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Predicting a Mathematical Models of Some Mechanical Properties of Concrete from Non-Destructive Testing

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Abstract
Nondestructive tests NDT are considered as a one of the methods of evaluation and quality control of concrete. The fundamental aim of the present study is constructing a mathematical models to predict some mechanical properties of concrete from Nondestructive testing, in addition the study of (NSC and HSC) properties (density, compressive strength ,modulus of elasticity and modulus of rupture) of concrete grade (20-100) MPa) by using NDT methods namely; Schmidt Hammer test (RN)and Ultrasonic Pulse Velocity test (UPV) with destructive test methods at different four ages (7, 28, 56 and 90) days. This study used ready mixes (1:2:4 and 1:1.5:3) and design mixes (C_{40}, C_{50}, C_{60}, C_{70}, C_{80}, C_{90} and C_{100}), in order to find the relationship between these properties. of concrete with (RN and UPV), and compressive strength of concrete-combined NDT(RN and UPV) relationship, for all mixes (as freelance and as group). The results of compressive strength for both types of concrete NSC and HSC exhibit an increase with the increase of bulk density and time of curing. Also, the results show a good correlation between compressive strength and (RN) and the relationship between the two is not affected by maximum aggregate size (MAS). Also, a good correlation between compressive strength and Ultrasonic Pulse Velocity (UPV) and The value of UPV in HSC increased 8% from 28 days to 90 days. Also, the results indicated that the percentages of increase in relationship between static modulus of elasticity and compressive strength for 28 days to 90 days are 15% at low strength, 5.6% at high strength and the relationship between static modulus of elasticity and rebound number for 28 days to 90 days is3.3%.The results indicate that the percentage of increase in direct method to surfacing method of UPV for (7, 28, 56 and 90) days is (7%, 5%, 4% and 3.5%) respectively, due to the higher the continuity of hydration of cement. Also, the pulse velocity of concrete is decreased by increasing the cement paste, especially for concrete with high w/c.
Keywords— Nondestructive tests, Schmidt hammer test(RN), Ultrasonic pulse velocity test (UPV) , Density , Compressive strength, modulus of elasticity , modulus of rupture.

1. Introduction

The concrete is a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate. In hydraulic cement concrete the binder is formed from a mixture of hydraulic cement and water**[1],**Concrete composites of (Cement ,Aggregates , Water and Admixtures).
ormal strength concrete NSC is defined by American Concrete Institute (ACI committee 211.1 -02) **[2]** as "concrete that has a specified average compressive strength of 40 MPa or less at 28 days" but should be not less than 17 Mpa (ACI committee 318M-05) **[3]** and the high strength concrete HSC is defined by American Concrete Institute (ACI committee 363R-97) **[4]** as "concrete that has a specified average compressive strength of 41MPa or more at 28 days. The Mix proportions for HSC are influenced by many factors, including specified performance properties, locally available materials, local experience, personal preferences and cost **[5]**.

HSC mix proportioning is a more critical process than the design of normal strength concrete mixtures (ACI Committee 363R-97) **[4].** When developing mixture proportions for HSC, three fundamental factors must be considered in order to produce a mix design satisfying its intended property requirements (mechanical properties of the aggregates; mechanical properties of the paste and Bond strength at the paste-aggregate interfacial transition zone**) [6]**, **[7]** .

For many years in concrete practice, the most widely used test for concrete has been the compression test of the standard specimens (cube or cylinder) . It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the concrete [8] . The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, through those where the concrete surface is slightly damaged, to partially destructive tests, such as core tests and pullout and pull off tests, where the surface has to be repaired after the testing. The range of properties that can be assessed using Non-destructive tests and partially destructive tests. Nondestructive test define as the test which either do not alter the concrete or result in superficial local damage **[9], [8]** .

Non-destructive testing can be applied to both old and new structures. For new structures, the principal applications are likely to be for quality control or the resolution of doubts about the quality of materials or construction. The testing of existing structures is usually related to an assessment of structural integrity or adequacy **[10]** .

In addition, in-situ NDT was introduced to supply the engineer with information on one or more of the following properties of the structural material: in-situ strength properties, durability, density, moisture content, elastic properties, extent of visible cracks, thickness of structural members having one face exposed, position of the steel reinforcement and concrete cover over the reinforcement. Most emphasis has been placed on the determination of in-situ strength and durability **[11]** .

Non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delaminating **[10]**one of types of Non-destructive test methods is Schmidt hammer test, In 1940S ERNst Schmidt, a Swiss engineer, developed a device for testing concrete based upon the rebound principle, This device consists of the following main components outer body, plunger, hammer, and spring. To perform the test, the plunger retracts against a spring when pressed against the concrete surface and this spring is automatically released when fully tensioned, causing the hummer mass to impact against the concrete through the plunger. The rebounding hammer moves the slide indicator, which records the rebound distance. The rebound distance is measured on a scale numbered from (10 to 100) and is recorded as the rebound number indicated on the scale **[12]**, **[13] .**

There are Factors influencing of the rebound test results, mix characteristics (cement type, cement content and coarse aggregate type) and member characteristic (mass, compaction, surface type, age, surface carbonation, moisture condition and stress state and temperature). The strength-rebound number relationship is depended on many factors that are influence on test results which may empirically affect the relationship between compressive strength and rebound number. Practically, it is agreed that there is no unique relationship between concrete strength and rebound number. Many investigations have been done to obtain a relationship between rebound number and compressive strength, locally (Raouf and Samurai-99) **[14]** obtained an experimental relationship to estimate concrete compressive strength using rebound number

$$f_{cu}=0.74\,RN^{1.12} \qquad \text{.........} \quad (1\text{-}1)$$

Where: f_{cu}: Concrete compressive strength in MPa. (cube) , *RN*: rebound number.

(Hussam -08) **[11]** obtained a mathematical relationship between concrete compressive strength (f_{cu}:) and rebound number (RN), as follows:

$$f_{cu}=-\,65.33+2.38\,RN \qquad \text{.........} \quad (1\text{-}2)$$

Where: f_{cu}: Concrete compressive strength in Mpa. (cube), *RN*: Rebound number.

Another method of Nondestructive test is ultrasonic pulse velocity test(UPV).The UPV method is a stress wave propagation method that involves measuring the travel time, over a known path length, of ultrasonic pulse waves. The pulses are introduced into the concrete by a piezoelectric transducer and a similar transducer acts as receiver to monitor the surface vibration caused by the arrival of the pulse. A timing circuit(t) is used to measure the time it takes for the pulse to travel from the transmitting to the receiving transducers during the materials path (L). The pulse velocity (V) is given by dividing path length (L) over transit time (t)

$$V=L\,/\,T \qquad \text{.........} \quad (1\text{-}3)$$

The presence of low density or cracked concrete increases the travel time which results in a lower pulse velocity. The factors affecting on strength-pulse velocity relationship water/cement ratio (w/c), aggregate size, grading, type, and content ,the concrete age, moisture condition, compaction ,curing temperature, path length, level of stress **[13]** .

In estimation, the strength of in-situ the concrete strength from pulse velocity measurements, an empirical relationship must be established on test specimens in the laboratory. In practice, it is generally agreed that there is no unique relationship between concrete strength and UPV. There exist factors which may affect one parameter only leading to existence of different relationships.

Locally (Raouf and Samurai-99)**[14]** obtained an experimental relationship to estimate concrete compressive strength using rebound number.

$$f_{cu}=2.8\,e^{0.58V} \qquad \text{.........} \quad (1\text{-}4)$$

Where: *fcu*: Concrete compressive strength in Mpa. (cube) , *V*: UPV in (km/sec)

(Hussam-08)[11] obtained a mathematical relationship between concrete compressive strength (fcu) in Mpa and ultrasonic pulse velocity UPV, as follows:

$$f_{cu}=0.086\,e^{1.58V} \qquad \text{.........} \quad (1\text{-}5)$$

Where: f_{cu} in (Mpa) and *V*: UPV in (km/sec).

In many time used combined nondestructive test methods to estimate concrete strength. By combining results from more than one NDT test, a multivariable correlation can be established to estimate strength.

Combined methods are reported to increase the reliability of the estimated strength. The underlying concept is that if the two methods are influenced in different ways by the same factor, their combined use results in a canceling effect that improves the accuracy of the estimated strength. For example, an increase in moisture content increases pulse velocity but decreases the rebound number. Locally (Raouf and Samurai -99)**[14]** obtained an experimental relationship to estimate concrete compressive strength using combined rebound number and ultrasonic pulse velocity at different ages (28, 60 and 90) days and by using statistical analysis methods, the following relation was obtained:

$$f_{cu} = 0.93RN^{0.63}\ e^{0.31V} \quad \ldots\ldots\ldots.(1\text{-}6)$$

Where: f_{cu} : in MPa , RN: Rebound number, V : UPV in (km/sec).

(Hussam -08)[11] obtained an experimental relationship to estimate compressive strength of concrete using combined rebound number and ultrasonic pulse velocity. By method of multiple linear regression analysis using (statistica-6.0) computer program, the following relation was obtained:

$$f_{cu} = 0.0031RN^{1.65}\ V^{2.075} \quad \ldots\ldots\ldots.(1\text{-}7)$$

Where: f_{cu} in (MPa), RN: Rebound number , V: UPV in (km/sec).

2. Experimental Works

This paragraph includes detailed information about description of material and mixes, mixing procedure, casting and curing and testing are carried out on sample to achieve the aim of this study.

2.1. Materials

NSC and HSC are obtained by selecting suitable materials, good quality control and proportioning. The material must be conforming to (ACIcommittee211.1-2002)**[2]**and (ACI committee 363R, 1997)**[4]** requirements.

2.1.1.Cement

Ordinary Portland cement (OPC) (Type I) was used in this study. The cement was produced by United Cement Company “UCC”, commercially known as “Tasluja” produced in Al-Sulaymaniyah City. The physical properties and chemical analysis of this cement were conformed with the (I.Q.S. No.5 -84) requirements **[15]** .

2.1.2 .Fine Aggregate (F.A)

Natural siliceous sand brought from (Al-Ukhaider) region was used in this study. the results showed that the grading and sulfate content conformed to the (I.Q.S. No.45 -84 Zone2) **[16]**.

2.1.3. Coarse Aggregate (C.A)

Coarse aggregate used in this study was cleaned, cubical, and 100% crushed gravel from (Al-Niba’ee) region with two maximum size are used (14 , 20) mm. The grading of the aggregate with size (14mm) , (20mm) and another properties were conformed to the (I.Q.S. No.45-84) **[16]** .

2.1.4. Silica fume (SF)

Silica fume used in this study was Turkey production , The physical properties and chemical composition of SF were conformed to the chemical and physical requirements of (ASTM C1240 - 03) **[17]** .

2.1.5. Superplasticizer (SP)

To produce HSC with silica fume a high range water reducer was used. It was based on polycarboxylic ether and had the trade mark “Glenium 51”. It was complied with (IQS No.1431-89)**[18]** and (ASTM C494-05)**[19]** type F,

2.1.6. Water

Tap water was used for both mixing and curing of concrete in this work.

2.2. Concrete mixes

In order to achieve the scopes of this study, the work is divided into fifteen sets of concrete mixes, divided into two sets (ready mixes and design mixes). Mix design for normal strength concrete was made using MAS (20) mm using (ACI committee 211.1-02)**[2]** method , the details of the two mix groups are shown in Table 1.

Table 1 Proportion of first set of mixtures

Mix symbol	The mix proportion by Vol.	The mix proportion by weight	w/c	Slump (mm)
A1	1:2:4	(1:2.5:4.63)	0.60	5
A2	1:2:4	(1:2.5:4.63)	0.576	10
A3	1:2:4	(1:2.5:4.63)	0.55	15
A4	1:2:4	(1:2.5:4.63)	0.525	20
B1	1:1.5:3	(1:1.91:3.5)	0.45	5
B2	1:1.5:3	(1:1.91:3.5)	0.427	10
B3	1:1.5:3	(1:1.91:3.5)	0.40	15
B4	1:1.5:3	(1:1.91:3.5)	0.375	20
C40	1:0.97:1.8	(1:1.17:2.2)	0.42	75-100
C50	1:0.88:1.68	(1:1.1:2.02)	0.38	75-100

Mix design for high strength concrete was depended on replacement SF (15) % by weight of cement were used, and using (ACI committee 211.4R)**[20]** and (ACI committee 211.1R)**[21]** to choose air content reduced by one percent by (Holland -05)method **[22]** .

The initial dosages of superplasticizer depending on slump test result **[23]** . The MAS of coarse aggregate was used (14mm), the Table 2 shows the proportion of mixes of high strength concrete .

Table 2 Proportion of second set of mixtures

Mix Symbol	The mix proportion by weight	Cement kg/m^3	SF kg/m^3	HRWR % wt of Cementitious	w/(c+p)	Slump (mm)
C60	1:1.07:2.03	527	---	0.08	0.36	75-100
C70	1:1.04:1.97	543	---	0.29	0.33	75-100
C80	1:0.96:1.82	585	---	0.55	0.3	75-100
C90	1:1.24:2.13	468	70	1.9	0.24	75-100
C100	1:1.28:2.20	442	78	2.4	0.22	75-100

2.3. Casting and curing of test specimens

The molds used were cleaned, assembled and oiled. The concrete was cast in molds in three layers; each layer compacted by using vibrating Table for adequate time to remove any entrapped air. In the second day the specimens were demolded and put in water for curing at temperature (24$\pm$ 3) $^{\circ}$C until the day of testing .

2.4 Testing fresh and harden concrete

2.4.1. Slump test

This test is used to determine the workability of concrete mixture according to (I.Q.S. No.354 -90) **[24]** by using standard slump cone.

2.4.2. Schmidt hammer test

This test has been done according to (I.Q.S. No.325 -93)**[25]** on cubic specimens of (150 , 100) mm for NSC and HSC respectively, edges which have been fixed by applying 7 MPa in a compression machine to avoid any movement during this test

2.4.3.Ultrasonic pulse velocity test

This test has been done according to (I.Q.S. No.300 -91)**[26]** on cubic specimens of (150,100) mm for NSC and HSC respectively, using transducers with frequency 54 kHz,

2.4.4.Compressive Strength

Standard cubes (150) mm for NSC and (100) mm for HSC are used according to (I.Q.S. No.284 -91)**[27].** The machine which used in the tests was one of the electronic type of 2000 kN capacity with (15 N/mm^2/minute) applied load rate.

3. Results and discussion

Both tests of Schmidt hammer rebound number and Ultrasonic pulse velocity are carried out simultaneously on the same cubes of (150 and 100) mm for NSC and HSC respectively. All tests are carried out at (7, 28, 56 and 90) days.

3.1. The relationship between density and (RN and UPV)

The density considered the measurement to describe the properties of concrete, increasing the density of concrete produce increasing in the surface hardness of concrete, as the result caused increasing in value of rebound number, and decrease the time of transference ultrasonic wave through the concrete, and consequently increase in velocity of ultrasonic wave produce high strength of concrete, because decreasing the pores due to using crushed aggregate, high content of cement and SF. The relationship between density and (rebound number and Ultrasonic Pulse Velocity) is presented in Figure1,2 respectively for all mixes as group the strength from (20-100) MPa.

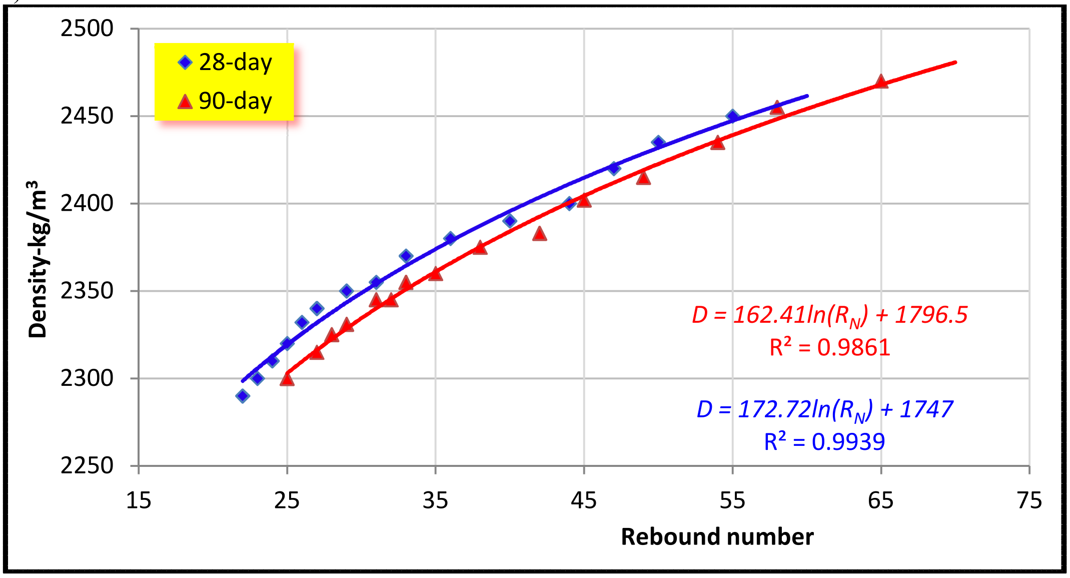

Figure 1 Relationship between Density and RN at (28-90) days

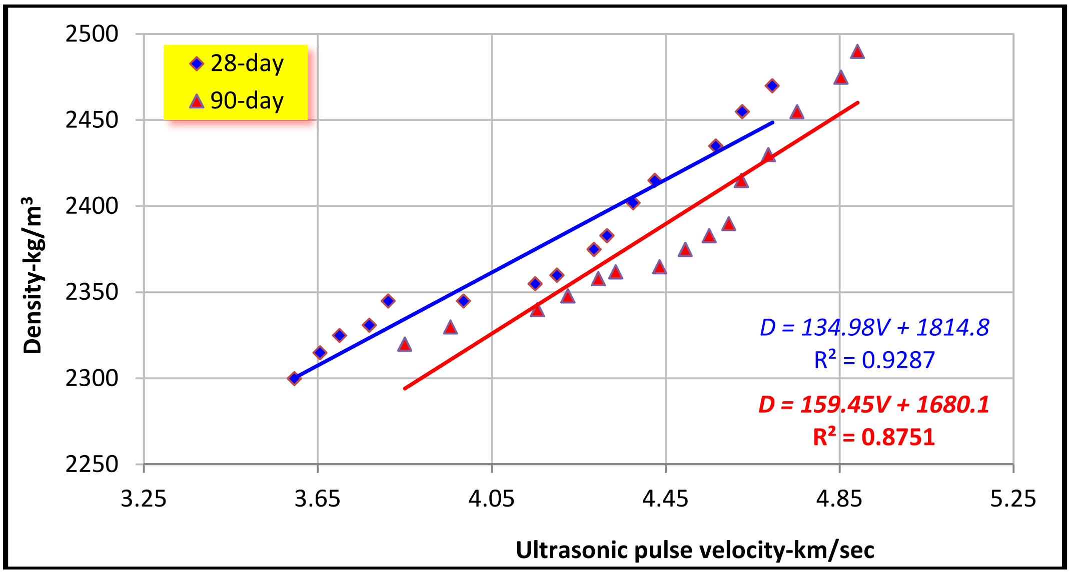

Figure 2 Relationship between Density and (UPV) at (28-90) days

3.2. The Relationship between Compressive Strength and RN

The results show that the relationship between compressive strength and rebound number is different from mix to other because the difference in properties of the mixes and (w/c) ratio. Also, the results show large similarity behavior of the mix (A1, A2, A3 and A4) and (B1, B2, B3 and B4) because it is ready mix and normal strength and just difference is the changing in (w/c) ratio, and show similarity behavior of the mix (C40, C50 and C60), and show similarity behavior of the mix(C70, C80, C90 and C100), as shown in Figure3.

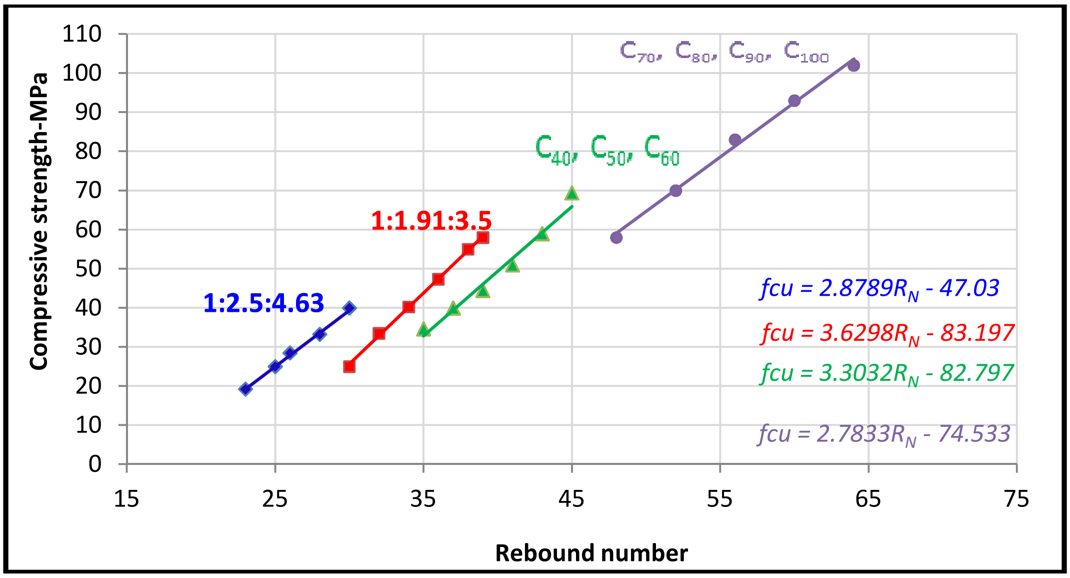

Figure. 3 Relationship between Compressive strength-RN at all ages for the mixes(1:2:4, 1:1.5:3, (C_{40}, C_{50}, C_{60}) and (C_{70}, C_{80}, C_{90}, C_{100}) at all ages.

The Figure 3 shows that the value of RN is affect by mix proportion of concrete, and increasing it because the increasing coarse aggregate and concrete homogeneity, and this properties caused increasing hardness of concrete. The Figure 4 shows the relationship between compressive strength of concrete and RN for the all mixes at all ages.

After using statistical analyses by (SPSS.19) program, it could be found that the linear expressions are giving higher coefficient of correlation than other expressions, the expression obtained from Figure 4 for (NSC and HSC) at (28 and 90) days as follows , it was similar patteRN to those obtained by (Ayden & ect -10)**[28]**

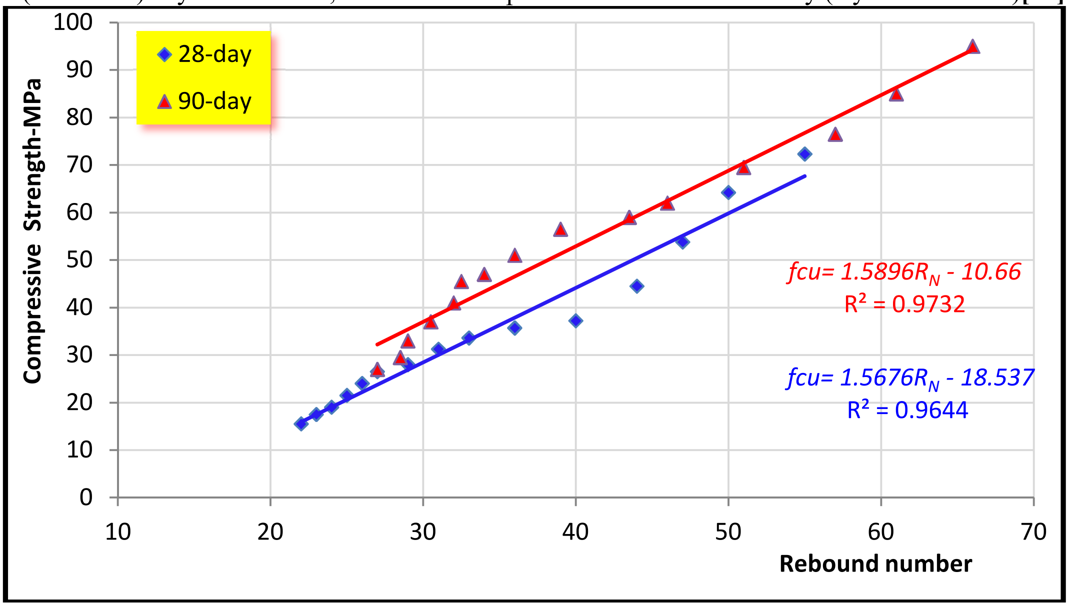

Figure 4 The relationship between Compressive strength-RN at (7, 28, 56, 90) day for all mixes

f_{cu}=1.5676 R_N –18.537 ……... (3 -1) at [28days ,R^2=0.964]

f_{cu}=1.5896 R_N –10.66 ……... (3-2) at[90days ,R^2=0.973]

Where: f_{cu}: Concrete compressive strength (cubic) in MPa, *RN*: Rebound number. , *R*: Coefficient of correlation.

3.3. Relationship between Compressive Strength and UPV

The pulse velocity is not related directly to compressive strength but it is agreed that as the concrete compressive strength increases, the pulse velocity increases**[29]**. Also, the results show large similarity behavior of the mix (A_1, A_2, A_3 and A_4) and (B_1, B_2, B_3 and B_4) because it is ready mixed and normal strength and just difference is with changing in (w/c) ratio, and show similarity behavior of the mix (C_{40}, C_{50} and C_{60}), and show similarity behavior of the mix(C_{70}, C_{80}, C_{90} and C_{100}), as shown in Figure5,the results show that the relationship between compressive strength and UPV is large similarity behavior of the all mixes are increasing the UPV by the increasing compressive strength of concrete and This increment is not linear and could be presented as exponential relationship, this result is similar to result from (Ramazan, & etc -04) **[30]** .

From the Figure5 below which shows that the value of UPV is affect by optimum selection of mix proportion for concrete, and increasing it because the increasing cement content and concrete homogeneity, and this properties caused decreasing porosity of concrete.

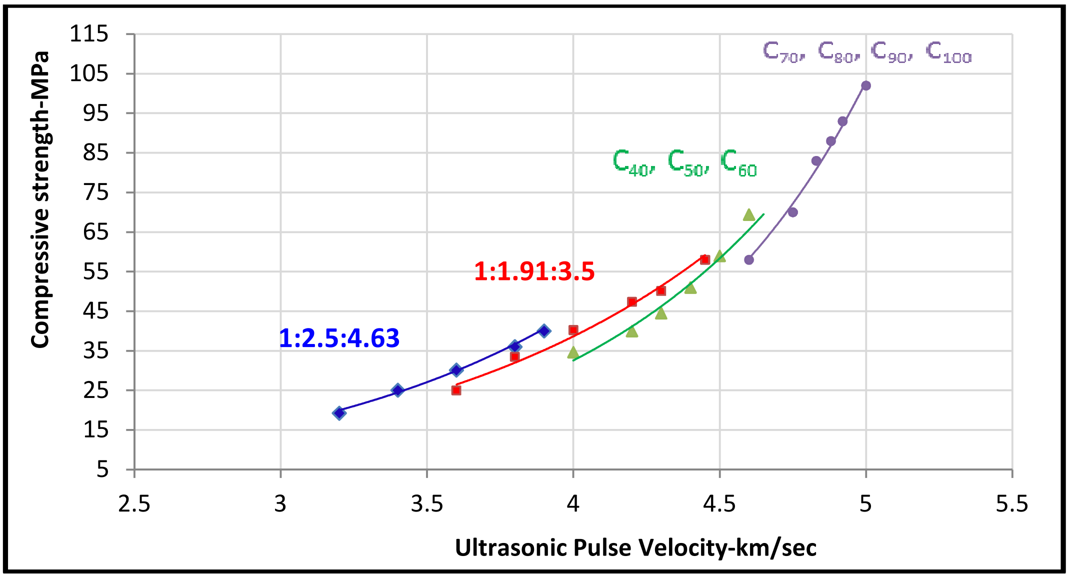

Figure**.** 5 the relationship between Compressive strength-(UPV) for the all mixes (1:2:4, 1:1.5:3, (C_{40}, C_{50}, C_{60}) and (C_{70}, C_{80}, C_{90}, C_{100}) at all ages.

The Figure 6 shows the relationship between compressive strength-UPV for all mixes as group, for (28 , 90) days.

The expressions which represent the relationship between compressive strength and UPV from Figure 6 for (NSC and HSC) at (28 , 90) days.

$f_{cu}=0.5993\, e^{0.9981V}$ ……….(3-3) at [28days ,R^2=0.9755]

$f_{cu}=0.4736\, e^{1.10351V}$ ……….(3-4) at [90days ,R^2=0.9753]

Where: f_{cu} in (MPa) and V:UPV in (km/sec).

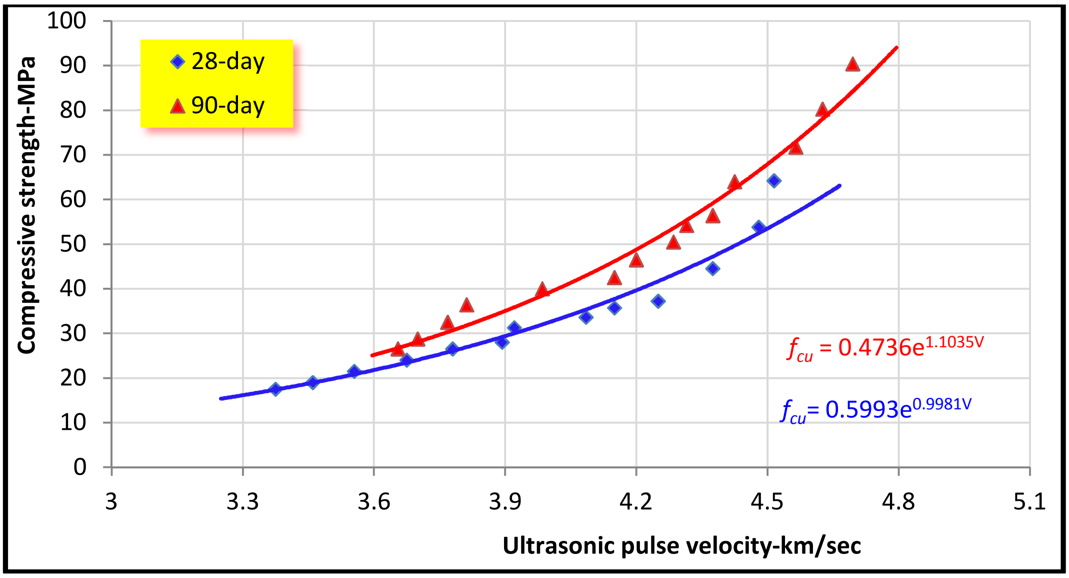

Figure 6 the relationship between Compressive strength-(UPV) at all ages for the mixes (1:2:4, 1:1.5:3, (C_{40}, C_{50}, C_{60}) and (C_{70}, C_{80}, C_{90}, C_{100}) at all ages.

3.4. Combined Non-destructive Tests

It is advantageous to use more than one method of NDT at a time, especially when a variation in properties of concrete affects the test results in opposite directions. Such as the case with the presence of moisture in concrete: an increase in the moisture content increases the UPV, but decreases the rebound number recorded by the rebound hammer **[31], [32]** .

The using combination of test results of UPV and RN to estimate compressive strength of concrete. By method of multiple linear regression analysis using (SPSS.19) computer program to obtained mathematical expression, graph it by (axcel.2010), it becomes easy to obtain an expression which represents the relation between UPV and rebound number versus compressive strength.

The Figures 7, 8, 9 and 10 show for all mixes as the group at (28 and 90) days, the results are similar to the results obtained from (Raouf and Samurai-99[14] and Qasrawi-2000[33]). The expressions can be expressed as follows:

$f_{cu}=0.42\ R_N^{\ 0.63}\ e^{0.58V}$ ……….(3-5) at [28days , R^2= 0.9929]

$f_{cu}=0.25\ R_N^{\ 0.45}\ e^{0.85V}$ ……….(3-6) at [90-days, R^2= 0.9954]

Where: f_{cu} in (MPa), and V:UPV in (km/sec).

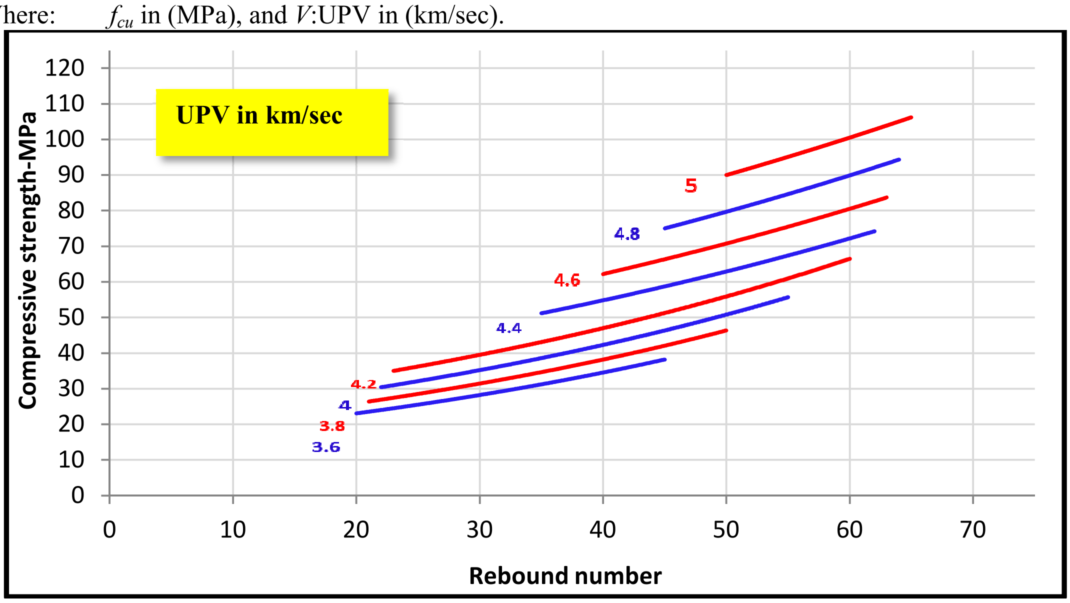

Figure 7 Curves for comp. strength of concrete and combined UPV and RN at 28 days

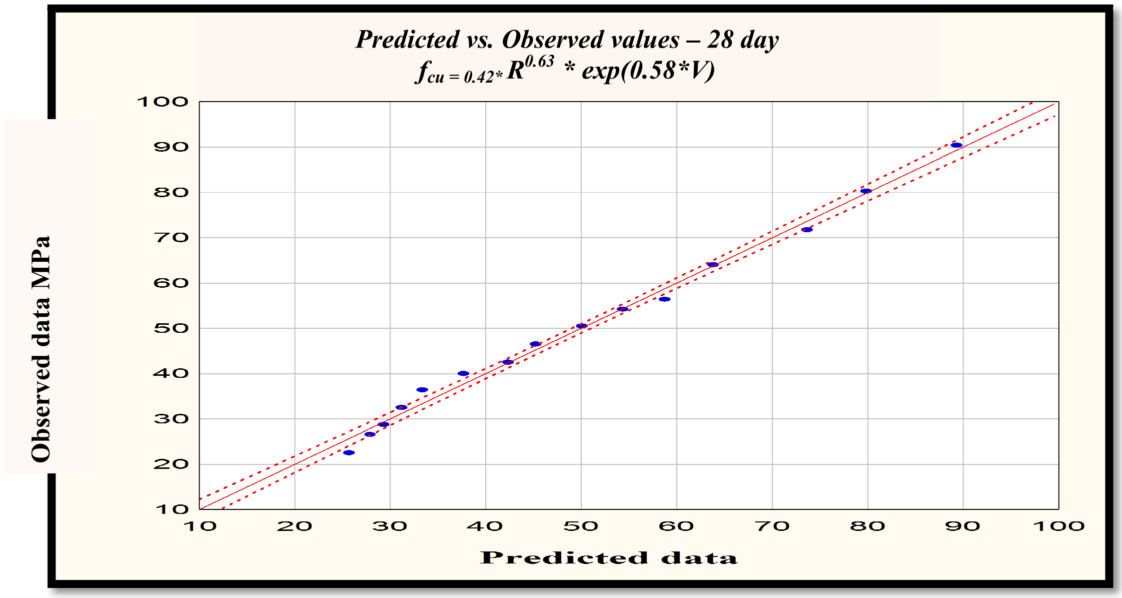

Figure 8 Comparison of predicted comp. strength with measured comp. strength of concrete at age 28 days

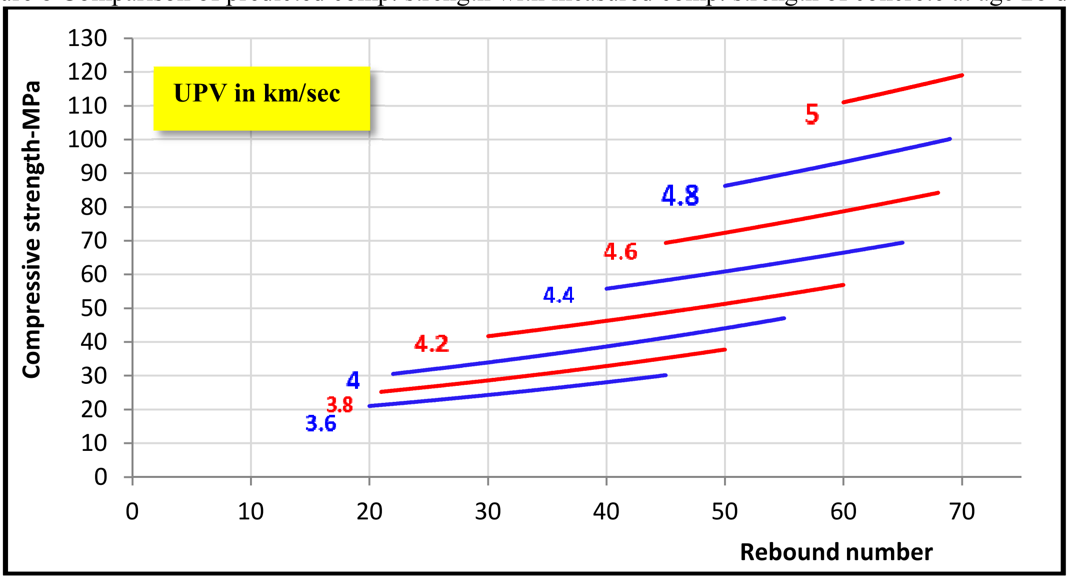

Figure 9 Curves for comp. strength of concrete and combined UPV and RN at 90 days

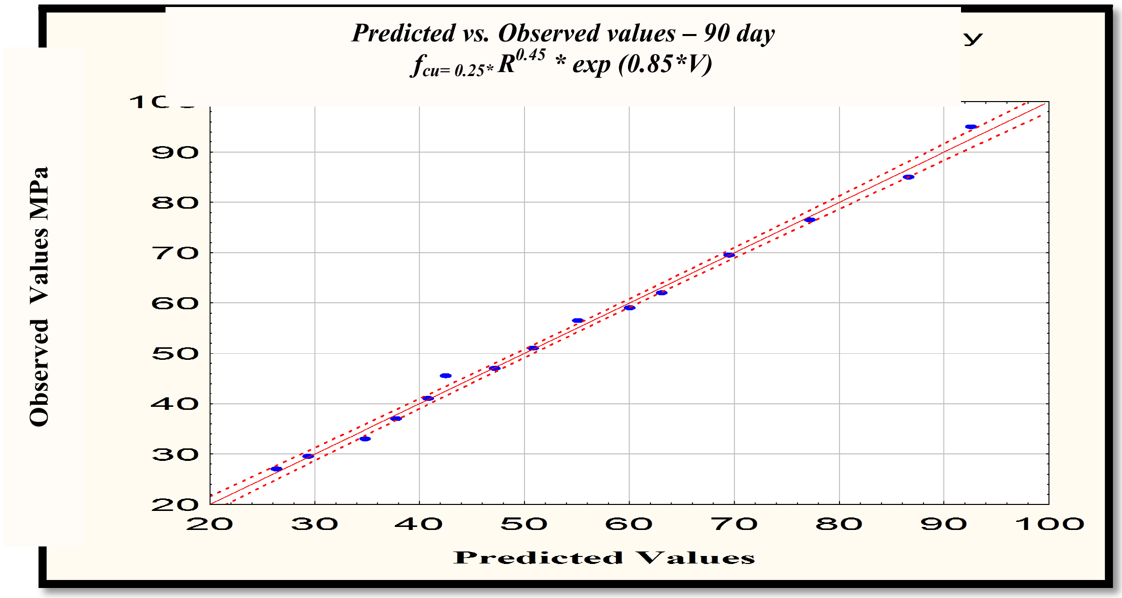

Figure 10 Comparison of predicted comp. strength with measured comp. strength of concrete at age 90 days

Figures 11 and 12 show for all mixes as the group and for all ages, the results are similar to the results obtained from (Raouf and Samurai-99)**[14].** The expressions can be expressed, as follows:

$f_{cu}=0.44\, R_N^{\ 0.65}\, e^{0.55V}$ ………(3-7) at[All ages $R^2 = 0.9729$]

Where: f_{cu} in (MPa) and V:UPV in (km/sec).

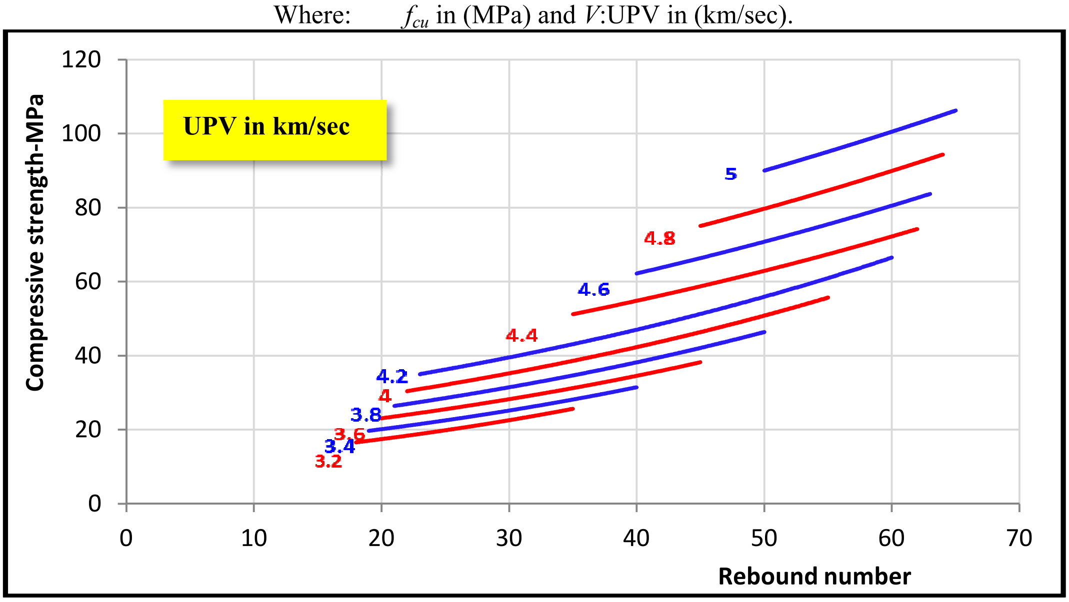

Figure 11 Curves for comp. strength of concrete and combined UPV and RN at (all ages)

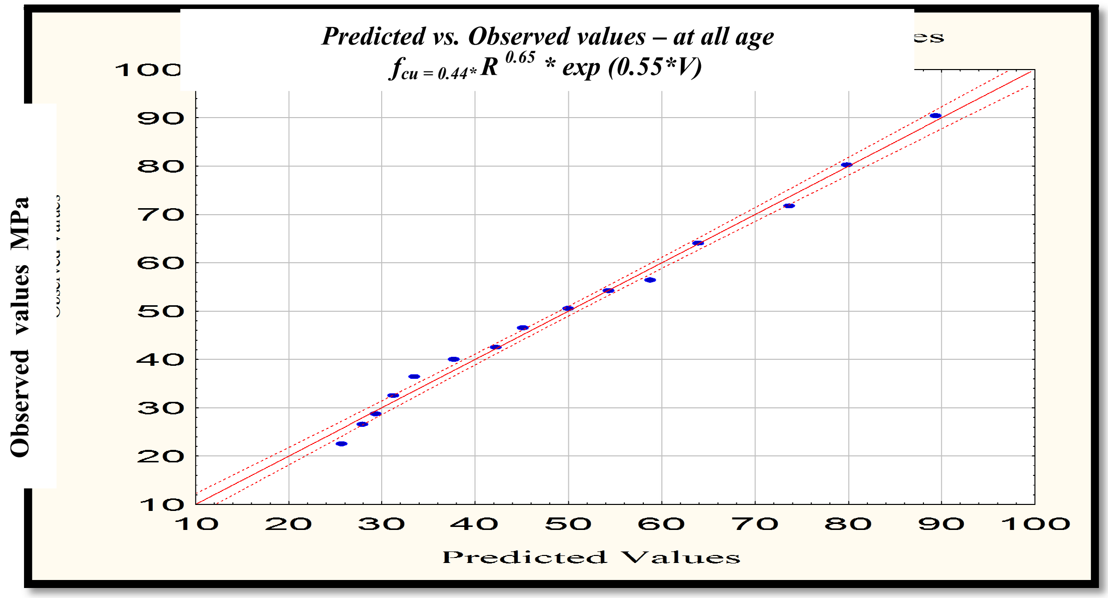

Figure 12 Comparison of predicted comp. strength with measured comp. strength of concrete at all ages

3.5. The relationship between Static Modulus of Elasticity &(Compressive Strength, RN & UPV)

The modulus of elasticity of concrete is one of the most important mechanical properties of concrete. It is closely related to the properties of cement paste, the stiffness and volume of selected aggregate. The modulus of elasticity of concrete increased for high contents of aggregate of high rigidity; whereas it decreases with the increase in hardened cement paste content and increasing porosity. The specimens were tested first by UPV before being tested for static elastic modulus.

Figure 13 shows that the increasing of compressive strength leads to increasing in the modulus of elasticity. The result is similar to the result obtained from (Hussam-08)[11].

Figure 14 shows that the relationship between the modulus of elasticity and RN. This relation is similar to the relation of modulus of elasticity with compressive strength [13]. The increasing in compressive strength of concrete produces increasing in the modulus of elasticity and this property gives the increasing in value of RN and UPV. Figure 15 shows the relationship between the modulus of elasticity and UPV. This relation is a linear regression model .

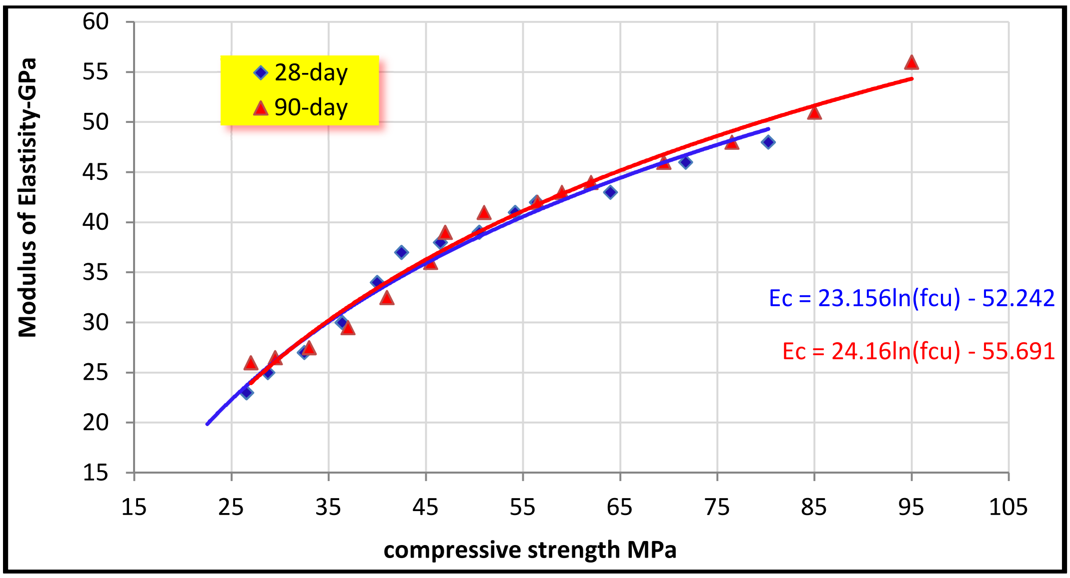

Figure 13 Relationship between compressive strength and static modulus of elasticity

The results indicate that the percentage of increase in static modulus of elasticity for 28 days to 90 days was 15% at low strength to 5.6% at high strength due to the continuity of hydration of concrete.

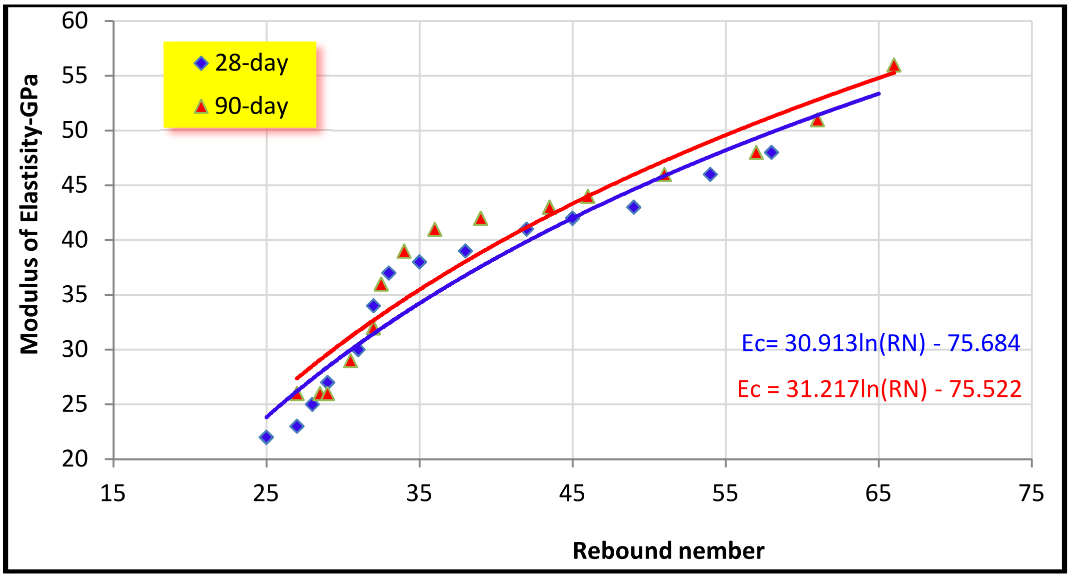

Figure 14 Relationship between Rebound number and modulus of elasticity

The relationship in Figure 15 indicates that the percentage of increase in relationship between Ec and RN for 28 days to 90days is 3.3% due to the continuity of hydration of concrete.

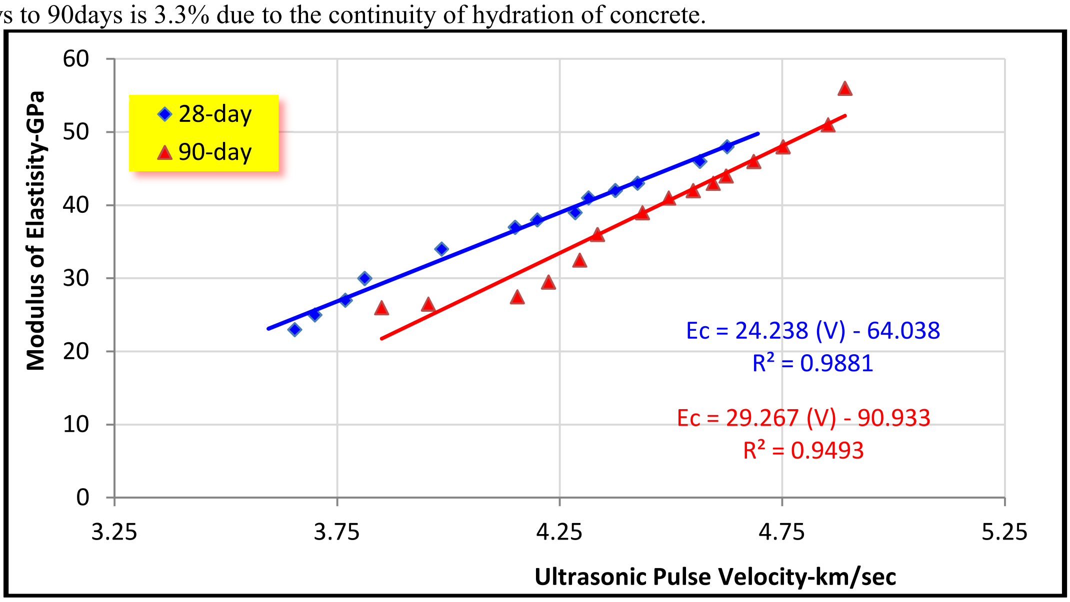

Figure 15 Relationship between (UPV) and modulus of elasticity

The relationship in Figure 15 indicates that the percentage of increase in relationship between Ec and UPV for 28 days to 90 days are 42% at low strength to 6.3% at high strength due to the continuity of hydration of concrete and SF.

3.6. The relationship between Modulus of Rupture &(Compressive strength, RN and UPV)

Results indicate that the two types of concretes NSC and HSC exhibited continuous increase in modulus of rupture with an increase of curing age. However, the rate of modulus of rupture gain of concretes at early ages is higher than those at later ages. It is well-accepted that as the concrete compressive strength increases, the modulus of rupture also increases but at a decreasing rate as shown in Figure 16.The relationship between modulus of rapture and RN is similar to those obtained for compressive strength, except that the scatter of the results is greater. These results are similar to the results obtained from (Malhotra &Carino -04))[13]. as shown in Figure 17. It is also well-accepted with the increase of UPV, the compressive strength increases and as a result the modulus of rapture but decreases with time lapse as shown in Figure 18.

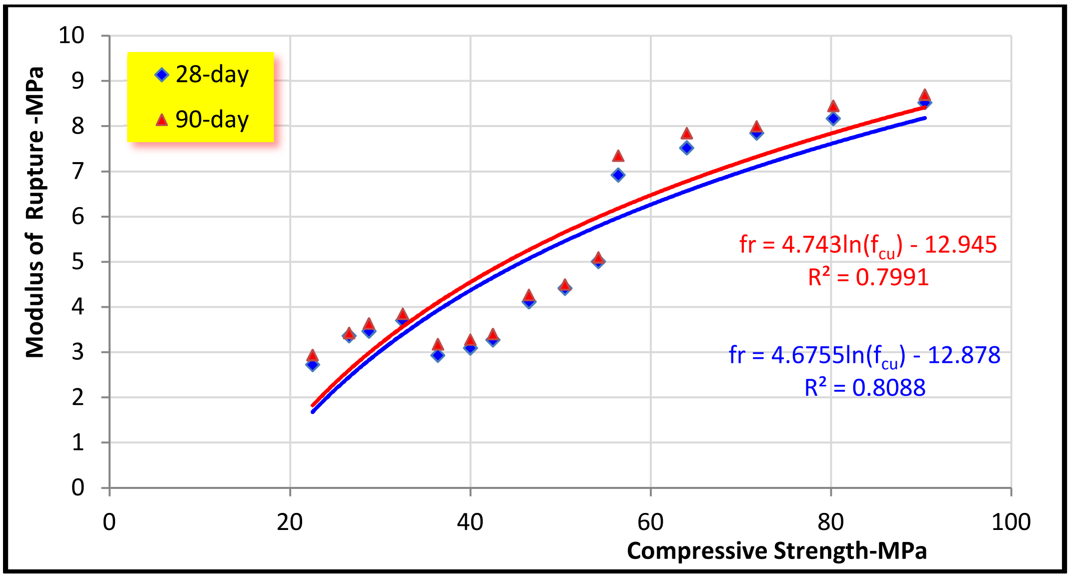

Figure 16 Relationships between modulus of rupture and compressive strength

The relationship in Figure 16 shows that the results indicate the percentage of increase in the relationship between fr and fcu for 28 days to 90 days is 3.6% due to the continuity of hydration of concrete.

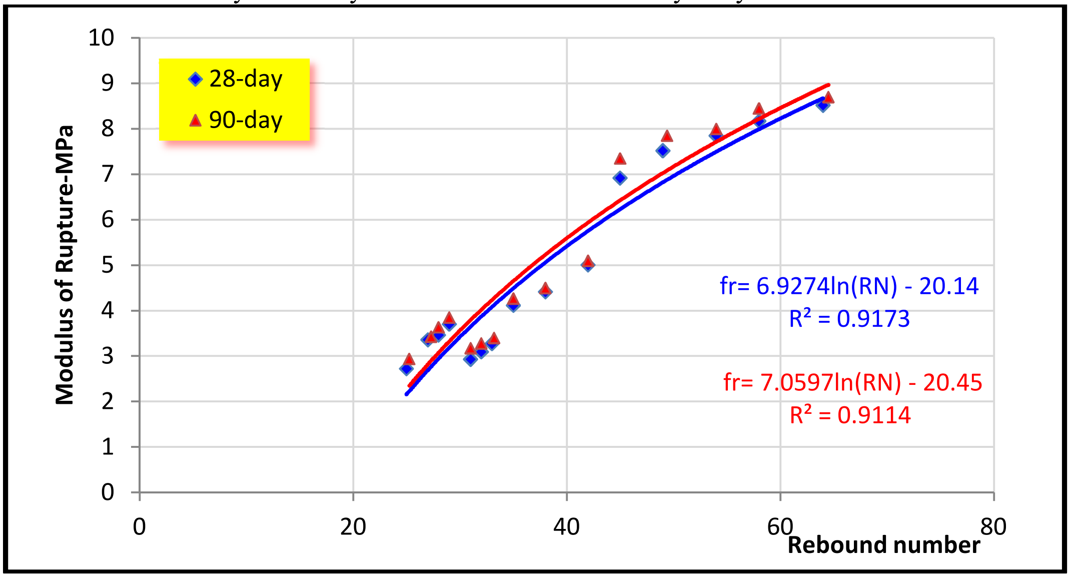

Figure 17 Relationship between Rebound number and modulus of rupture

The Figure 17 shows the results which indicate that the percentage of increase in the relationship between fr and RN for 28 days to 90 days is 3.64% due to the continuity of hydration of concrete.

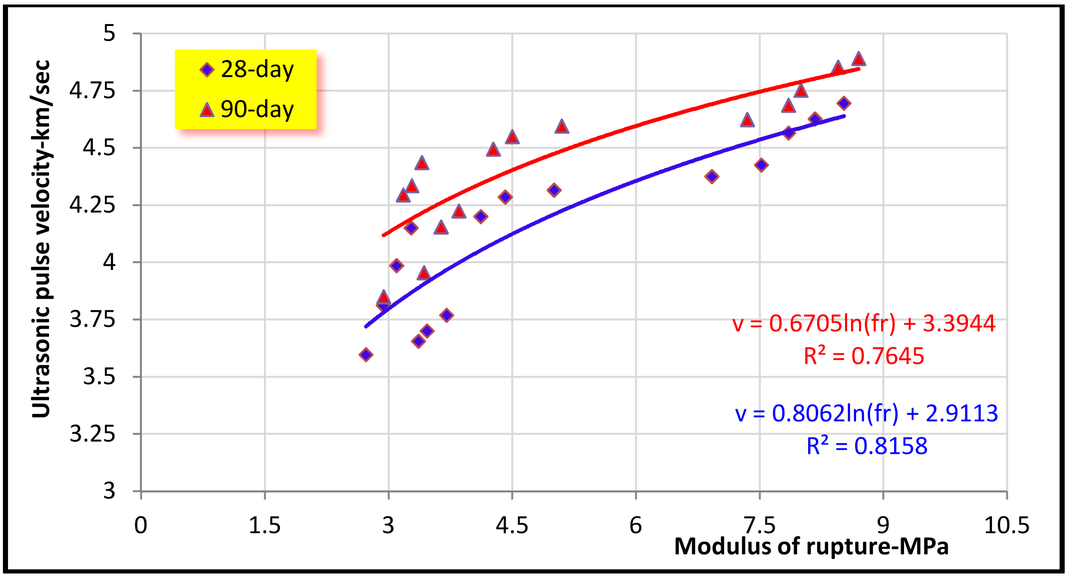

Figure 18 Relationship between (UPV) and modulus of rapture

The relationship in Figure 18 indicates that the percentage of increase in relationship between fr and UPV for 28 days to 90 days are 7.3% at low strength to 4.4% at high strength due to the continuity of hydration of concrete.

3.7. Relationship between direct (D) and surfacing (S) test of UPV

Indirect transmission should be used when only one face of the concrete is accessible, when the depth of a surface crack is to be determined or when the quality of the surface concrete relative to the overall quality is of interest. Furthermore, this arrangement gives pulse velocity measurements which are usually influenced by the concrete near the surface. This region is often of different composition from that of the concrete within the body of a unit and the test results may be unrepresentative of that concrete. The indirect velocity is invariably lower than the direct velocity on the same concrete element. This difference may vary from 5% to 20% depending largely on the quality of the concrete under test [10], the relationship between direct and surfacing method of UPV is shown in Figs. 19, 20 and 21.

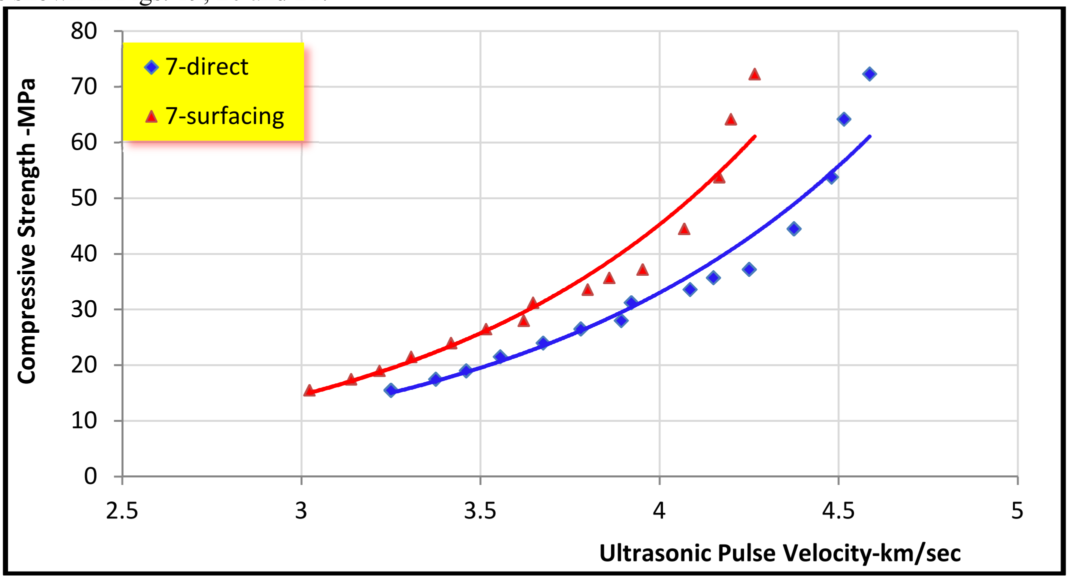

Figure 19 Relationship between direct and surfacing method of UPV at 7 days all mixes

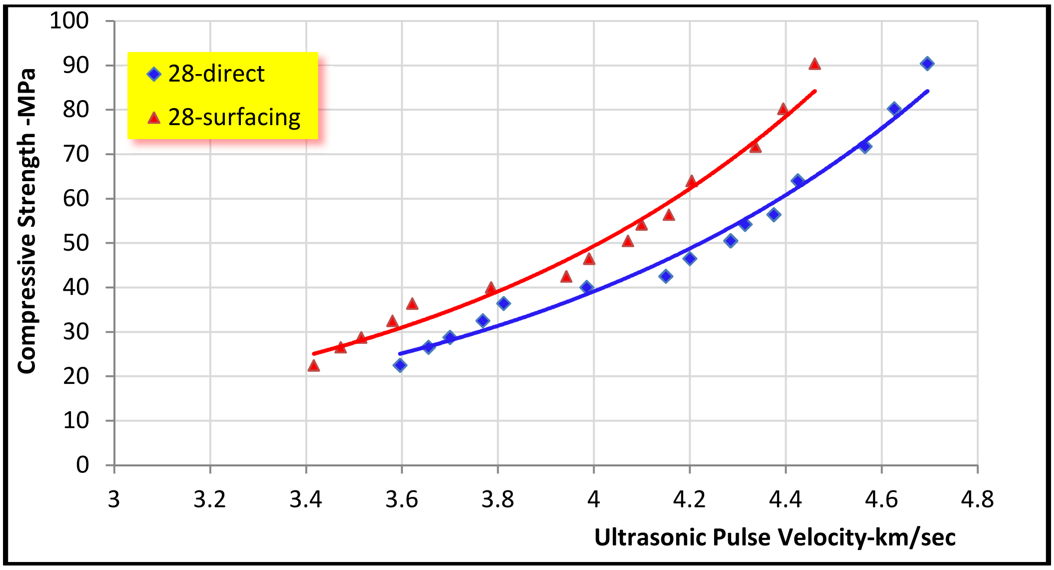

Figure 20 Relationship between direct and surfacing method of UPV at 28 day all mixes

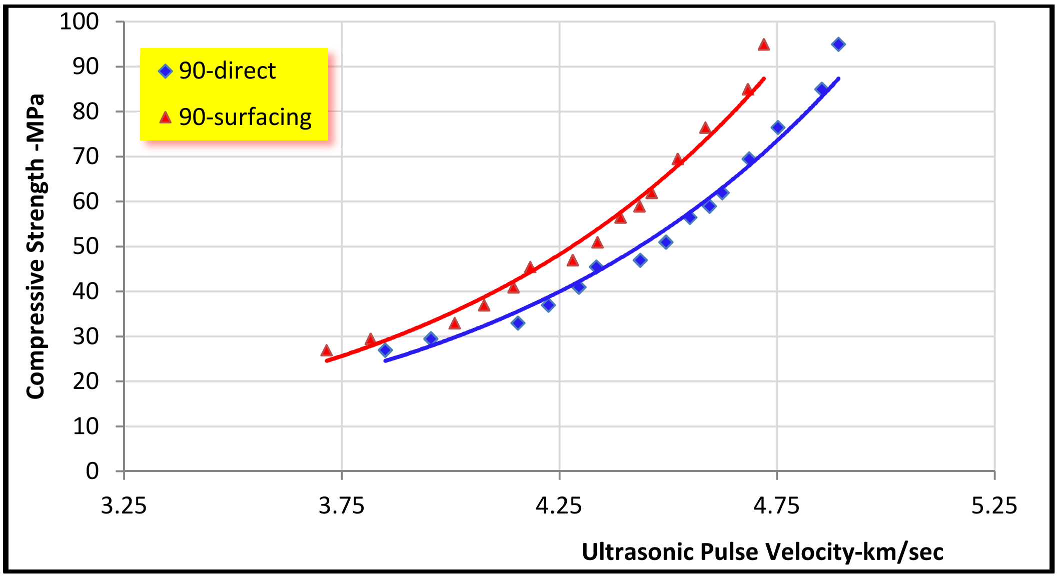

Figure 21 Relationship between direct and surfacing method of UPV at 90 day all mixes

The Figures above show that the waves velocity of surfacing method less than the waves velocity of direct method by (7, 5 and 3.5)% at (7, 28and 90) days respectively because the porosity of concrete that is near the surface more than the porosity of deep concrete [10] [34] .

3.8. Effect the properties of concrete and the age on Non-destructive tests

Since cement content, aggregate content and w/c ratio, may affect the readings obtained from RN and UPV, any attempts to compare or estimate concrete strength will be valid only if they are all standardized for the concrete under test and for the calibration specimens. These influences have different magnitudes. Figures 22 and 23 show the increase of the cement content results in the increase of cement paste and decrease of the porosity. This property affected UPV greater than RN as the final results increase the value of RN and UPV [35].

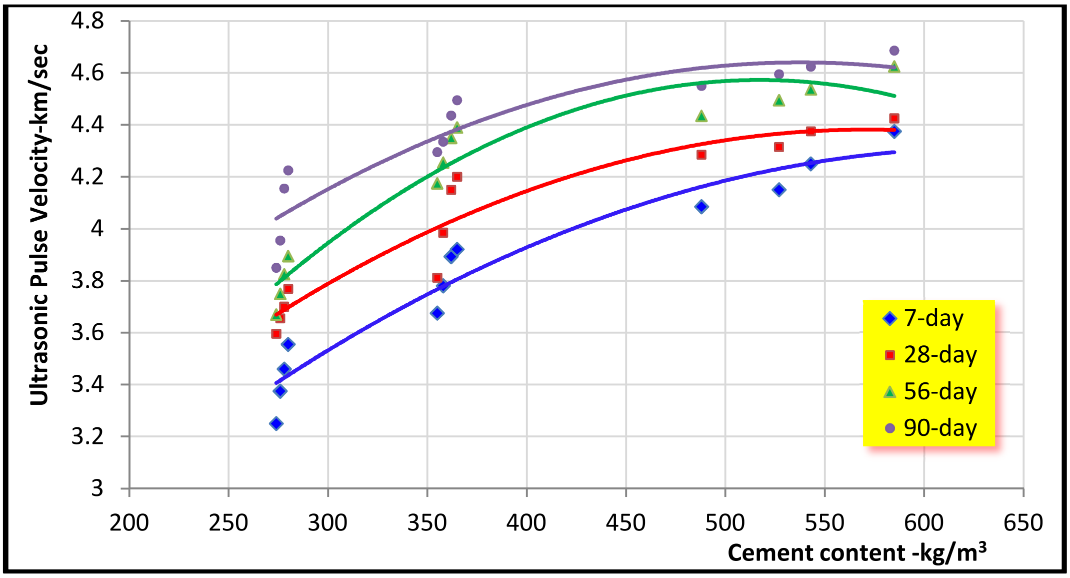

Figure 22 Relationship between UPV and cement content

Figures 24 and 25 show that the increase of coarse aggregate content in concrete results in an increase the density of concrete and in turn result in an increase in value of the UPV and RN.

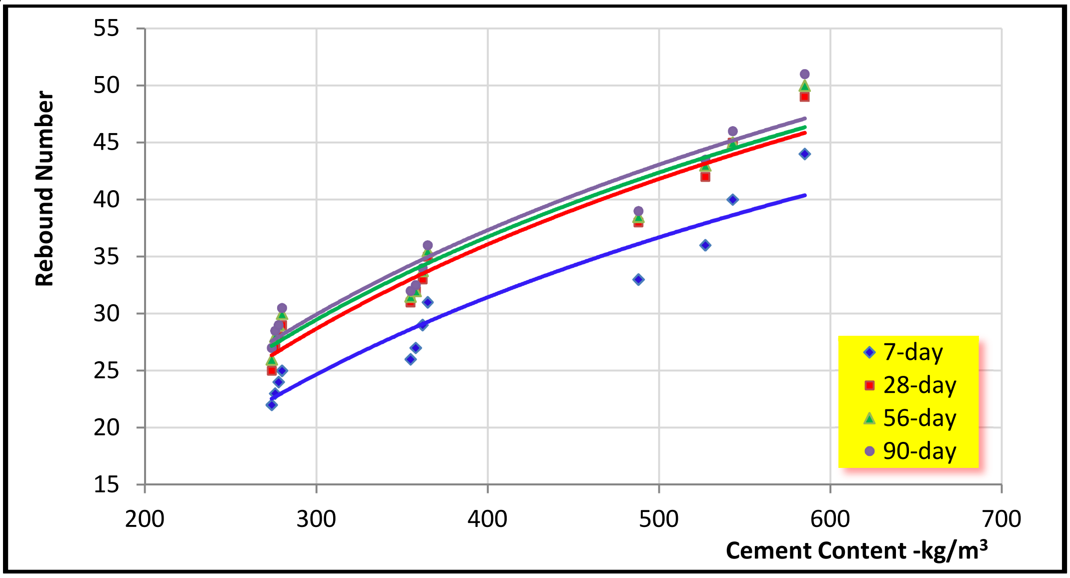

Figure 23 Relationship between RN and cement content

In the Figures above, the increase of cement content increases the value of UPV without exceeding (500 kg/m^3) because side effects, such as shrinkage increase ,porosity increase, need high water content and consequently less strength of concrete. The RN increases with increase of the cement content but with less rate when high content of cement is available.

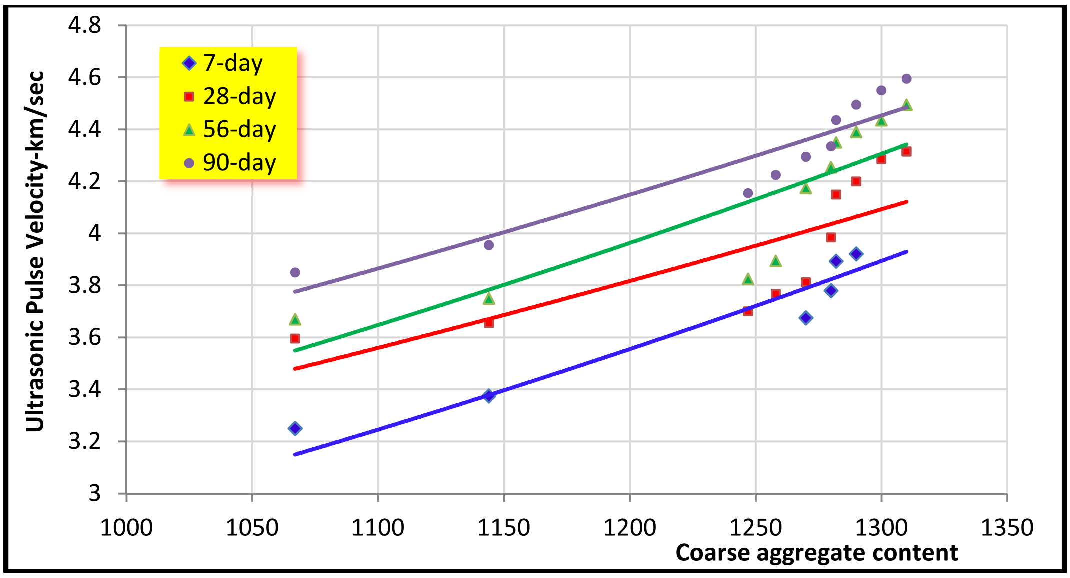

Figure 24 Relationship between UPV and aggregate content

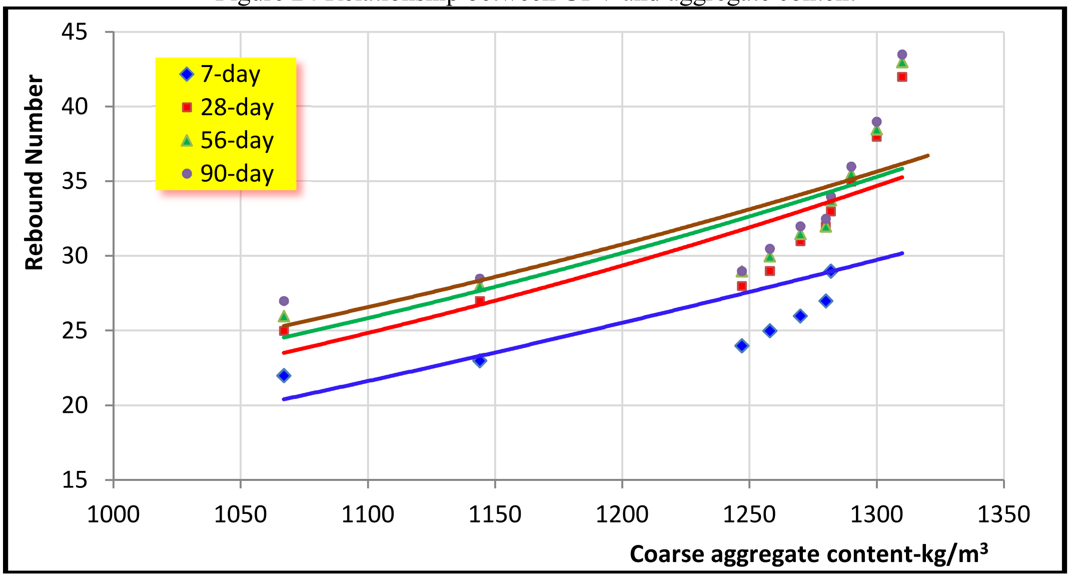

Figure 25 Relationship between RN and aggregate content

In the Figures 24 and 25 above, it can be observed that the increase of coarse aggregate content produces increase in the value of UPV and RN, and the rate of increasing seems at last ages because the difference value of UPV and RN minimizes at last ages. The use of high content of coarse aggregate and crushed give the merger between aggregate and the paste consequently gives high density of concrete which in turn produces an increase of the UPV and RN value.

Water/Cement ratio variation in concrete mixes has often been used to establish the relationship of (compressive strength of concrete and ultrasonic pulse velocity) with w/c ratio, especially when checking the quality of concrete at a particular age. The presence of water voids due to changes in the w/c ratio in fully compacted concrete, leads to a similar decrease in both strength and pulse velocity [36]. Figures 26 and 27 show the relationship between (compressive strength and UPV) with w/c ratio.

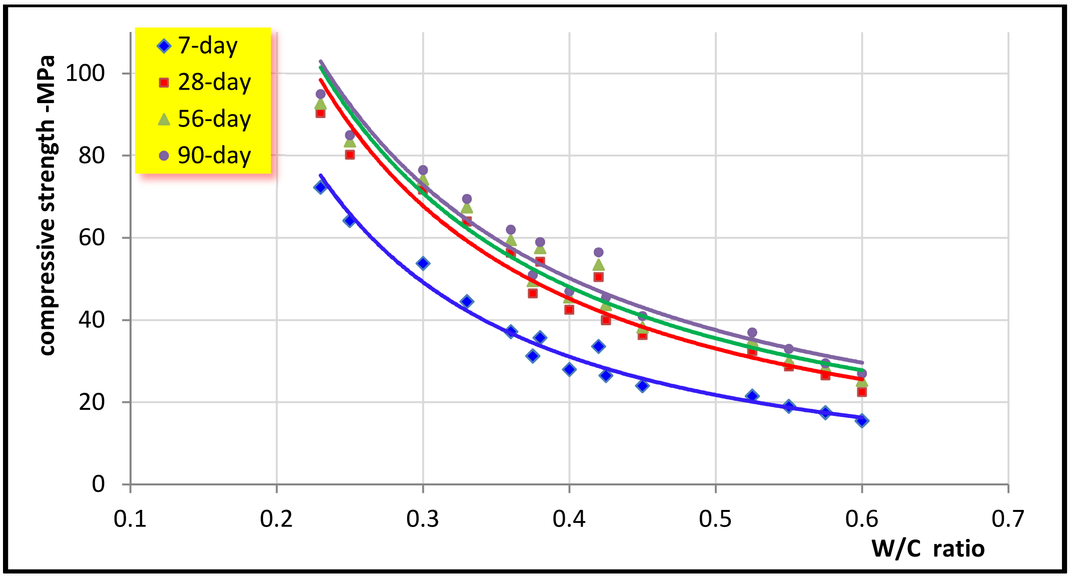

Figure 26 Relationship between compressive strength and w/c ratio

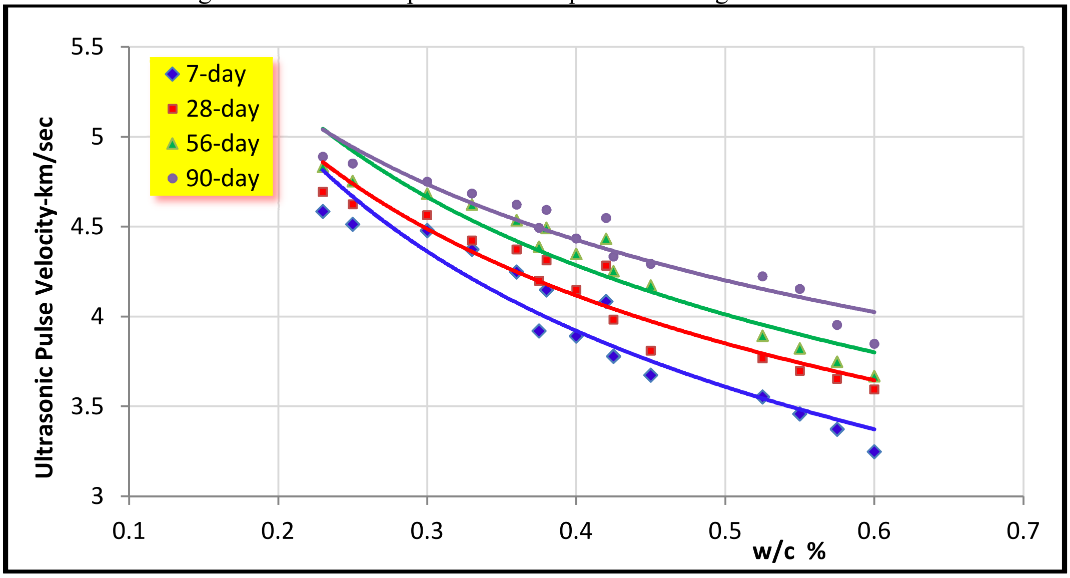

Figure 27 Relationship between UPV and w/c ratio

Figures above exhibits that the increasing w/c ratio decreases compressive strength and UPV because of the access in porosity of concrete and consequently decreases the compressive strength and give low UPV [35]

4. Conclusion

- Concretes with compressive strengths in excess of 60 N/mm^2 are more easily achieved with SF.
- High early compressive strength (in excess of 25 N/mm^2 at 24 hours) can be achieved.
- Linear expressions are obtained to represent the relationship between density and UPV for (28 and 90) days respectively, as follows:

  D = 134.98(V)+1814.8 ....(4-1) [28-day, R2 = 0.9287]

  D = 159.45(V)+1680.1 ....(4-2) [90-day, R2 = 0.8751]
- The results show a good correlation between compressive strength and rebound number and the relationship between the two is not affected by maximum aggregate size (MAS)
- Linear expressions are obtained to represent the relationship between compressive strength and RN for all mixes as group for (28 and 90) days respectively, as follows:

  $f_{cu} = 1.5676\ RN - 18.537$ ....(4-3) [28-day, R2 = 0.964]

  $f_{cu} = 1.5896\ RN - 10.66$ ....(4-4) [90-day, R2 = 0.973]
- The value of UPV in HSC increased 8% from (28 to 90) days because of using SF.
- Exponential expressions are obtained to represent the relationship between compressive strength and UPV

for 28 and 90days respectively, as follows:

$f_{cu} = 0.5993\ e^{0.9981\,V}$ ....(4-5) [28-day, R2 = 0.9755]

$f_{cu} = 0.4736\ e^{1.1035\,V}$ ....(4-6) [90-day, R2 = 0.9753]

- The results indicate that the percentage of increase in direct method to surfacing method of UPV for (7, 28, 56 and 90) days are (7%, 5%, 4% and 3.5%) respectively, due to the higher the continuity of hydration of cement.
- The combined use of UPV and rebound number improves the accuracy of the process of estimation of concrete compressive strength of (HSC).
- The results show that the relation between UPV and RN versus compressive strength, can be expressed for all the mix as a case freelance for all ages, as follows:

$f_{cu} = 0.37\ RN^{0.75}\ e^{0.5V}$ ....(4-7) [all ages, R2 = 0.9908] for (1:2:4)

$f_{cu} = 0.172\ RN^{0.7}\ e^{0.75V}$ ....(4-8) [all ages, R2 = 0.994] for (1:1.5:3)

$f_{cu} = 0.15\ RN^{0.47}\ e^{0.95V}$ ....(4-9) [all ages, R2 = 0.8416] for (C40, C50 and C60)

$f_{cu} = 0.18\ RN^{1.33}\ e^{0.17V}$ ....(4-10) [all ages, R2 = 0.962] for (C70, C80, C90 and C100)

- The results show that the relation between UPV and rebound number versus compressive strength, can be expressed for all the mix as group, for (28 and 90) days, as follows:

$f_{cu} = 0.42\ RN^{0.63}\ e^{0.58V}$ ....(4-11) [28-days, R2 = 0.9929]

$f_{cu} = 0.25\ RN^{0.45}\ e^{0.85V}$ ....(4-12) [90-days, R2 = 0.9954]

- The results show that the relation between UPV and rebound number versus compressive strength, can be expressed for all the mix as group, for all ages, as follows:

$f_{cu} = 0.44\ RN^{0.65}\ e^{0.55V}$ ....(4-13) [all ages, R2 = 0.9729]

- The pulse velocity of concrete is decreased by increasing the cement paste, especially for concrete with high w/c ratio.
- The increasing of cement content gives increasing in value of UPV but not exceeded (500 kg/m^3).
- Rebound number can't be affected by changing MAS of coarse aggregate.
- The increasing of coarse aggregate content produces increasing the value of RN and UPV.

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