An evaluation of concrete strength using Non-Destructive testing methods

Kishan savliya*, chetan Solanki[1],

* M.Tech. Research Scholar, Student, Darshan University, Rajkot, Gujarat, India

1. Assistant professor, Faculty of School of Engineering, Darshan University, Rajkot, Gujarat, India

*21010302008@darshan.ac.in, [1]chetan.solanki@darshan.ac.in,

Abstract: *In an effort to improve the prediction of concrete compressive strength and durability for several decades, researchers have In this study, experiments was conducted to identify approaches for calculating concrete strength utilizing ultrasonic wave testing and rebound hammer measurements. Experiment concentrated on determining the strength of concrete and the impact of aggregate size on the concrete's ultrasonic wave velocity and rebound number was examined. It was discovered that the compressive strength, and overall performance of the 20+10mm aggregate concrete mix outperformed those of the 10mm aggregate concrete mix, In comparison to the 20mm size of aggregate concrete mix, the compressive strength, rebound number, and ultrasonic pulse velocity were lower in the 10mm size of concrete mix. Tried to construct statistical models through the individual and combined use of ultrasonic pulse velocity (UPV) and rebound hammer data. By using measurements from the UPV and rebound hammer, this work suggests statistical univariate and multivariable regression models to forecast the compressive strength of concrete. The proposed models were developed using stepwise regression analysis.*

Keyword: ***Rebound hammer, ultrasonic pulse velocity, compressive strength, statistical mode***

1. INTRODUCTION

The compressive strength assessment of concrete elements is frequently required for this type of structure during its life cycle, even from the early stages of erection, when doubts about the quality of execution may arise, or, even more frequently, during the service stage, when some of the designed performance requirements are no longer met.

Obtaining the compressive strength of concrete elements based on non-destructive results is a difficult process that can be influenced by a variety of circumstances. As a result, evaluating the five characteristic stages visual inspection, damage identification & analysis, obtaining information from technical documents, selection of the appropriate non-destructive method, and testing approach is a critical step in designing a feasible investigation plan. Furthermore, the most important factors that strongly influence the selection of the appropriate non-destructive testing method are the required depth of penetration into the structure, the vertical and lateral resolution for the investigated element, the contrast in physical properties between the target and its surroundings, the signal to noise ratio, and historical information about the methods used in the construction of the structure.

The ultrasonic pulse velocity (UPV) and the rebound hammer (RH) are two of the most commonly used non-destructive test methods for evaluating quality and concrete mechanical properties. The investigations in this sector indicated that using a single non-destructive method to determine the compressive strength of concrete does not provide results with reliable accuracy. Thus, at least two methods should be used, and the results should be combined using appropriate mathematical models.

2. OBJECTIVE OF STUDY

- The main objective of this study is to determine the strengths of concrete prepared with varying size of coarse aggregate by using destructive and non-destructive testing methods.
- To establish new relationships between the compressive strength of concrete and Schmidt rebound values, and ultrasonic wave velocities.
- Compressive strength, and both rebound number and ultrasonic pulse velocity were measured. In addition, the relationship between compressive strength and rebound number as well as ultra-sonic pulse velocity (UPV) was discussed.

3. Raw materials

- **Cement:** Cement is used to work according to IS: 1489-2015 (part – 1) – PPC
- **Fine aggregate:** Fine aggregate is used to work according to IS: 383-2016 specification for fine aggregate from natural sources for concrete which fraction is from 4.75 mm to 150 micron.
- **Coarse aggregate:** Coarse aggregate is used to work according to IS: 383-2016 specification for coarse aggregate from natural sources for concrete which fraction is from 20 mm to 4.75 mm.
- **Water:** Water is an important ingredient of concrete. As a general guidance, if the water is fit for drinking if is fit for making concrete. Other yard-stick adopted is if the PH is between (6 to 8) the water is accepted to be suitable

4. Methodology

- The collection of all information and study of research papers related to non-destructive testing of concrete.

- Collection of materials required for research.

- Testing on materials.
  - Specific gravity of fine aggregate
  - Specific gravity of Coarse aggregate
  - Gradation of fine aggregate
  - Gradation of Coarse aggregate
  - Blending of Coarse aggregate

- Summary and conclusion of the test result.

Sr. No	Material Properties	Fine Aggregate	Coarse Aggregate(20mm)	Coarse Aggregate(10mm)
1	Specific Gravity	2.64	2.86	2.86
2	Water Absorption	1.50%	0.34%	0.56%

In this experiment, I have studied on influence of coarse aggregate size on concrete. For the experiment, the concrete was designed with varying size of Coarse aggregate of 10mm, 20m and 10&20mm.

5. Mixture proportion

This study developed three concrete mixes, and the mix proportion are shown in below. The mix design was conducted by following IS: 10262-2019.

- Mix proportion for M25 grade of concrete for 20mm size of aggregate.

1) Volume of concrete **= 1 m^3**
2) Mass of cement **= 392 kg/m^3**
3) Mass of water **= 206 kg/m^3**
4) Mass of Coarse aggregate **= 1170 kg/m^3**
5) Mass of fine aggregate **= 656 kg/m^3**

- Mix proportion for M25 grade of concrete

1) Volume of concrete **= 1 m^3**
2) Mass of cement **= 439 kg/m^3**
3) Mass of water **= 232 kg/m^3**
4) Mass of Coarse aggregate **= 879 kg/m^3**
5) Mass of fine aggregate **= 804 kg/m^3**

6. Test program

6.2 Ultrasonic pulse velocity (UPV) testing

An ultrasonic pulse velocity (UPV) test is a non-destructive, in-situ examination of the quality of concrete. Ultrasonic testing is carried out in accordance with IS: 516 (PART5/SEC 1): 2018.This test determines the quality of workmanship and identifies cracks and faults in concrete. The velocity of an ultrasonic pulse flowing through a concrete construction or natural rock formation is measured in this test to determine the strength and quality of concrete.

6.3 Rebound hammer testing

Rebound hammer test is a non-destructive, in-situ examination of the quality of concrete. Rebound hammer testing is carried out in accordance with IS: 516 (PART5/SEC 4): 2018.This test determines the quality & uniformity concrete.

7. Result and discussion

7.1 Effect of size of aggregate on rebound number

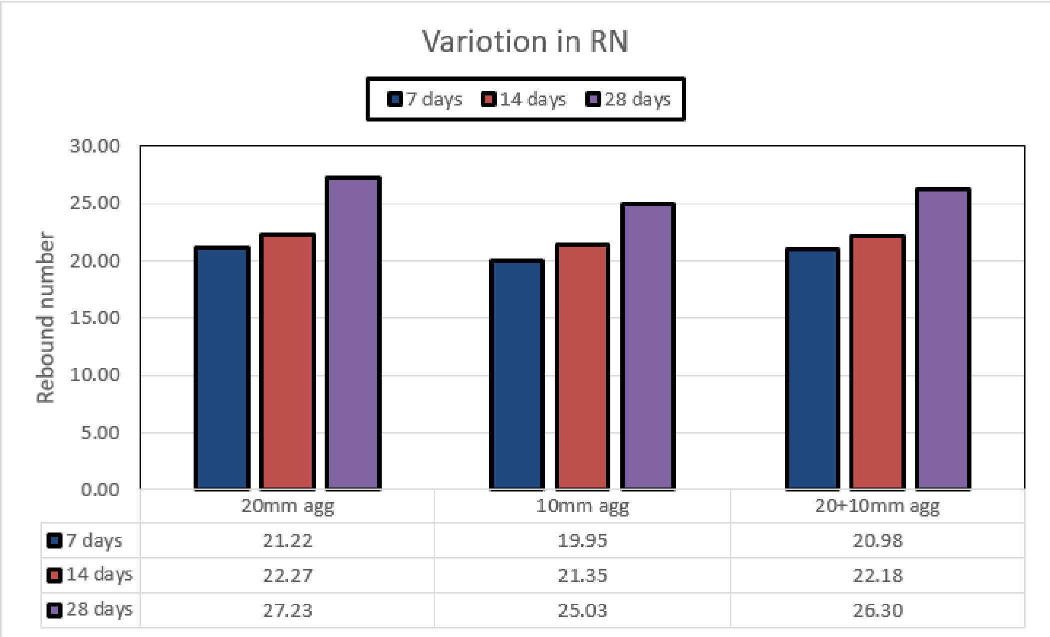
From the rebound hammer test investigation, it was observed that the mean rebound number (N) enlisted in range of 19.95 to 27.23, as present in **Table 1**. The standard deviation among all data ranges from 0.743 to 1.041, with the corresponding co-efficient of variance (COV) of 2.218 to 4.691 and the standard error of 0.15 to 0.329. This statistical analysis could assess the interpretation of results. It can be noticed that RN value of porous concrete increases as increases in age of concrete.

In **Chart 1** the rebound number (N) is obtained on 7, 14 and 28-day cured specimens which are exhibited proportionally in increasing fashions. In addition rebound number shows a higher value for incorporating 28 day concrete age in the concrete mix than 7 & 14 day concrete age, though the NDT strength value increase by increment of curing age.

Table 1: Summery of rebound number of concrete

Mixes (ID)	Days	Mean RN	Standard deviation	COV	Standard Error	95% Confidence Interval	
						Lower Limit	Upper Limit
Agg. Size 20mm	7	21.22	0.782	3.686	0.247	20.73	21.7
	14	22.27	1.025	4.603	0.324	21.63	22.9
	28	27.23	0.785	2.784	0.24	26.76	27.7
Agg. Size 10mm	7	19.95	0.743	3.723	0.235	19.49	20.41
	14	21.35	0.474	2.218	0.15	21.06	21.64
	28	25.03	0.765	3.054	0.242	24.56	25.51
Agg. Size 20+10mm	7	20.98	0.907	4.323	0.287	20.42	21.55
	14	22.18	1.041	4.691	0.329	21.54	22.83
	28	26.3	0.661	2.514	0.209	25.89	26.71

Chart 1: variation in RN for different concrete mixes at various ages



7.2 Effect of size of aggregate on UPV

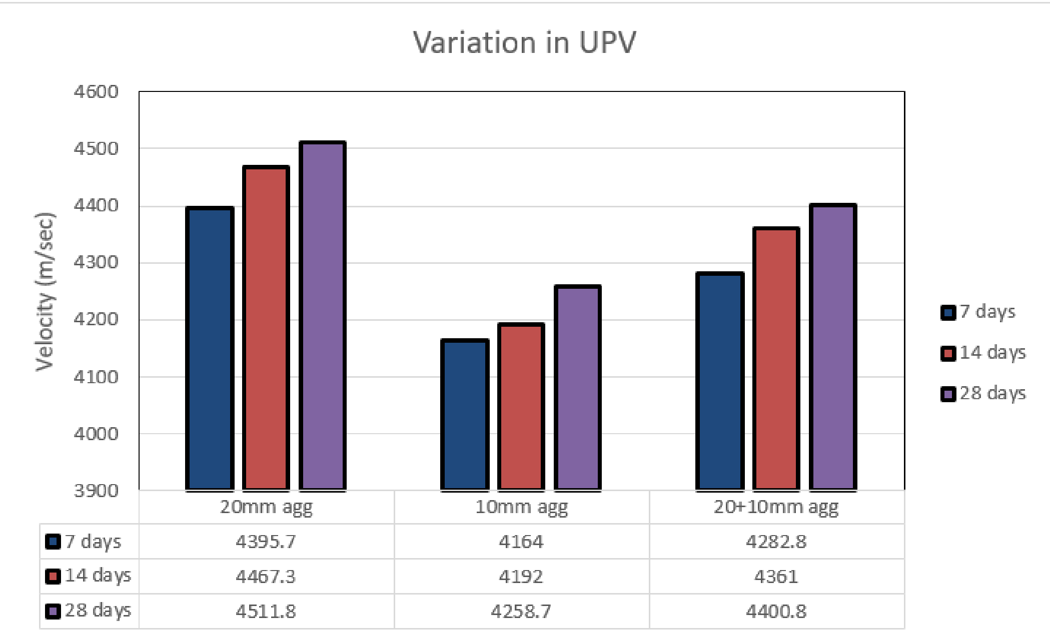
The UPV test results on specimen at 7, 14 and 28 days are conducted with different size of aggregate. It is observed that the mean UPV is enlisted in range of 4164 m/s to 4511.8 m/s. the standard deviation among the UPV data ranges from 38.8 to 83.365, with the corresponding co-efficient of variance of 0.74 to 1.897, and standard error ranges between 10.195 and 25.373. The 95% confidence interval analysis obtained the lowest and highest UPV values as 4139.93 m/s to 4545.35 m/s, respectively.

In **Chart 2** the rebound number (N) is obtained on 7, 14 and 28-day cured specimens which are exhibited proportionally in increasing fashions. In addition rebound number shows a higher value for incorporating 28 day concrete age in the concrete mix than 7 & 14 day concrete age, though the NDT strength value increase by increment of curing age.

Table 2: Summery of UPV of concrete

Mixes (ID)	Days	Mean UPV	Standard deviation	COV	Standard Error	95% Confidence Interval	
						Lower Limit	Upper Limit
Agg. Size 20mm	7	4395.7	83.365	1.897	26.362	4344.03	4447.37
	14	4467.3	64.334	1.44	20.344	4427.42	4507.17
	28	4511.8	54.184	1.201	17.134	4478.18	4545.35
Agg. Size 10mm	7	4164	38.8	0.932	12.27	4139.93	4188.03
	14	4192	50.249	1.199	15.89	4160.88	4223.17
	28	4358.7	32.239	0.74	10.195	4338.74	4378.7
Agg. Size 20+10mm	7	4282.8	65.365	1..491	20.67	4342.27	4423.29
	14	4361	44.498	1.02	14.071	4333.42	4388.58
	28	4400.8	80.238	1.823	25.373	4351.11	44500.58

Chart 2: variation in UPV for different concrete mixes at various ages

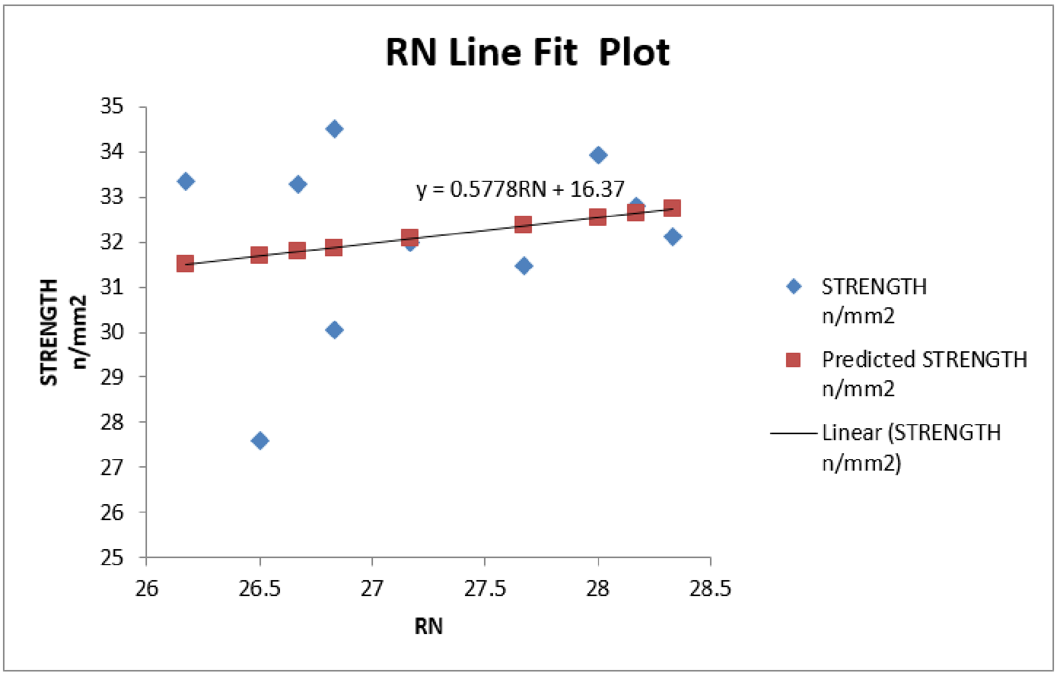


7.3 Relationship between compressive strength (f'_c) *and RN*

Size of aggregate 20mm

This study also suggests a single variable regression equation for calculating the compressive strength of concrete based on multiple regression analysis. **Chart 3 shows** the concrete's compressive strength (f'_c) and rebound number (RN). The equation $\mathbf{f'_c = -0.5778RN + 16.37}$ represents the straight line, which is the best-fit line. This equation also illustrates the relationship between the RN value of the porous concrete specimen and the destructive strength.

Chart 3: Relationship between the (f'_c) and RN of 20mm size aggregate concrete



Size of aggregate 10mm

This study also suggests a single variable regression equation for calculating the compressive strength of concrete based on multiple regression analysis. **Chart 4** shows the concrete's compressive strength (f'c) and rebound number (RN). The equation f'_c **= -0.2155RN + 37.188** represents the straight line, which is the best-fit line. This equation also illustrates the relationship between the RN value of the porous concrete specimen and the destructive strength.

Size of aggregate 20+10mm

This study also suggests a single variable regression equation for calculating the compressive strength of concrete based on multiple regression analysis. **Chart 5** shows the concrete's compressive strength (f'c) and rebound number (RN). The equation f'_c **= -0.4927RN + 45.702** represents the straight line, which is the best-fit line. This equation also illustrates the relationship between the RN value of the porous concrete specimen and the destructive strength.

Chart 4: Relationship between the (f'_c) and RN of 10mm size aggregate concrete

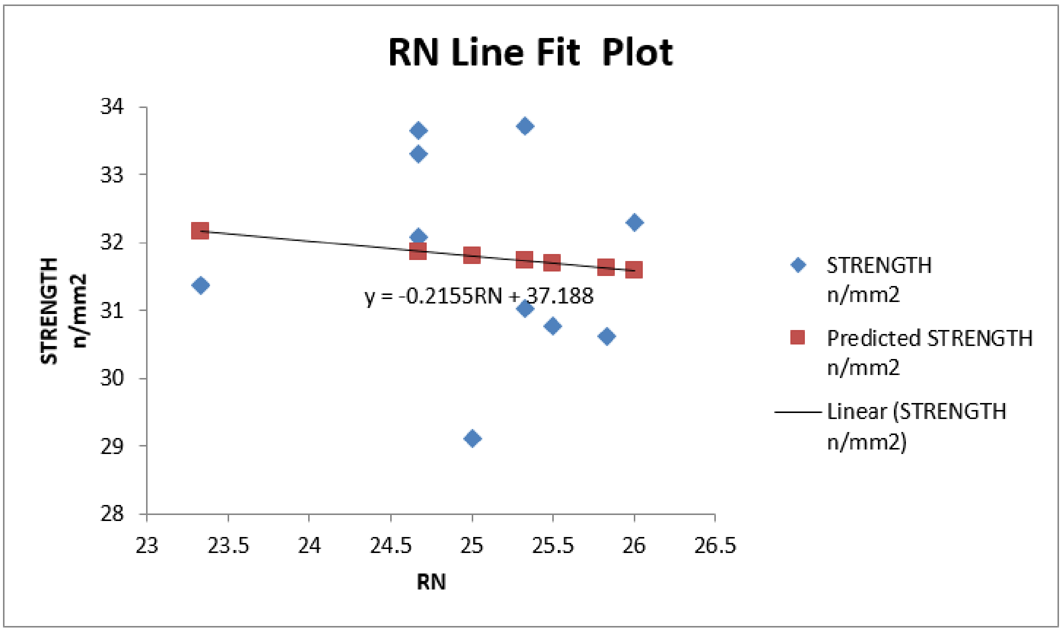
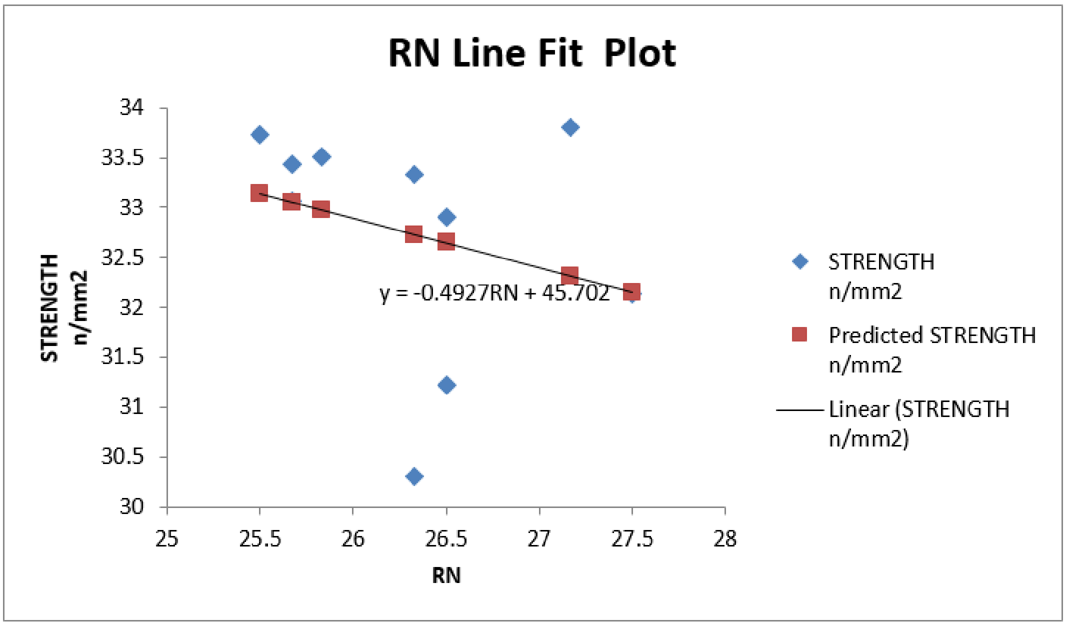


Chart 5: Relationship between the (f'_c) and RN of 20+10mm size aggregate concrete



7.4 Relationship between compressive strength (f'_c) *and UPV*

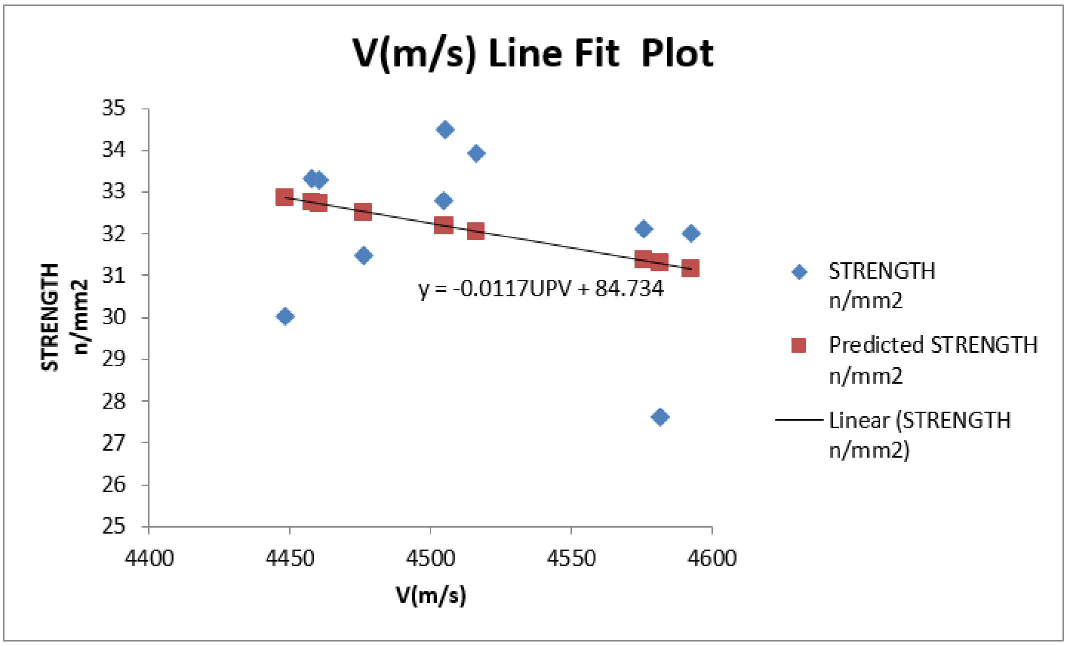
Size of aggregate 20mm

This study also suggests a single variable regression equation for calculating the compressive strength of concrete based on multiple regression analysis. The comparison between UPV and concrete's compressive strength (f'_c) is shown in **Chart 6** The straight line with the following equation $f'_c = -0.0117UPV + 84.734$ is the best-fit line. This

8

equation also illustrates the relationship between the RN value of the porous concrete specimen and the destructive strength.

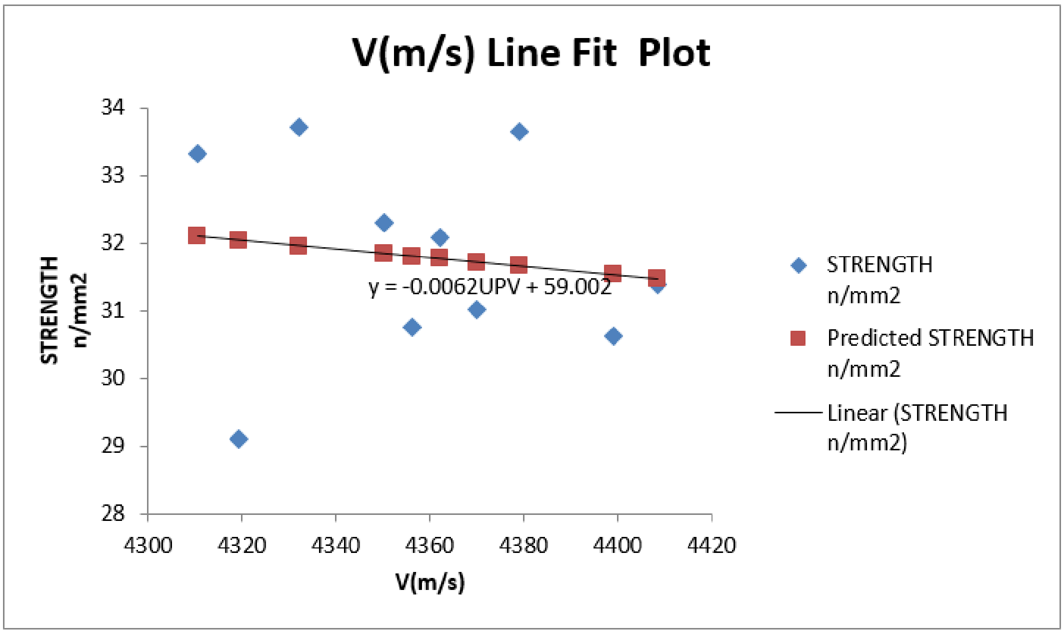
Chart 6: Relationship between the (f'_c) and UPV of 20mm size aggregate concrete



Size of aggregate 10mm

This study also suggests a single variable regression equation for calculating the compressive strength of concrete based on multiple regression analysis. The comparison between UPV and concrete's compressive strength (f'_c) is shown in Error! Reference source not found. The straight line with the following equation **f'_c = -0.0062UPV + 59.002** is the best-fit line. This equation also illustrates the relationship between the RN value of the porous concrete specimen and the destructive strength.

Chart 7: Relationship between the (f'_c) and UPV of 10mm size aggregate concrete

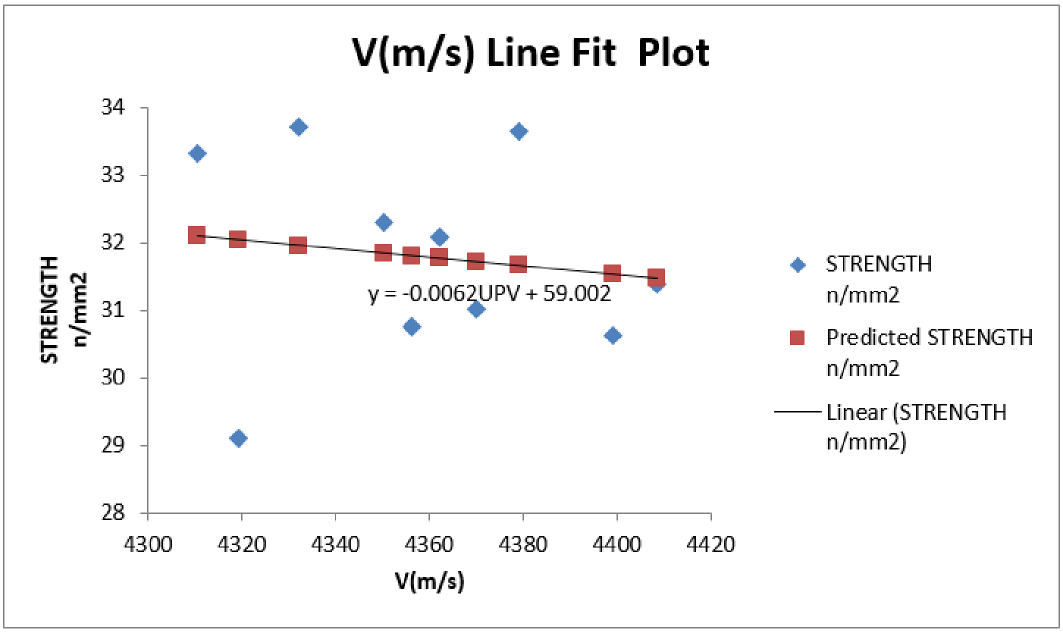


9

Size of aggregate 20+10mm

This study also suggests a single variable regression equation for calculating the compressive strength of concrete based on multiple regression analysis. The comparison between UPV and concrete's compressive strength (f'_c) is shown in Error! Reference source not found. The straight line with the following equation **f'_c = -0.0062UPV + 59.002** is the best-fit line. This equation also illustrates the relationship between the RN value of the porous concrete specimen and the destructive strength.

Chart 7: Relationship between the (f'_c) and UPV of 10mm size aggregate concrete



7.5 Relationship between compressive strength (f'_c), *UPV and RN*

Size of aggregate 20mm

The compressive strength (f'_c) of concrete specimens is estimated using the results of rebound number (RN) and ultrasonic pulse velocity (UPV). RN, UPV, and f'_c are represented by the following equation: **f'_c = -0.015UPV + 0.906RN + 77.071**. The accuracy in determining the compressive strength was improved by the combination of rebound number and UPV data. The application of the two-variable equation technique is significant because the variation in some concrete parameters resulted in the opposing effects for rebound number and UPV. For example, a rise in moisture content lowers the rebound number while increasing UPV value. Therefore, using this balancing method, one may determine an accurate prediction of compressive strength.

Size of aggregate 10mm

The compressive strength (f'_c) of concrete specimens is estimated using the results of rebound number (RN) and ultrasonic pulse velocity (UPV). RN, UPV, and f'_c are represented by the following equation: **f'_c = -0.008UPV – 0.301RN + 74.437**. The accuracy in determining the compressive strength was improved by the combination of rebound number and UPV data. The application of the two-variable equation technique is significant because the variation in some concrete parameters resulted in the opposing effects for rebound number and UPV. For example, a rise in moisture content lowers the rebound number while increasing UPV value. Therefore, using this balancing method, one may determine an accurate prediction of compressive strength.

Size of aggregate 20+10mm

The compressive strength (f'_c) of concrete specimens is estimated using the results of rebound number (RN) and ultrasonic pulse velocity (UPV). RN, UPV, and f'_c are represented by the following equation: $\mathbf{f'_c = 0.007UPV - 0.576RN + 17.671}$. The accuracy in determining the compressive strength was improved by the combination of rebound number and UPV data. The application of the two-variable equation technique is significant because the variation in some concrete parameters resulted in the opposing effects for rebound number and UPV. For example, a rise in moisture content lowers the rebound number while increasing UPV value. Therefore, using this balancing method, one may determine an accurate prediction of compressive strength.

8. Conclusion

The purpose of this experimental program was to assess the NDT qualities using the DT of porous concrete and concrete containing aggregates of various sizes. The following conclusions can be obtained from the above experimental investigation.

- The investigation's findings showed that whereas the 20+10mm aggregate concrete mix performed better than the 10mm aggregate concrete mix, the compressive strength, rebound number, and ultrasonic pulse velocity decreased in the 10mm size of concrete mix compared to the 20mm size of aggregate concrete mix.
- The comparisons of the empirical relationships indicated that the proposed equations are comparable to other equations with respect to functional form and accuracy.
- The comparison of the NDT and DT relationship found is useful. The site-specific adjustment would be required for field applications. The relationship cannot be universally accepted since the properties of concrete and associated materials may changes.
- The analysis revealed that the non-destructive rebound hammer test and ultrasonic velocity test can be used to evaluate changes in size of aggregate. The in-situ experiments may use this NDT methodology further.

9. References

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