Journal of Engineering and Development, Vol. 18, No.3, May 2014, ISSN 1813- 7822

Evaluation of Compressive Strength by Non- Destructive Test Using Ultrasonic Pulse Velocity With Maximum Size Aggregate (10 And 20)mm

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Abstract :

The concrete is tested non destructively to determine its mechanical properties (compressive strength) which is considered as the main property and the parameter used in its evaluation.

This research aims to establish a fairly accurate relation between the ultrasonic pulse velocity and the concrete strength. The concrete was poured in the moulds [(30) cubes of size (150X 150X150)mm] are used to test ultrasonic pulse velocity for each size 10mm and 20mm coarse aggregate. The samples tested by ultrasonic test with direct ultrasonic pulse velocity (DUP) for each sample. The results obtained from the experimental work are analysed and studied by using statistica software.

An empirical mathematical equation is derived by using statistic software program. In this paper the effect of maximum size of aggregate (20mm and 10mm) size on the result of ultrasonic pulse velocity.

Keyword: Concrete, Non-destructive tests, Mechanical properties, Maximum size aggregate

قتييم مقاومة الخرسانة بطريقة الفحص اللا إتلافي للموجات فوق الصوتية باستخدام المقاس الأقصى للركام (10 و 20) مم

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الخلاصة :

تم فحص للخرسانة الفحص اللا إتلافي لتحديد الخواص الميكانيكية (فحص مقاومة الانضغاط) حيث يعتبر من أهم الخواص للخرسانة . ويهدف هذا البحث لتخمين العلاقة مابين فحص الموجات فوق الصوتية وفحص المقاومة للخرسانة باستعمال مقاس مختلف من الركام الخشن (10مم و20 مم)، حيث تم صب (30 نموذج) من المكعبات بإبعاد (150×150×150مم) وتم فحص الموجات فوق الصوتية و فحص مقاومة الانضغاط للنماذج وتحليل النتائج باستخدام برنامج الإحصائي statistica software .

واستنادا إلى النتائج لوحظ إن مقاومة الانضغاط للنماذج باستخدام ركام خشن ذو مقاس 20مم اقل من مقاومة الانضغاط للنماذج باستعمال ركام خشن ذو مقاس 10 مم وذلك بسبب المناطق الضعف مابين عجينة السمنت وحبيبات الركام الخشن مما يؤدي إلى تقليل مقاومة الانضغاط .

1. Introduction

The ultrasonic pulse velocity is a non-destructive test method, which measures the velocity of an ultrasonic wave passing through the concrete. In this, the path length between transducers is divided by the travel time to determine the average velocity of wave propagation. The test method is prescribed by ASTM C597-91. It is found that the velocity depends primarily upon the elastic properties of the material and is almost independent of geometry. Ultrasonic testing is a useful tool for the uniformity of concrete and detecting voids, cracks, honeycombing and internal deterioration in the structure of concrete [1,2]. The concrete strength for cubes made from the same concrete in the structure differ from the strength determined in situ because the methods of measuring the strength influenced by many parameters [3].

The pulse velocity of concrete depends on the modulus of elasticity of the actual aggregate and the aggregate content of the mix[4].

The ultrasonic pulse velocity (UPV) is popular nondestructive techniques to assess the concrete properties. They are fast and easy to perform. Therefore, they can be considered as successful methods for quick checking of uniformity of concrete in different parts of a structure. Ultrasonic measurements are also used to determine the changes in the properties of the concrete and to indicate the presence of voids or cracks[5] .

Although the application of both methods is very simple and fast, the interpretation of the test results is very difficult since the results are affected by a number of factors such as mix proportions of concrete, type and maximum size of aggregate, presence of voids or cracks, and wetness of concrete. In the present investigation, the effects of type and maximum size of aggregate on the UPV values measured on concrete specimens were examined [5].

1.1. The Factors Affected on Ultrasonic Pulse Velocity:

The measurement of pulse velocity is affected by a number of factors which are [6,7]:

1. Smoothness of contact surface under test: if the surface are not reasonably smooth, they should be ground smooth.
2. Moisture condition of concrete: In general, pulse velocity through concrete increases with the increased moisture content of concrete.
3. Influence of path length on pulse velocity: As concrete is inherently heterogeneous, it is essential that path lengths are sufficiently long so as to avoid any errors introduced due to its heterogeneity.

4. Temperature of concrete: It has been reported that variations of the ambient temperature between 5 and 30 °C do not significantly affect the pulse velocity measurements in concrete. At temperatures between 30 and 60°C, there is up to 5% reduction in pulse velocity. This is probably due to the initiation of microcracking in concrete . At below freezing temperature, the free water freezing within concrete thus resulting in an increase in pulse velocity.
5. Presence of reinforcing steel: The presence of steel bars will tend to increase the pulse velocity because pulse velocity in steel is 1.2 to 1.9 times the velocity in plain concrete.
6. Age of Concrete: For a give pulse velocity, the compressive strength is higher for older specimens.

1.2. Concrete Evaluation considering Nondestructive Testing*:*

To extend the life-time of a structure, it is necessary to characterize the material. In order to cover the project necessities about the strength and concrete structures lifetime, it is interesting to use an evaluation system to check the conditions and estimate the homogeneity and compactly of concrete. The use of Nondestructive is an attractive strategy considering this context. Nondestructive tests allow making an analysis about the structures conditions, with no damage caused on that. Nondestructive has been defined as those test methods used to examine an object, material or system without impairing its future usefulness. Nondestructive methods have developed from a laboratory curiosity to an indispensable tool of production. These methods are used to check variations in structure, changes in surface, the presence of cracks or other physical discontinuities, to measure the thickness of materials and to determine other characteristics of industrial products [8]. Nondestructive determination of materials properties is becoming increasingly important in design and life assessment consideration of components and systems. The application of Nondestructive in civil engineering has become a subject of interest in various countries. Nondestructive methods not only allow the evaluation of aged and deteriorated structures, but can also be used for the quality control of new structures [9].

One of the main advantages of Nondestructive methods is that they do not affect the appearance or the functioning of the structures under analysis. Furthermore, data can be periodically collected from the same test points, making possible the control of variations over time. This systematic monitoring scheme might help to make an early detection of possible defects and degradation mechanisms, prompting quick interventions that are more economical and efficient.

The Ultrasonic Pulse Velocity (UPV) is suitable for evaluation of composite material, such as the concrete. However, it is necessary to know the influence of the variables that affect the concrete characteristics [9].

1.3. Ultrasonic Pulse Velocity:

Among the available methods of Nondestructive, the Ultrasonic Pulse Velocity (UPV) methods can be considered as one of most promising methods for evaluation the concrete structures, once it makes possible an examination of the material homogeneity. It is possible to obtain a total control of a structure, using the properties variations with the time. Using the analysis of the propagation variations of ultrasonic velocity wave, it is possible to verify the compacity or detect heterogeneous regions in the concrete.

These methods allow the examination of material homogeneity and also turn easier the diagnosis of defects. The UPV methods make possible the continuous evaluation of concrete conditions during the entire structure service life. The UPV results can be used for diagnosis, prognosis and quality control. The method is based on the propagation of a high frequency sound wave which passes through the material [9] [10]. The speed of the wave varies in function of the density of the material, allowing the estimation of the porosity and the detection of discontinuities [8].

2. Experimental Work :

2.1. Materials:

Optimum proportions for conventional concrete (CC) must be selected according to the mix design methods, considering the characteristics of all the materials used. Satisfactory CC is achieved by selecting suitable materials, good quality control and proportioning.

2.1.1. Cement:

The proper selection of the type and source of cement is one of the most important steps in the production conventional concrete especially Ordinary Portland cement (OPC) (typeI). This cement is manufactured in Iraq by Taslooja factory and commercially known (Taslooja). **Table (1)** shows chemical and physical properties for Ordinary Portland cement (OPC) (type I). These properties of cement comply with Iraqi Standard Specification I.Q.S. No.5, 1984 requirement [11].

Table (1): Chemical and Physical Properties of (Taslooja) for Ordinary Portland Cement Type

Chemical Composition			IQS 5:1984
Oxides		%	
Calcium oxide	CaO	64.01	
Silicon oxides	SiO_2	20.05	
Aluminum oxides	Al_2O_3	5.15	
Ferric oxides	Fe_2O_3	3.27	
Magnesium oxides	MgO	2.8	5.00 max.
Sulfur trioxides	SO_3	2.6	2.80 max.
Loss on Ignition	L.O.I	2.01	4.00 max.
Insoluble residue	I.R	1.01	1.50 max.
Lime saturation factor	L.S.F	0.96	0.66 -1.02
C3A		8.10	
Physical Properties		**Test Result**	**IQS 5:1984**
Fineness: specific surface, Blaine (cm^2/gm)		270	230 min
Soundness		0.1	0.8
Setting time, Vicat's method:- Initial (min) Final (hrs:min)		 125 3:5	 45 min. 10 max.
Compressive strength of cement 3 days 7 days 28 days		25.30 35.60 51.60	15 min. 23 min. -----

Where: Tests of cement were made in the National Center for Construction Laboratories and Research

2.1.2. Water:
Ordinary potable water is used without any additives.

2.1.3. Coarse Aggregate:

Crushed gravel of maximum size of 20mm and 10mm from Al-Niba'ee region is used. **Table (2)** and **Table (3)** show the grading of this aggregate respectively This coarse aggregate conforms to the Iraqi specification No.45/1984 [12].

2.1.4. Fine Aggregate:

Natural sand from Al-Ukhaider region is used. **Table (4)** shows the grading of the fine aggregate. This fine aggregate conforms to the Iraqi specification No.45/1984 [12].

Table (2): Grading of Coarse Aggregate with maximum size 20mm.

Sieve Size (mm)	% Passing by Weight	
	%Coarse Aggregate Passing	Limits of Iraqi Specification No.45/1984
20	99.05	95-100
14	81	---
10	40.90	30-60
5	3.00	0-10
2.36	0	------

Table (3): Grading of Coarse Aggregate with maximum size 10mm.

Sieve Size (mm)	% Passing by Weight	
	%Coarse Aggregate Passing	Limits of Iraqi Specification No.45/1984
20	100	100
14	94.00	90-100
10	60.88	50-85
5	5.00	0-10
2.36	0	------

Table (4): Grading of Fine Aggregate.

Sieve Size (mm)	**% Passing by Weigh**	
	Fine Passing	**Limits of Iraqi Specification No.45/1984 for Zone2**
10	100	100
4.75	95.00	90-100
2.36	88.60	75-100
1.18	70.50	55-90
0.6	44.00	35-59
0.3	15.00	8-30
0.15	0.08	0-10

2.1.5. Superplasticizer:

For the production of high strength, water proof admixture based on polycarboxylic ether is used and complies with ASTM C494. It is compatible with all Portland cements that meet the recognized international standards.

2.2. Mix Design for Conventional Concrete:

Conventional concrete strength is investigated in this work, namely 40 MPa. British Standard BS 5328: part 2: 1991 mix design method is used in this work due to its wide range of strengths. The details of the mix are shown in **Table (5)** and **Table (6).**

Table (5): Details of Conventional Concrete Mix for 20mm Maximum size of Aggregate.

Mix	W/C	Water kg/m^3	Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	%SP by weight of cement
C40	0.38	160	420	750	1040	2

Table (6): Details Of Conventional Concrete Mix For 10mm Maximum Size Of Aggregate.

Mix	W/C	Water kg/m^3	Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	%SP by weight of cement
C40	0.38	160	420	710	1080	2

2.3. Testing for Hardened Concrete:

After testing the fresh properties, the concrete was poured in the moulds. For testing the compressive strength and direct Ultrasonic Pulse Velocity (30)cubes of each maximum size of aggregate (20mm) and (10mm) are used according to BS 1881:part116:1983 [13] and BS 4408: part5 [14] respectively. When conventional concrete is used, the specimens are fully compacted on a vibrating table. The vibration time to reach full compacting is decided upon by the stop of air bubbles migration from fresh concrete, which is found to be 25-30 seconds per layer. The specimens were demolded and were put in water for 28 days for curing.

3. Results and Discussions

3.1. General:

The results obtained from the experimental work are analysed and studied. This study includes the influence maximum size of aggregate on evaluation of compressive strength by non-destructive test using ultrasonic pulse velocity. The results are analysed by using statistica software.

3.2. Compressive Strength and Ultrasonic Pulse Velocity :

The results of compressive strength and ultrasonic pulse velocity for concrete are shown in **Tables (7)** and **Table (8)** at 28 days for maximum size of aggregate 20mm and10mm respectively . **Figures (1 and 2)** show the relation between compressive strength at 28 days versus the Direct Ultrasonic Pulse Velocity at (20mm and 10mm) maximum size of aggregate respectively.

Table (7): Result of Compressive Strength and Ultrasonic Pulse Velocity at 28 days with (20mm maximum size of aggregate)

Mix	Compressive Strength at (MPa)	Ultrasonic Pulse Velocity
C 40	42.41	4.65
	42.43	4.66
	42.89	4.81
	42.9	4.84
	42.44	4.67
	42.45	4.69
	43.08	4.86
	43.18	4.87
	42.09	4.58
	42.41	4.63
	42.5	4.7
	42.69	4.75
	43.74	4.93
	42.86	4.78
	42.87	4.79
	42.9	4.85
	43	4.85
	43.3	4.89
	43.31	4.9
	44.2	5.11
	44.3	5.14
	43.31	4.9
	43.5	4.91
	44	4.99
	44.19	5.06
	43.75	4.98
	43.75	4.98
	43.63	4.91
	43.7	4.93
	43.66	4.92

Table (8): Result of Compressive Strength and Ultrasonic Pulse Velocity at 28 days with (10mm maximum size of aggregate)

Mix	Compressive Strength at (MPa)	Ultrasonic Pulse Velocity
C40	45.74	4.68
	45.98	4.7
	46.89	4.8
	46.89	4.81
	46.41	4.73
	46.44	4.76
	47.69	4.85
	47.95	4.87
	45.09	4.63
	45.52	4.68
	46.65	4.76
	46.66	4.77
	52.59	4.94
	46.72	4.76
	46.88	4.79
	46.89	4.84
	47.08	4.83
	49.11	4.87
	49.15	4.88
	53.13	5.01
	53.57	5.1
	49.5	4.89
	49.5	4.88
	53	4.97
	53.04	5
	52.68	4.94
	53.67	4.95
	49.55	4.9
	50.38	4.89
	50.89	4.94

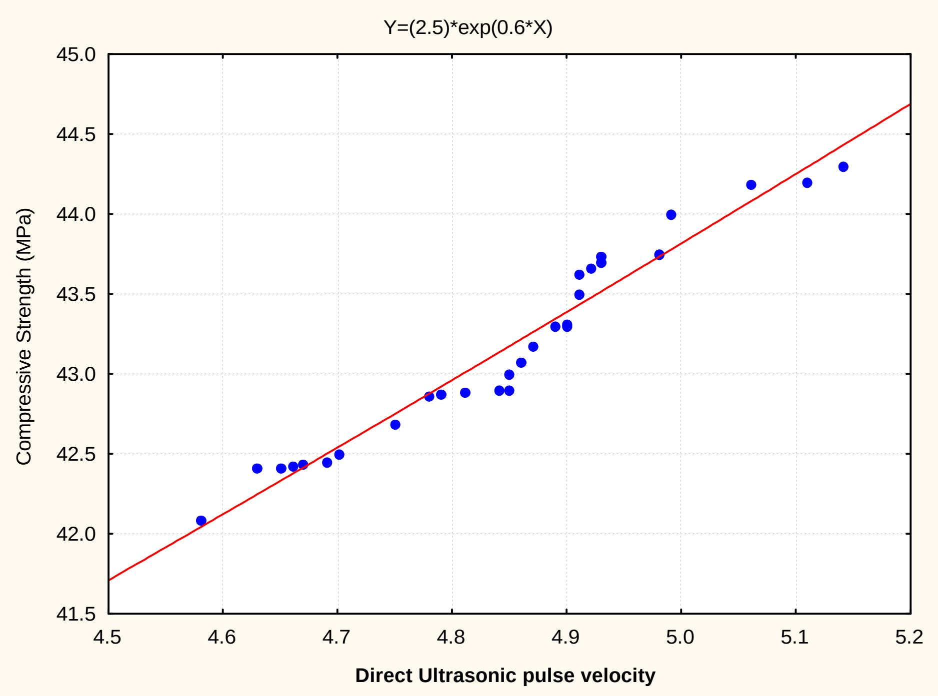

Fig .(1) The relation between compressive strength at 28 days versus the Direct Ultrasonic Pulse Velocity at 20mm maximum size of aggregate

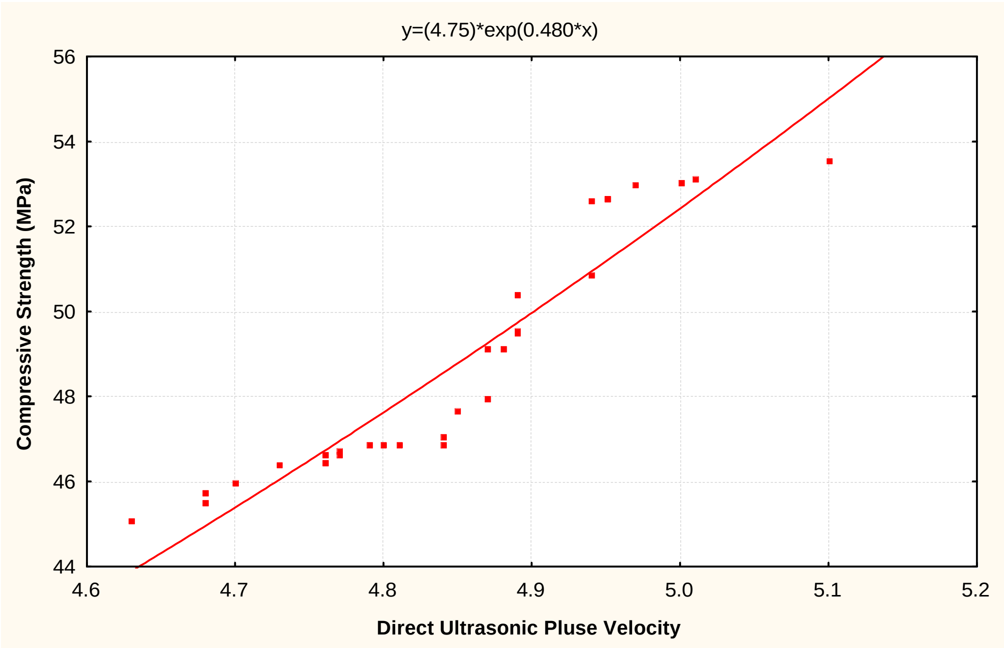

Fig .(2) the relation between compressive strength at 28 days versus the Direct Ultrasonic Pulse Velocity at 10mm maximum size of aggregate

Figures (3 and **4)** show the relationship between 10mm maximum size of aggregate versus 20mm maximum size of aggregate for direct ultrasonic pulse velocity and compressive strength respectively. This explained this figures that as volume ratio of coarse aggregate increases, direct pulse velocity also increases as well as compressive strength.

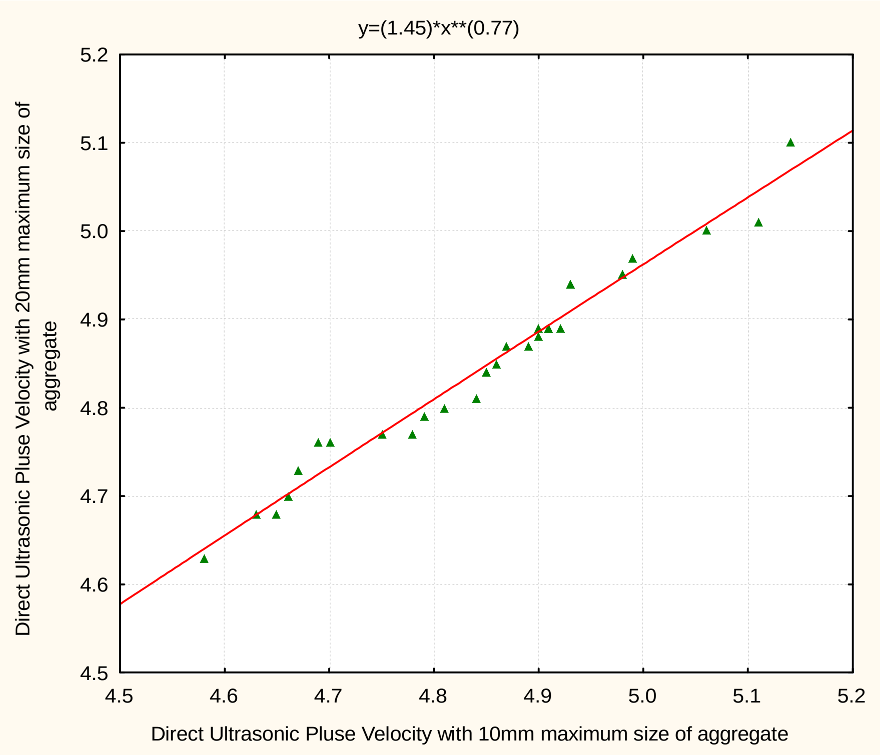

Fig .(3) the relationship between the Direct Ultrasonic Pulse Velocity at 10mm maximum size of aggregate versus 20mm maximum size of aggregate

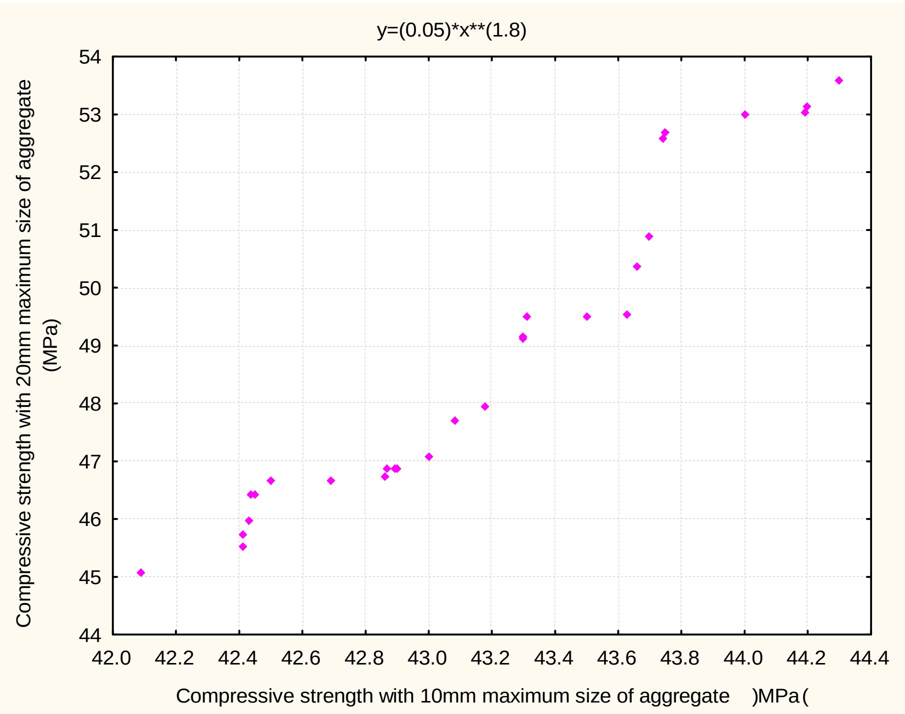

Fig .(4) the relationship between the Compressive strength at 10mm maximum size of aggregate versus 20mm maximum size of aggregate

The Ultrasonic pulse velocity increase when the maximum size increase. It may be caused by wall effect which is more pronounced for concrete produced by larger aggregate sizes. This may be attributed to the weaker bond strength between the aggregate and the cement paste show Fig.5.

By using the software Statistica 6.0, a nonlinear statistical model was generated considering a strategy of traditional modeling. The nonlinear estimative is an appropriate procedure to estimate relationship between one dependent variable and a list of independent variables. In this case the dependent variable was the concrete strength and ultrasonic pulse velocity of 10mm size aggregate estimate the ultrasonic pulse velocity of 20mm maximum size of aggregate. Figure 6 show inputs and the ultrasonic pulse velocity of 20mm coarse aggregate.

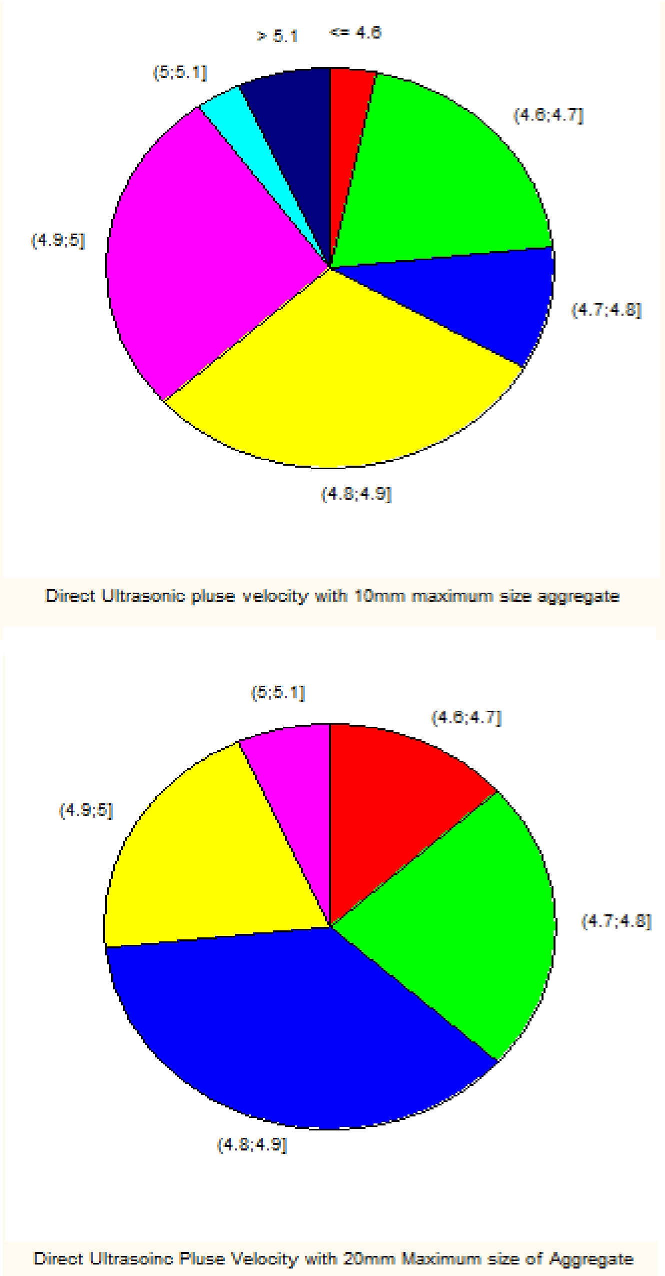

Fig .(5) the results of Ultrasonic pulse velocity of two size of aggregate

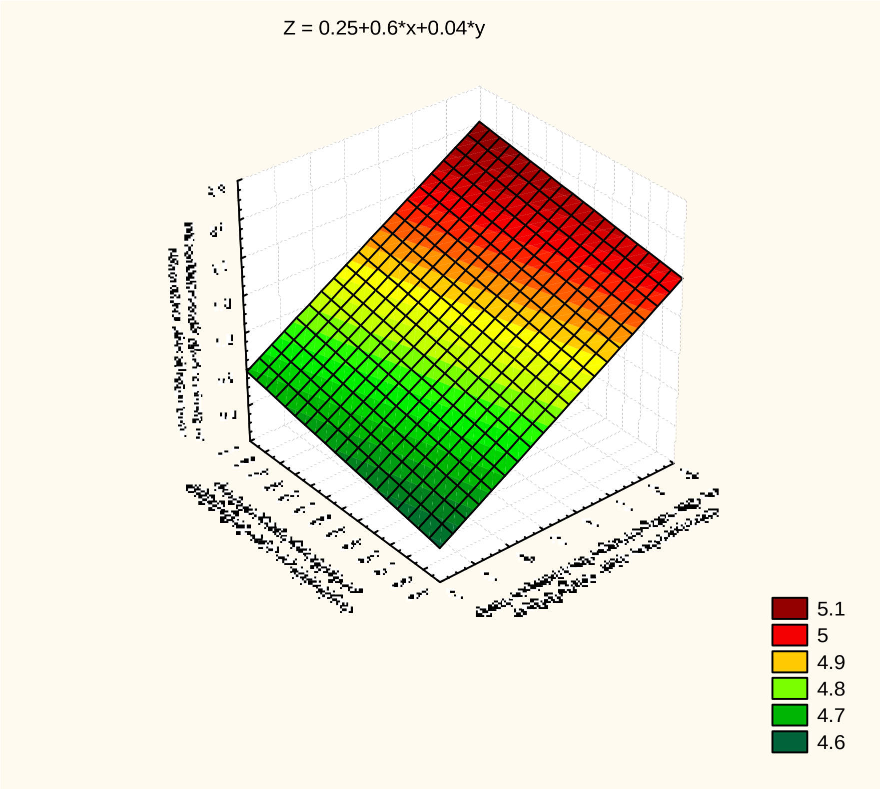

Fig .(6) Statistics Simulation – Statistica 6.0

4. Conclusion

From this study, the influence of the aggregate content size on the determination of strength using ultrasonic pulse velocity. It has been concluded that:

a. Aggregates with low pulse velocity reduce both the strength and UPV of concretes, when compared to aggregates with high pulse velocity.

b. For the same UPV level, mixtures with the lowest and the highest nominal aggregate size have the highest and the lowest compressive strength.

c. At the same UPV level, a mixture with the 20mm coarse aggregate grains has lower compressive strength than mixture with 10mm coarse aggregate , which can be explained by weaker contact between aggregate grains and cement paste in the case of 20mm coarse aggregate grains, leading to a reduction in the concrete strength

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