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COMPARATIVE ANALYSIS OF DESTRUCTIVE AND NON-DESTRUCTIVE TESTING TECHNIQUES FOR ASSESSING CONCRETE STRENGTH

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Abstract -This project research carried out a comparative analysis of destructive and non-destructive testing techniques for assessing hardened concrete's strength. Since concrete is a critical building material, the study seeks to compare the compressive strength properties of hardened concrete obtained experimentally by applying both destructive and non-destructive methods of testing as a measure to ensure structural integrity. The method used in the research involved destructive testing (DT) and non-destructive testing (NDT) techniques in determining the strength properties of hardened concrete cubes. The research involves preparing concrete mixtures with identical proportions of cement, aggregates, and water. Then 12 concrete cube samples were molded with dimensions of 150mm*150mm*150mm. At the end of each curing age, a non-destructive test using a portable ultrasonic non-destructive indicating tester (PUNDIT) machine was carried out on each cube after which a destructive test was also carried out to determine the compressive strength of the concretes. The result indicated that at 28 days, the concrete cubes were molded, cured, and tested, the non-destructive testing technique predicted that the concrete structure might have gained $21.0N/mm^2$ (84%) of its initially designed characteristic target strength (offers rapid, cost-effective, and non-invasive assessment with lower accuracy) while the destructive testing technique predicted $22.50N/mm^2$ (90%) (provides high accuracy but is time-consuming, expensive, and sample-destructive). The research recommended that a combined approach, using DT for calibration and NDT for ongoing monitoring, can provide a comprehensive concrete evaluation. And that understanding the strengths and weaknesses of each method is crucial for effective concrete testing and structural assessment.

Keywords: hardened concrete's strength, destructive testing technique, non-destructive testing techniques, concrete mixture, ensure structural integrity.

1.1 Introduction

Concrete is the oldest and most widely used building material in the world due to its availability, affordability, and durability (Hassan, 2015and Gupta, 2018). The most economical and effective building material is concrete. In their most current worldwide research, "Global Construction 2020," India was ranked as the third-largest global construction market, behind the United States and China. Due to improvements in their design capability, India has achieved the capability to develop concrete with strengths exceeding 100 MPa, something that was not possible in the past. Concrete testing varies from non-destructive testing. China has already constructed high-rise buildings using concrete with strengths of up to 80 MPa while adhering to code requirements for cement usage (Chatterjee, 2014 and 2015).

Concrete testing varies from non-destructive and destructive testing techniques.

Destructive Test Technique

The destructive technique involves conducting operations that entail the synthesis and analysis of the concrete specimen to determine its mechanical characteristics, such as strength and hardness. The methodology yields a greater amount of data and is uncomplicated to employ and evaluate (Shankar and Joshi, 2010 Dauji, et al 2019). Tensile testing is a destructive testing method used to ascertain the tensile strength and elements of materials, including concrete. Bending Testing also known as flexural testing is a destructive testing method used to determine the flexural strength and properties of materials, including concrete. Compressive testing is a destructive testing method used to determine the compressive strength and properties of materials, including concrete. Disadvantages of destructive testing techniques may include pores and air voids in hardened concretes inducing internal defects that cannot be detected. Destructive testing leads to damaging of the concrete specimens thereby rendering them useless after the testing. Destructive testing cannot be used to detect early-age deformities in concrete (Kumavat *et al*., 2017 and Kumavata et al, 2021).

Non-Destructive Test Technique

Non-destructive testing (NDT) is majorly concerned with the evaluation of flaws or weaknesses in materials which are in the form of cracks, and which might lead to loss of strength in a concrete structure (Samson *et al*. 2014). It is a method for the testing of existing concrete structures to determine durability and strength. In contemporary construction, NDT has become a vital part and tool for the quality control process. Deterioration, crack depth, and micro-cracks present in concrete can be investigated through NDT. Using NDT techniques, parameters such as density, strength, and surface hardness can be ascertained. The structure integrity as well as the quality of workmanship can be checked by detecting cracks and voids (Kumavat*et al*., 2017 and Kumavata et al, 2021). The different methods of Non-Destructive Testing include Penetration, rebound hammer, Pull test, Ultrasonic pulse velocity, and Radioactive. The advantages of deploying non-destructive testing technique include: The Schmidt Hammer Test offers a rapid, easy, and affordable way to determine the strength of concrete with a 15% -20% accuracy, the quickest way to determine the quality and maturity of concrete, although it yields inconsistent results. The disadvantage of non-destructive testing is that result interpretation is seemingly difficult. It is hard to understand or even interpret the results, Skilled and experienced technicians are needed for the manual operation, and Uneven and void-filled concrete specimens are challenging to inspect (Kumavat*et al*., 2017).

Non-destructive testing (NDT) facilitates in-service inspection of structures and components to identify defects such as corrosion-induced cracks, damage, fatigue, and creep. NDT also assesses concrete uniformity in slabs, walls, and foundations. Moreover, it predicts the service life of existing and new structures by evaluating the effectiveness of structural and surface protection measures.

Samson et al. (2014)**:** M20, M30, and M35 grade concrete were used to cast concrete cubes measuring 100 x 100 x 100 mm, and they were allowed to cure for 7, 14, and 28 days. Materials underwent preliminary testing. A rebound hammer test was conducted on a total of ninety cubes that were created. For every specimen, ten measurements of the compressive strength of the rebound hammer were made. The findings of the regression analysis indicated that high compressive strength was associated with a high rebound number. The regression models' correlation coefficients, which varied from 92.1% to 97.9%, demonstrated a strong correlation between compressive strength and rebound number. The results also showed that it was possible to forecast the compressive strength of concrete with ease if just the rebound number was known.

Onyeka, F.C. and Mama, B.O (2019)**:** This research investigated the efficacy of destructive and non-destructive testing methods utilizing the Schmidt Rebound Hammer. Seventy (70) 150*150*150mm cube samples were prepared with a 1:2:4 mix design and a consistent 0.45 water-cement ratio. Testing occurred at 7, 14, 21, and 28 days. Results showed a steady increase in rebound numbers from 12(7 days) to 32(28 days), indicating uniform strength gain. However, a 5-unit discrepancy was observed. Therefore, destructive testing conforms to target characteristic design values while Non-destructive testing (Schmidt Rebound Hammer) was field-friendly and economical.

The research gap: The assessment of strength of concrete have been done mainly with the deployment of destructive testing technique. However, the steel mould used in the production of cubes for destructive testing are not the same with formworks provided at site during construction. The steel mould are better structured, easily placement and compaction of fresh concrete. While at the site, most of the formworks are done with timber planks or boards of different dimensions making concrete placement and compaction difficult at times and could bust. Nevertheless, the method of curing the cubes by total immersion inside water-tank for the 28 days provides means for better strength gain than by sprinkling water on concretes as practiced at sites during construction. The non-uniform treatment of concrete cubes and what was obtainable at site may have impact on the strength development at the end. The utilization of both destructive and non-destructive testing techniques will serve as quality control in confirming that what was obtained from cube test was statistically the same with what is on site. Destructive test Involves physically damaging or destroying concrete samples to assess properties while Non-destructive test evaluates concrete properties without causing damage.

Statement of Problem

Despite the widespread application of destructive and non-destructive tests on concrete, there is a lack of comprehensive comparative analysis between the two methods, leading to; Inadequate understanding of the strengths and limitations of each testing method, Inconsistent test results and interpretation, High testing costs due to the use of multiple testing methods, Limited knowledge on the correlation between destructive and non-destructive test results and Difficulty in selecting the most appropriate testing method for specific concrete structures and applications. This problem statement highlights the need for a comprehensive comparative examination of destructive and non-destructive tests on concrete to address the limitations and challenges associated with these testing methods.

Aim of the Study

This study aims to compare the compressive strength properties of hardened concrete obtained experimentally by applying both destructive and non-destructive methods of testing.

Objectives of the Study

The objectives include.

1. To carry out experimental tests on concrete using a destructive testing technique
2. To carry out an experimental test on concrete using a non-destructive testing technique
3. Compare results observed from the two testing techniques above

2 Research Methodology

The adopted design method in this research involved experimental design of concrete mix with uniform material components. This concrete mix was used to mould twelve (12) concrete cubes of dimensions $150mm * 150mm * 150\ mm$ that were cured and tested using a non-destructive technique, followed by destructive testing technique on the same specimens for the respective testing days of 7, 14, 21 and 28.

Materials:

Cement: This was used as the hydraulic binder. The type used was ordinary Portland cement of 32.5 grade manufactured by UNICEM.

Coarse Aggregate: The coarse aggregate used for this research work was crushed aggregate from Abakaliki in Ebonyi State. The material was characterized through sieve analysis, ensuring that it was free from deleterious substances and organic materials. A maximum size of 20mm granite was used in this research work.

Fine Aggregate: The fine aggregate used for this research work was sharp river sand collected from the Nyama River in Enugu South Local Government Area, Enugu State. The fine aggregate was washed, and a surface-dried and sieve analysis test was done which conformed to zone 3 of the aggregate zoning chart.

Water: For this research, the water utilized for the process of blending and solidifying the concrete was devoid of any discernible contaminants.

Tests Carried Out

The trial test carried out during this project was done by the specifications of the appropriate BS code methods for the determination of particle size distribution through sieve analysis. Non-destructive tests were carried out using a portable ultrasonic non-destructive indicating tester (pundit) machine, and Destructive tests were done through Compressive strength tests using a universal testing machine.

Curing and testing condition of concrete cube samples:

The curing of the samples was done by immersion in the water curing tank. The cubes after removal from the moulds were immersed in a curing tank filled with borehole water at room temperature. This was to provide the humid condition required for curing and to keep the cubes wet to reduce cracking caused by the chemical reaction of cement. During this period of curing, the concrete gains strength with time. The cubes were cured for 7, 14, 21, and 28 days. The three specimens of the samples (each set labeled by date and mould number) were air-dried and weighed. The pundit machine was used to carry out a non-destructive test on each cube before placing them in the crushing machine for a destructive test, at the end of each curing age, with the square faces in contact with the plate of the testing machine. The machine crushed all three (3) specimens for each stage and the mean of the values taken.

Data Collection Method and Analysis: Statistical methods like T-tests were used to analyze and compare results observed from the experiment.

The Concrete Mix Design Summary:

The mix proportions of the constituent materials were obtained using the CP 110 code. The target characteristic strength value = $25\ N/mm^{\mathbf{2}}$**,** The slump test value of range 30 – 60mm, Free-water/cement ratio of 0.61. Wet density value = 2426kg/m^3

Free water content = 190 kg/m^3, Cement content = 311.48kg/ m^3,

Fine aggregate content = 769.8kg/m^3, Coarse aggregate content = 1154.7kg/m^3.

Non-destructive test using portable ultrasonic non-destructive indicating tester (pundit) machine

Components of a pundit machine

1. Transducer: A small, handheld device with a flat or curved surface typically made of metal or ceramic that converts electrical energy into ultrasonic pulses and receives reflected pulses.
2. Probe: A small, cylindrical, or rectangular device attached to the transducer, making contact with the concrete surface, usually with a flat or rounded tip.
3. Pulse Generator: A small electronic device that produces high-frequency electrical pulses, often housed in a rectangular box with cables and connectors.
4. Receiver: A small electronic device that amplifies and processes the reflected pulses, often integrated into the control unit.
5. Analyzer: A small electronic device or software module that calculates the ultrasonic pulse velocity (UPV) and performs signal analysis, often integrated into the control unit.
6. Display Unit: A small screen or display, typically an LCD or LED, showing test results, graphs, and histograms.
7. Control Unit: A compact electronic device housing the electronics, software, and user interface, often with buttons, knobs, or a touch screen.
8. Power Source: A rechargeable battery pack or external power supply, typically a small rectangular device with cables and connectors.
9. Cables and Connectors: Color-coded cables and connectors linking the components together.

10. Calibration Module: A small device or software module used for calibrating and verifying the machine's accuracy.

Procedure:

Using a PUNDIT (Portable Ultrasonic Non-Destructive Digital Indicating Tester) machine:

Preparation:

Ensure the concrete surface is clean, dry, and free from debris.

Select the appropriate transducer and couplant (gel or spray) for the test.

Setup:

Turn on the PUNDIT machine and allow it to warm up.

Calibrate the machine according to the manufacturer's instructions.

Select the test mode and parameters (e.g., pulse frequency, gain).

Testing:

Apply the couplant to the transducer and concrete surface.

Place the transducer on the concrete surface, ensuring good contact.

Take readings at multiple points, moving the transducer between each reading.

3 Results and Discussions

The following results were observed from the experiments on non-destructive and destructive testing methods on the strength of concrete.

Table 1: Compressive Strength Test Results for 7 days

Sample ID	Cross-section of samples (mm)	Weight of samples (Kg)	Compressive strength (N/mm^2)	
			Non-Destructive Test Technique (Pundit Machine) (N/mm^2)	Destructive Test Technique (Universal Testing Machine, UTM) (N/mm^2)
MS1	150*150	8750	10.5	12.5
MS2	150*150	8690	12.0	14.0
MS3	150*150	8785	13.0	14.0

Table 1 above presents the strength test results for both destructive and non-destructive testing techniques after seven (7) days the concrete cube samples were moulded and cured. The early gain in strength of the sample cubes was determined using a Pundit Machine, before being crushed with UTM. From the table, the destructive testing technique gave a higher strength value ranging from $12.5 \text{ to } 14.0 N/mm^2$ while the non-destructive testing technique gave values within the range of $10.5 \text{ to } 13.0 N/mm^2$. The result indicated that at the 7th day, the concrete cubes have gained average strength of 13.5N/mm^2 (54%) of characteristic design strength using Destructive testing technique while Non-destructive technique indicated average strength gain of 11.83N/mm^2 (47.32%). However, when the two results were tested for significant difference at 0.05 level of significance, using T- a test calculator, it was revealed that there was no significant difference between the mean strength of concrete obtained using destructive and non-destructive testing techniques after the seventh-day test (t-value is -1.88982, the *p*-value is .065889 at $p < .05$). This early strength test indicated that both destructive and non-destructive testing techniques are reliable means of detecting early gain in strength of concrete structures and should be deployed during construction of projects as means of quality control measures.

Table 2: Compressive Strength Test Result for 14 days

Sample ID	Cross-section of samples (mm)	Weight of samples (Kg)	Compressive strength (N/mm^2)	
			Non-Destructive Test Technique (Pundit Machine) (N/mm^2)	Destructive Test Technique (Universal Testing Machine) (N/mm^2)
MS1	150*150	8802	14.5	16.0
MS2	150*150	8710	15.5	17.5
MS3	150*150	8805	15.0	17.0

Table 2 above displayed the strength test results for both destructive and non-destructive testing techniques after fourteen (14) days the concrete cube samples were moulded and cured. The table showed that the destructive testing technique gave a higher strength value of $17.50N/mm^2$ as the maximum value while the non-destructive testing technique gave $15.5N/mm^2$ as its maximum strength value. The progressive/ continuous gain in strength test revealed that, with the destructive testing technique, the concrete samples have gained about 68% of the target mean characteristic strength they were designed for while the non-destructive testing technique indicated that the concrete samples have gained about 62% of the designed target mean characteristic strength. In other words, the destructive testing technique is more reliable in determining the strength of concrete at this stage of strength development in concrete structures, that is, high accuracy of result, but not cost-effective. While the non-destructive testing technique has low accuracy of results, though easy to operate and cost effective. The implication of the result is that, as the concrete continues in strength gain and development, destructive testing technique was able to predict higher strength values than the non-destructive testing equivalent. At this stage, destructive testing value is more reliable than non-destructive technique.

Table 3: Compressive Strength Test Result for 28 days

Sample ID	Cross-section of samples (mm)	Weight of samples (Kg)	Compressive strength (N/mm^2)	
			Non-Destructive Test Technique (Pundit Machine) (N/mm^2)	Destructive Test Technique (Universal Testing Machine) (N/mm^2)
MS1	**150*150**	**8802**	**19.5**	**21.0**
MS2	**150*150**	**8710**	**21.0**	**22.5**
MS3	**150*150**	**8805**	**19.0**	**21.5**

Table 3 above demonstrates the strength test results for both destructive and non-destructive testing techniques after twenty-eight (28) days the concrete cube samples were moulded and cured. The table exposed that the destructive testing technique gave a maximum strength value of $22.50N/mm^2$ while the non-destructive test technique gave a maximum strength value of $21.0N/mm^2$. The result implies that at 28 days, the concrete cubes were moulded, cured, and tested, the non-destructive testing technique predicted that the concrete structure might have gained 84% of its initially designed cGharacteristic target strength while the destructive testing technique predicted 90%. Nevertheless, when the two results were subjected to statistical tests at 0.05 level of significance, it was revealed using a T-test calculator, that there was a significant difference between the mean strength of concrete obtained using destructive and non-destructive testing techniques after the twenty-eight-day test (t-value is -2.45968, the *p*-value is .034858 at $p < .05$). In likely manner, the two techniques of testing the strength of concrete can be deployed as reliable means of predicting compressive strength of concrete structures at every stage of construction of projects for quality control purposes.

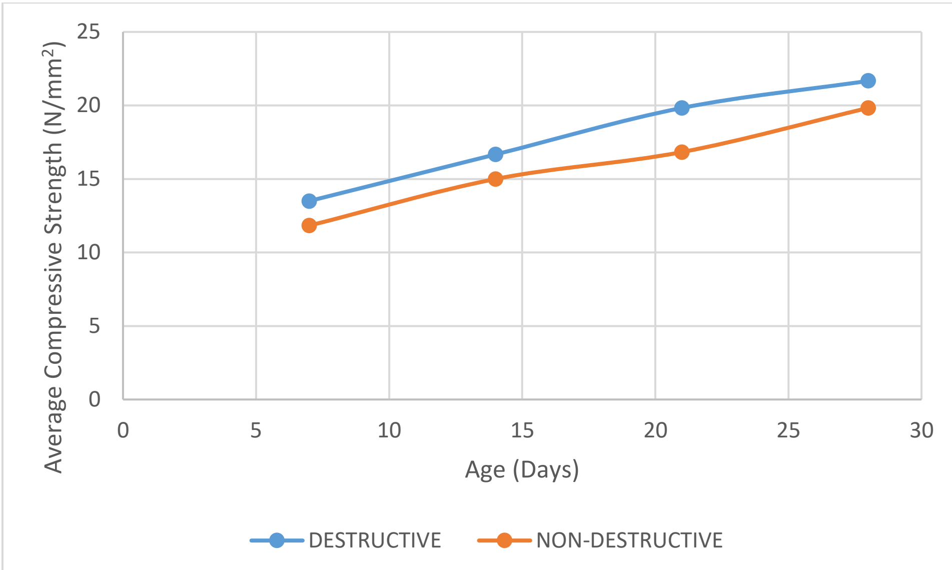

Figure 1: Graph of Average Compressive Strength against Age of testing (days) for Destructive and Non-destructive Testing Techniques.

Figure 1 above presents, for comparison and better understanding, a pictorial view of the compressive strengths of concretes assessed using destructive and non-destructive testing techniques at different testing ages of 7 to 28 days. The figure shows that destructive testing technique gave maximum strength values at all testing ages while non-destructive testing technique values was least at every testing age. The results observed from this study was in line with the finding obtained by Onyeka, F.C and Mama, B.O (2019) that destructive process are closer to the design mix strength value whereas that of Rebound Hammer values was below the design value. The implication of the findings is that, though destructive testing technique gave maximum values of strength at all testing ages, it cannot be used to assess the strength of concrete elements at serviceability state. This entails the employment of non-destructive testing technique at this stage for ensuring structural integrity and stability. However, the non-destructive testing technique gives the actual value of strength of concrete in the field (at site) as other factors (adequate curing, and condition of testing concrete) influences the strengths of concrete. Bearing in mind that concrete cubes collected during concreting and what was obtained at site (e.g. beam) were not compacted, cured and tested at the same conditions which may likely create discrepancies their respective strength values. This makes the adoption of both testing techniques very important during construction to ensure quality control.

4 Conclusions and Recommendations

The following conclusions and recommendations were made from the experimental results obtained in this research work

4.1 Conclusion

The early strength gain test on the seventh (7^{th}) day, indicated that both destructive and non-destructive testing techniques are reliable means of detecting early gain in strength of concrete structures and should be deployed during the construction of as a means of quality control measures. Even though the destructive test technique gave a higher strength value than the non-destructive test technique, there was no significant difference between the mean strength values of the two methods when tested with a T-test projects calculator.

The continuous gain in strength test on the 14th day revealed that, with the destructive testing technique, the concrete samples have gained about 68% of the target mean characteristic strength they were designed for while the non-destructive testing technique indicated that the concrete samples have gained about 62% of the designed target mean characteristic strength. In other words, the destructive testing technique is more reliable in determining the strength of concrete at this stage of strength development in concrete structures.

On the 28th day of testing the concrete cubes, the non-destructive testing technique predicted that the concrete structure might have gained 84% of its initially designed characteristic target strength while the destructive testing technique predicted 90%. Nevertheless, there was a significant difference between the mean strength values of the two methods when tested with a T-test calculator.

The destructive testing technique gave a higher accuracy of the result but was not cost-effective. While the non-destructive testing technique has low accuracy of results, though easy to operate and cost effective.

4.2 Recommendation

- The research work recommended that the two techniques of testing the strength of concrete be deployed as reliable means of predicting the compressive strength of concrete structures at every stage of construction of projects for quality control purposes.
- The research work recommended that understanding the strengths and weaknesses of each testing technique is crucial for effective concrete testing and structural assessment

Refernces

Hassan Y (2015) Introduction to Concrete Technology. Research gate 1(6): 21-29

Gupta S (2018) Comparison of Non-destructive and Destructive Testing on Concrete; a Review. Trends in Civil Engineering and Architecture. Volume 3, Issue 1

Global Construction (2020) A Global Forecast for the Construction Industry over the next Decade to 2020. Global Construction Perspective and Oxford Economics. An Overview. www.globalconstruction2020.com

Chatterjee, P (2014) Urban Building Collapse: what are the Health Implications. BMJ 2014;349: g5256, New Delhi

Chatterjee, P. (2015) Our changing world: let's be ready, royal institution of Chartered Surveyors. Volume 1

Shankar, S and Joshi, H.R. (2014) Comparison of Concrete Properties, determined by Destructive and Non-destructive Tests. *Journal of the Institute of Engineering*, volume 1. 5

Dauji, S, Bhalerao S, Srivastava P.K and Bhargava K (2019) Conservative Characteristic Strength of concrete from non-destructive and partially destructive testing. *Journal of Asian Concrete Federation.* Engineering material science

Kumavat R., Patel V., Tapkire G., Patil R., (2017), "Utilization of Combined NDT in the Concrete Strength Evaluation of Concrete Specimen from Existing Building", International Journal of Innovative Research in Science, Engineering and Technology, Volume 6, Issue 1: 556-562

Kumavata H.R, Chandaka, N.R and Patilb, I.T (2021) Factors Influencing the Performance of rebound hammer used for non-destructive testing of concrete. https://doi.org/10.1016/j.cscm.2021.e00491

Samson D., Omoniyi, Moses T., (2014), "Correlation between Non-destructive Testing and Destructive Testing of Concrete", International Journal of Engineering Science Invention, Volume 3, Issue 9, pp. 12-17.

Onyeka, F.C and Mama, B.O (2019). "Comparative Analysis of Destructive and Non-destructive Testing Method of Concrete Strength Using Compressive and

Rebound Harmmer Testing Method". International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Vol. 4, Issue 1, https://www.ijtsrd.com/papers/ijtsrd2989.pdfpaper

Patil H, Khairnar D, and Thube R (2015) Comparative Study of Effect of Curing on Compressive Strength of Concrete by using NDT and DT. International Journal of Science and Advanced Research in Technology 1(6): 1-5.

Shang H, Ting Y, Yang L (2012) Experimental Study on the Compressive Strength of Big Mobility Concrete with Non-destructive Testing Method. Advances in Material Science and Engineering 2(1): 225-231.