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Comparative Analysis of Concrete Compressive Strength using a Destructive Compression method and Non-destructive Rebound Hammer

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ABSTRACT

Assessment of concrete compressive strength is important in ensuring structural integrity and durability of concrete structures. Traditionally, destructive testing methods using compression machines have been the standard for determining concrete strength. However, advancements in technology have introduced non-destructive testing methods such as the rebound hammer, which offer quick and economical alternatives. This study was aimed at comparing the accuracy, reliability, and practicality of these two methods in assessing concrete compressive strength. The experimental investigation involved conducting tests on concrete specimens using both the rebound hammer and compression machine. Data on rebound values and compressive strength measurements were collected and analyzed using statistical approaches to evaluate the correlation between results obtained from these two methods. Factors such as surface conditions and moisture content were considered in the analysis to understand potential influences on test outcomes. Results from the research indicated strong correlations between compressive strength values obtained using the rebound hammer and compression machine tests. The comparative analysis highlighted scenarios where methods have very strong correlations and thus more likely to give comparable results. The findings of this research also offer insights that can enhance the reliability and accuracy of assessing concrete compressive strength on construction projects.

Keywords: Non-destructive testing, Compression machine, Structural integrity

1. INTRODUCTION

Concrete, regarded as one of the oldest construction materials, is believed to have been discovered over 20,000 years ago [1], and it has continued become an integral part of the construction industry in the modern times. According to [2], the rate of use of concrete globally is second to water with every individual estimated to consume three tonnes per year. There are several examples of structures where concrete has been used and these include high raised buildings, bridges, dams, retaining structures and rigid pavements [3] among others.

Structural engineers have embraced use of concrete because of its great resistance to compressional forces [4] as compared to other available alternative materials. Besides concrete being easy to make and the ease of availability of constituent materials, it is also comparatively cheaper than other materials such as steel [5] and it has compressive strength properties which are better than other materials when it is in the hardened form [6]. Since compressive strength is the major attribute for hardened concrete, it therefore implies that it is of very great importance for engineers to conduct assessment of concrete to determine this parameter accurately to aid their decision making [7].

During the construction phase, quality assurance and control has become norm and more often, enough samples are picked during the casting of concrete on site. These samples (concrete cubes or cylinders), often times are taken to the testing laboratories at 7 days or 14 days for strength development monitoring [7] and at 28 days to assess the maturity of concrete [2]. The laboratory compressive strength test is done by crushing the concrete using a compression machine. This method is the most accurate and widely preferred in determining the actual compressive strength of concrete [8] although it is rendered time consuming [9] because of the curing processes and also being destructive in nature.

On the other hand, however, there are instances when the results from the test specimens are not satisfactory or other times when confirmatory tests may be required or when concrete compressive strength results are required for structures that have existed for a long time and repairs may need to be made. In these scenarios, Non Destructive Techniques (NDTs) have been widely employed to determine the concrete compressive strength of hardened surfaces [10]. Such NDTs include use of rebound hammer and Ultrasonic Pulse Velocity (UPV) which have become common, in rapidly determining the in-situ concrete compressive strength [11].

NDTs, particularly use of rebound hammer is a method that has widely been adopted in determining approximate concrete compressive strength insitu by relating the surface hardness rebound number (R) with compressive strength. Although testing agencies continue to depend on the manufacturer's relationships and correlations to evaluate the strength from the rebound number [8], the outcome results have been highly dispersed and with significant deviations [12]. These deviations are brought about by a number of factors which include smoothness of the surface, depth of carbonation, concrete age, aggregates within the concrete, presence of voids, temperature and the depth of steel reinforcements – all of which affect the surface hardness [8]. Much as there are numerous advantages of using NDTs to determine compressive strength, it does not add any value if the results are not reliable [13]. In view of the above presented factors, disparity and deviations in the use of NDTs, it is imperative that localized experiments are performed to establish the relationships of such NDTs with actual concrete compressive strength if these results are to be relied on.

This study was aimed at establishing a correlation between concrete compressive strength obtained using the rebound hammer and actual strength from compression of concrete cubes. This correlation will be helpful for engineers particularly in Uganda to reliably predict the insitu concrete compressive strength of structural members by rapidly conducting a rebound hammer test. It will also bridge the gap for situations where concrete samples are no longer available for testing but yet it is required to determine the compressive strength. At the same time, the research will help in determining the degree of reliability of rebound hammer results in evaluating actual cube strength.

2. METHODOLOGY

In this research, concrete cubes of 150 mm cubic dimensions were considered for the compressive strength test by both the compression and rebound hammer. Three Hundred Ten (310) samples were considered for which results were analysed for this research. For each of the samples, the compression test was conducted to determine the maximum compression load and compressive strength evaluated. In the same way, the rebound hammer test was conducted, rebound number determined and equivalent compressive strength determined.

2.1. Compression Testing Machine

A semi-automatic compressive strength machine of Controls make conforming to specifications of BS EN 1290-4: 2019 [14] was used during the testing of concrete cubes. The machine is composed of a load frame, a hydraulic cylinder for applying the load, disc spacers and auxiliary platens where the test sample is placed.

The compression test was conducted by applying a uniform and continuous load at a constant rate of 0.6 MPa/s as provided in BS EN 12390-3: 2019 [15] until failure of the specimen, and the failure load recorded.

2.2. Rebound Hammer

In this research, an ELE International make Type N rebound hammer conforming to BS EN 12504-2: 2021 [16] and ASTM C805 [17] was used for the experiment.

The rebound hammer according to its manual (ELE International Test Hammer 35-1480) is composed of an elastic spring which rebounds when the plunger is placed against the hardened concrete surface to give a rebound reading (R) depending on the surface hardness.

The rebound reading is then converted into equivalent concrete cube compressive strength using the graphs provided by the device manual and also based on the direction of impact to the surface as shown in Figure 1.

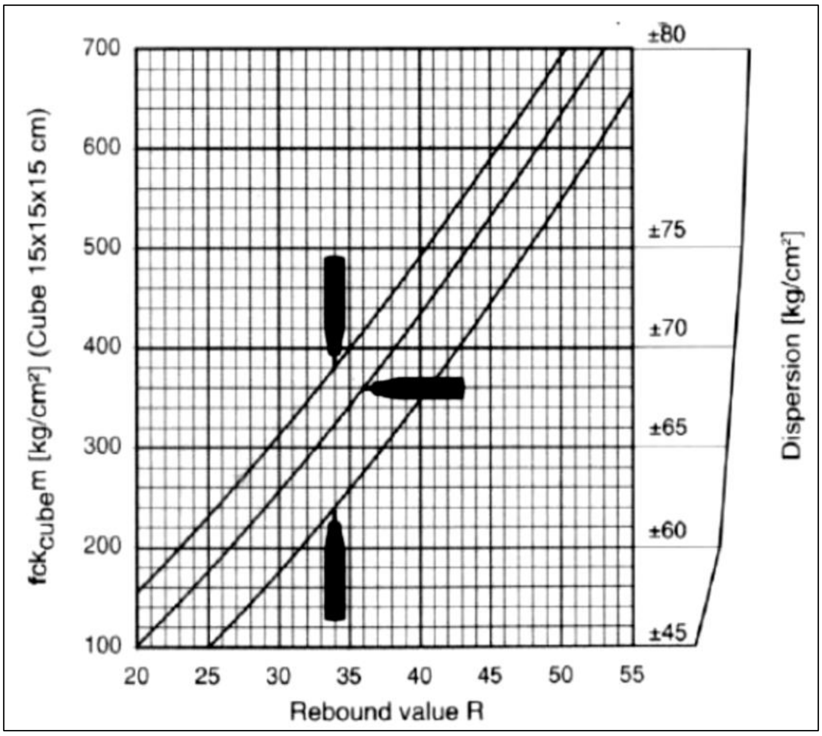

Figure 1. Conversion Curves for the ELE Type N Rebound Hammer

The direction of impact of the surface for the specimen was vertical downwards (-90 degrees) for this experiment.

2.3. Experimental Testing

For all the tests in this research, all the tested samples for compressive strength were also tested with the rebound hammer. The rebound hammer test was conducted prior to subjecting the concrete cube to compression test. At least 10 rebounds were taken for each recorded rebound hammer test. In this experiment, surface hardness was the critical parameter in consideration and hence the age of concrete under test was not considered as a reference parameter.

3. RESULTS AND DISCUSSION

A total of 310 samples were tested in this experiment from which a data set of 50 was evaluated from the analysis as presented in Table 1. The standard deviation and coefficient of each data set is depicted for each set and includes the variation in each individual actual compressive strength, rebound number and equivalent rebound hammer compressive strength.

Table 1. The standard deviation and coefficient of each data set

Data Set No.	Compression Test Results			Rebound Hammer Test Results					
	Compressive Strength (MPa)	Standard Deviation (MPa)	Coefficient of Variation (%)	Average Rebound Number (R)	Standard Deviation (MPa)	Coefficient of Variation (%)	Equivalent Compressive Strength (MPa)	Standard Deviation (MPa)	Coefficient of Variation (%)
1	4.3	0.08	1.90	12.0	0.08	0.68	4.6	0.10	2.28
2	6.5	0.13	1.99	12.7	1.69	13.31	5.5	2.19	39.97
3	8.1	0.09	1.17	14.9	0.66	4.42	8.4	0.89	10.55
4	8.8	0.12	1.41	15.3	0.96	6.29	8.9	1.30	14.64
5	11.3	0.27	2.40	15.4	1.38	8.99	9.1	1.89	20.83
6	12.3	0.21	1.72	16.2	1.48	9.15	10.1	2.04	20.28
7	13.8	0.12	0.91	17.2	1.82	10.56	11.6	2.55	22.04
8	14.6	0.29	2.02	17.9	2.43	13.56	12.6	3.50	27.81
9	15.6	0.21	1.33	18.2	3.31	18.20	13.0	4.79	36.72
10	16.6	0.17	1.04	19.2	2.71	14.11	14.4	3.87	26.81
11	17.2	0.11	0.61	19.7	3.14	15.96	15.1	4.61	30.45
12	17.7	0.17	0.96	19.7	2.67	13.52	15.2	3.95	26.03
13	18.3	0.16	0.88	20.2	1.52	7.53	15.7	2.24	14.21
14	18.7	0.14	0.77	20.8	2.75	13.22	16.8	4.13	24.57
15	19.2	0.12	0.62	21.1	1.57	7.47	17.1	2.33	13.61
16	19.7	0.08	0.41	21.6	2.12	9.80	17.9	3.19	17.83
17	20.2	0.14	0.67	21.8	2.79	12.81	18.3	4.16	22.80
18	20.6	0.19	0.91	22.5	1.71	7.61	19.2	2.60	13.57
19	21.2	0.09	0.40	22.6	1.57	6.96	19.4	2.41	12.44
20	21.6	0.15	0.71	22.8	2.61	11.45	19.8	3.96	20.05
21	22.2	0.12	0.55	23.1	3.53	15.31	20.2	5.65	27.91
22	22.8	0.12	0.54	23.4	1.47	6.26	20.6	2.26	10.96
23	23.1	0.05	0.21	23.6	1.94	8.20	21.0	2.99	14.22
24	23.8	0.12	0.52	23.8	1.68	7.08	21.2	2.60	12.24
25	24.2	0.13	0.54	24.2	1.43	5.93	21.8	2.22	10.19
26	24.7	0.15	0.61	24.5	2.89	11.81	22.3	4.54	20.33
27	25.2	0.16	0.65	24.8	1.07	4.31	22.8	1.66	7.30
28	25.7	0.16	0.63	25.0	3.45	13.82	23.2	5.59	24.14
29	26.2	0.13	0.51	25.1	4.19	16.72	23.4	6.73	28.76
30	26.6	0.15	0.55	25.3	2.45	9.71	23.5	3.79	16.10
31	27.6	0.14	0.50	25.4	0.59	2.31	23.7	0.92	3.89
32	28.4	0.29	1.01	25.8	0.76	2.96	24.3	1.22	5.01
33	29.1	0.05	0.16	25.9	1.13	4.37	24.5	1.81	7.38
34	29.7	0.15	0.50	26.7	0.86	3.21	25.8	1.38	5.34
35	30.4	0.25	0.82	27.7	1.93	6.99	27.4	3.18	11.61
36	31.3	0.00	0.00	27.8	0.00	0.00	27.5	0.00	0.00
37	32.5	0.38	1.16	27.9	0.11	0.40	27.6	0.18	0.66
38	33.4	0.30	0.90	28.0	0.80	2.86	27.9	1.31	4.70
39	34.9	0.46	1.31	27.9	1.72	6.16	27.7	2.84	10.27
40	36.7	0.30	0.82	28.4	3.52	12.40	28.6	5.91	20.65
41	37.6	0.22	0.57	28.9	2.29	7.92	29.4	3.79	12.91
42	38.4	0.32	0.85	29.1	1.79	6.16	29.8	3.00	10.07
43	39.5	0.11	0.28	29.4	2.59	8.82	30.3	4.35	14.37
44	40.4	0.19	0.48	29.9	0.95	3.19	31.0	1.60	5.17
45	41.2	0.14	0.33	30.1	2.88	9.59	31.4	4.86	15.50
46	43.7	0.05	0.11	30.4	0.30	0.99	31.9	0.51	1.59
47	44.4	0.21	0.46	30.7	1.88	6.13	32.4	3.19	9.86
48	46.4	0.33	0.70	31.9	3.42	10.71	34.6	5.79	16.73
49	49.0	1.94	3.95	32.3	3.17	9.80	35.3	5.58	15.80
50	54.2	1.58	2.91	33.7	3.03	9.00	37.7	5.43	14.39

In general, the compressive strength results analysed from the experiment were normally distributed ranging between 4 and 55 MPa with the mean strength of 26 MPa. Over 60% of the results lied between 15 to 35 MPa which depicts the normal range of the classes of concrete used in Uganda. The highest frequency of the results were distributed from 20 – 25 MPa, covering 20% of the samples tested.

The distribution of the strength of individual data sets did not show much disparity with the average standard deviations of 0.23 for actual cube compressive strength and 3.30 for equivalent rebound hammer compressive strength with their respective average coefficients of variation of 0.92% and 15.51%.

Similarly, the rebound numbers (R) or individual sets of results did not show a lot of variation with the average standard deviation of 1.94 and average coefficient of variation of 8.37% as shown in Table 1.

3.1. Correlation between Rebound Number (R) and Actual cube compressive strength

From the analysis of the results as illustrated in Figures 2, 3, 4 & 5, it is observed and evident that there is a very good relationship between the rebound number as read from the rebound hammer during insitu concrete testing and actual cube compressive strength.

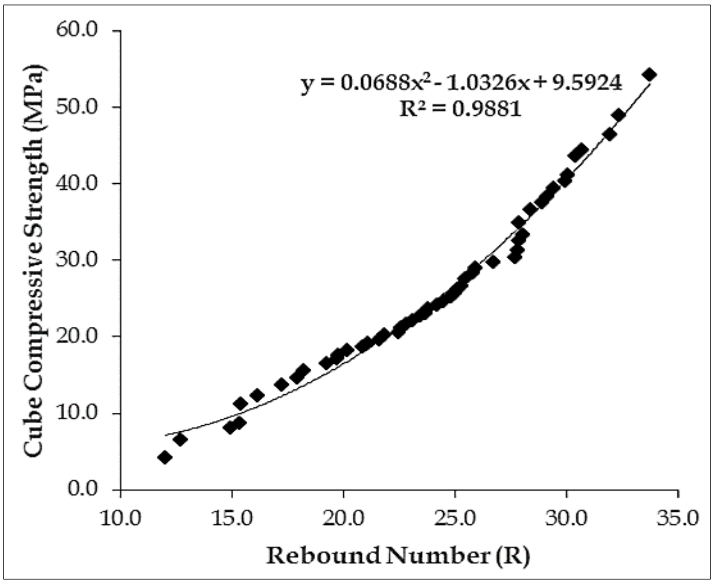

Figure 2. A Polynomial relationship between Rebound Number and Actual Cube compressive strength

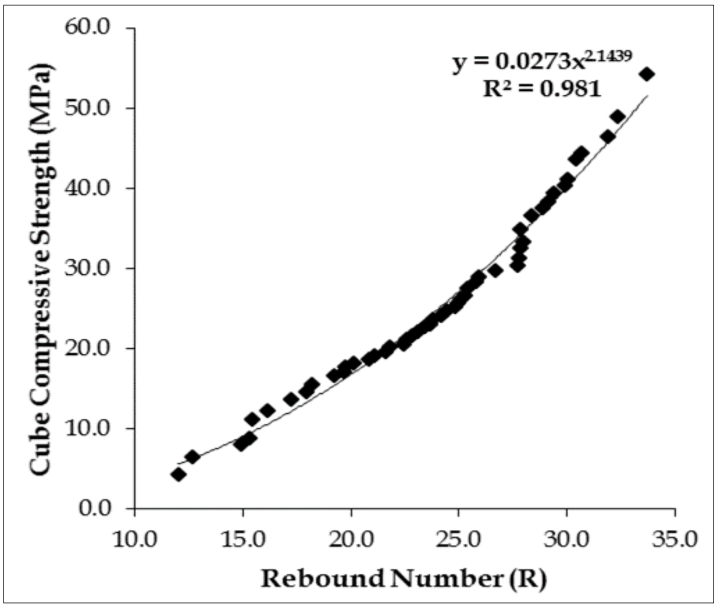

Figure 3. A Power relationship between Rebound Number and Actual Cube compressive strength

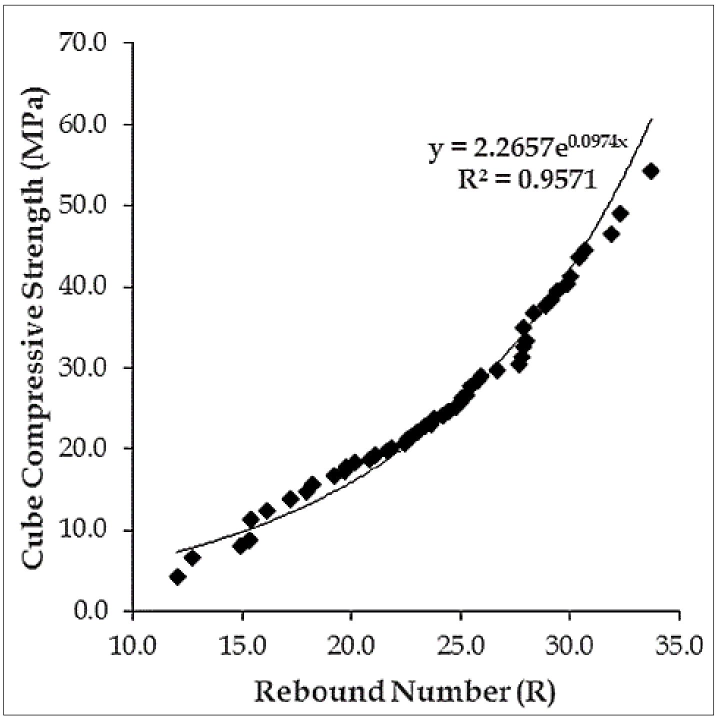

Figure 4. An Exponential relationship between Rebound Number and Actual Cube compressive strength

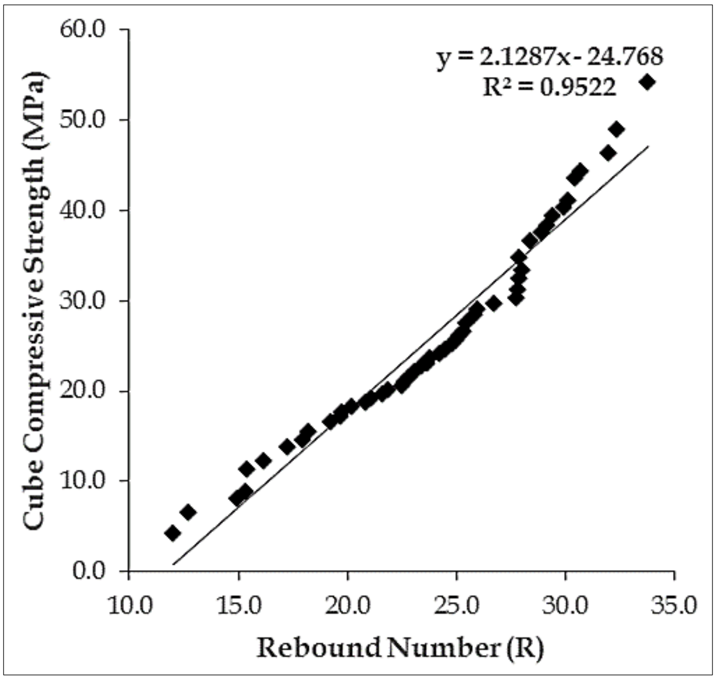

Figure 5. A Linear relationship between Rebound Number and Actual Cube compressive strength

Analysis of the relationships from Figures 2 to 5 are summarized in Table 2 for rebound number (R) and Actual Cube compressive strength (fcm).

Table 2. Summary of regression relationships between Rebound Number(R) and Actual Cube compressive strength (f_{cm})

SN	Equation	R^2	Regression
1.	$f_{cm} = 0.0688R^2 - 1.0326R + 9.5924$	0.9881	Polynomial
2.	$f_{cm} = 0.0273R^{2.1439}$	0.9810	Power
3.	$f_{cm} = 2.2657e^{0.0974R}$	0.9571	Exponential
4.	$f_{cm} = 2.1287R - 24.768$	0.9522	Linear

From all the four equations presented in Table 2, it can be observed that there exists a very good relationship between the rebound number and actual cube compressive strength in all the regression approaches. It is also vivid that the polynomial and power relations are more accurate with a coefficient of over 98%.

3.2. Correlation between Rebound Hammer Compressive Strength and Actual cube compressive strength

Regression analysis was also done to establish the correlation between the rebound hammer evaluated compressive strength and the actual cube compressive strength. Graphical representation of the analysis is presented in Figures 6, 7, 8 & 9 and the figures show this relationship.

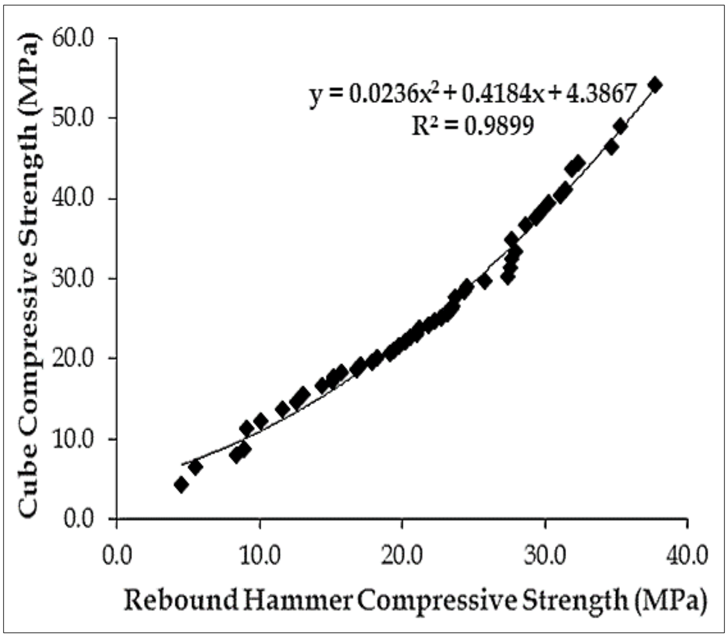

Figure 6. A polynomial relationship between Rebound Hammer Compressive strength and Actual Cube compressive strength

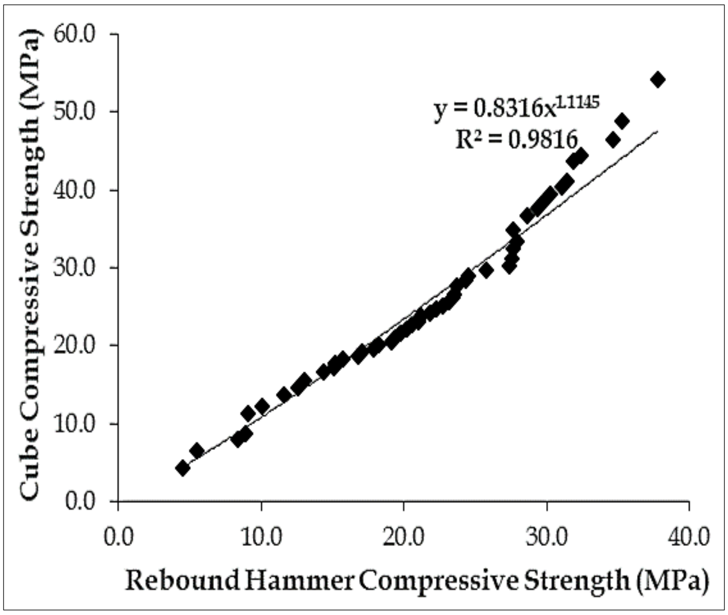

Figure 7. A power relationship between Rebound Hammer Compressive strength and Actual Cube compressive strength

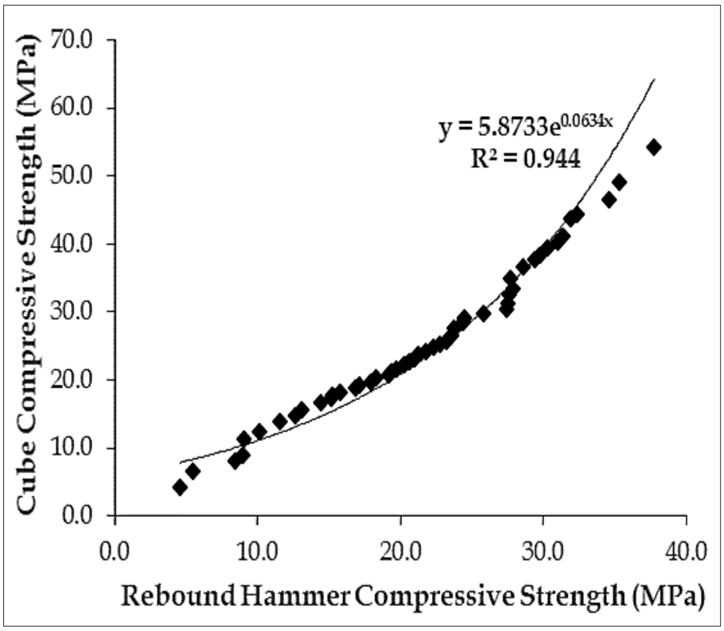

Figure 8. An exponential correlation between Rebound Hammer Compressive Strength and Actual Cube compressive strength

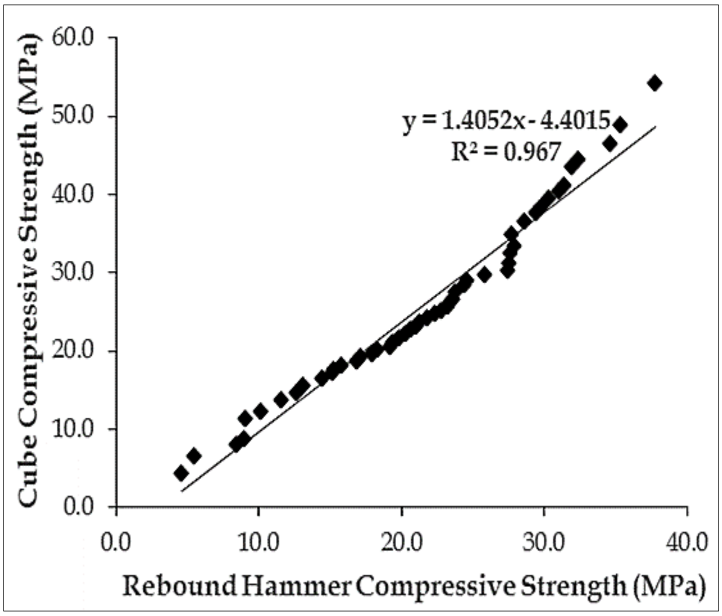

Figure 9. A linear correlation between Rebound Hammer Compressive strength and Actual Cube compressive strength

It can be observed from the figures 6 to 9 that there also exists a very good relationship between the evaluated compressive strength from rebound hammer and actual concrete compressive strength of concrete specimen. It is also clear that the polynomial relationship gives a better prediction with a correlation coefficient of 99% followed by the power relationship with a correlation coefficient of 98%.

Table 3 provides a summary of the correlation equations for predicting the actual concrete compressive strength from the insitu rebound hammer results which are based on surface hardness.

Table 3. Summary of regression equations for estimation Actual cube compressive strength (f_{cm}) from Rebound hammer results

SN	Equation	R^2	Regression
1.	$f_{cm} = 0.0236x^2 + 0.4184x + 4.3867$	0.9899	Polynomial
2.	$f_{cm} = 0.8316x^{1.1145}$	0.9816	Power
3.	$f_{cm} = 5.8733e^{0.0634x}$	0.9440	Exponential
4.	$f_{cm} = 1.4052x – 4.4015$	0.9670	Linear

x – is the evaluated rebound hammer compressive strength

3.3. Other analyses and observations

In this research, it was noted that the actual concrete cube compressive strength is always higher than the evaluated concrete strength by use of the NDT rebound hammer. Figure 10 shows the graphical distribution of all the analysed data sets for actual concrete cube compressive strength and the evaluated concrete strength from rebound hammer.

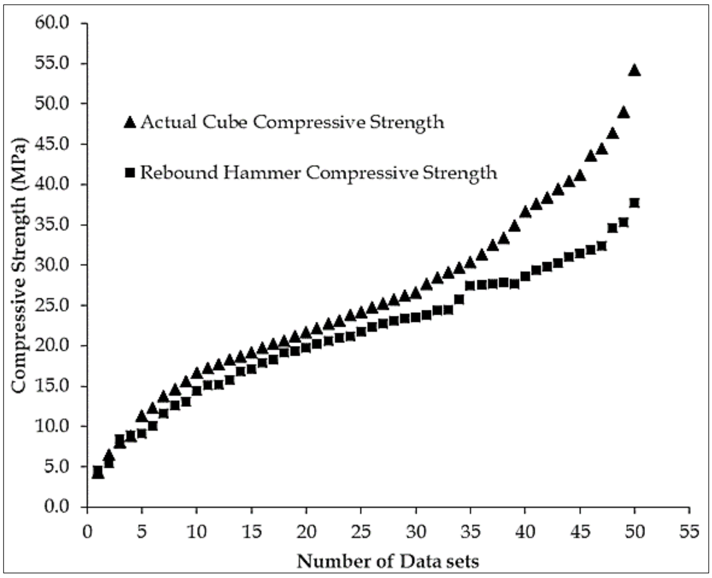

Figure 10. Graphical representation of the compressive strength of both actual cube crushing and NDT rebound hammer

It can be observed from the graph that beyond 30 MPa, the gap between the two graphs increases greater than from 5-30 MPa. This implies that as the surface hardness increases, the accuracy in estimation of compressive strength using the rebound hammer also reduces. Table 4 shows the grouped data distribution and the average difference and percentage for each group.

Table 4. Mean difference in Actual Cube compressive strength and rebound hammer compressive strength

Cube Compressive Strength (MPa)	Frequency	Mean Difference from Rebound hammer (MPa)	Mean Percentage difference (%)
0 - 10	4	0.1	1.1
10 - 15	4	2.2	16.8
15 - 20	8	2.2	11.9
20 - 25	10	2.1	9.2
25 - 30	8	3.4	12.4
30 - 35	5	4.9	14.8
35 - 40	4	8.5	22.4
40 - 45	4	10.8	25.3
45 - 55	3	14.0	27.9

It can be seen from Table 4 that the meaning difference between the actual compressive strength and rebound hammer strength increases as the strength increases.

4. CONCLUSION

From the research, several correlations have been drawn and the following conclusions can be drawn;

There exists a strong correlation between actual concrete compressive strength and the surface hardness of concrete represented by the rebound number (R). The most accurate relationship is derived from the polynomial regression with R-square of 98.9%.

Actual concrete cube compressive strength has a strong relationship with the evaluated concrete compressive strength from rebound hammer. Similarly, the strongest correlation is defined by a polynomial regression equation with R-square value of 99.0%.

The evaluated rebound hammer concrete compressive strength results from this research were found to be lower than the actual concrete cube compressive strength. The percentage difference in the actual cube strength and rebound hammer strength was found to be less than 2% for values between 0 to 10 MPa whereas those ranging between 10 and 20 MPa were found to have a difference in the range of 11 to 17%. The strength values between 20 and 35 MPa showed a well distributed difference in strength that ranged between 9 and 15%. Strengths greater than 35 MPa but less than 60 MPa showed higher differences between actual cube compressive strength results and evaluated strength from rebound hammer and this ranged between 20 to 30%.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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