Proposed UPV-Strength Relationship for Concrete Subjected to Sulfate Attack

Feras Latef Khlef
Technical College – University of Arbel

ABSTRACT.

The purpose of this paper is to developing a mathematical relationship between the Ultrasonic Pulse Velocity (UPV) and the compressive strength for concrete specimens subjected to different amounts of exposure of sulfate attack.

The experimental data were collected from a research work by the author using concrete subjected to sulfate exposure and form a literature used an extensive concrete work without sulfate exposure. The sulfate exposures studied were 0%, 3%, and 6% of fine aggregate. It is found that with the same amount of sulfate exposure a clear relationship curve can be drawn to describe the UPV and compressive strength.

This paper proposes the UPV-strength mathematical expression suitable for prediction of the concrete strengths when subjected to sulfate attack.

Keywords: Concrete, Compressive Strength, Sulfate Attack, Ultrasonic Pulse Velocity.

1. INTRODUCTION AND PREVIOUS WORKS.

Some work in previous literature made use of the Ultrasonic Pulse Velocity (UPV) of concrete to predict compressive strength[1-6]. At early age of concrete, the pulse velocity increases rapidly relative to strength[7,8].

Pulse velocity is influenced by many variables, however, including mixture proportions, aggregate type, age of concrete, moisture content, and others.[1] The factors significantly affecting the concrete strength might have little influence on UPV. As a result, a strength estimate made with the pulse velocity method is not reliable if a pre-established calibration curve is not available.[2]

No clear rules have been presented to describe how the relationship between UPV and the compressive strength of concrete changes with its mixture proportion. Therefore, there exists a high uncertainty when one tries to make use of UPV to predict the strength of concrete in different mixture proportions.

This paper uses certain mixture proportion of concrete and varies in water/cement ratio (w/c). The UPV measurement and compressive strength tests were carried out at the age from 4 to 40 days. The influence of three factors: age, w/c, and sulfate amount-on UPV and the compressive strength of concrete is studied and used to determine how these factors affect the relationship between UPV and the compressive strength of concrete.

2. ULTRASONIC THROUGH TRANSMISSION METHOD.

One of the oldest nondestructive NDT methods for concrete is based on measuring the travel time over a known path length of a pulse of ultrasonic compression waves. The technique is known as ultrasonic through transmission, or, more commonly, the ultrasonic pulse velocity (UPV) method.

The principle is that the speed of propagation of stress waves depends on the density and the elastic constants of the solid.

In a concrete member, variations in density can arise from non-uniform consolidation, and variations in elastic properties can occur due to variations in materials, mix proportions, or curing. Thus, by determining the wave speed at different locations in a structure, it is possible to make inferences about the uniformity of the concrete. The compression wave speed is determined by measuring the travel time of the stress pulse over a known distance.

3. INSTRUMENTATION.

The main components of modern devices for measuring the ultrasonic pulse velocity are shown in **diagram (1)** which is used in this work. A transmitting transducer is positioned on one face of the member and a receiving transducer is positioned on the opposite face. The transducers contain piezoelectric ceramic elements. Piezoelectric materials change dimension when a voltage is applied to them, or they produce a voltage change when they are deformed. A pulser is used to apply a high voltage to the transmitting transducer (source), and the suddenly applied voltage causes the transducer to vibrate at its natural frequency. The vibration of the transmitter produces the stress pulse that propagates into the member. At the same time that the voltage pulse is generated, a very accurate electronic timer is turned on. When the pulse arrives at the receiver, the vibration is changed to a voltage signal that turns off the timer, and a display of the travel time is presented. The transducers are coupled to the test surfaces using a viscous material, such as grease, or a non-staining ultrasonic gel couplant if staining of the concrete is a problem.

4. RESEARCH SIGNIFICANCE.

Currently, the influence of amount of sulfate attack on the relationship between UPV and the compressive strength of concrete is unclear. This study uses concrete subjected to amounts of sulfate attack and study the relationship between UPV and the compressive strength of concrete and to clarify its influence. Furthermore, this paper presents clear relationship curves between UPV and the compressive strength of concrete under such attack to improve the application of the UPV method on nondestructive evaluation of concrete strength. A proposed equation is presented to reflect the influence of sulfate attack on UPV in the concrete.

5.Experimental Details[9]

Materials.

Materials used for making specimens include cement, fine aggregate (F.A.), and coarse aggregate (C.A.). The cement used was Portland Type I. River sand with a Saturated-Surface Dry (SSD) density of 2.62 and gravel with an SSD density of 2.60 were used as fine and coarse aggregates, respectively. Sand was brought from a quarry in 70-km area in Ar-ramadi city/ Al-Anbar governorate[4] . For more details see reference (9).
The sulfate used is Calcium sulfate $CaSO_4$ with ratios of 0%, 3% and 6% of the FA.

Experimental Specimens[10].

The concrete was mixed according to a volumetric proportion of (1:2:4) (C:F.A.:C.A.). Two water/cement ratios of 0.45 and 0.65 were used in the study.
All the specimens were cast in steel molds (150×150×150) mm cubes and kept in their molds for approximately 24 hours in the laboratory. After removing the molds, the specimens were tested at ages of 4 days to 40 days for all control and sulfate attacked specimens. At each age, the pulse velocity and compressive strength of three SSD specimens were measured according to the specification of ASTM C 597 and ASTM C 39, respectively.

Experimental Equipment [9]·

Ultrasonic pulse velocities were measured by a commercially available pulse meter with an associated transducer pair. The transducer pair had a nominal frequency of 54 kHz. The principle of ultrasonic pulse velocity measurement involves sending a wave pulse into concrete and measuring the travel time for the pulse to propagate through the concrete. The pulse is generated by a transmitter and received by a receiver. In the experimental studies, the transmitter and receiver were placed at the top and bottom surfaces of a cube or a prism specimen, respectively. As a result, the traveling length of the ultrasonic pulse was the length of the specimen, which was measured by using a vernier with a minimum reading of 0.01 mm.

Knowing the path length, the measured travel time (Δt) can be used to calculate the pulse velocity (υ) as follows:

$$\upsilon = D/\Delta t \qquad (1)$$

Where D is the travel path length of ultrasound in the specimen. The concrete surface must be prepared in advance for a proper acoustic coupling. Light pressure is needed to ensure firm contact of the transducers against the concrete surface.

6. RESULTS AND DISCUSSION.

The experimental data presented in the figures discussed in this paper are intended to address the relationship between UPV and the compressive strength of concrete. The effect of sulfate exposure on the development of UPV and strength of concrete along with age is discussed.
Subsequently, the influence of sulfate exposure and w/c ratio on the UPV-strength relationship of concrete is investigated. In the end, the relationship curves between UPV and strength of hardened concrete are developed.

7. **PULSE VELOCITY AND COMPRESSIVE STRENGHT DEVELOPMENT OF CONCRETE**.

Fig.(1) shows the relationship between UPV and compressive strength of concrete specimens (w/c between 0.4 and 0.6)[9] . The results of UPV for the specimens of reference (9) are shown in the same figure.
Fig.(2) is a plot of the data of concrete specimens (at the age of 28 days) taken from **fig.(1)**. **Fig.(2)** shows the UPV-strength relationship from reference (10) and the control specimens of the author's work.

8. UPV-AGE RELATIONSHIP.

Fig.(3) show the UPV with the age of concrete having different w/c. The UPV in the concrete grow along with the advancement of age. At the same age, UPV with low w/c are higher than those with high w/c, as shown in **fig.(3)** mainly because of the denser structure of concrete with a lower w/c.
The relationship between UPV and strength of concrete is better presented when studying both effects of w/c ratio and age in the manner shown in **fig.(3)**. The results of this study (extended to 40 days) are shown in these figures along with those of reference (10) (up to 28 days) and the present study results generally have close match to those of reference (10).

9. Relationship between UPV and Strength of Hardened Concrete, and with the Effect of Sulfate Exposure.

Fig.(4) shows the relationship between UPV and strength for the all data points. A relationship curve is drawn by exponential regression of all data points and its coefficient of determination (R^2 = 0.97), as shown in **fig.(4)**. For 0% sulfate exposure, equations (2) and (3) can be evaluated from **fig.(4)** as:

$$fc(R^2=0.85) = 0.0014 \times \exp.(0.0023 \times \upsilon) \quad (2)$$

$$fc(R^2=0.97) = 4.6308 \times \exp.(0.0004 \times \upsilon) \quad (3)$$

For 3% and 6% sulfate exposure, eq. (4) & eq. (5) can be obtained (see figure (4)).

$$fc(3\%) = 9.7802 \times \exp.(0.0002 \times \upsilon) \quad (4)$$

$$fc(6\%) = 8.8791 \times \exp.(0.0003 \times \upsilon) \quad (5)$$

Where fc and υ are compressive strength of concrete (MPa) and UPV (m/s), respectively.
For a given sulfate amount of exposure (% of FA) it is feasible to simulate the UPV-age curve for concrete with a particular sulfate amount. **Fig.(5)** shows the results of this work regarding effect of sulfate exposure.
The equation for the simulation curve of this sulfate amount of exposure is as follows:

$$\upsilon\ (0\%) = 4022.2 \times \exp(0.005 \times T) \quad (6)$$

$$\upsilon\ (3\%) = 4237.5 \times \exp(-0.005 \times T) \quad (7)$$

$$\upsilon\ (4\%) = 3930.3 \times \exp(-0.004 \times T) \quad (8)$$

Where T represents the age of hardened concrete (days).
The aforementioned equations can be used to study the relationship between UPV and the age of hardened concrete subjected to sulfate attack.
It is clearly shown in **fig. (5)** the decline (negative power of exponential function) in the UPV with age. As the sulfate percentage increase the UPV decrease. Thus, it is better to separately consider the effect of percentage of exposure of sulfate. The percentage of decline in UPV at age 40 days is about (15%) for 3% - sulfate exposure and about (11%) for 6% - sulfate exposure.

10. CONCLUSIONS.

1- This study uses concrete subjected to amounts of sulfate attack and study the relationship between UPV and the compressive strength of concrete and under such influence.
2- Exponential trend of equations is shown for various categories of concrete used.
3- For 3% and 6% sulfate exposure, the concrete UPV had changed (reduced) for all ages of concrete specimens. The equations have negative power of exponential function (see equations 7 and 8).
4- The UPV technique is shown effective and successful in detecting the strength reduction due to exposure of sulfate.

5- The percentage of decline in UPV at age 40 days is about (15%) for 3% - sulfate exposure and about (11%) for 6% - sulfate exposure.

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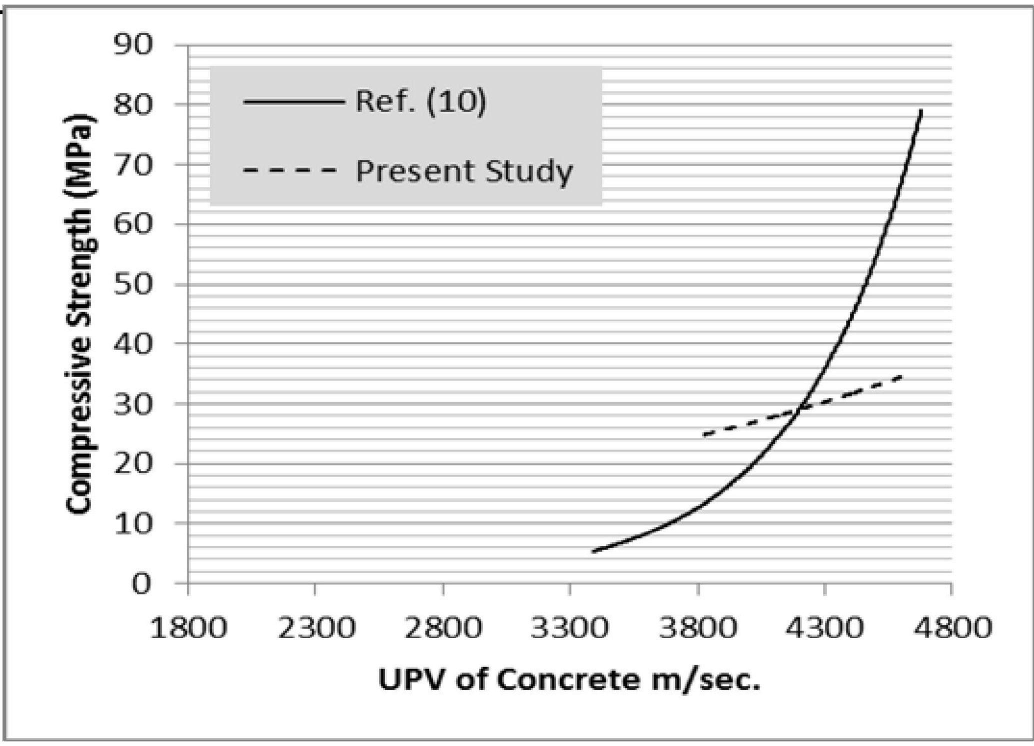


Figure (1): The Relationship between UPV and Compressive Strength of the Concrete.

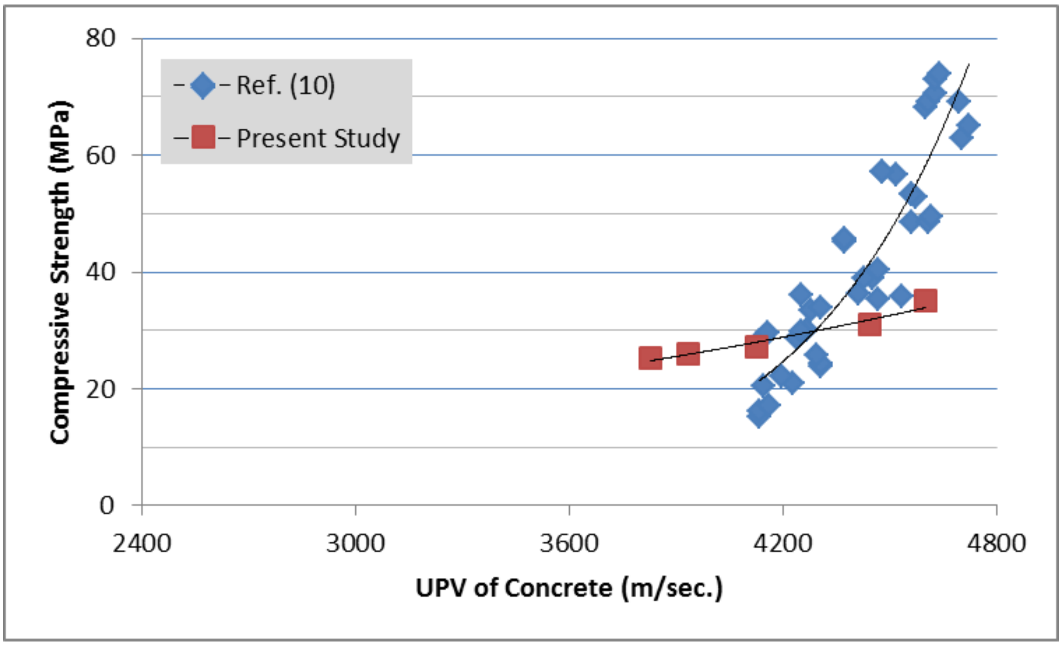
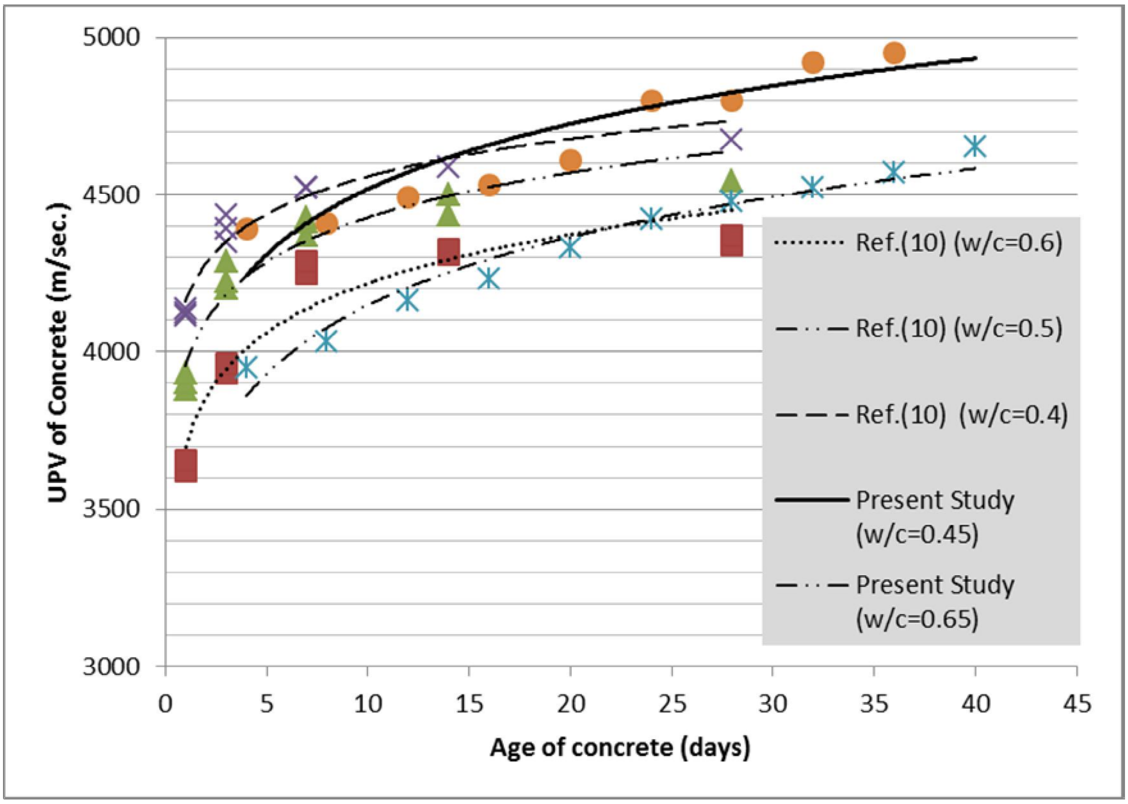
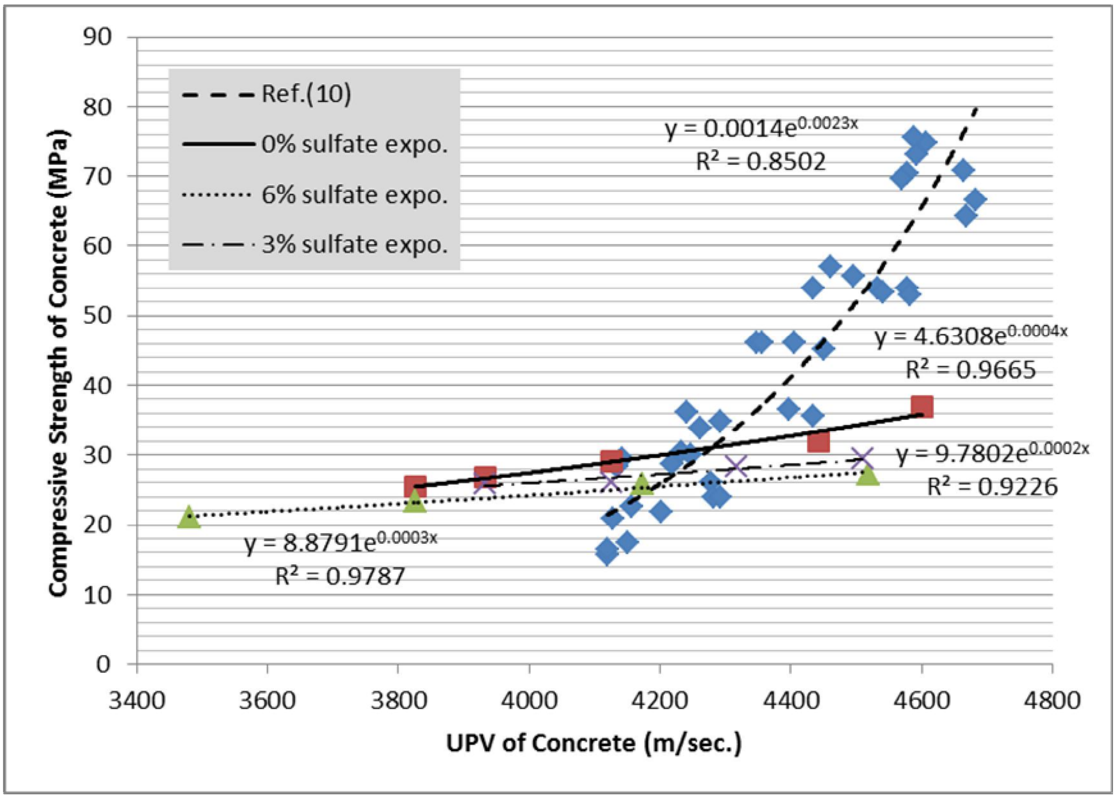


Figure (2): UPV-Compressive Strength Relationship of Concrete at Age 28 days.



Figure(3): UPV and Compressive Strength Development of Concrete with Age.



Figure(4): UPV - Compressive Strength Relationship of Concrete.

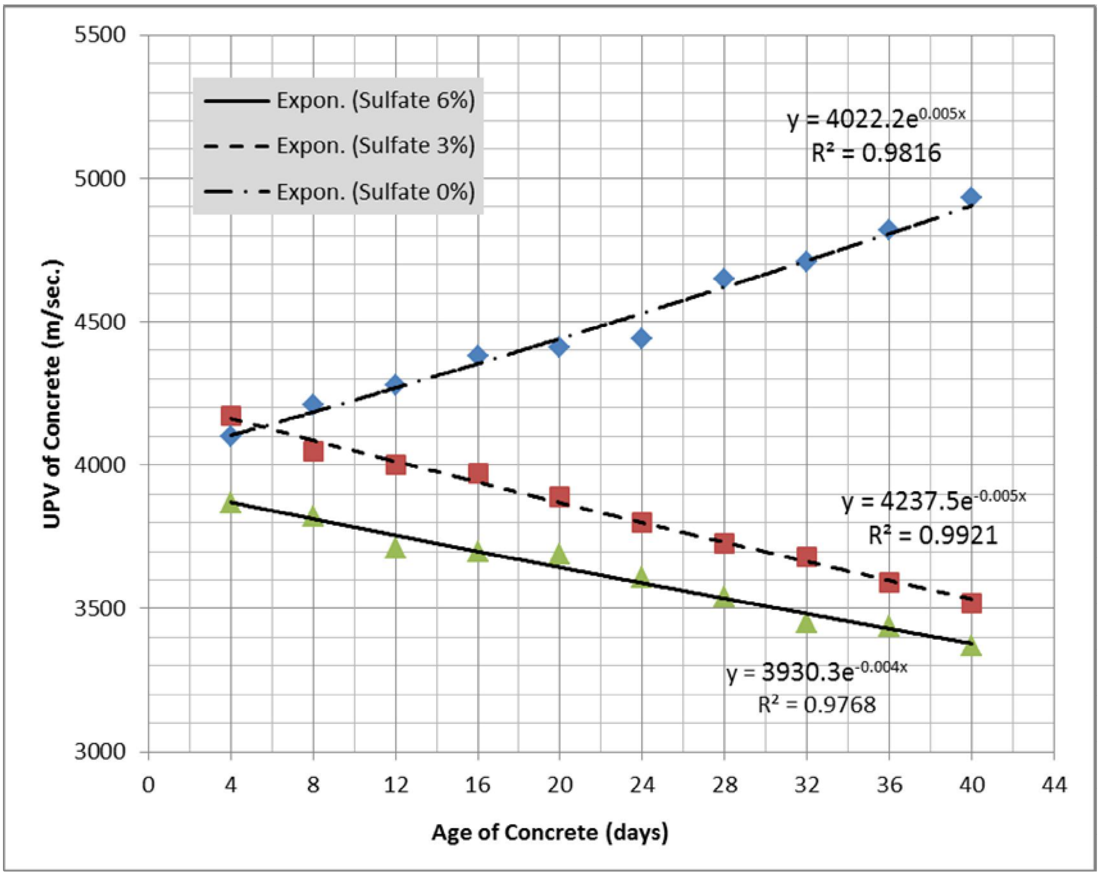


Figure (5): UPV-Age strength relationship of Concrete with Various Sulfate Exposure Amount.

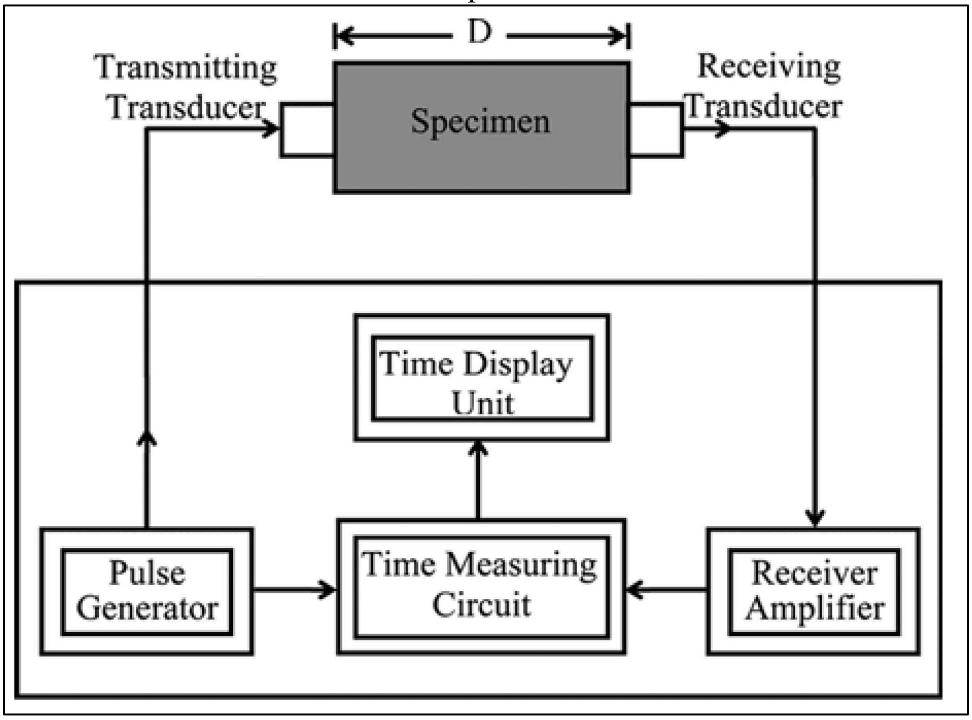


Diagram (1): Schematic diagram of pulse velocity measurement.

علاقة مقترحة بين سرعة الموجات الفوق صوتية ومقاومة الخرسانة المعرضة الى هجوم الاملاح الكبريتية

فراس لطيف خليف
الكلية التقنية – أربيل

الخلاصة

الغرض من هذا البحث هو استحداث علاقة رياضية لتمثيل العلاقة بين سرعة الموجات الفوق صوتية و مقاومة الانضغاط للخرسانة لعينات معرضة الى نسب مختلفة من هجوم الكبريتات.
تم جمع النتائج المختبرية من بحث قام بها الناشر نفسه للعينات المعرضة الى هجوم الكبريتات وبحوث اخرى لعينات لم تتعرض الى هجوم كبريتات. كانت نسب الاملاح الكبريتية التي تم دراستها (0%، 3%، و 6%) كنسبة من كمية الركام الناعم. وتبين بانه بالامكان رسم علاقة واضحة بين سرعة الموجات الفوق صوتية ومقاومة الانضغاط.
يقدم هذا البحث علاقة رياضية يمكن من خلالها توقع مقدار مقاومة الانضغاط للخرسانة المعرضة للهجوم الكبريتي.

الكلمات الرئيسية:خرسانة،مقاومة الإنضغاط،هجوم الكبريتات،فحص الموجات فوق الصوتية.