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# Comparative Study of Concrete Structural Properties using various Non-Destructive Testing against Destructive Test

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## ABSTRACT

Non-destructive testing is becoming a major tool for estimating the adequacy of concrete for existing structures. However, there is a need to establish reliability of the non-destructive testing equipment as compared to the conventional destructive test methods. The study focuses on comparisons conducted on a sample size of 24 concrete cubes prepared by two different batches of concrete ratios. i.e (1:2:4) and (1:1.5:3). This research study was designed to compare strengths and behavior of concrete using the two batches of concrete. Cubes that were tested at 03, 07, 14, and 28 days by using Rebound Hammer, Compression Testing Machine (CTM), Cut and Pull out (CAPO) test, Air permeability Coefficient and Ultra Sonic Pulse Velocity Tester available with the Council for Works and housing Research (CWHR). The results of all tests indicate that non-destructive test methods are by and large reliable and comparable to the destructive testing methods at CWHR.

**KEYWORDS:** Non-Destructive Testing, Destructive Testing, Comparisons and Correlations, Compressive Strength of Concrete.

## 1 INTRODUCTION

Conventional concrete testing services have been available at Council for Works and Housing Research (CWHR) since its inception in 1964, whereas non-destructive testing facilities at CWHR have been available since 2008. Non-destructive testing of concrete is still in a nascent stage in Pakistan. These techniques are rarely used in construction sector to determine onsite properties of concrete and material specifications that cause some major conflicts arising in projects during and post construction stages. There is always a need to conduct proficiency testing of different test methods for determining the properties of concrete to establish reliability of test results. This paper introduces to different test methods and equipment available with CWHR in an attempt to establish the reliability of concrete properties tested by using these equipments.

## 2 OBJECTIVES AND SCOPE OF THIS STUDY

The objective of this study is to compare results obtained from different test methods and equipments to ascertain their reliability. The study was carried out from April 2019 to June 2019.

The scope of the study is limited to a sample size of 24 numbers of 6 inches concrete cube samples prepared from two different batches of concrete mixes.
The comparison of test results is carried out between the following destructive and non-destructive testing (NDT) equipments available at CWHR:

i. Cube Compressive Strength by Universal Testing Machine. (Destructive testing in accordance to BS1881-116,)
ii. Cube surface compressive strength through Rebound Hammer Test. (NDT in accordance to ASTM C-805)
iii. Cube compressive strength by Cut and Pull Out Test. (NDT in accordance to ASTM C-900)
iv. Co-efficient of permeability test for clear cover concrete test.(Using TORRENT Equipment)
v. Ultra Sonic Pulse Velocity Test. (NDT in accordance to ASTM C-597-83).

## 3 METHODOLOGY

Five types of tests were performed on concrete samples cast from 2 different batches of concrete. They are briefly described as follows:

### 3.1 Compression Testing Machine (CTM)

The testing by the Universal Testing Machine is a destructive testing method. The model of the Compression Testing Machine used in this study is FORNEY Ltd. The machine has a capacity of testing tensile strength and compressive strength of concrete up to a maximum of 20,000KN.

The tests on concrete sample cubes were carried in accordance to BS1881-116. The loading applied axially on test specimen was at **the rate of 140kg/sq cm/min**. till the specimen collapsed. Due to the constant application of load, the specimen started cracking at a point and final breakdown of the specimen was noted. (See Figure. 3.1.1. & 3.1.2)

Compressive Strength of Cube = Max Load Carried by Specimen/Top Surface Area of Specimen.

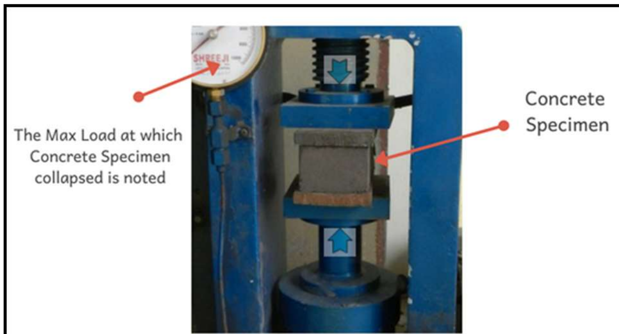


*Figure 3.1.1.: Compression Testing Machine (CTM)*


*Figure 3.1.2: Cubes Steel Mould & Concrete Cubes Samples*

### 3.2 Rebound Hammer Test

The Rebound Hammer Test is performed as per ASTM C805. This test is convenient and provides a rapid indication of the quality of concrete. The rebound hammer consists of a spring controlled mass that slides on a plunger within a tubular housing. When the plunger of rebound hammer is pressed against the surface of concrete, a spring controlled mass with a constant energy is made to hit concrete surface to rebound back. The extent of rebound, which is a measure of surface hardness, is measured on a graduated scale. This measured value is designated as Rebound Number. A concrete with low strength and low stiffness will absorb more energy to yield in a lower rebound value.


*Figure 3.2.1: Schimidt Rebound Hammer*

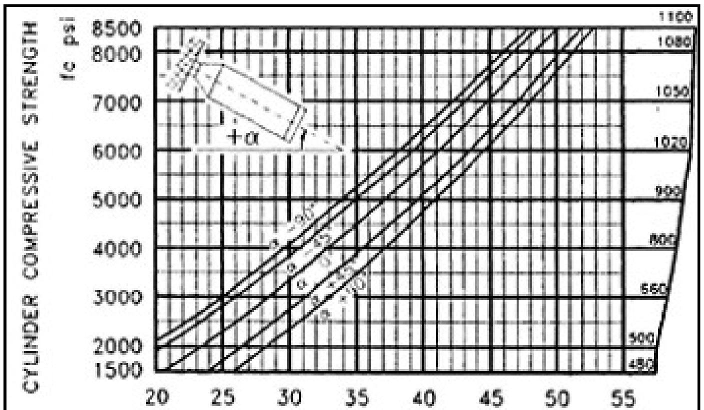


*Figure 3.2.2: Schimidtic Graph*

Thus, the hardness of concrete and rebound hammer reading can be correlated with compressive strength of concrete. The rebound value is read off along a graduated scale and is designated as the rebound number. (See Figure. 3.2.1)
The compressive strength can be read directly from the graph provided on the body of the hammer. (See Figures 3.2.2)

### 3.3 Cut And Pull-Out Test (CAPO Test)

The CAPO test is semi Non-Destructive test used to estimate the compressive strength of concrete in a structure. The basic principal of this equipment is to find out pull of force of concrete and then find its compressive strength from pre developed correlation curve value. The CAPO tests are performed in accordance to ASTM C900.

When selecting the location for a CAPO test, it is first ensured that reinforcing bars are not within the testing region. The surface at the test location is level using a planning tool and a 18.4 mm hole is made perpendicular to the surface using a diamond-studded core bit. A recess (slot) is routed in the hole to a diameter of 25 mm and at a depth of 25 mm. A split ring is expanded in the recess and pulled out using a pull machine reacting against a 55 mm diameter counter pressure ring, the concrete between the expanded ring and the counter pressure ring is in compression. Hence, the ultimate pull out force F is related directly to compressive strength. The test is performed until the conical frustum between the expanded ring and the inner diameter of the counter pressure is dislodged.


*Figure 3.3.1: Concrete Frustum from the Concrete Member is dislodged.*

*Figure 3.3.2: The expanded ring and the counter pressure is dislodged.*

**Crushed material**

**Sharp 55 mm diameter edge from counter pressure free from any cracks**

### 3.4 Air Permeability Test TORRENT

This is purely a Non-Destructive test used to find out the Air permeability of concrete using Coefficient of permeability. Its principle is based on the porosity of air and water penetration. The particular features of the TORRENT method are a two-chamber vacuum cell and a pressure regulator, which ensure that an airflow at right angles to the surface is directed towards the inner chamber. This permits the calculation of the concrete or cement permeability coefficient KT based on a simple theoretical model.

The Permeability of concrete is a measure of its durability, i.e. a less permeable concrete is more durable and vice versa. Currently acceptance criteria for hardened concrete are based on compressive strength test results. These results never represent the quality of the covercrete, as they assess bulk behavior and are made in labs. The actual quality of the cover layer is thus ignored. It is now established that permeability of concrete against air and water is an excellent measure of its resistance to ingress by other aggressive media (gaseous / liquid).


Figure 3.4.1: Control Unit


Figure 3.4.2: Two Chamber Vacume Cell with Sealing Rings

As shown in Figure 3.4.1 and 3.4.2, a double chamber cell and a pressure regulator, that balances the pressure in both chambers during the test. Principal of measuring air permeability is diagrammatically shown in Figure 3.4.3.

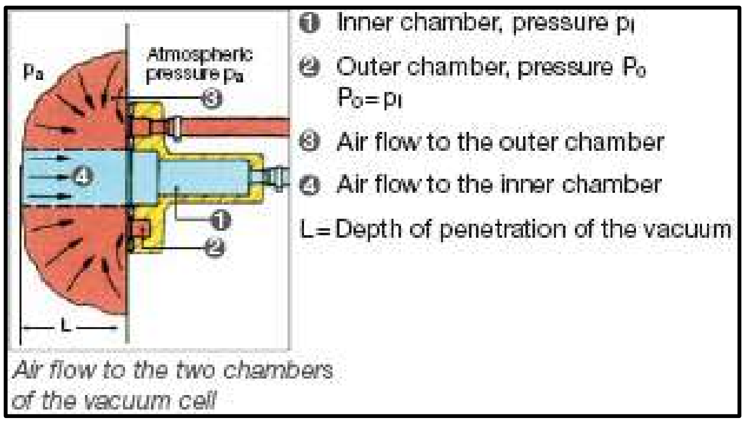


Figure 3.4.3: Principal of Measuring Air Permeability

The special features of double chamber allow a controlled, uni-directional flow of air from the pores of concrete into the inner chamber, while the outer chamber acts as a guard-ring. Under these conditions, it is possible to calculate the coefficient of permeability of the covercrete and to estimate the depth of concrete affected by the test (normally between 10 – 50 mm, depending on the permeability). A single determination takes between 1-1/2 min. to 12 min. for completion, depending on the permeability. The coefficient of permeability KT is measured in $m^2$. KT is influenced by the presence of moisture in concrete; hence, corrections need to be applied. Electrical resistivity (ρ) measurements are made and corrections are applied.

### 3.5 Ultra Sonic Pulse Velocity Test

The ultra-sonic pulse velocity test is a non-destructive test and is conducted in accordance to ASTM C-597-83)The principal of this test is to transmit an ultrasonic pulse through the material to be tested by means of a piezoelectric transducer (transmitter) and picked up by another piezoelectric transducer (receiver) placed on the other side of the object that is tested. See Figure 3.5.1 Each Transducer has a natural frequency of 54 kHz which is suitable for most common applications. The Receiver Transducer has a button which facilitates manual memory log function. Five display options are available: *transit time, path length, velocity, limits, and elastic modulus*.


*Figure 3.5.1: PUNDIT Test Calibration Configuration*

## 4 PHYSICAL PROPERTIES OF THE MATERIAL USED IN CONCRETE BATCHES

Concrete used for this testing program consisted of cement, sand (fine aggregate) and coarse aggregate.

***Cement:*** Falcon Cement conforming to PS-232-2008 (BS-12: 1978 34 Grade) was used to cast test samples for the experimental program.

***Sand:*** The sand used for the experimental program contained 2% of gravel.

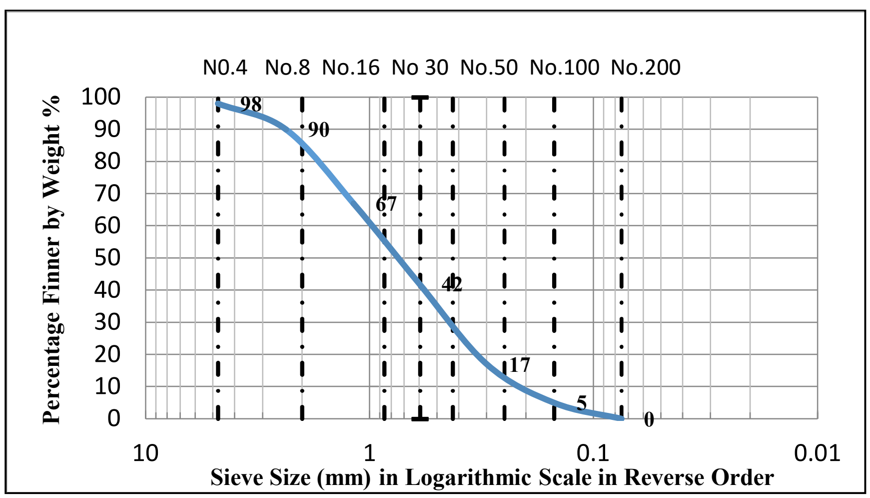


*Figure 4.1: Sand Size Distribution Curve*

The particle size distribution curve derived as per ASTM D6913-03 is shown at Figure 4.1 the gradation criterion for fine aggregate as per ASTM C33-03 is shown in Table 4.1. It is evident from Table 4.1 that the graduation of sand used in the experimental program i.e. percentage passing in specified sieve is within limits of ASTM C33-03.

*Table No. 4.1: Percentage passing in sieves*

| Sieve # | Percent passing | Tested soil sample value |
|---|---|---|
| **9.5-mm (3⁄8-in.)** | 100 | -- |
| **4.75-mm (No. 4)** | 95 – 100 | 98 |
| **2.36-mm (No. 8)** | 80 – 100 | 90 |
| **1.18-mm (No. 16)** | 50 – 85 | 67 |
| **600-µm (No. 30)** | 25 – 60 | 42 |
| **300-µm (No. 50)** | 5 – 30 | 17 |
| **150-µm (No. 100)** | 0 – 10 | 5 |

***Coarse Aggregate:*** The sample selected was as per ASTM C136-05. Particle size distribution curve is shown at Figure 4.2.

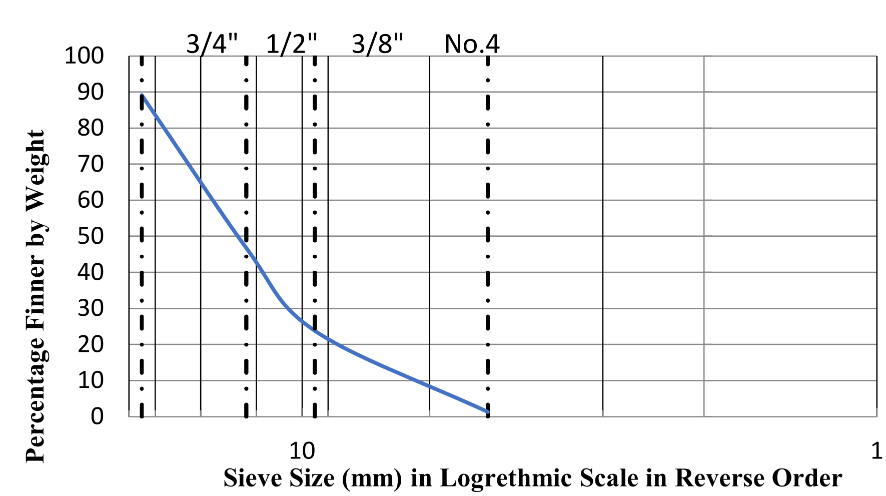


*Figure 4.2: Coarse Aggregate Size Distribution Curve*

As per ASTM C33, Standard specification for concrete aggregate of nominal size (sieve with square opening) from 19 – 4.7mm (3/4” – No.4) with amount finer than sieve, mass passing percentage is shown in Table 4.2.The coarse aggregate satisfied the graduation requirement of ASTM C33 except 9.5mm sieve, which is much below the specified limit.

*Table No. 4.2: Sieve analysis results*

| Sieve # | Percent passing | % Passing of coarse aggregate used in experimental program |
|---|---|---|
| **25 mm (1 inch)** | 100 | 100 |
| **19 mm (3/4 inch)** | 90 – 100 | 95.0 |
| **12.5 mm (1/2 inch)** | -- | -- |
| **9.5 mm (3/8 inch)** | 22 – 55 | 6.0 |
| **4.75 mm (No. 4)** | 0 – 10 | 0 |

Concrete Samples: 02 Nos. batches of concrete were prepared as follows:

**Batch 1:** Mix Ratio of 1:2:4 by weight (1 part cement, 2 parts fines and 4 parts coarse aggregate) with water cement ratio w/c = 0.5 prepared dated 18.4.2019.
**Batch 2:** Mix Ration of 1:1.5:3 by weight (1 part cement, 1-1/2 parts fines and 3 parts coarse aggregate) with water cement ratio w/c = 0.5 prepared dated 30.04.2019.

12 Cubes were cast from each batch of concrete to test their compressive strengths at 03, 07, 14, and 28 days. Test cubes were prepared in accordance to ASTM-31. The testing schedule of 24 sample cubes is shown in Tables 4.3 and 4.4.

*Table 4.3: Testing Schedule of 12 Sample Cubes Cast from Batch 1 Concrete (1:2:4) W/C = 0.5, Casting Date: 18-04-2019*

| Sample No. | Tests Performed | Density (pcf) | Testing Dates (Average Density in pcf) |
|---|---|---|---|
| Cube 1 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CTM (Destructive Test) | 158.688 | **at 3 Days**<br>22-04-2019<br>**( 160 pcf)** |
| Cube 2 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CAPO Test (NDT) | 160.45 | |
| Cube 3 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Coefficient of Air Permeability (NDT)<br>iii. Ultra Sonic Pulse Velocity Test (NDT) | 160.45 | |
| Cube 4 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CTM (Destructive Test) | 158.688 | **at 7 Days**<br>26-04-2019<br>**(163pcf)** |
| Cube 5 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CAPO Test (NDT) | 162.214 | |
| Cube 6 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Coefficient of Air Permeability (NDT)<br>iii. Ultra Sonic Pulse Velocity Test (NDT) | 169.26 | |
| Cube 7 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CTM (Destructive Test) | 167.50 | **at 14 Days**<br>03-05-2019<br>**( 163pcf)** |
| Cube 8 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CAPO Test (NDT) | 160.45 | |
| Cube 9 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Coefficient of Air Permeability (NDT)<br>iii. Ultra Sonic Pulse Velocity Test (NDT) | 160.45 | |
| Cube 10 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CTM (Destructive Test) | 167.50 | **at 28 Days**<br>17-05-2019<br>**(168pcf)** |
| Cube 11 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CAPO Test (NDT) | 163.977 | |
| Cube 12 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Coefficient of Air Permeability (NDT)<br>iii. Ultra Sonic Pulse Velocity Test (NDT) | 171.03 | |

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*Table 4.4: Testing Schedule of 12 Sample Cubes Cast from Batch 2 Concrete (1:1.5:3) W/C = 0.5 Casting Date: 30-04-2019*

| Sample No. | Tests Performed | Density (pcf) | Testing Dates (Average Density in pcf) |
|---|---|---|---|
| Cube 13 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CTM (Destructive Test) | 172.5 | **at 3 Days** 03-05-2019 **(175pcf)** |
| Cube 14 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CAPO Test (NDT) | 176.32 | |
| Cube 15 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Coefficient of Air Permeability (NDT)<br>iii. Ultra Sonic Pulse Velocity Test (NDT) | 174.55 | |
| Cube 16 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CTM (Destructive Test) | 172.7 | **at 7 Days** 08-05-2019 **(168 pcf)** |
| Cube 17 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CAPO Test (NDT) | 160.45 | |
| Cube 18 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Ultra Sonic Pulse Velocity Test (NDT) | 169.2 | |
| Cube 19 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CTM (Destructive Test) | 174.5 | **at 14 Days** 14-05-2019 **(166 pcf)** |
| Cube 20 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CAPO Test (NDT) | 167.5 | |
| Cube 21 | i. Compressive Strength by Rebound Hammer Test (NDT) | 156.9 | |
| Cube 22 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CTM (Destructive Test) | 167.5 | **at 28 Days** 28-05-2019 **(166pcf)** |
| Cube 23 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Compressive Strength by CAPO Test (NDT) | 156.9 | |
| Cube 24 | i. Compressive Strength by Rebound Hammer Test (NDT)<br>ii. Coefficient of Air Permeability (NDT) | 172.7 | |

## 5.0 SUMMARY OF TEST RESULTS

*Table 5.1: Results of Batches 1 & 2 at 03, 07, 14 and 28 Days*

| Sample No: | Type of Test | | | | |
|---|---|---|---|---|---|
| | *Average Compressive Strength by Rebound Hammer Test in psi (NDT) | Compressive Strength by CTM in psi (Destructive Test) | Compressive Strength by CAPO Test in psi (NDT) | Coefficient of Air Permeability (NDT) KT Value | Average Ultra Sonic Pulse Velocity Test (NDT) Average Velocity m/sec |
| **Results at 3 Days for Samples cast from Batch 1 Concrete (1:2: 4)** | | | | | |
| Cube 1 | 3000 | 3796 | - | - | - |
| Cube 2 | | - | 4219.5 | - | - |
| Cube 3 | | - | - | 0.173 | 4340 |
| *Average Standard Deviation 2.77 (See Figure-6.1) | | | | | |
| **Results at 7 Days for Samples cast from Batch 1 Concrete (1:2: 4)** | | | | | |
| Cube 4 | 2960 | 4853 | - | - | - |
| Cube 5 | | - | 4248.5 | - | - |
| Cube 6 | | - | - | 0.214 | 3353 |
| *Average Standard Deviation 2.57 (See Figure-6.1) | | | | | |
| **Results at 14 Days for Samples cast from Batch 1 Concrete (1:2: 4)** | | | | | |
| Cube 7 | 3360 | 5413 | - | - | - |
| Cube 8 | | - | 4263 | - | - |
| Cube 9 | | - | - | 0.333 | 3910 |
| *Average Standard Deviation 3.14 (See Figure-6.1) | | | | | |
| **Results at 28 Days for Samples cast from Batch 1 Concrete (1:2: 4)** | | | | | |
| Cube 10 | 3090 | 5600 | - | - | - |
| Cube 11 | | - | 5046 | - | - |
| Cube 12 | | - | - | 0.607 | - |
| *Average Standard Deviation 1.78 (See Figure-6.1) | | | | | |
| **Results at 3 Days for Samples cast from Batch 2 Concrete (1:1.5:3)** | | | | | |
| Cube 13 | 2240 | 3236 | - | - | - |
| Cube 14 | | - | 2943.5 | - | - |
| Cube 15 | | - | - | 2.707 | 2723 |
| *Average Standard Deviation 1.89 (See Figure-6.1) | | | | | |
| **Results at 7 Days for Samples cast from Batch 2 Concrete (1:1.5:3)** | | | | | |
| Cube 16 | 3360 | 3360 | - | - | - |
| Cube 17 | | - | 4350 | - | - |
| Cube 18 | | - | - | NA | 4461 |
| *Average Standard Deviation 2.77 (See Figure-6.1) | | | | | |

| Sample No: | Type of Test | | | | |
|---|---|---|---|---|---|
| | *Average Compressive Strength by Rebound Hammer Test in psi (NDT) | Compressive Strength by CTM in psi (Destructive Test) | Compressive Strength by CAPO Test in psi (NDT) | Coefficient of Air Permeability (NDT) KT Value | Ultra Sonic Pulse Velocity Test (NDT) Average Velocity m/sec |
| **Results at 14 Days for Samples cast from Batch 2 Concrete (1:1.5:3)** | | | | | |
| Cube 19 | 3640 | 5228 | - | - | - |
| Cube 20 | | - | 4582 | - | - |
| Cube 21 | | - | - | NA | NA |
| *Average Standard Deviation 2.16 (See Figure-6.1) | | | | | |
| **Results at 28 Days for Samples cast from Batch 2 Concrete (1:1.5:3)** | | | | | |
| Cube 22 | 3960 | 5537 | - | - | - |
| Cube 23 | | - | 4727 | - | - |
| Cube 24 | | - | - | 1.19 | NA |
| *Average Standard Deviation 2.85 (See Figure-6.1) | | | | | |

## 6.0 DISCUSSION OF RESULTS

### 6.1 Re-Bound Hammer Test

Figure 6.1 shows the variation in rebound values on different test cubes. The variation indicates the change of surface conditions on test samples with different concrete properties. It is observed that variation are high in fresh concrete in early days and becomes less as approaching strength at 28 days.

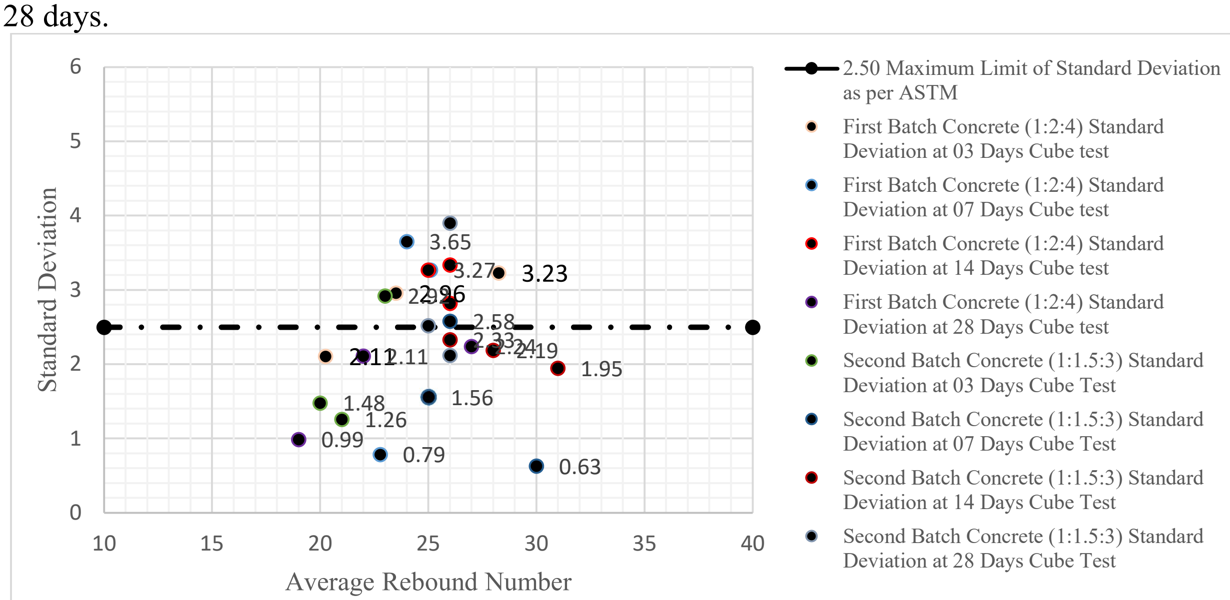


*Figure 6.1: Average Rebound Number VS Standard Deviation*

For both batches of concrete, the deviation is scattered in random manner with clustered pattern in between 19 to 32 Rebound number.

### 6.2 Comparison of Cube Compressive Strengths obtained from Rebound Hammer Test, CAPO Tests and CTM

Figs 6.2.1 and 6.2.2 depict that concrete compressive strengths at different ages are highest when tested by the CTM tests followed by CAPO tests and rebound hammer tests respectively. The 28 day strength of rebound hammer of batch 1 show a trend of strength reduction. The reason could be that being a sensitive test with respect to surface texture of concrete and due to less stiff surface of concrete on that sample, low 28 days strength was achieved as compared to 14-day strength.

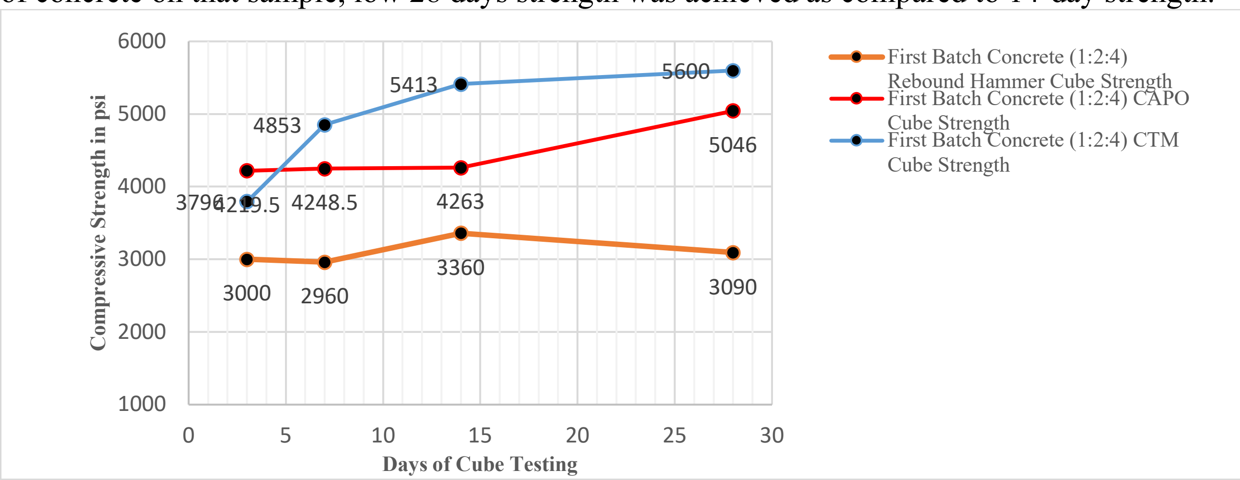


*Figure 6.2.1: Comparison of Compressive Strength Test Results at Different Ages for Concrete Batch 1 (1:2:4)*

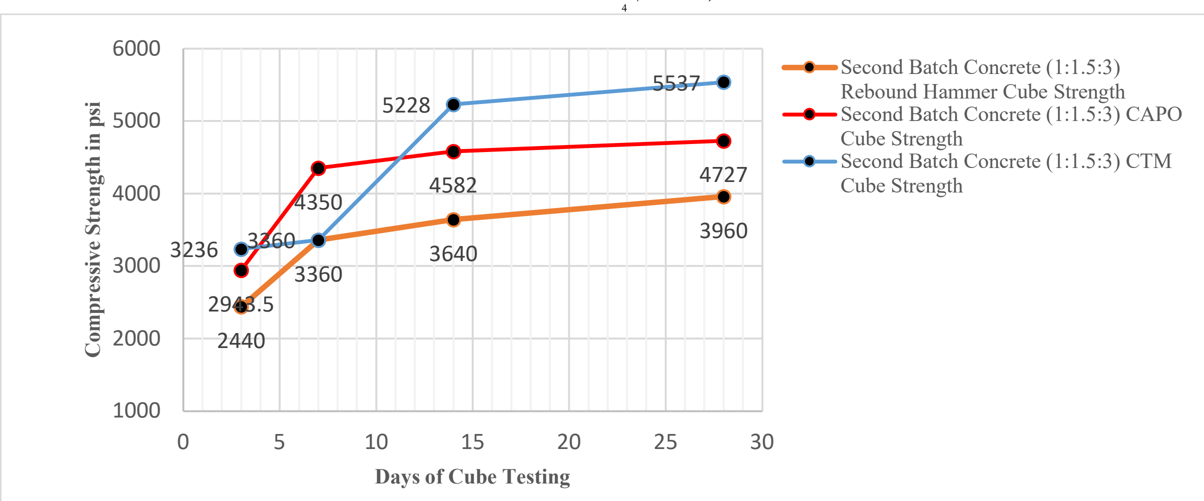


*Figure 6.2.2: Comparison of Compressive Strength Test Results at Different Ages for Concrete Batch 2 (1:1.5:3)*

A comparison of Capo test results and Rebound Hammer tests results with CTM results is summarized in table 6.2.1:

*Table 6.2.1: Comparison of Capo and Rebound Hammer test results*

| Concrete Batch | CAPO Test Results at Different Ages (Days) in % | | | | Rebound Hammer Test Results at Different Ages(Days) in % | | | |
|---|---|---|---|---|---|---|---|---|
| | 3 | 7 | 14 | 28 | 3 | 7 | 14 | 28 |
| Batch 1 Concrete(1:2:4) | -11.5 | 12.45 | 21.24 | 9.89 | 20.96 | 39 | 37.92 | 44.82 |
| Batch 2 Concrete (1:1.5:3) | 9.03 | -29.46 | 12.35 | 14.62 | 24.59 | 0 | 30.37 | 28.48 |

## 7 CONCLUSIONS AND RECOMMENDATIONS:

The following conclusions are deduces from the research study:

### 7.1 Conclusions

The following conclusions are deduced from the research study:

- **i.** Reasonably comparative results are obtained by Non-Destructive Testing and conventional destructive testing methods.
- **ii.** CAPO Test results are more reliable than Rebound Hammer Test when compared with conventional destructive testing.
- **iii.** Air permeability coefficient reduces at higher concrete densities, indication that durability of concrete improves at higher densities of concrete.
- **iv.** The ultrasonic pulse velocities are higher for higher strength of concrete as well as high density of concrete.

### 7.2 Recommendations

In order to develop logical correlations between various tests a comprehensive study must be carried using a variety of locally available aggregates popularly used in the vicinity of Karachi (Pakistan) with a larger number of test samples and larger series of testing ages.

## 8 ACKNOWLEDGMENTS

The authors are very thankful for the support of NDT Team of CWHR including Engr. Sohail Zafar, Muhammad Rizwan, Muhammad Shamim, and Muhammad Aslam to complete the challenging tasks for casting, curing and performing tests on targeted periods with compliance of ASTM Standards. The authors also acknowledge the personnel of LTES Laboratory for their cooperation for conducting the compressive strength test by CTM machine.

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**[10]** Standard Test Method for determining Permeability Coefficient using Permeability Tester (TORRENT) of concrete structural members compliance with DIN 28400.