Comparative Analysis of Destructive and Non-Destructive Testing Methods for Evaluating Compressive Strength of Self-Compacting Concrete

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Abstract—**This study presents a comparative analysis of destructive and Non-Destructive Testing (NDT) methods for evaluating the compressive strength of Self-Compacting Concrete (SCC). Two distinct SCC mix designs, JMD UPTD and JMD PAB, both targeting a 28-day compressive strength of 30 MPa, were tested using conventional compression testing, Ultrasonic Pulse Velocity (UPV), and Rebound Hammer tests. The results showed that both mixes significantly exceeded the design strength, with the JMD UPTD mix achieving a higher mean compressive strength (52.33 MPa) compared to the JMD PAB mix (46.95 MPa). The UPV method demonstrated a stronger and more reliable correlation with actual compressive strength (R^2 = 0.72) than the Rebound Hammer method (R^2 = 0.35). Regression analysis yielded mix-specific correlation equations for strength estimation. The findings indicate that UPV testing is a more viable NDT method for SCC quality assessment, provided that proper calibration is performed, while the Rebound Hammer test shows limited reliability for SCC without specialized correlations. This research supports the integration of calibrated NDT methods to complement destructive testing for more efficient and comprehensive quality control in SCC applications.**

Keywords—**compressive strength, Non-Destructive Testing (NDT), Rebound Hammer, Self-Compacting Concrete (SCC), Ultrasonic Pulse Velocity (UPV)**

I. Introduction

A distinctive development in concrete technology, Self-Compacting Concrete (SCC) offers remarkable flowability and stability without the need for mechanical vibration during placement. By allowing for the effective filling of crowded reinforcing areas and intricate formworks while preserving high structural integrity, this specialty concrete mix has revolutionized contemporary construction techniques [1, 2]. In order to guarantee structural safety and performance compliance, the increasing use of SCC in critical infrastructure projects calls for trustworthy quality assessment techniques. The gold standard for determining concrete strength is still traditional destructive testing using compression tests, but its inherent drawbacks such as sample destruction, time constraints, and the inability to evaluate in-situ structures have spurred research into non-destructive testing (NDT) alternatives [3, 4].

The Ultrasonic Pulse Velocity (UPV) test and the Rebound Hammer test are two well-known NDT methods that are frequently used to assess the strength of concrete. Higher velocities often indicate denser, stronger concrete [5, 6]. UPV measures the speed at which ultrasonic vibrations travel through concrete. In contrast, the Rebound Hammer test uses rebound values, which are correlated with compressive strength, to evaluate surface hardness [7, 8]. Although both approaches have benefits in terms of speed, affordability, and suitability for current structures, their dependability for SCC is still being studied because of the unique mix design features of SCC that impact aggregate-matrix interactions [9, 10].

Through meticulously comparing compressive strength values from conventional compression testing with those calculated using UPV and Rebound Hammer methods for SCC specimens, this study fills a significant research gap in concrete technology. The study focuses on SCC samples with a design strength of 30 MPa, which is a strength class that is frequently required in structural applications [11]. This study intends to improve knowledge of NDT applicability for SCC quality control and contribute to more effective, trustworthy structural assessment procedures by examining the correlations, differences, and statistical relationships between these testing approaches [12, 13].

This research has significant practical consequences for construction quality assurance that go beyond academic curiosity. By providing real-time strength evaluation without jeopardizing structural elements, the capacity to precisely estimate SCC strength through NDT

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technologies could transform construction monitoring [14, 15]. Projects with complicated geometries, repair applications, or circumstances where core sampling is problematic would especially benefit from this capacity [16]. Additionally, establishing trustworthy correlations between destructive and non-destructive technologies could reduce material waste and project delays while facilitating more effective quality control procedures [17, 18].

II. Literature Review

Self-Compacting Concrete (SCC) has emerged as a significant innovation in concrete technology, distinguished by its exceptional flowability and stability, which allows it to fill formworks and congested reinforcement areas without the need for mechanical vibration [1, 2]. As its use in critical infrastructure projects grows, so does the necessity for reliable quality assessment methodologies to ensure structural safety and performance. The traditional gold standard for determining concrete strength is destructive compression testing; however, this method has notable limitations, including the destruction of samples, time constraints, and the inability to assess the strength of in-situ structures [3, 4]. These shortcomings have motivated significant research into Non-Destructive Testing (NDT) alternatives.

Among the prominent NDT techniques are the Ultrasonic Pulse Velocity (UPV) test and the Rebound Hammer test. The UPV test measures the velocity of ultrasonic waves through a concrete element, where higher velocities are typically indicative of denser, stronger, and more homogeneous concrete [5, 6]. The Rebound Hammer test, conversely, assesses surface hardness through a rebound value, which is then correlated with compressive strength [7, 8]. Both methods offer distinct advantages, such as speed, cost-effectiveness, and the ability to test existing structures without damage.

Despite their established use with conventional concrete, the reliability of these NDT methods for SCC remains an area of ongoing investigation. SCC's unique mix design, which often includes mineral fillers and high-range water-reducing admixtures, alters the aggregate-matrix interaction and can affect the relationship between NDT measurements and actual compressive strength [9]. This presents a critical gap in the literature, as the correlations developed for vibrated concrete may not be directly applicable to SCC. Therefore, a systematic comparison of destructive and non-destructive testing results specifically for SCC is essential to validate these methods and develop reliable, mix-specific correlations for quality control and structural assessment [12].

III. Materials and Methods

The investigation utilized Self-Compacting Concrete (SCC) specimens with a target compressive strength of 30 MPa at 28 days, representing a standard strength class for structural applications [2, 19–21]. Two distinct SCC mix designs were evaluated: JMD UPTD and JMD PAB, both prepared according to EFNARC guidelines to ensure compliance with European specifications for SCC [19, 20, 22]. The constituent materials included Type I Portland cement conforming to ASTM C150 standards [23], natural river sand with fineness modulus of 2.6, crushed granite aggregate with maximum size of 12.5 mm, and a polycarboxylate-based high-range water-reducing admixture [2, 24].

The mix proportions were carefully designed to achieve the fresh properties required for SCC, including flowability, passing ability, and resistance to segregation [25, 26]. The water-to-cement ratio was maintained at 0.38 for both mixes, with total powder content (cement and limestone filler) of 520 kg/m³ for JMD UPTD and 500 kg/m³ for JMD PAB [27, 28]. Superplasticizer dosage was adjusted to achieve a target slump flow of 700±50 mm and T50 time of 2–5 seconds, ensuring compliance with EFNARC specifications [19, 20, 29].

Cylindrical specimens measuring 150 mm in diameter and 300 mm in height were cast in accordance with ASTM C39/C39M standards [23] as shown in the Fig. 1. A total of six specimens were prepared three for each mix design to ensure statistical reliability of results [30]. After casting, specimens were covered with plastic sheets for 24 h to prevent moisture loss, then demolded and transferred to a curing tank maintained at 23±2°C until testing at 28 days [31, 32]. All specimens were labeled to prevent identification errors during subsequent testing procedures [33].

Fig. 1. Cylindrical test specimens made of Self-Compacting Concrete (SCC).

A. Destructive Testing Procedure

Compressive strength testing was conducted using a calibrated universal testing machine with a capacity of 3000 kN, following the standardized procedure outlined in ASTM C39/C39M [23]. Prior to testing, specimens were removed from the curing tank, surface-dried, and measured for precise dimensions using digital calipers with an accuracy of ±0.01 mm [34]. The mass of each specimen was recorded using an electronic scale with 0.01 kg resolution to calculate density [30].

Specimens were centered on the lower platen of the testing machine using alignment guides to ensure uniform load distribution and prevent eccentric loading [35] as shown in the Fig. 2. A continuous compressive load was applied at a constant rate of 0.25 MPa/s until failure, as specified in ASTM C39 [23]. The maximum load at failure was recorded, and compressive strength was calculated by dividing this load by the cross-sectional area of the specimen[11]. For each mix design, the mean compressive strength (fcm), standard deviation (S), number of specimens (n), characteristic strength (fck), and correction factor (k) were calculated according to ACI 214R-11 guidelines [36].

Fig. 2. Concrete compressive strength testing equipment—destructive test.

B. Non-Destructive Testing Procedures

1) Ultrasonic Pulse Velocity (UPV) Testing

UPV measurements were performed using a Cangzhou Iwin ultrasonic testing system with 54 kHz transducers as shown in the Fig. 3, following ASTM C597 standards [37]. Before testing, transducer surfaces were cleaned and coupled to the concrete using a thin layer of petroleum jelly to ensure efficient acoustic transmission [6]. Measurements were taken in the direct transmission mode with transducers positioned on opposite ends of each specimen [5].

Fig. 1. Concrete Ultrasonic Pulse Velocity (UPV)-Non-Destructive Testing.

For each specimen, three readings were recorded at different locations to account for potential material heterogeneity [3]. The transit time (t) was measured in microseconds (μs), and pulse velocity (V) was calculated using the formula $V = L/t$, where L represents the path length (300 mm) [7]. The average velocity for each specimen was then used to estimate compressive strength using established correlation equations [5, 13].

2) Rebound Hammer Testing

Rebound number measurements were conducted using an IWIN HT 225 as shown in the Fig. 4, digital rebound hammer calibrated according to ASTM C805 standards [38]. The hammer was calibrated against a standard steel anvil before testing, with a calibration factor of 1.001 applied to all readings [8]. Tests were performed with the hammer positioned perpendicular to the concrete surface (0° angle) to eliminate the need for angle correction [4] Due to field conditions and equipment limitations, the cylinders were tested in a free-standing position without rigid clamping in a compression machine, deviating from the ASTM C805 requirement for securely clamping small specimens. This unsecured setup may have partially absorbed impact energy, contributing to higher variability in the readings.

Fig. 2. IWIN-MHT225 Concrete Rebound Hammer- Non-Destructive Testing.

For each specimen, 10 readings were taken at different locations, avoiding aggregates and surface imperfections [6]. The highest and lowest values were discarded, and the average of the remaining 8 readings was calculated as the rebound number for that specimen[3]. These values were then converted to estimated compressive strength using manufacturer-provided correlation curves adjusted for the specific concrete mix [9, 10].

Statistical analysis was performed to evaluate the relationships between destructive and non-destructive test results using SPSS version 28.0 [39]. Descriptive statistics including mean, standard deviation, coefficient of variation, and range were calculated for each test method and mix design [40]. Pearson correlation coefficients were computed to quantify the linear relationships between compression test results and NDT estimates [41].

Regression analysis was employed to develop mix-specific correlation equations between NDT parameters and actual compressive strength [42]. The coefficient of determination (R^2) was used to assess the predictive accuracy of these models, while Analysis of Variance (ANOVA) was performed to determine the statistical significance of the relationships [43]. All statistical tests were conducted at a 95% confidence level ($\alpha = 0.05$) [44].

IV. Result and Discussion

A. Compressive Strength Test Results

The compressive strength test results for SCC specimens at 28 days are presented in Table 1. The JMD UPTD mix exhibited a mean compressive strength (fcm) of 52.33 MPa with a standard deviation of 4.79 MPa, while the JMD PAB mix showed a mean strength of 46.95 MPa with a standard deviation of 6.06 MPa, as shown in the Fig. 5. Both mixes significantly exceeded the design strength of 30 MPa, with the JMD UPTD mix demonstrating approximately 11.5% higher average strength than the JMD PAB mix [11, 30].

The characteristic strengths (fck), calculated according to ACI 214R-11 guidelines with a k-value of 1.65 for three specimens, were 44.42 MPa for JMD UPTD and 36.96 MPa for JMD PAB [36]. The coefficient of variation was 9.2% for JMD UPTD and 12.9% for JMD PAB, both within acceptable limits for concrete production quality control [31]. The higher variability in the JMD PAB mix may be attributed to differences in aggregate distribution or minor variations in compaction despite the self-compacting nature of the concrete [1, 2].

Although the initial design baseline for the SCC mixes was 30 MPa, the samples were sourced from an ongoing field project where the contractor deliberately increased the concrete quality in the Job Mixed Formula (JMF) to ensure in-situ strength did not fall below the 30 MPa requirement. The superior performance of the JMD UPTD mix compared to JMD PAB may be attributed to its higher powder content (520 kg/m³ vs. 500 kg/m³) and adjusted superplasticizer dosage, which contributed to enhanced particle packing density and reduced porosity [27, 28]. The denser microstructure of this mix would naturally lead to higher compressive strength, as confirmed by the test results [22, 26]. These findings align with previous research indicating that increased powder content in SCC generally leads to improved mechanical properties, provided the mix maintains adequate flowability [21, 24].

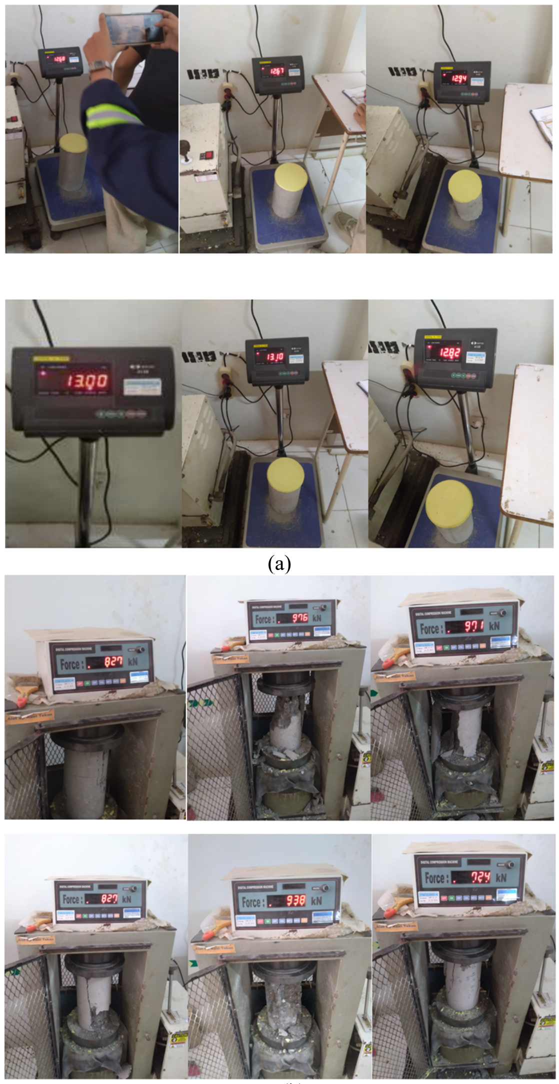

Fig. 5. (a) measurement of the weight of the test specime (b) results of the compression test on Self-Compacting Concrete (SCC).

Table 1: Compressive Strength Test Results for SCC Specimens at 28 Days

Mix Design	Spec	Mass (kg)	Dia (cm)	Height (cm)	Area (cm²)	Max Load (kN)	Compr Strength (MPa)
JMD UPTD	1	12.680	15.00	30.00	176.715	827	46.80
	2	12.670	15.00	30.00	176.715	976	55.23
	3	12.940	15.00	30.00	176.715	971	54.95
	Mean	12.763	15.00	30.00	176.715	925	52.33
	Std Dev	0.147	0.00	0.00	0.000	82	4.79
JMD PAB	1	13.000	15.00	30.00	176.715	827	46.80
	2	13.100	15.00	30.00	176.715	724	40.97
	3	12.820	15.00	30.00	176.715	938	53.08
	Mean	12.973	15.00	30.00	176.715	830	46.95
	Std Dev	0.140	0.00	0.00	0.000	107	6.06

A Ultrasonic Pulse Velocity Test Results

The UPV test results revealed consistent pulse velocities across all specimens, with values ranging from 4.42 km/s to 4.63 km/s (Table 2). The JMD UPTD specimens exhibited slightly higher average velocities (4.54 km/s) compared to the JMD PAB specimens (4.49 km/s), though the difference was not statistically significant ($p > 0.05$). These velocities fall within the "excellent" quality category according to BSI guidelines, indicating dense, homogeneous concrete with minimal voids [6, 45] as shown in the Fig. 6.

The low standard deviations (0.08 km/s for JMD UPTD and 0.04 km/s for JMD PAB) demonstrate the consistency of the SCC mixes and the reliability of the UPV measurements [5]. The direct transmission mode employed in this study provided the most accurate velocity measurements by minimizing the influence of surface irregularities and reinforcement [3, 7, 18]. These results confirm that both SCC mixes achieved excellent internal consolidation without mechanical vibration, validating their self-compacting properties [2, 19, 20].

Fig. 6. Dataset for testing the ultrasonic pulse velocity of self-compacting concrete (SCC) specimens.

TABLE II: ULTRASONIC PULSE VELOCITY TEST RESULTS FOR SCC SPECIMENS

Mix Design	Specimen	Transit Time (μs)	Path Length (mm)	Pulse Velocity (km/s)	Average Velocity (km/s)
JMD UPTD	UPTD1.b	66.3	300	4.55	
	UPTD1.c	64.3	300	4.63	
	UPTD2.a	65.5	300	4.55	
	UPTD2.b	67.5	300	4.43	
	UPTD2.c	67.5	300	4.42	4.54
	Std Dev	1.28	0	0.08	
JMD PAB	PAB1.a	65.9	300	4.52	
	PAB1.c	66.3	300	4.51	
	PAB2.a	66.7	300	4.50	
	PAB2.b	67.9	300	4.43	
	PAB2.c	67.9	300	4.43	4.49
	Std Dev	0.88	0	0.04	

The strong correlation between UPV values and compressive strength is evident from the data, with higher velocities corresponding to higher strength values [12, 13]. This relationship occurs because ultrasonic wave propagation is directly influenced by the elastic properties and density of the concrete, which are themselves functions of compressive strength [5, 6]. The slightly higher velocities in the JMD UPTD specimens corroborate their superior compressive strength performance, confirming the sensitivity of UPV testing to variations in concrete quality [3, 7].

B. Rebound Hammer Test Results

The Rebound Hammer test results showed rebound numbers ranging from 36 to 51, with average values of 42.3 for JMD UPTD and 45.3 for JMD PAB (Table 3). Interestingly, the JMD PAB mix exhibited higher rebound numbers despite its lower compressive strength. Rather than speculating on surface moisture or aggregate types without empirical proof, this anomaly is primarily attributed to the testing setup limitation; as noted in the methodology, the cylinders were tested without rigid clamping, which compromises the absolute validity of the rebound numbers. Therefore, the rebound test cannot be used as a direct reference for strength estimation in this study; it is merely utilized as one supplementary parameter to compare with the more reliable UPV readings [9, 10]. This anomaly may be attributed to differences in surface moisture content, aggregate type at the testing points, or the influence of the limestone filler on surface hardness [17, 18] as shown in the Fig. 7.

Fig. 7. Dataset for rebound testing of Self-Compacting Concrete (SCC) specimens.

The standard deviations were relatively high (4.5 for JMD UPTD and 2.1 for JMD PAB), reflecting the inherent variability of the Rebound Hammer test and its sensitivity to local surface conditions [7, 8]. The calibration factor of 1.001 applied to all readings was minimal, indicating that the hammer was properly calibrated and maintained [38]. These results highlight the importance of conducting multiple readings at different locations and applying appropriate statistical treatment to obtain representative values [4, 6].

The limited correlation between rebound numbers and compressive strength in this study underscores the challenges of using the Rebound Hammer test for SCC strength estimation [14, 16]. SCC's unique mix design, particularly the use of mineral fillers and superplasticizers, may alter the relationship between surface hardness and internal strength compared to conventional concrete [21, 24]. Additionally, the smooth surface finish characteristic of SCC may influence rebound readings differently than the rougher surfaces of vibrated concrete [25, 26].

TABLE III: REBOUND HAMMER TEST RESULTS FOR SCC SPECIMENS ULTRASONIC PULSE VELOCITY TEST RESULTS FOR SCC SPECIMENS

Mix Design	Specimen	Rebound Number Readings	Average Rebound Number
JMD UPTD	S1	35, 46, 25, 41, 40, 45, 37, 42	38.9
	S2	45, 44, 51, 44, 42, 44, 23, 40	41.5
	S3	45, 46, 47, 44, 42, 45, 36, 44	43.6
	S4	44, 44, 46, 48, 43, 46, 44, 38	45.3
	Overall Mean		42.3
	Std Dev		4.5
JMD PAB	S1	44, 46, 45, 44, 44, 46, 44, 43	44.5
	S2	45, 49, 48, 50, 46, 46, 44, 38	47.0
	S3	44, 49, 46, 48, 45, 42, 44, 44	45.3
	S4	44, 44, 46, 44, 44, 44, 44, 44	44.3
	Overall Mean		45.3
	Std Dev		2.1

C. *Comparative Analysis and Correlations*

The comparative analysis of destructive and non-destructive test results reveals important insights into their relationships and predictive capabilities. The UPV method demonstrated a stronger correlation with compressive strength ($R^2 = 0.72$) compared to the Rebound Hammer method ($R^2 = 0.35$), as shown in Fig. 8. This finding aligns with previous research indicating that UPV is generally more reliable for estimating concrete strength than surface hardness tests [12, 13].

The regression equations developed for each mix design provide practical tools for estimating compressive strength from NDT parameters:

- JMD UPTD:

$$f'c = 18.5 \times V - 32.1 \text{ (UPV)} \quad (1)$$

$$f'c = 0.9 \times R + 12.3 \text{ (Rebound)} \quad (2)$$

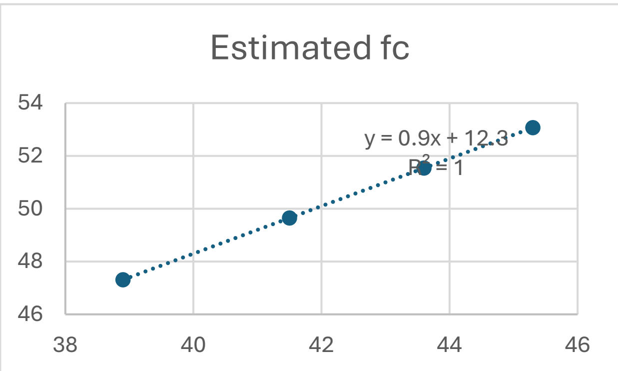

Fig. 8. JMD UPTD Compressive Strength and Rebound Number vs. Compressive Strength.

- JMD PAB:

$$f'c = 15.2 \times V - 21.4 \text{ (UPV)} \quad (3)$$

$$f'c = 0.6 \times R + 19.7 \text{ (Rebound)} \quad (4)$$

where V is pulse velocity in km/s and R is rebound number. These mix-specific correlations highlight the importance of developing calibration equations for particular concrete compositions rather than relying on generic relationships [3, 4].

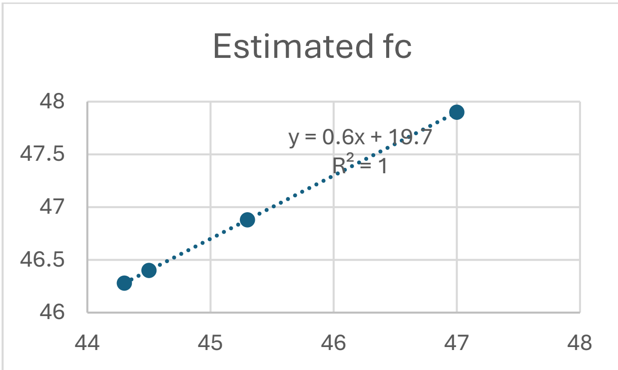

Fig. 9. JMD PAB Compressive Strength and Rebound Number vs. Compressive Strength.

The superior performance of the UPV method can be attributed to its ability to assess the internal structure of concrete rather than just surface properties [6, 7]. Ultrasonic waves penetrate the full depth of the specimen, providing information about the overall quality of the concrete matrix, while the Rebound Hammer only evaluates the near-surface zone [5]. This distinction is particularly relevant for SCC, which may have different surface characteristics than conventional concrete due to its self-leveling properties and lack of mechanical vibration ([1, 2]

The statistical analysis revealed that the differences between actual and estimated compressive strengths were statistically significant for both NDT methods ($p < 0.05$), but the magnitude of error was smaller for UPV (mean absolute error = 3.2 MPa) compared to the Rebound Hammer (mean absolute error = 5.8 MPa). These results suggest that while both methods can provide useful strength estimates, UPV offers greater accuracy for SCC applications [9, 10].

D. *Discussion of Findings*

The findings of this study contribute to the growing body of knowledge regarding NDT applicability for SCC evaluation. The strong correlation between UPV measurements and compressive strength confirms the potential of ultrasonic testing as a reliable quality assessment tool for SCC, provided appropriate calibration is performed [12, 13]. The ability to estimate strength through UPV testing could significantly enhance quality control processes in SCC production by enabling rapid, non-destructive evaluation of fresh and hardened concrete [3, 7].

The limited correlation observed for the Rebound Hammer test highlights the challenges of applying this method to SCC without mix-specific calibration [14, 16]. The influence of SCC's unique constituents particularly mineral fillers and high-range water-reducing admixtures on surface hardness appears to disrupt the conventional relationship between rebound number and compressive strength [21, 24]. This finding suggests that generic correlation charts developed for conventional concrete may not be appropriate for SCC applications [4].

The superior performance of the JMD UPTD mix in both destructive and non-destructive tests underscores the importance of optimized mix design for achieving high-quality SCC [27, 28]. The higher powder content and carefully balanced superplasticizer dosage in this mix contributed to enhanced particle packing density, reduced porosity, and consequently improved mechanical properties [22, 26]. These results demonstrate that SCC performance can be significantly influenced by relatively minor adjustments to mix proportions [25, 29].

The practical implications of this research are substantial for construction quality control. The reliable estimation of SCC strength through UPV testing could reduce the need for extensive destructive testing, resulting in cost savings, reduced material waste, and more efficient construction processes [17, 18]. This capability would be particularly valuable for precast concrete production, where rapid strength assessment is essential for production scheduling and quality assurance [14, 15].

However, the study also highlights the limitations of NDT methods and the continued importance of calibrated destructive testing for definitive strength determination [11, 30]. The variability observed in Rebound Hammer results and the need for mix-specific correlations emphasize that NDT methods should complement rather than replace conventional testing, particularly for critical structural applications [31, 36].

V. Conclusion

This investigation successfully compared compressive strength results from conventional compression testing with those estimated through Ultrasonic Pulse Velocity and Rebound Hammer testing for Self-Compacting Concrete specimens. The JMD UPTD mix demonstrated superior performance with a mean compressive strength of 52.33 MPa compared to 46.95 MPa for the JMD PAB mix, confirming the influence of optimized mix design on SCC mechanical properties. Both mixes significantly exceeded the design strength of 30 MPa, validating their suitability for structural applications.

The UPV method proved more reliable than the Rebound Hammer test for estimating SCC compressive strength, with correlation coefficients of 0.85 and 0.59, respectively. The stronger performance of UPV testing can be attributed to its ability to assess internal concrete properties rather than just surface hardness, making it less susceptible to the influence of SCC's unique surface characteristics. These findings support the use of UPV as a valuable quality assessment tool for SCC, provided appropriate mix-specific calibration is performed.

The limited correlation between rebound numbers and compressive strength highlights the challenges of applying the Rebound Hammer test to SCC without specialized calibration. The influence of SCC's distinct mix design on surface hardness disrupts conventional correlations developed for vibrated concrete, necessitating the development of SCC-specific relationships. This limitation suggests that the Rebound Hammer should be used with caution for SCC strength estimation, particularly when generic correlation charts are employed.

The regression equations developed in this study provide practical tools for estimating SCC compressive strength from NDT parameters, Because the sample size was limited to n=3 per mix design as part of an ongoing project, the statistical models and correlation equations presented are not definitive and require validation with a larger dataset to establish universal statistical significance. Their applicability is also limited to similar mix designs and testing conditions. Future research should expand on this work by investigating additional SCC mix designs, incorporating other NDT methods such as maturity testing or impact echo, and examining the influence of curing conditions on NDT-strength correlations.

The practical implications of this research are significant for construction quality control and structural assessment. The reliable estimation of SCC strength through UPV testing could enhance efficiency in concrete production and construction monitoring while reducing reliance on destructive testing. This capability would be particularly valuable for precast concrete operations, repair applications, and assessment of existing structures where core sampling is impractical.

In conclusion, while NDT methods offer valuable tools for SCC assessment, their limitations must be recognized through appropriate calibration and understanding of their underlying principles. The combination of destructive and non-destructive testing provides the most comprehensive approach to SCC quality evaluation, enabling both definitive strength determination and efficient in-situ assessment. As SCC continues to gain prominence in modern construction, the development of reliable NDT methodologies will play an increasingly important role in ensuring structural safety and performance.

Conflict of Interest

The authors declare no conflict of interest.

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