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Correlation between destructive and non-destructive tests results for concrete compressive strength

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Abstract

In building construction concrete strength is evaluated through destructive compression tests of concrete cubes after 28 days of casting. When there is doubt about whether cube test results may not be in compliance with those recommended by standard or when the actual compressive strength test is not available, in these cases non-destructive tests (NDT) may be of great value. In this investigation a total of 288 cubes of concrete with different compressive strengths have been tested using two methods of nondestructive tests namely Rebound Number (RN) and Ultra Pulse Velocity (UPV), then the cubes were tested to destruction for determination of their compressive strengths. The aim of the study was to find correlation between nondestructive and destructive tests for practical application.

The test program consisted of testing concrete cubes made from five different mixes, their strength ranged from (35-65) MPa. The cubes were tested at ages (1, 7, 28, 90) days. Out of the total tests (108) cubes were tested at different temperatures (25, 50, 125, 180) ºC, all at the age of 28 days. It was found that the increase in (RN) and UPV value for all concrete strengths are proportional to the increase of the cube compressive strength. The regression equations found from the test results for 1 day for all mixes are more accurate than for (7, 28, 90) days, and the combined use of UPV and RN method is more reliable than UPV or RN methods separately. Equations of correlation to be used based on the tests results are proposed for each method and for the combined method.

Introduction

Structural construction from concrete requires knowledge of its properties. Many tests have been developed to measure the properties of concrete before and after casting. The most important property is the compressive strength of concrete, because it is used to assess the quality of concrete. There are several methods adopted to determine the compressive strength of concrete, for instance, destructive and non-destructive test (NDT) methods. In order to control concrete production, non-destructive tests are used to determine the deterioration in building under service load [1].

The NDT is a direct method to find in situ compressive strength of concrete [2]. Advantages of the NDT were summarized by Leshchinsky [3] quoted below as compared to core testing as:

1. A reduction in the labor consumption of testing.
2. A decrease in labor consumption of preparatory work.
3. A smaller amount of structure damage in testing.
4. A lower probability of such structural damage which may cause the need for reinforcement.
5. A possibility of testing concrete strength in structures where cores cannot be drilled (thin-walled, densely reinforced, etc...).
6. An application of less expensive testing equipment.

Raouf Z [4], has published a research in which he evaluated the combined method using both RN and UPV for concrete strength prediction. He tested specimens at ages 7, 28, 60 and 90 days, the proposed equations were: ($C=0.74RN^{1.12}$) for RN and compressive strength, ($C=2.8\ e^{0.53U}$) for UPV and strength, and ($C=0.93RN^{0.63}\ e^{0.31U}$) for combined method. Kheder [5] used the result of two nondestructive test (UPV and hammer test), a total number of 103 different mixes were tested at ages ranging between 7-90 days, his equations for dry concrete were: ($fc=0.403\ RN^{1.2083}$ with $R^2=0.805$) for RN and strength, ($fc=1.2*10^{-5}U^{1.7447}$ with $R^2=0.409$) for UPV and strength, while ($fc=0.0158\ RN^{1.1171}\ U^{0.4254}$ with $R^2=0.822$) for combined method. Qasrawi[1] published a research about combined method, various concrete mixes were used, and concrete cubes of unknown history made under site condition were also brought from various sites for testing. The correlation equation proposed between RN and strength was ($S=1.353RN-17.393$ with $R^2=0.88$) while for UPV the equation was ($S=36.72U-129.077$ with $R^2=0.9562$) , the combined method was proposed graphically between the UPV and strength in the plot RN reading were arranged in groups of increment of 2, straight line relationship were obtained with R^2 values of all lines where above 0.95, he found that lower strength of concrete is less predictable by the combined method, better result for strength prediction was found for concrete cubes exceeding 20Mpa.

Nasht [7] et al published a study on combined method, with 15 and 25 Mpa design strength, two types of cement were used (ordinary and sulphate resisting Portland cement), the correlation equations were: ($Sc=0.788\ RN^{1.03}$ with $R^2=0.77$) between strength and RN ($Sc=1.19\ e^{0.715U}$ with $R^2=0.59$) between strength and UPV, and the combined equation was ($Sc=0.356\ RN^{0.866}\ e^{0.302U}$ with $R^2=0.8$). Hobbs and Kebir [8], in their research, two different molds (plastic and wood) were used, for all specimens, wet semi crushed gravel max size 20mm and wet sharp sand were used, the correlation equations were: ($fc=2.168RN-27.747$ with $R^2=0.9252$) between RN and strength, while for UPV ($fc=12.289V^2-49.02V+24.271$ with $R^2=0.9031$), and for combined method ($-173.033-4.069V^2 57.693V+1.307RN$ with $R^2=0.9490$).

Youkhanna [9] carried out research in Kurdistan of Iraq, ordinary Portland cement, natural and crushed coarse aggregate with max size 19mm, natural fine aggregate was used, concrete cubes were tested at ages (7,14,28,56 and 90) days and the strength ranged from 10-50 Mpa. The correlation equations for all samples were ($C=0.319\ RN^{1.31}$ with $R^2=0.825$) between RN and strength, while for UPV ($C=0.676\ e^{0.818U}$ with $R^2=0.593$) and for combined method ($C=0.163\ RN^{1.132}\ e^{0.277U}$ with $R^2=0.854$). Pucinotti [10] carried out a series of destructive and non-destructive tests on an important historic building to calibrate the strength obtained by non-destructive methods with the strength of cylindrical specimens (cores) which were extracted from the same structural elements in the proximity of the non-destructive test. He found the following regression equations ($fc=0.00724\ RN^{2.012}$ with $R^2=0.24$) between RN and strength, while for UPV ($fc=0.184\ e^{0.0011U}$ with $R^2=0.82$) and for the combined ($9.61*10^{-14}\ RN^{3.55}\ U^{0.9}$ with $R^2=0.89$).

Research significance:

Many research work on RN, and UPV for concrete of different strength and at different ages have been carried out for evaluating concrete strength, the main differences in this study from previous researches may be the followings:

1. Tests were carried out at age 3, 7, 14, 28, 56, 90 days or more, however no test at age of 1 day has been reported, which is important for construction work like tunnel shuttering where the formwork is removed after passing one day only.
2. Many equations have been derived for combine method (RN and UPV) tests at normal temperature, in this study equations have been extended to combine method above normal temperature, by increasing temperature to 50°C, 125°C, 180°C.
3. No experimental data is available for local (Sulaimani) area materials. This is important because all tests depend on type of materials used in specimen preparation.

Materials and methods:

The experimental work consists of testing 288 concrete cubes with effective compressive strength ranging from (35 to 65) MPa. The cubes were tested using rebound hummer and ultrasonic pulse velocity methods of testing before finally crushed to failure under compression, Ordinary Portland Cement Type I Tasluja cement is used, the chemical composition and physical properties which conforms to ASTM C150[11] Limits. Darbandikhan sand was used, the gradation of sand conformed to ASTM C33[12] standard specification for fine aggregate, grade from (0.15 to 9.5), and crashed gravel from Tanjaro crusher source with nominal size (25 to 2.36) mm was used, the grading of gravel conformed to ASTM C33 standard specification. Super-plasticizer admixture commercially known as Structuro 520 was used. The silica fume was used in only one mix to know the relation between non-destructive testing and cube strength of concrete that have silica fume in it. The specimens were cast, cured and tested according to specifications, for later ages (90 days) the samples were rewetted for not less than 48 hours prior testing in order to maintain the same internal moisture content, this was done to eliminate the effect of moisture content within samples on the UPV and RN readings.

Selected mix proportion:

After many several trial mixes were done, the following mixes were selected as shown in Table 1, only mix E contained silica fume.

Table 1— Selected mix proportion

Mix Name.	Cement (kg)	Silica fume (kg)	W/C	HRWR %	Average cube strength Range MPa
A	411	-	0.45	-	35-40
B	350	-	0.35	-	40-45
C	480	-	0.23	1.16	45-55
D	550	-	0.25	2	60-65
E	550	44	0.23	2	50-55

Testing Program:

From the selected mixes, 9 samples were taken for each duration (1,7,28,90) days at normal (25˚C) temperature, also 9 samples for each heating degree (50°C, 125°C, 180°C) were taken for the same mix. For the mix E that contain silica fume, 36 samples were taken at normal heat at 25°C, Table 2 shows the test program and samples designation.

Table 2— Test Program and samples designation

Mix	9 samples	9 samples	9 samples	9			
Temp	25°C	25°C	25°C	25°C	50°C	125°C	180 °C
A	A1/25	A7/25	A28/25	A90/25	A28/50	A28/125	A28/180
B	B1/25	B7/25	B28/25	B90/25	B28/50	B28/125	B28/180
C	C1/25	C7/25	C28/25	C90/25	C28/50	C28/125	C28/180
D	D1/25	D7/25	D28/25	D90/25	D28/50	D28/125	D28/180
E	E1/25	E7/25	E28/25	E90/25			

Heating process:

108 cubes were tested to know the effect of temperature on RN and UPV reading, and their relation with destructive tests on same specimens. The cubes were taken out from water after 28 days and were put in an oven. In each four mix (A, B, C, and D) 27 cubes were provided for heating at different temperatures, 9 cubes for each (50°C,125°C,180°C) as shown in Table 2 the heating process was as follows:

The oven was switched on to the required temperature 180°C, and left to reach that temperature. Once the required temperature was reached and stabilized as shown in Figure 1, the cubes were put inside as soon as possible, as the opening and cube placement would reduce the oven temperature, sometime was required for the oven to reach back the required temperature 180°C again and stabilize. The cubes were left for one hour to heat at that stabilized temperature, hence the heating duration was about one hour, after which the cubes

were taken out from the oven and left to cool down at laboratory temperature, after which all the three tests were performed (RN, UPV, and Compression). The same procedure was followed for the next temperature level 125°C, 50°C.

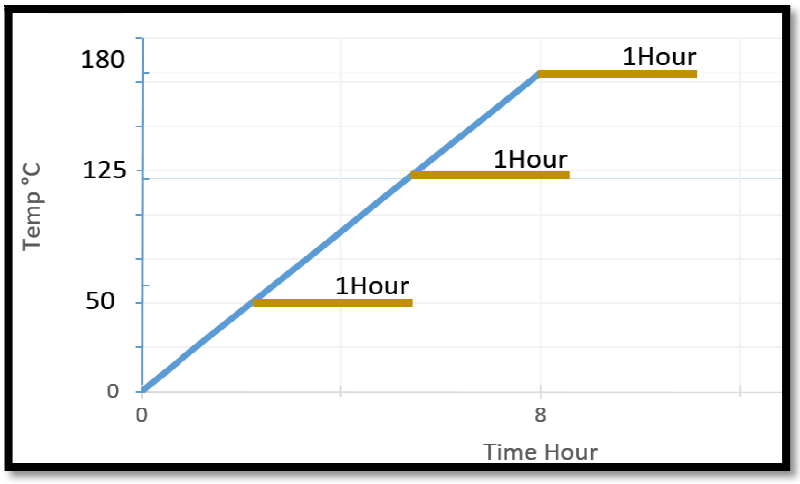


Figure 1 Heating time -temperature relationship

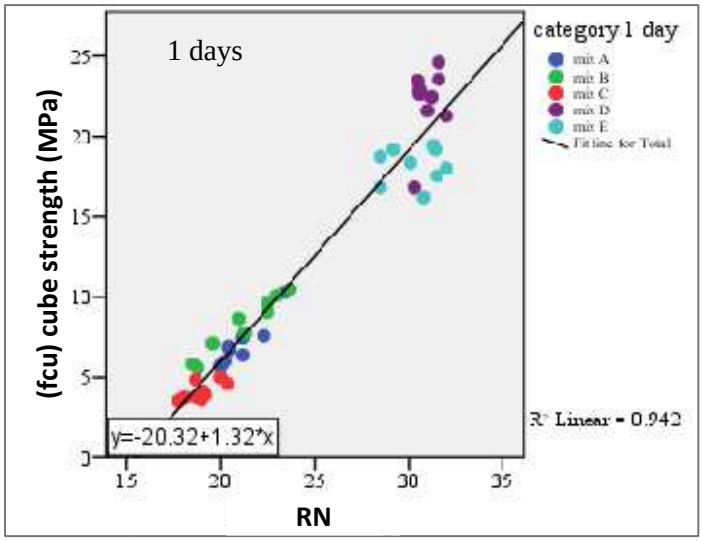
Test Results and Discussion:

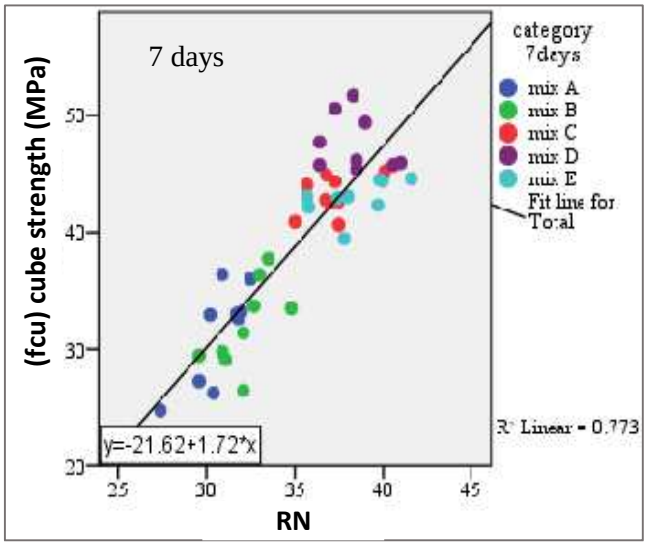
All tests were done according to specification. The experimental results for the RN, UPV, cube compression strength and densities were recorded. The rebound number for each sample represent the average of 18 readings taken from two opposite faces of the cube, while the UPV represent the average of three reading taken from top, side and bottom of the cubes.

A. Comparisons between RN and cube strength for all mixes combined:

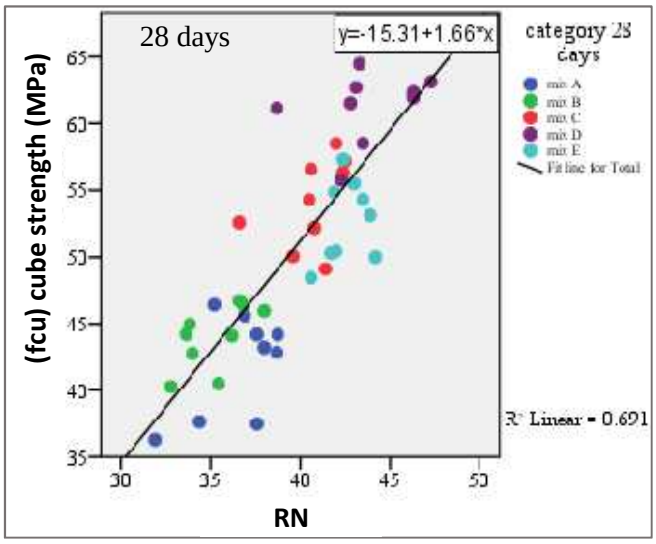
The relation between RN and cube strength for all mixes combined and for different combination of testing ages is shown in Figures 2. The figures show that by increasing cube strength RN increases, and that relation between age of concrete, RN and cube strength are directly proportional with each other.

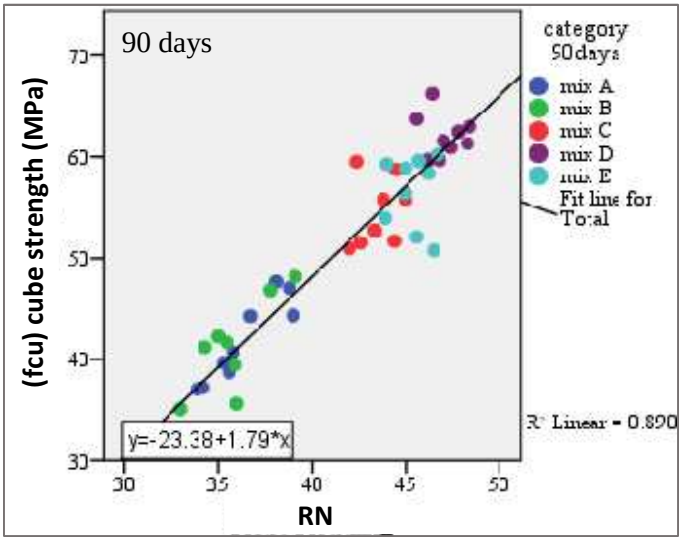
The graph for age 1 day for all mixes is more accurate ($R^2 = 0.942$) as indicated on the figures, and more proportional than other ages (7, 28 and 90) days, because of similarity of early hydration of cement, next to this in accuracy is for all the mixes combined for all ages ($R^2 = 0.928$). The rate of strength increase with RN are similar for all mixes.

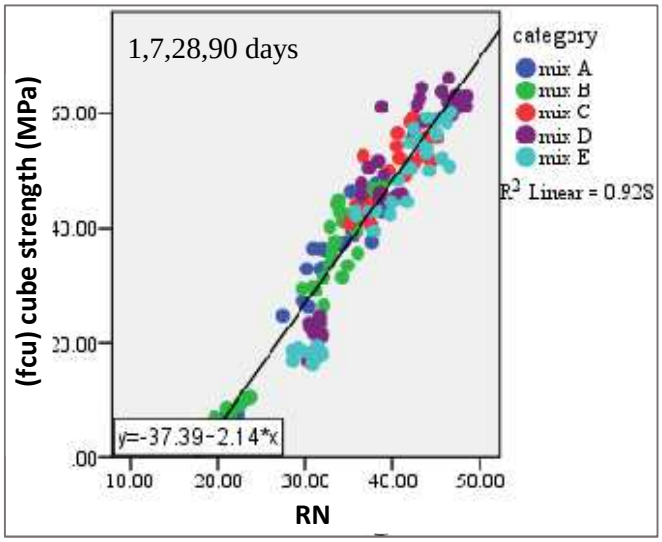


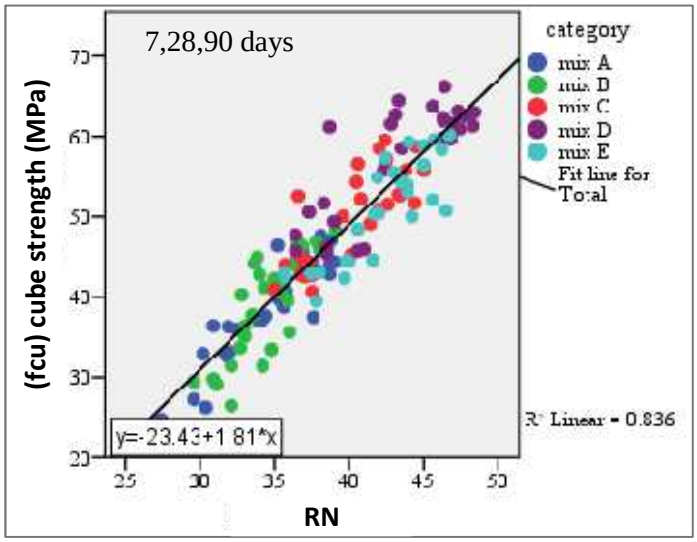


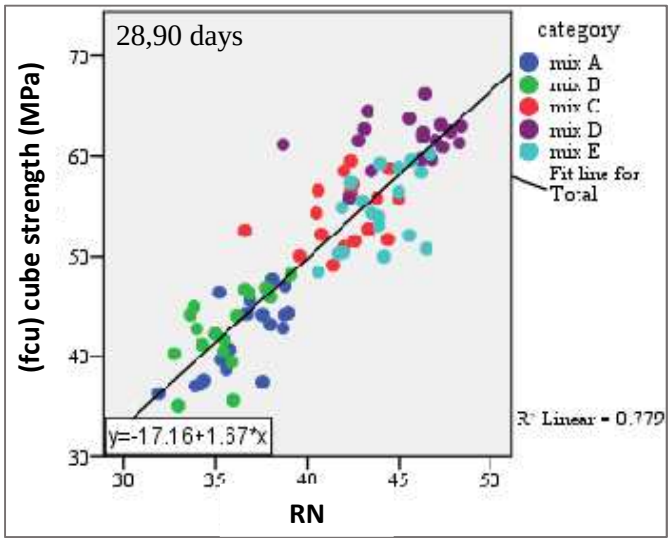
Figures 2 Relation between cube strength and RN for ages 1,7,28 and 90 for all mixes (continued.....)











Figures 2 Relation between cube strength and RN for ages 1,7,28, and 90 for all mixes

B. Relation between concrete strength and temperature:

The compressive strength of concrete when exposed to heating, changes due to change in moisture content. Initially as the temperature increased from 25ºC to 50ºC the cube strength decreased compared to

the room temperature strength, and at a rate lower than increasing rate from 50ºC to 125ºC, with further increase in temperature from 125ºC to 180ºC, the strength loss is recovered and reaches the strength as at room temperature. The reason for this is due to loss of moisture content in the concrete, because the moisture from the concrete flow out to its surface at temperature 125ºC, causing a decrease in strength, when heated at 125ºC to 180ºC the moisture content totally minimized and there is an increase in strength compared to cubes heated at 125ºC temperature.[13] The adsorbed moisture in specimens of normal strength concrete escaped sooner if compared to HSC.[14,15] The test was limited to 180ºC because of the oven, but according other researchers [16-18] the concrete strength after 180ºC will decrease again depending on temperature.
The relation of RN with temperature as shown in Figure 3 is similar to the relation of cube strength with temperature, the figure shows the same pattern like cube strength-temperature relationship, decreasing in the range (50 -125) ºC then increasing to 180ºC as described before.

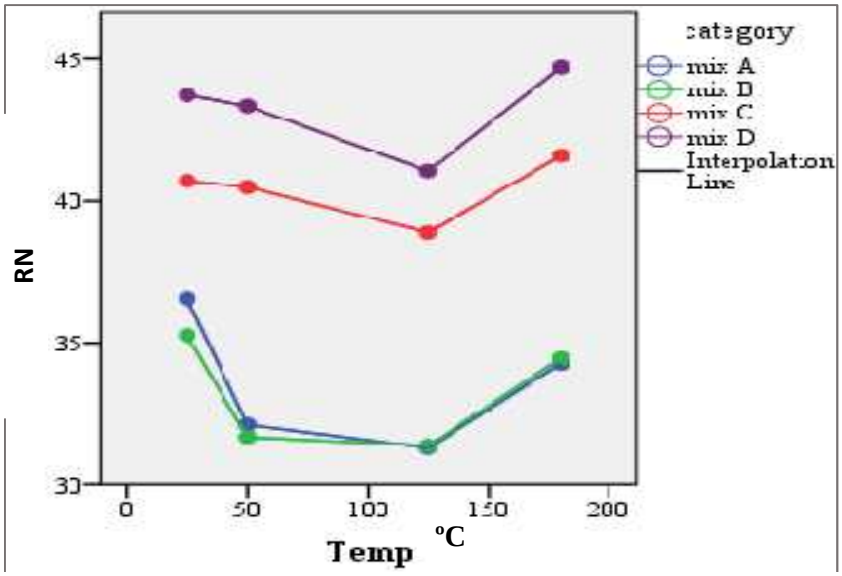


Figure 3 Relation between RN and temperature for age 28 for all mixes

C. Comparisons between UPV and cube strength for all mixes combined:

The relation between UPV and strength is shown in Figures 4 for all mixes. The figures show that by increasing strength UPV increases in different random rates. For early age 1 day UPV increases faster and the data fit better compared to other ages 7, 28, 90 days. the figures also show combining all mixes at different ages for comparison.

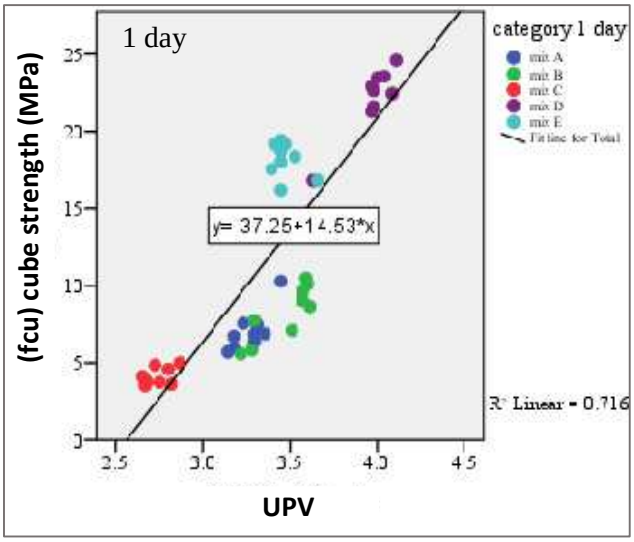
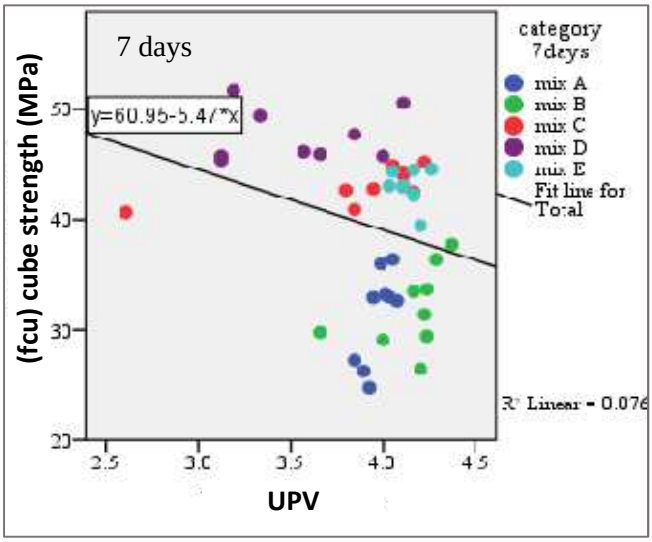
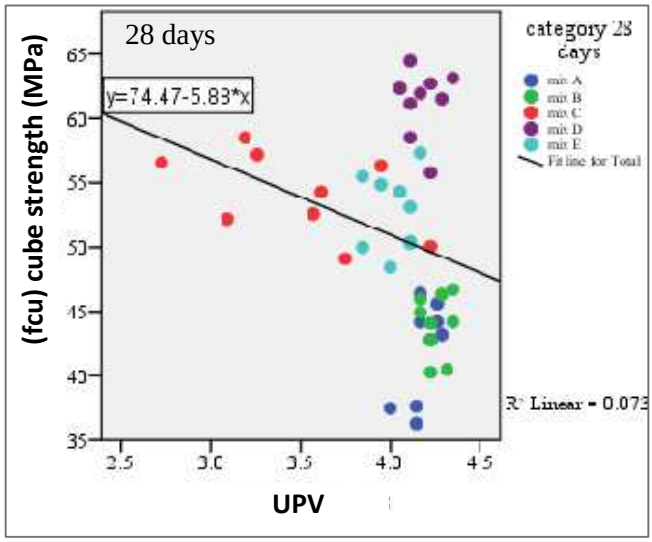


Figure 4 Relation between UPV and cube strength at different ages 1,7,28, and 90 for all mixes (continued……)





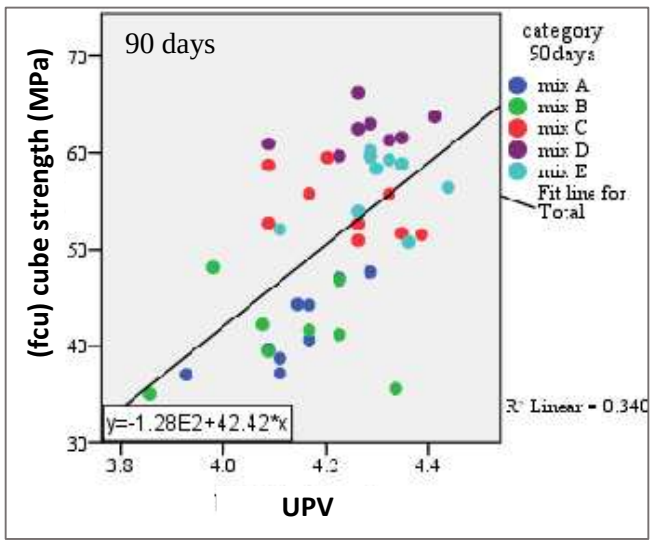


Figure 4 Relation between UPV and cube strength at different ages 1,7,28, and 90 for all mixes (continued……)

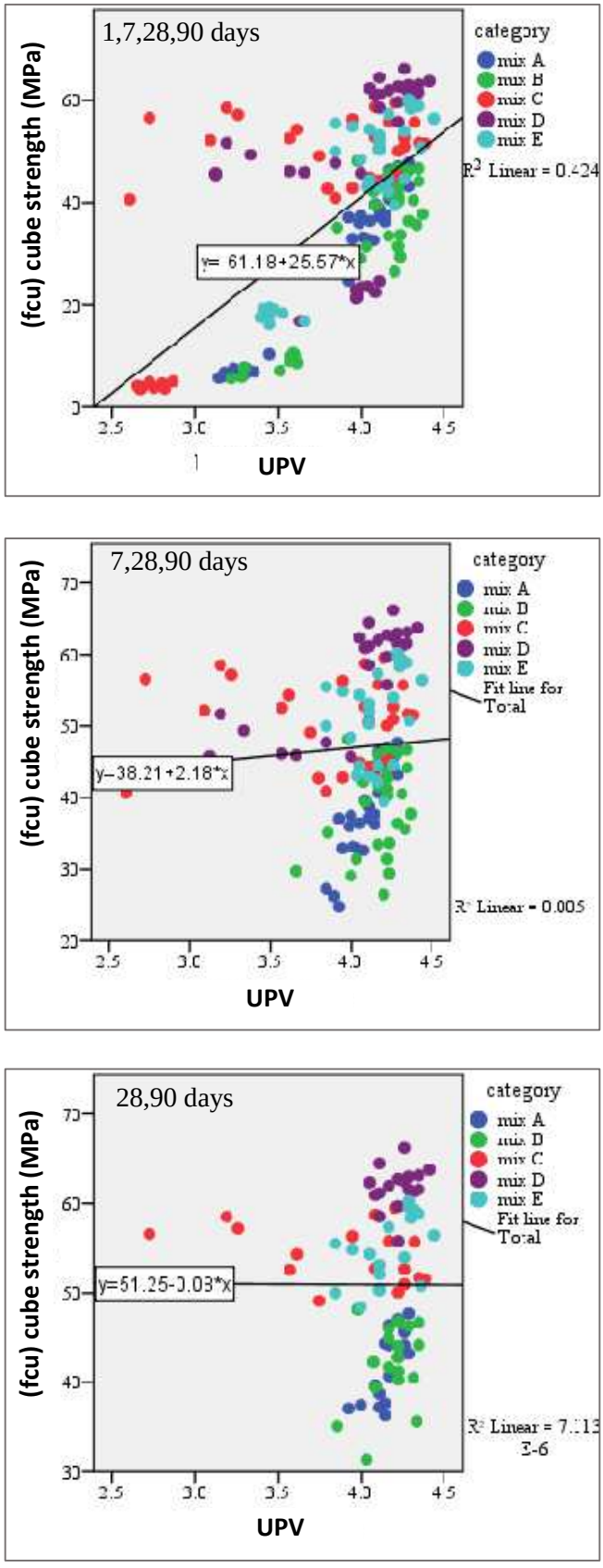


Figure 4 Relation between UPV and cube strength at different ages 1,7,28 and 90 for all mixes

D. Relation between UPV and temperature:

Figure 5 shows relation between UPV and temperature; in general the figure shows as temperature increased UPV decreased in a similar pattern same as discussed with RN, but with less correlation.

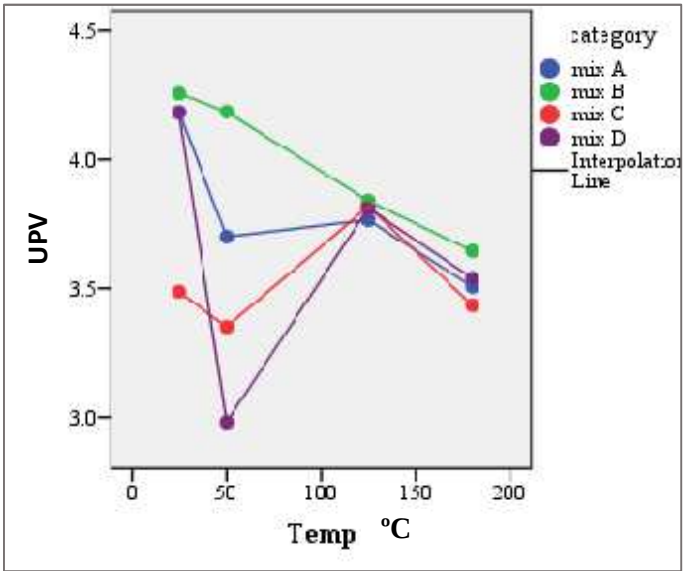


Figure 5 Relation between UPV and Temp for all mixes

E. Relation between UPV and cube strength at different temperature:

Relation between UPV and cube strength as shown in Figures 6 are the same for all different temperatures, an increase in cube strength corresponds to a decrease in UPV, but with different rate for different temperatures. Increase in temperature has more effect on UPV than RN tests, therefore the estimation of UPV should be neglected in this condition.

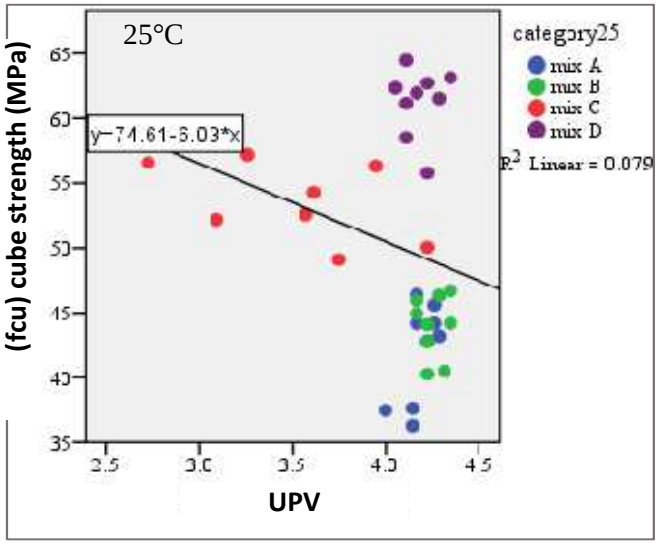


Figure 6 Relation between UPV and cube strength for all mixes at different temperatures (continued…)

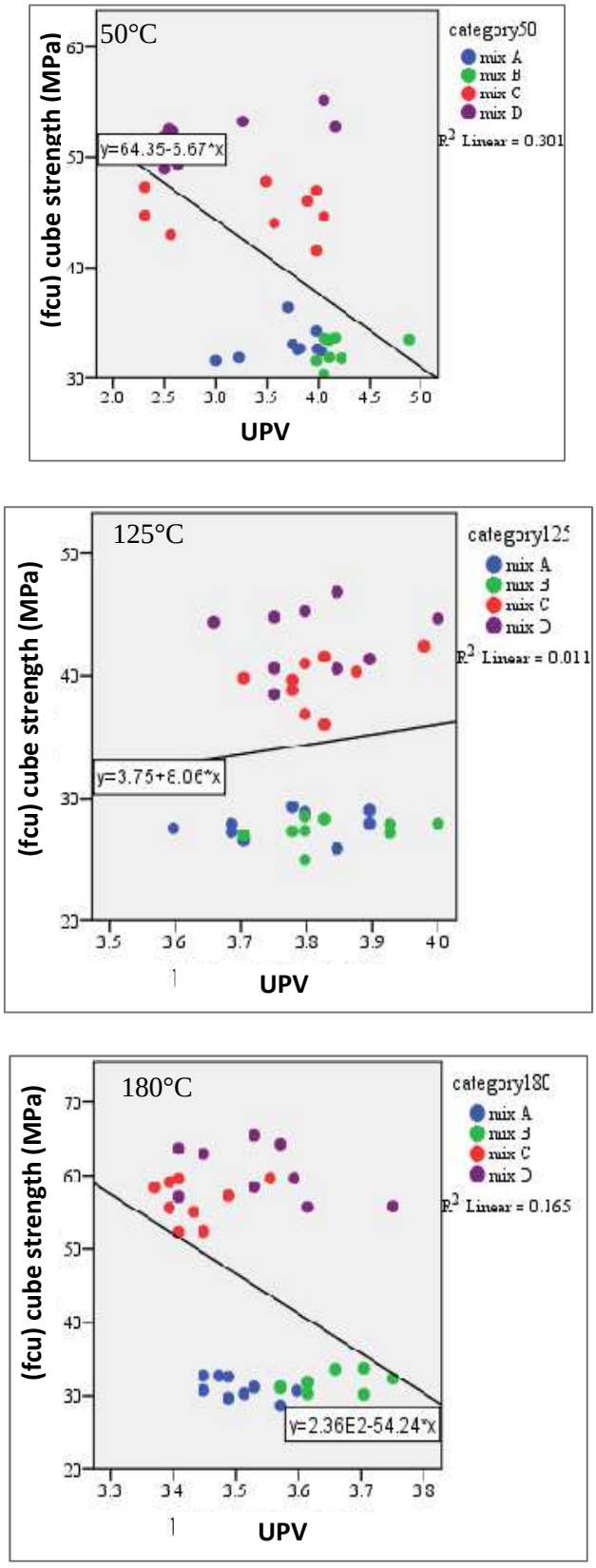


Figure 6 Relation between UPV and strength for all mixes at different temperatures

F. Proposed equations:

Based on the correlation analysis it is preferred to use the proposed equations shown in Table 3, for correlation between RN and the strength also RN and UPV combined and strength. These are divided in to two set of equations; at 1-day age and for all ages. For concrete cast and tested after 1day use equations for

1-day age, for all other ages the other equations should be used. UPV correlation is not included in the table because it is not recommended alone.

Table 3— proposed Equations

Proposed equation	NDT	Correlation Equation	R^2
1day for any mixes	RN	132RN-20.32	0.942
All days for any mixes	RN	1.67RN-17.16	0.779
1day for any mixes	Combined	$0.002* RN^{2.2}*e^{0.395U}$	0.976
All days for any mixes	Combined	$0.216* RN^{1.505}*e^{-0.033U}$	0.834
Any temp for concrete	Combined	$0.331* RN^{1.407}*e^{-0.034U}$	0.756

G. Combined method vs. strength comparison:

Table 4 show all proposed equation from previous investigations; they vary largely with each other, because of changing the source of aggregate that affects the results of the ultra-sonic pulse velocity and the rebound number of the Schmidt hammer. Briefly There is no generalized formula that can be used for predicting concrete compressive strength using nondestructive testing. Equations may be useful when derived from cubes tested at a location and applied to the same location but not applicable to other locations.

Table 4- proposed combined equations from previous investigations

Researchers	Combined	R^2
Raouf [4] (1986)	$fcu = 0.93RN^{0.63} * e^{0.31U}$	Not known
Kheder [5] (1999)	$fcu = 0.0158RN^{1.1171} * U^{0.425}$	0.822
Qasrawi[6] (2000)	Graphically showed	0.95
Nash't[7] (2005)	$fcu = 0.356RN^{0.866} * e^{0.302U}$	0.8
Youkhanna[9] (2012)	$fcu = 0.163RN^{1.132} * e^{0.277U}$	0.854
Pucinotti[10] (2015)	$fcu = 9.61.10^{-14} RN^{3.55} * U^{0.9}$	0.89
Proposed in this study(2015)	$fcu = 0.216 * RN^{1.505} * e^{-0.033U}$	0.834

Conclusions:

From the experimental results and the statistical analysis performed in this investigation, the following conclusions may be drawn:

1. RN test results are more reliable than UPV result (high variation is obtained with UPV) if tested separately, the coefficient of determination R^2 in Rebound readings is higher than UPV readings.
2. Both of RN and UPV readings increased with strength increase but at different rates.
3. The correlation for 1day age concrete is more reliable as compared separately to the other ages 7, 28, 90 days.
4. Generally, the compressive strength of the cubes decreased as temperature increased, however at 125°C it regained strength up to the tested temperature 180°C.
5. The combined use of UPV and RN method is more reliable than UPV or RN methods separately because it minimizes the effect of moisture content on UPV while RN is not affected.

References:

[1] Aydin Ferhat and Mehmet Saribiyik. "*Correlation between Schmidt Hammer and destructive compressions testing for concretes in existing buildings*". Scientific Research and Essays Vol. 5, No. 13, pp 1644-1648. (2010).

[2]Yüksel I "*Determination of concrete strength using combined nondestructive tests and application on a reinforced concrete structure*". MSc. Thesis, Yildiz Technic University, Science of Technology Institute, Istanbul, (1995).

[3]Leshchinsky A. "*Non-destructive methods Instead of specimens and cores, quality control of concrete structures"*. Proceedings of the International Symposium held by RILEM, Belgium, E&FN SPON, U.K., pp 377-386. (1991).

[4]Raouf Z. "*Assessment of Combined Nondestructive Method for Testing Concrete*". Journal of building research, Vo1.5, No.1, pp133-151. (1986).

[5]Kheder G. F. "*A two stage procedure for assessment of in situ concrete strength using combined non-destructive testing*". Materials and Structures Vol. 32, No. 6, pp 410-417. (1999).

[6]Qasrawi Hisham Y. "*Concrete strength by combined nondestructive methods simply and reliably predicted*". Cement and Concrete Research Vol. 30, No. 5, pp 739-746. (2000).

[7]Nash't Isam H., Saeed Hameed A'bour, and Anwar Abdullah Sadoon. "*Finding a unified relationship between crushing strength of concrete and non-destructive tests"*. In Middle East Nondestructive Testing Conference & Exhibition, Bahrain. (2005).

[8]Hobbs Brian, and Mohamed Tchoketch Kebir. *"Non-destructive testing techniques for the forensic engineering investigation of reinforced concrete buildings"*. Forensic science international Vol. 167, No. 2, pp167-172. (2007).

[9]Dinkha Youkhanna. "*Strength Estimation of Concrete Produced in Kurdistan Region Using Non-Destructive Tests (Combined Method)"*. MSc Thesis, University of Salahaddin (2012).

[10]Pucinotti Raffaele. "*Reinforced concrete structure: Nondestructive in situ strength assessment of concrete"*. Construction and Building Materials Vol. 75, pp 331-341, (2015).

[11]ASTM Designation C150. *"Standard Specification of Portland Cement"*. Annual Book of ASTM Standard, Vol. 4, (2012).

[12]ASTM Designation C33."*Standard Specification for Concrete Aggregates*". Annual Book of ASTM Standard, Vol. 4, October (2005).

[13]Castillo Carlos, and A. J. DurraniI. "*Effect of transient high temperature on high-strength concrete*". ACI Materials journal Vol. 87, No. 1, (1990).

[14]Chew, Michael Yit Lin. *"Residual Compressive Strength of Heated Concrete*". Architectural Science Review Vol. 36, No. 2, pp 49-52, (1993).

[15]Ahmed A. E., A. H. Al-Shaikh and T. I. Arafat. *"Residual compressive and bond strengths of limestone aggregate concrete subjected to elevated temperatures*". Magazine of Concrete Research Vol. 44, No. 159, pp 117-125, (1992).

[16]Mohamedbhai, G. T. G. *"Effect of exposure time and rates of heating and cooling on residual strength of heated concrete"*. Magazine of Concrete Research Vol. 38, No. 136, pp 151-158, (1986).

[17]Carette, G. G., K. E. Painter, and V. M. Malhotra. "*Sustained high temperature effect on concretes made with normal Portland cement, normal Portland cement and slag, or normal Portland cement and fly ash*". Concrete International Vol. 4, No. 7, pp 41-51, (1982).

18]Abrams, Melvin S. *"Compressive strength of concrete at temperatures to 1600F"*. ACI Special Publication Vol. 25, (1971).