Journal of University of Babylon for Engineering Sciences, Vol. (26), No. (6): 2018.

# Non- Distractive Testing of Reactive Powder Concrete

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## Abstract:

This research focuses on estimating of three important properties of reactive powder concrete; the distractive, a non-distractive testing and statistical analysis suggest mathematical model. The ultrasonic pulse velocity test (NDT) method to study the properties of concrete. Fifty cubes with size (150mm), fifty cylinders with diameter (150mm), height (300 mm), and fifty prisms of dimensions (100*100*500) mm., Statistical analysis was used to estimate the mechanical properties of reactive powder concrete (RPC), compressive strength, splitting tensile strength and flexural strength. Results showed that it is possible to estimate the mechanical properties using a mathematical model.

**Keywords**: Reactive powder concrete, Nondestructive testing, Ultrasonic pulse velocity, Statistical analysis.

## 1 - Introduction

A Reactive powder concrete is one type of concrete that possess ultra-high performance strength and high ductility combined material with advanced mechanical properties. Reactive powder concrete extensively utilizes the pozzolanic properties of very much refined silica fume and optimization of the Portland cement. A Reactive powder concrete consists of fiber-reinforced, chemical admixture, a very low water/cement ratio (W/C) of silica fume-cement blend and very downy sand of grain sizes between 0.15 to 0.40 mm. The obscurity of coarse aggregate could not be considered reactive powder concrete (RPC) as a concrete, but can be deem as a special mortar.

The compressive strength of reactive powder concrete was achieved in the range of 200 to 800 MPa, fracture energizes was in the range of 1200 to 40,000 J/m2, flexural strength in the range of 30 to 60 MPa, while its ductility is about 250 times higher than that of traditional concrete [1].

Richard and Cheyrezy [1], developed an ultrahigh strength ductile concrete with the main principles of promote the homogeneity by eliminating the coarse aggregate, promote the microstructure by post-set heat remediation and the tensile strength of concrete was by blend small, straight, high tensile microfiber. Two sorts of concretes were developed and specified as RPC200 and RPC800, which had unusual mechanical properties. The mean compressive stress gained for RPC200 was 218MPa and for RPC800 was skipping 600MPa. For RPC800, a value of 810MPa has been gained with a mixture combined steel aggregate. The concrete finds its implementation in industrial and nuclear trash storage silos.

Estimation of the mechanical properties of concrete can be carrying out in situ using a very easy and quick technique, which is known a non-destructive test (NDT). In this technique, no damage to the mechanical trait of concrete can be rated in the situated structures, but the accuracy of this technique is suspicious so appropriate validity and calibration is required.

The chemical and physical features of the other types of concrete can be influenced relative to their mix composition.

Non-destructive testing (NDT) is defined by Workman, & Moore [2], as the excess course of investigated, testing, or evaluating materials, components or assemblies without damage the serviceability of the portion or system.

The main objective of nondestructive testing (NDT) is to assess the state of structure wanting affecting its performance, [3]. (NDT) methods have seen considerable developments pending recent decades, [4] [5]. However, many of the civil engineering programs have not yet inserted (NDT) in their concrete teaching. For instance, in the U.S., less than 1 out of 12 civil engineering programs are teaching (NDT) in their concrete paths[3]. Bray, 1993 submitted that (NDT) should be integral portion of engineering education [6]. Generally, determination of the in-place goodness and strength of concrete can be achieved using the ultrasonic pulse velocity test and rebound hammer experiment. The series of these two tests is also mention as SonReb. SonReb is very helpful because rebounded hammer (RH) test supply surface strength of concrete whereas UPV test reflects the internal properties of concrete [7].

(Shariati *et.al.*, [3] finished that (RH) test provides better prognosis of concrete strength as contrast to UPV test. Researchers[3][8][9] have found that combined procedure that refer to the use of two duo or more NDT methods can furnish better prediction of in-place property of concrete.

A number of researchers used the traditional destructive approach to study the mechanical properties of UHPRC [10] [11] [12] [13] [14].

There are several (NDT) methods and two of the most commonly used for in-situ implementation are rebound hammer (RH) and the ultrasonic pulse velocity (UPV) techniques to evaluate the mechanical properties of Ultra-High Performance Fiber Reinforced Concretes (UHPFRC). (Washer *et.al.*, [14]. examined the applicability of (UPV) on UHPFRC, and the effect of steel fibers content on the wave velocity was investigated. The objectives of this research are to investigate the possibility of using two most applicable methods of (NDT) techniques are ultrasonic pulse velocity and rebound hammer techniques.

## 2-Experimental Material

The RPC considered here is prepared by the following ingredients:-

### 2-1 Cement

Sulfate resisting Portland cement (type V) of Aljisir are used .It is manufactured locally in Iraq. The physical and chemical analysis of cement which conforming to Iraqi specification No. 5 / 1984, are presented in Tables (1) and (2).

**Table 1: chemical composition of Al-Aljisir Cement (type V)**

| Chemical Composition | | Specification Iraqi Limits (IQS) No. 5/1984 |
|---|---|---|
| Oxides | % | |
| Loss on Ignition (L.O.I) | 2.06 | Not greater than 4% |
| Silicon Dioxide ($SiO_2$) | 22.00 | |
| Aluminum Oxide ($AL_2O$) | 3.64 | |
| Iron Oxide($FeO_2$) | 4.45 | |
| Calcium Oxide (CaO) | 62.41 | |
| Magnesium Oxide(MgO) | 2.05 | Not greater than 5% |
| Sulphur Trioxide ($SO_3$) | 1.95 | Not greater than 2.5% & 2.8 for (O.P.C) |
| Insoluble residue (I.R) | 0.98 | Not greater than 1.5% |
| Tricalcium Aluminate ($C_3A$) | 2.85 | Not greater than 3.5% |

Table 2: Physical properties of AL- Aljisir Cement Type (V)

| **Physical properties** | | **Specification Iraqi Limits (IQS) No. 5/1984 [ 15 ]** |
|---|---|---|
| Specific Surface Area ($cm^2/g$) | 3000 | Not less than 2500 |
| Initial setting time (min) | 155 | Not less than 45 |
| Final setting time (min) | 260 | Not greater than10 hr. |
| Comp. Str. 3days (MPa) | 28.7 | Not less than 15 |
| Comp. Str. 7 days (MPa) | 31.8 | Not less than 23 |

## 2.2 Superplasticizer

In this research GLENIUM 51 was used. GLENIUM® 51 is different from normal superplasticizer in that it is based on a unique carboxylic ether polymer with long lateral chains. This greatly improves cement dispersion. At the incipience of the mixing process the same electrostatic dispersion happened as described prior but the presence of the lateral chains, joint to the polymer backbone, generate a steric hindrance which stabilizes the cement particles capacity to dismiss and disperse; it's satisfied with ASTM C494- 1988 Type F. Table (3) shows the main property of Glenium51,these characteristics according to the manufacture editor

**Table 3: Characteristics of superplasticizer used ***

| **Properties** | **Admixture** |
|---|---|
| colures | light brownish liquid |
| Chemical Composition | Modified polycarboxyate based polymer |
| Density kg/L | 1.09 at 20 C° |
| pH | 7 |
| Chloride ion content (%) | Free |
| Effect on setting | Non-retarding |

## 2.3 Fine Aggregate

Al-Ukhydr from Karbala government sand has been applied. The sieve analysis and grading showed in Table (4) which conforming with Iraqi specification No. 45 / 1984 zone (2).

Table 4: Grading of fine aggregate

| Sieve Size(mm) | Passing (%) | specification Limits (IQS 45/1984) [16] | | | |
|---|---|---|---|---|---|
| | | Z (1) | Z (2) | Z (3) | Z (4) |
| 9.5 | 100 | 100 | 100 | 100 | 100 |
| 4.75 | 95.3 | 90-100 | 90-100 | 90-100 | 95-100 |
| 2.36 | 88.3 | 60-95 | 75-100 | 85-100 | 95-100 |
| 1.18 | 66.6 | 30-70 | 55-90 | 75-100 | 90-100 |
| 600 | 43.8 | 15-34 | 35-59 | 60-79 | 80-100 |
| 300 | 20.9 | 5-20 | 8-30 | 12-40 | 15-50 |
| 150 | 1.7 | 0-10 | 0-10 | 0-10 | 0-15 |

## 2.4 Silica Fume

Indian silica fume with specific surface area 20000 ($m^2$/kg).was used in this study. The properties and chemical composition of silica fume according to the manufacturer editors as showed in Table (5).

Table (5): Composition and Properties of Silica Fume

| Composition | Symbol | Test result (%) | ASTM-C1240-03 Specification |
|---|---|---|---|
| Silicon dioxide | ($SiO_2$) | 98.87 | Minimum 85% |
| Aluminum oxide | ($AL_2O_3$) | 0.01 | - |
| Ferric oxide | ($Fe_2O_3$) | 0.01 | - |
| Calcium oxide | ($CaO$) | 0.23 | - |
| Magnesium oxide | ($MgO$) | 0.1 | - |
| Potassium oxide | ($K_2O$) | 0.08 | - |
| Sodium oxide | ($Na_2O$) | 0.00 | - |

## 2.5 Steel Fiber

The characteristics of steel fiber s which is used in the experimental work are given in Table (6) according to the manufacturer editors.

Table 6: Characteristics of steel fiber used *

| Type of steel | Hooked |
|---|---|
| Relative Density (kg/m$^3$) | 7860 |
| Yield strength (MPa) | 1130 |
| Modulus of Elasticity ( MPa) | 200000 |
| Strain at proportion limit | 5650*10$^{-6}$ |
| Poisson s ratio | 0.28 |
| Average length ( L) (mm) | 30 |
| Nominal diameter (d) | 0.375 |
| Aspect Ratio (L/d) | 80 |

### 2.6 Water of Mixing and Curing

Tap water was used for concrete mixing and curing of this research

## 3- Experimental Work

Many mix proportions were tried in this study to get maximum compressive strength of reactive powder concrete ( RPC).( 930 cement, 1030 sand , 230 silica fume ) kg/m$^3$, with 0.27 w/c and 4.5 l/m$^3$ Super plasticizer, were used to mix preparation.

### 3.1 Mixing Procedure

According to the ACI committee report 544-1998 a method was used. A rotary mixer of 0.1 m$^3$ was used to achieve the reactive powder concrete mixes. A dry mixture of the silica fume and cement were first blended for 3.0 minutes, and then the fine aggregate was added to the mixture and blends for 5 minutes.. At the same time a solution of water and super plasticizer was prepared and then added to the mixture and mixed for 3 minutes. Any portion of the mixture that has not mixed very well by the mixer a manual procedure was used to mix it to get a homogeneous mixture. After that the mixture was mixed well again for 5 minutes to get a feasible fluidity. In addition, fibers were added uniformly into the mixture in 3.0 minutes and blended with the mix for further two minutes. This process requires 15 minutes from adding water to the mixture.

### 3.2 Curing

All specimens were demoded after 24 hours, immerse in water for 28 day and examined to study three important properties of RPC. These properties are compressive strength, tensile strength, and flexural strength. 50 cubes of (150 mm) were used for the compressive strength tests, 50 cylinders of (150*300) mm were used for the tensile strength and (100*100*500) mm prisms were used for the flexural strength.

### 3.3 Testing of Specimens

Destructive testing and Nondestructive test methods, ultrasonic pulse velocity was used in this study.

### 3.3.1 Ultrasonic Pulse Velocity Test

This experiment uses the ultrasonic velocity transit through the concrete to estimate its strength based on standards specified in BS 1881(part 203, 1986) and ASTM C597-09-2009. The device used for the test is a removable Pundit ultrasonic pulse instrument. It consists of a gauge for measuring the pulse, a transducer and receiver. The machine generates an ultrasonic plus in the transmitting transducer and measures the transition time taken by the pulse to reach the receiving transducer. The pulse velocity is then calculated by dividing the length of the path travelled through the concrete by the transmission time.

## 4. Results Analysis

Tables (7) shown the ultrasonic test results which the velocity ranged between (4.13E+01 – 4.47E+01) km/sec respectively.

### 4.1 Compressive Strength (Fcu)

The results of the compression tests on RPC cubes are shown in tables (7), and figure (1) explain the relationship between compressive strength and velocity.

### 4.2 Splitting Tensile ($F_{sp}$)

**Table (7): test results**

| No. | Velocity km/sec | Destructive test results | | | No. | Destructive test results | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $f_{cu}$ MPa | MR MPa | $f_{sp}$ MPa | | Velocity km/sec | $f_{cu}$ MPa | MR MPa | $f_{sp}$ MPa |
| **1** | 4.37E+01 | 1.18E+02 | 18.2 | 9.7 | **26** | 4.20E+01 | 1.17E+02 | 11.3 | 6.3 |
| **2** | 4.34E+01 | 1.18E+02 | 18.6 | 8.8 | **27** | 4.14E+01 | 1.15E+02 | 11.6 | 6.3 |
| **3** | 4.35E+01 | 1.19E+02 | 18.0 | 8.1 | **28** | 4.13E+01 | 1.11E+02 | 11.2 | 6.5 |
| **4** | 4.11E+01 | 1.12E+02 | 11.4 | 4.9 | **29** | 4.13E+01 | 1.11E+02 | 11.3 | 6.2 |
| **5** | 4.34E+01 | 1.17E+02 | 17.8 | 8.3 | **30** | 4.13E+01 | 1.11E+02 | 11.6 | 6.3 |
| **6** | 4.36E+01 | 1.18E+02 | 19.0 | 9.4 | **31** | 4.29E+01 | 1.11E+02 | 14.6 | 6.1 |
| **7** | 4.37E+01 | 1.20E+02 | 19.7 | 9.3 | **32** | 4.13E+01 | 1.17E+02 | 11.3 | 6.3 |
| **8** | 4.19E+01 | 1.11E+02 | 12.1 | 6.6 | **33** | 4.29E+01 | 1.11E+02 | 14.2 | 7.6 |
| **9** | 4.21E+01 | 1.15E+02 | 12.3 | 6.0 | **34** | 4.19E+01 | 1.16E+02 | 11.1 | 6.5 |
| **10** | 4.19E+01 | 1.14E+02 | 13.0 | 6.0 | **35** | 4.18E+01 | 1.14E+02 | 11.6 | 6.2 |
| **11** | 4.33E+01 | 1.18E+02 | 18.2 | 8.8 | **36** | 4.10E+01 | 1.13E+02 | 10.9 | 6.9 |
| **12** | 4.13E+01 | 1.11E+02 | 12.2 | 6.8 | **37** | 4.36E+01 | 1.10E+02 | 15.1 | 8.4 |
| **13** | 4.39E+01 | 1.18E+02 | 19.1 | 9.4 | **38** | 4.40E+01 | 1.18E+02 | 19.0 | 9.3 |
| **14** | 4.42E+01 | 1.19E+02 | 19.2 | 9.4 | **39** | 4.38E+01 | 1.19E+02 | 18.8 | 8.2 |
| **15** | 4.36E+01 | 1.18E+02 | 18.3 | 8.2 | **40** | 4.34E+01 | 1.18E+02 | 19.3 | 8.8 |
| **16** | 4.39E+01 | 1.21E+02 | 19.0 | 8.6 | **41** | 4.43E+01 | 1.22E+02 | 18.6 | 9.5 |
| **17** | 4.44E+01 | 1.22E+02 | 18.7 | 9.3 | **42** | 4.31E+01 | 1.17E+02 | 18.8 | 8.6 |
| **18** | 4.43E+01 | 1.22E+02 | 19.7 | 9.2 | **43** | 4.31E+01 | 1.18E+02 | 17.9 | 8.3 |
| **19** | 4.39E+01 | 1.20E+02 | 18.7 | 8.4 | **44** | 4.34E+01 | 1.18E+02 | 18.1 | 8.4 |
| **20** | 4.42E+01 | 1.21E+02 | 19.8 | 8.6 | **45** | 4.40E+01 | 1.18E+02 | 19.2 | 9.4 |
| **21** | 4.40E+01 | 1.21E+02 | 19.3 | 9.3 | **46** | 4.39E+01 | 1.18E+02 | 19.8 | 7.3 |
| **22** | 4.44E+01 | 1.22E+02 | 19.2 | 8.4 | **47** | 4.38E+01 | 1.18E+02 | 18.3 | 8.1 |
| **23** | 4.39E+01 | 1.21E+02 | 18.8 | 9.8 | **48** | 4.37E+01 | 1.18E+02 | 18.9 | 9.0 |
| **24** | 4.47E+01 | 1.23E+02 | 20.9 | 10.2 | **49** | 4.20E+01 | 1.14E+02 | 11.3 | 6.6 |
| **25** | 4.29E+01 | 1.17E+02 | 17.6 | 6.3 | **50** | 4.14E+01 | 1.11E+02 | 10.6 | 7.3 |

The results of the tensile on RPC cylinders are shown in tables (7) and Figure (2) showing the relationship between flexural strength and velocity .

### 4.3 Flexural Strength (MR)

Tables (7) shows the results of the flexural strength tests, and Figure (3) showing the relationship between flexural strength and velocity.

After the tests and get results, the data were statically analyzed by Microsoft Excel computer program version 10. Microsoft Excel has the basic features of all spreadsheets. Using a grid of cells arranged in numbered rows and letter- named columns to organize data manipulations like arithmetic operations.

## Relationship between Velocity (V) and Compressive Strength ($f_{cu}$) MPa

Figure (1) shown the relationship between the compressive strength and velocity. A Excel version 10 computer program has been adapted to equation to predictd the relationship between velocity and comoressive strength ($f_{cu}$).

**$Fcu = 36.281e^{0.0272V}$** .................................... [1]

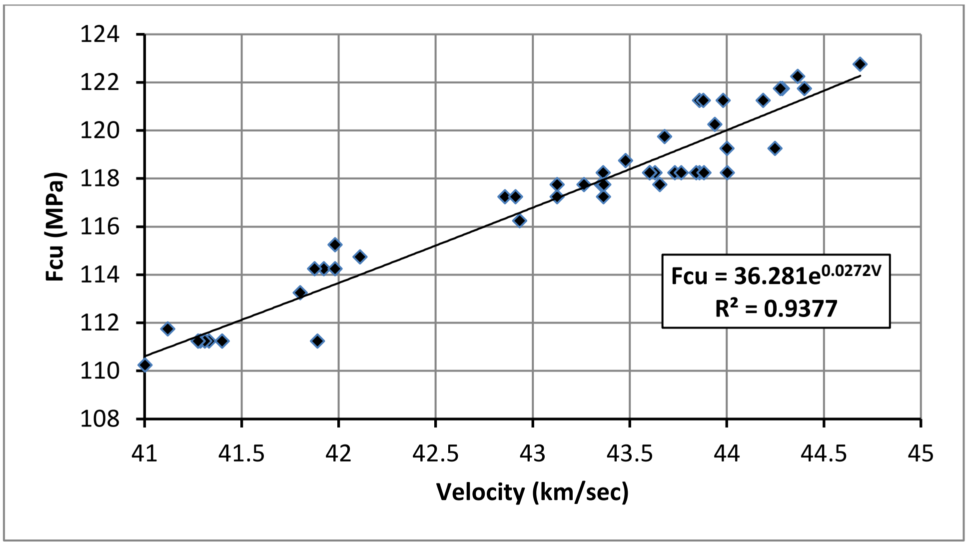


**Fig. (1) Velocity - compressive strength relationship**

## Relationship between Velocity (V) and Tensile Strength ($f_{sp}$) MPa

Figures (3) show the relationship between velocity (v) km/sec and tensile strength ($f_{sp}$) MPa. An Excel version 10-computer program has been adapted to equation to predict the relationship between velocity (V), and tensile strength ($f_{sp}$) MPa.

**$Fsp = 1E\text{-}06e^{0.359V}$** ................................ [2]

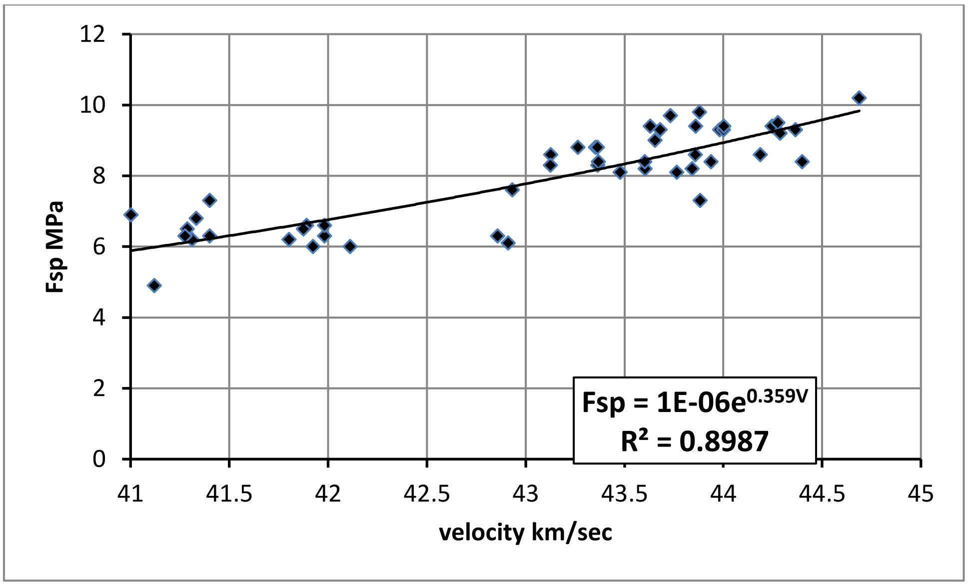


**Fig. (2) Velocity -tensile strength relationship**

## Relationship between Velocity (V) and Flexural Strength (M.R) MPa

Figure (3) shown the relationship between velocity (v) km/sec and flexural strength (MPa). An Excel version 10-computer program has been adapted to equation to predict the relationship between velocity (V), and flexural strength.

**M.R = 0.0029 $e^{0.1999V}$** ………………………….. **[3]**

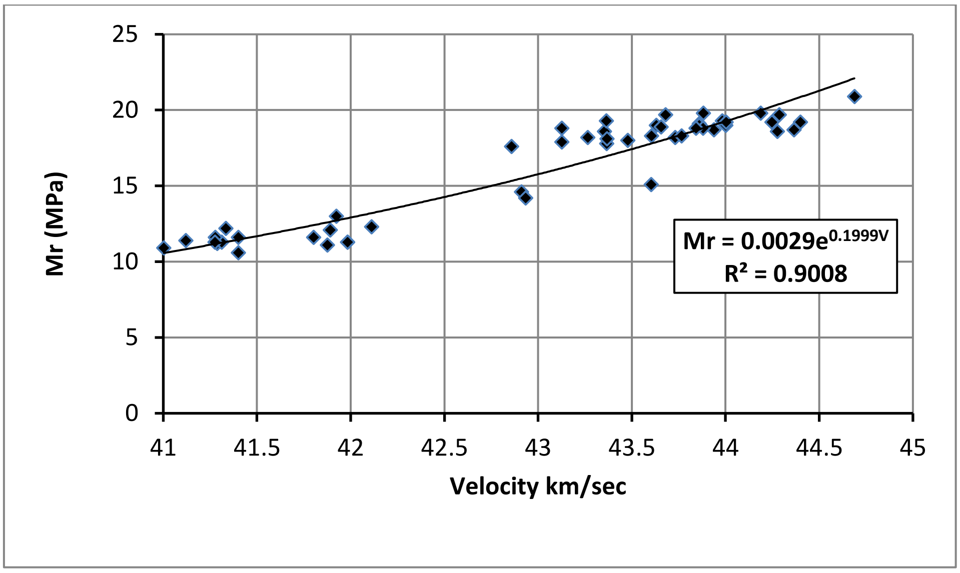


**Fig. (3) Velocity -flexural strength relationship**

## Conclusion

The results recorded significantly higher values than normal concrete in this study. Three equations from the experiments results can be possible to estimate the compressive strength, tensile strength and flexural of reactive powder concrete by ultrasonic plus velocity.

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# اختبار غير تدميري للبودرة الخرسانية التفاعلية

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**الخلاصة:**

يهدف هذا البحث الى تخمين ثلاثة من اهم خواص خرسانة المساحيق الفعالة باستخدام فحوصات إتلافيه وفحوصات لإتلافيه بالإضافة الى برنامج تحليل الاحصائي لغرض اقتراح موديل رياضي لتخمين مقاومة انضغاط، مقاومة الانثناء، ومقاومة الشد الانفلاقي لخرسانة المساحيق الفعالة. تم صب 50 مكعب خرساني مقاس 150 مم ، 50 اسطوانة بقطر 150 مم وارتفاع 300 مم وايضا صب 50 موشور بأبعاد (100*100*500مم) وبعد معالجتها معالجة اعتيادية في الماء لمدة 28 يوم تم فحصها فحصا لا ا تلافيا بوسطة فحص الامواج الفوق الصوتية كفحوصات لإتلافيه ومن ثم فحصها اتلافيا" لإيجاد مقدار مقاومة الانضغاط والشد والانثناء، وبعد ادخال قيم الفحص الاتلافي والائتلافي في برنامج التحليل الاحصائي تم التوصل الى امكانية تخمين الخواص الميكانيكية باستخدام المعادلات الرياضية المستنتجة.

**الكلمات المفتاحية**: خرسانة المسموح الفعال، فحوصات لا اتلافية، فحص الأمواج فوق الصوتية، تحليل احصائي.