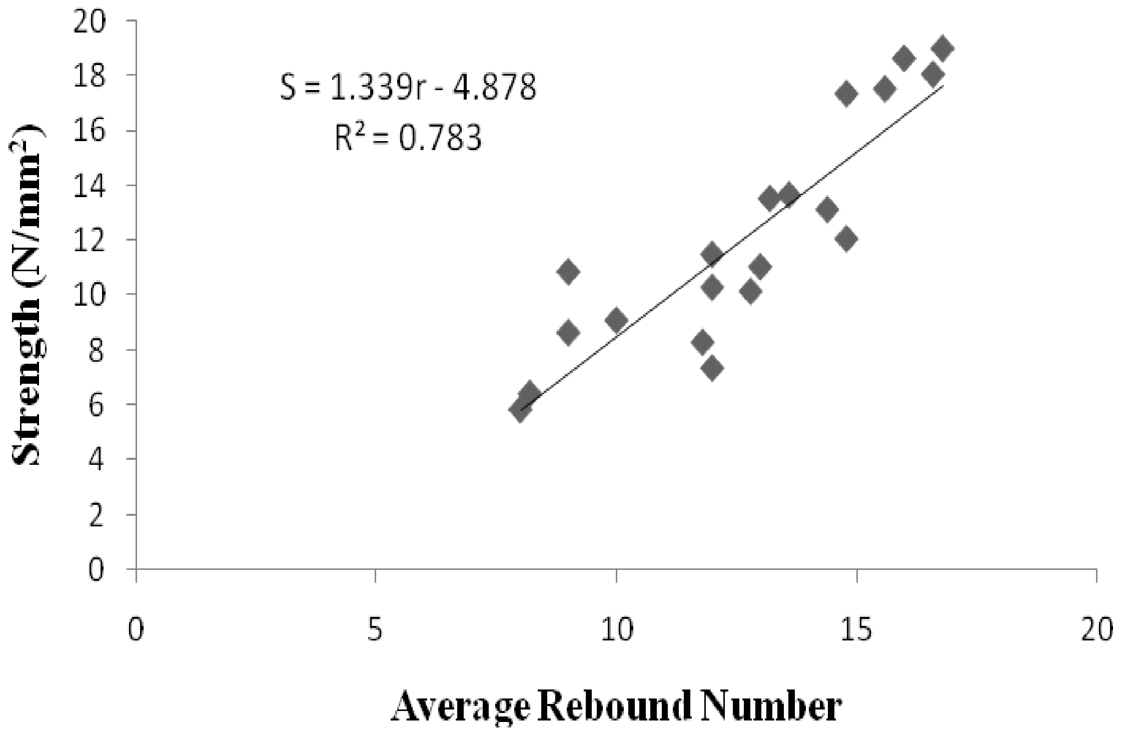

Figure 7: Correlation Chart for Rebound Hammer Number for 1:3:6 mix.

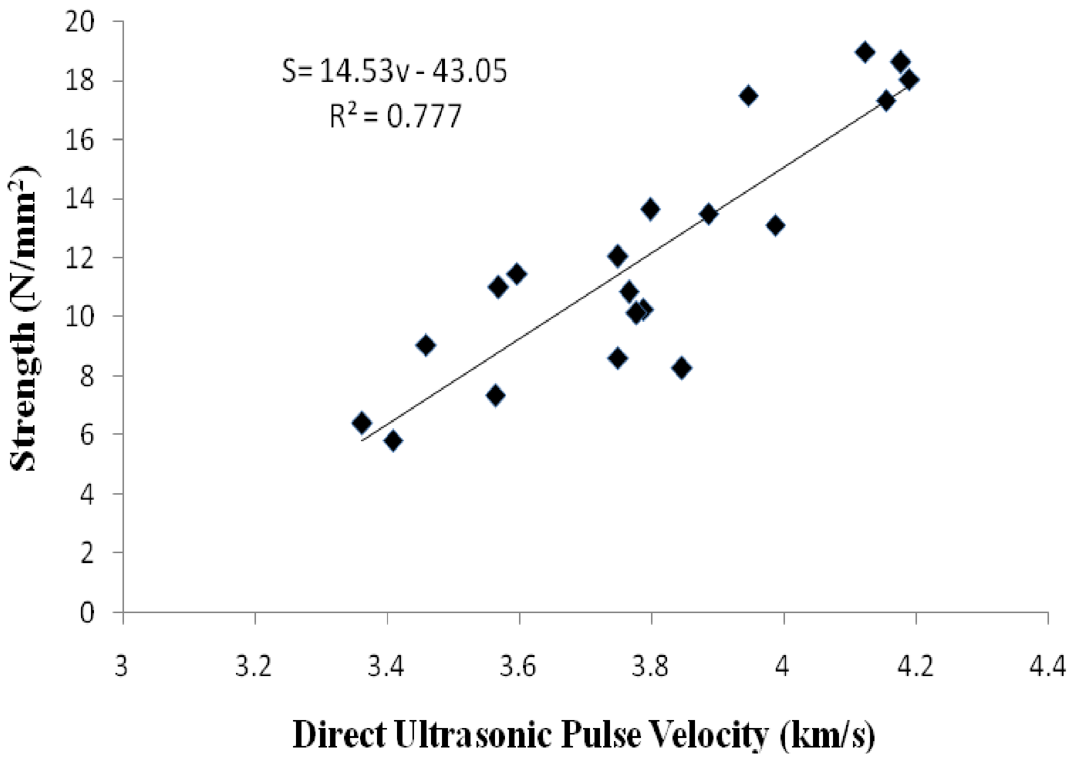

Figure 8: Correlation Chart for UPV for 1:3:6 mix.

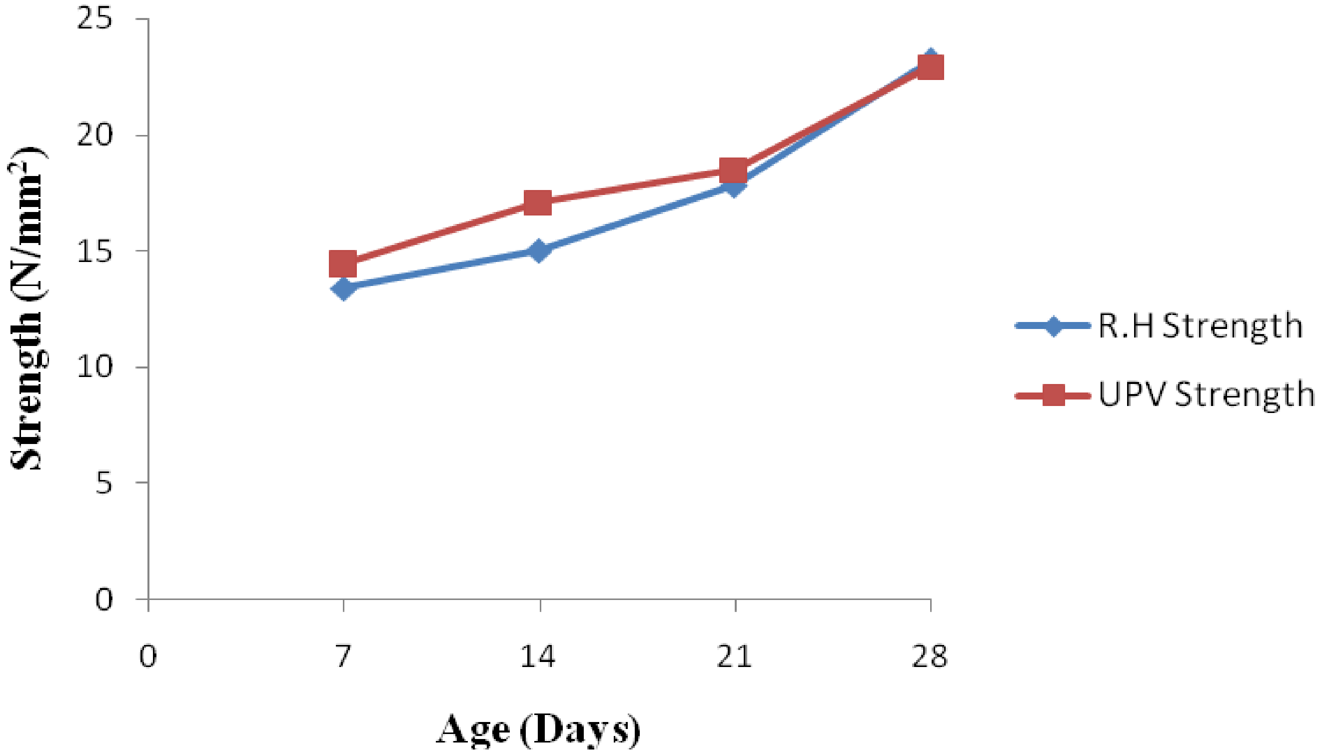

Figure 9: Strength against Age for 1:2:4 mix.

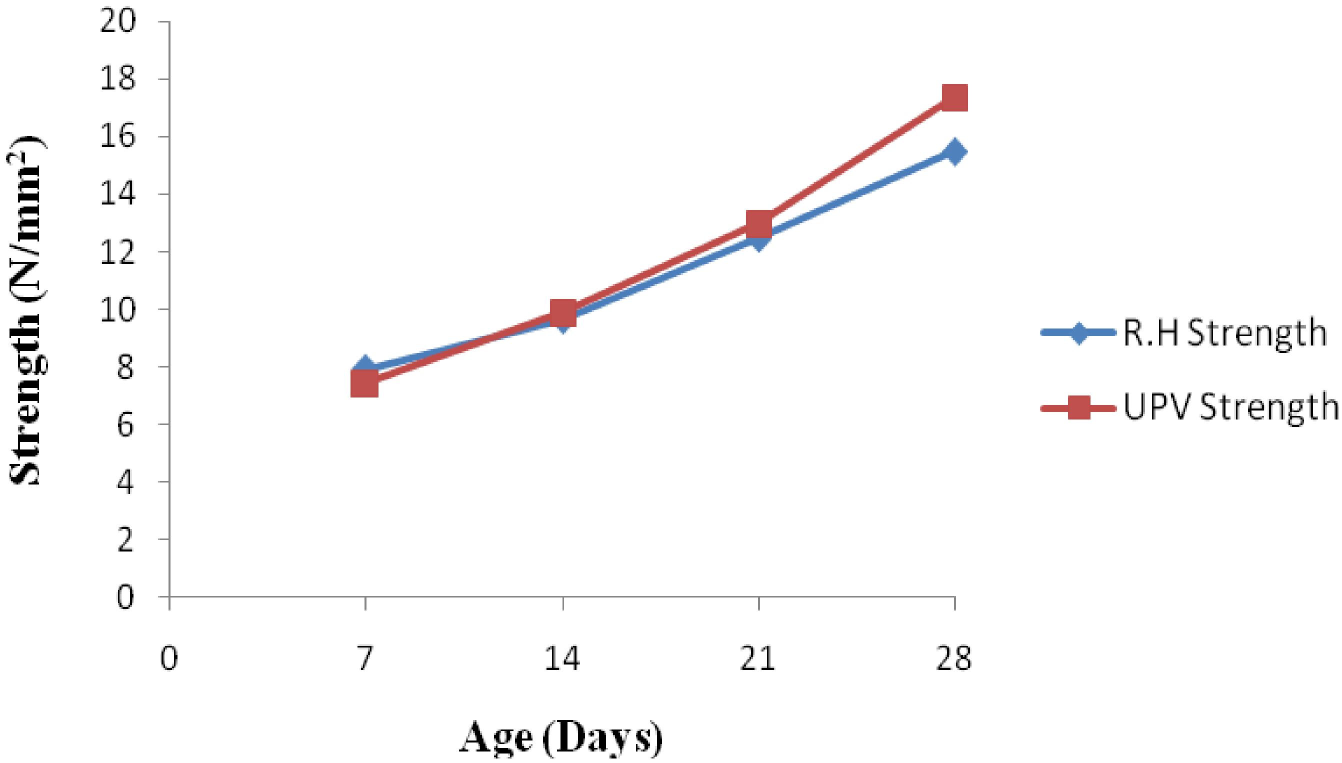

Figure 10: Strength against age for 1:3:6 mix.

above 7 days there is little or no gain in surface hardness.

From the correlation for the two mix designs, estimates of in-situ strength can be attained if the correlation between the compressive strength and the non-destructive test measurement for the same kind of concrete is established. Analysis of the results show that no significant difference exists between the set of results obtained from both methods, hence both methods can be used in estimating in-situ strength (Table 2 and 3).

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