Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 6 Volume 26 June 2020

Civil and Architectural Engineering

Evaluating Asphalt Concrete Properties by the Implementation of Ultrasonic Pulse Velocity

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ABSTRACT

In past years, structural pavement solution has been combined with destructive testing; these destructive methods are being replaced by non-destructive testing methods (NDT). Because the destructive test causes damage due to coring conducted for testing and also the difficulty of adequately repairing the core position in the field.

Ultrasonic pulse velocity was used to evaluate the strength and volumetric properties of asphalt concrete, of binder course. The impact of moisture damage and testing temperature on pulse velocity has also been studied. Data were analyzed and modeled. It was found that using non-destructive testing represented by pulse velocity could be useful to predict the quality of asphalt concrete, the good correlation between the pulse velocity and the volumetric and strength properties.

The potential benefit of using the wave parameters is for condition assessment of asphalt concrete. The moisture damage exhibits a negative influence on pulse velocity by 13%, while the testing temperature shows an effect on the pulse velocity.

Keywords: Non-destructive test, pulse velocity, asphalt concrete, tensile, shear strength, volumetric properties.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2020.06.12

Article received: 16/7/2019
Article accepted: 9/10/2019
Article published:1/6 /2020

تقييم خصائص الخرسانة الاسفلتية باستخدام سرعة تردد الموجات

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الخلاصة

في السنوات السابقة، كانت الفحوصات الانشائية للتبليط مرتبطة بالفحوصات الاتلافية. تم استبدال هذه الاختبارات الاتلافية بطرق اختبار غير الاتلافية (NDT). لأن الفحوصات الاتلافة تسبب الضرر بسبب كور الفحص الذي ينتج من اجراءالفحص ، وبالإضافة إلى ذلك لا يمكن إصلاح موقع كورات الفحص مثل ما كان سابقا . عمليا سيتم دراسة الاختبارات اللااتلافية باستخدام سرعة الموجات وعلاقتها بالخواص الفيزياوية و الحجمية للإسفلت فيما يخص الطبقة الرابطة للخرسانة الإسفلتية وتاثير الرطوبة ودرجة الحرارة على سرعة الموجات. تم تحضير العينات في المختبر بنسب مختلفة من الإسفلت وتم اختبارها لتحديد سرعة الموجة، ثم اخضاعها الشد غير المباشرة وتحديد قوة القص. كما تمت دراسة تأثير الضرر بالرطوبة واختبارتاثير درجة الحرارة على تردد سرعة الموجات. تم تحليل البيانات ونمذجتها. واستنتاج العلاقات المحتملة بين سرعة الموجة وفقا لشروط فحص الخرسانة الإسفلتية. ونستنتج ان للضرر بالرطوبة تأثيرًا سلبيًا على سرعة الموجات بنسبة 12٪ ، بينما لا تظهر درجة حرارة الفحص أي تأثير ملموس على سرعة الموجة.

الكلمات الرئيسية: الفحوصات اللااتلافية , سرعة الموجات ,الخرسانة الاسفلتية ,اجهادات الشد , القص ,الخصائص الحجمية .

1. INTRODUCTION.

The main goal of NDT test results is the achievement of data on a specific structure with no downfall or harm to the test. The main methods of non-destructive tests like Ultrasonic pulse velocity, impact echo, and surface wave spectral analysis were applied to determine material properties. Meanwhile, some of the testing asphalt Concrete requiring extensive **(Arabani M, 2007) .**

The asphalt concrete material should be capable of sustaining stress from direct traffic loading **(Sarsam, and Sultan, 2015).** Several graphical procedures have been established to estimate the strength ability of Hot Mixed Asphalt mixture properties, including those developed by **(Van-derpole and Heukelom, 1974)**. All such graphic procedures have been used for decades, is usually agreed in case the results of specific laboratory tests are not easily accessible (**Quintus V.H., 1979)**. Many factors may affect the mechanical properties of HMA mixtures, such as fractures particle percentage (F.P percentage), Bitumen content, method of compaction, temperature, gradation, and filler content (**Cooper K.E., 1989**) Studying the relationship of parameters between stiffness modulus and ultrasound pulse velocity on the basis of the literature would be useful. The first step was to explore the effects of various mixing limits then the precision of UPV's outcomes for this purpose.

The ultrasound pulse velocity (UPV) was metrical, on cylindrical HMA specimens prepared **(Abo-Qudais S, 2005)**.

Using 40/50 asphalt cement and crushed limestone, aggregate gradations (maximum nominal aggregate size equal to19.0mm), the UPV measurements were performed.

2. MATERIALS CHARACTERISTICS

2.1. Asphalt Cement

Asphalt cement was acquired from Dora refinery; Physical properties are shown in **Table1**. It can be observed that it comply with **(SCRB, 2003)** specifications.

Table1. Asphalt cement's physical properties.

Test Procedure (ASTM)	Result	Unit	*SCRB Specification
Ductility (25°C, 5cm/min). ASTM D 113	156	cm	≥100
Penetration (25°C, 100g, 5sec) ASTM D 5	43	1/10 mm	40-50
Softening point (ring & ball). ASTM D 36	49	℃	non
After Thin-Film Oven Test ASTM D-1754			
Retained penetration of original, % ASTM D	31	1/10mm	<55
Loss in weight (163°C, 50g,5h)% ASTM D-	0.2	%	non
Ductility at 25 °C, 5cm/min, (cm) ASTM D-	47	cm	>25

*SCRB: State Commission for Roads and Bridges 2003.

2.2 Coarse and Fine Aggregate

From Al-Nibaee quarry, coarse and fine aggregates have been obtained. **Table 2** illustrates the physical properties of coarse and fine aggregates.

Table2. Physical properties of the fine and coarse aggregate of Al-Nibaee.

Property	Coarse	Fine
Bulk Specific Gravity (ASTM C 127 and C128)	2.610	2.631
Apparent Specific Gravity (ASTM C 127 and C128	2.641	2.6802
Percent Water Absorption (ASTM C 127 and C 128)	0.423	0.542
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	20.10%	-

2.3 Mineral Filler

The mineral filler passes sieve No.200 (0.075 mm. The filler used in this work is limestone dust and has been obtained from the Karbala Governorate. **Table 3** shows the physical properties of filler**.**

Table 3. Physical properties of filler (Limestone dust).

Property	Coarse Aggregate
Bulk Specific	2.610
% Passing Sieve	94

2.4 Selection of combined gradation for Asphalt concrete

The selected gradation in this study is based on the SCRB (2003) requirements of binder course specifications. With 19 (mm) of nominal maximum aggregate sizes. The selected aggregate gradations list is shown in **Table 4**.

Table 4. Aggregate gradation for binder course.

Sieve Opening (mm)	Percentage Passing by total aggregate weight	
	Limits for Specification (SCRB *)	Gradation approved
25	100	100
19	90-100	95
12.5	70-90	80
9.5	56-80	68
4.75	35-65	50
2.36	23-19	21
0.3	5-19	12
0.075	3-9	6

*SCRB: State Commission for Roads and Bridges (2003).

2.5 Preparation Hot Mix Asphalt Concrete

The aggregate was dehydrated at 110 °C to a fixed weight and then separated into different sizes and stored. Coarse and fine aggregates were combined with mineral filler to meet the requirements by sieving of gradation specified in **Table 4**. Before mixing with asphalt cement, the collective mixture was heated to a temperature of (150 °C). At the same temperature (150 °C), asphalt cement was heated, then added to a heated aggregate to achieve the ideal quantity and thoroughly mixed for two minutes using a mechanical mixer to coat all aggregate particles with thin asphalt cement film. Specimens of Marshall Size were prepared according to the American Society for Testing and Materials (ASTM, 2009)**,** D1559, using 75 Marshall hammer blows on each specimen's face. As per the procedure above, the optimum asphalt content was 4.75 by the weight of aggregates. The Marshall Specimens Size were divided into three sets; the first set was subjected to the indirect tensile strength test at 25 ºC and 40 ºC, testing temperature. The second set was subjected to double punching shear strength. As per the procedure by the American Association of State Highway and Transportation Officials **(AASHTO, 2013).** The third set was subjected to moisture damage**.** Using asphalt cement 0.5 % above and below the optimum asphalt content, additional asphalt concrete specimens were prepared. Specimens were tested in triplicate, and the average value was considered for analysis. **Plate 1** displays part of the prepared specimens.

Plate 1. Part of the tested samples.

3. ULTRASONIC PULSE VELOCITY TEST

The pulse velocity is one of the non-destructive tests determined and approved by **(ASTM, 2009) (B.S, 1986)** The portable ultrasonic pulse velocity non-destructive digital indicating tester (Pundit) was implemented in this study.

A 54 kHz frequency of ultrasonic pulse velocity was implemented in this study to test asphalt concrete specimens. This frequency has been used recently by**, (Araban , and, Kheiry., 2007).** Even though asphalt concrete is a viscoelastic material, the theory of elasticity can be used, since the displacements and corresponding strains are very small and the actual movements are very short in duration. This is a reasonable assumption; the testing was carried out at 25 °C. The asphalt mixture is considered as homogeneous, isotropic, solid, for simplicity **(Birgisson, 2003)**. The ultrasonic pulse velocity device takes the form of a pulse generator and an exact timing circuit, combined with superconducting transmitters and receivers. UPV test use is: quick and non-destructive, simple, and requires inexpensive testing equipment and setup. In the UPV test, a pulse wave emitted by a transmitter propagates through the material and is detected by a receiver; mechanical waves can assess the state of materials propagation of the low-strain without causing damage. To compute the ultrasonic pulse velocity, the distance between transducers is divided by the measured travel time of the stress pulse, which is related to the modulus of the asphalt concrete. To measure the pulse velocity passing through the specimens using the device generates and receives, the direct transmission arrangement was used in this study. The pulse and the receiver were installed on hot mix asphalt specimen faces. Before testing to check the accuracy of the transit time measurements, calibration of the pundit was done, with the reference bar on the surface of the tested points to act as a couplet and to prevent dissipation of transmitted energy. Use Vaseline as a couplet between the HMA specimen's surface and the transducer. The ultrasonic pulse velocity transit length has been measure carefully, and the time of the trip was recorded. The HMA thickness was equal to the distance between the transducers to calculate the wave's velocity, which was divided by the time measured. Eight readings were performed and averaged for each specimen. To evaluate the ultrasonic pulse velocity using **Eq. (1)** (**ASTM, 2009**), the ultrasonic pulse velocity test setup is demonstrated in **Plate 2**.

$$V = L / T \tag{1}$$

Where:

V: Ultrasonic pulse velocity (mm/μsec)

L: The path length (mm)

T: Transmit time (μsec).

Plate 2. Ultrasonic pulse velocity test setup.

4. INDIRECT TENSILE STRENGTH TEST.

The indirect tensile strength test was conducted according to the **(ASTM** C597-09). Marshall specimens were kept in the water bath at 25 ºC and 40 ºC for 30 minutes. Then every specimen was centered on the vertical diametrical plane between the two parallel strips loading of 12.7 mm width. Vertical compression load at a rate of 50.8 mm/min by Versa tester machine, was applied until the dial gauge of proofing ring reading reached the maximum load resistance. The indirect tensile strength (ITS) was calculated by using **Eq. (2)**, **(ASTM, C597-09).**

$$ITS = 2000 * P / \pi * T * D \qquad (2)$$

Where,
ITS = indirect Tensile Strength, kPa.
P = maximum load resistance at failure, N.
T = thickness of the specimen immediately before the test, mm.
D = diameter of specimen, mm.

5. DOUBLE PUNCHING SHEAR STRENGTH TEST.

This test procedure was conveyed and referred to by many studies **(SarsamI, and Alwan., 2015)**. For this test, used Marshall specimen was immersed in a water bath at 60 ºC for 30 min. The test was performed by centrally loading the cylindrical specimen. Two cylindrical steel punches were placed on the top and bottom surface of the sample, 2.54 cm in diameter, the specimen was centered, perfectly aligned one over the other, and then loaded at a rate of 2.54 cm in diameter until failure. The reading of dial gauge was recorded at the maximum load resistance as unconditioned Punching Shear Strength (PST). The punching shear strength was calculated using **Eq. (3)** **(ASTM, C597-09, 2007). Plate 3** exhibits the tensile strength test setup.

$$\sigma t = p / (1.2bh - a^{**}2) * \pi$$
(3)

Where,
σt = punching stress, Pa

a= radius of punch, mm
b=radius of the specimen, mm
h=height of the specimen, mm
P= maximum load, N

Plate 3. Tensile strength test setup.

6. TESTING OF MOISTURE DAMAGE.

As per the procedure described by AASHTO 2013, the third set of asphalt concrete specimens in this study was subjected to moisture damage according to **(AASHTO, 2013**), **(Tarefder. and, Yousefi , 2012)** and **(SarsamI, and Alwan., 2015).** The set was divided into two groups specimens of conditional and unconditional; the first group was indicating an unconditioned specimen which was tested for Indirect Tensile Strength (ITS) at 25°C. The second group of asphalt concrete specimens was immersed in water at 25 °C into the desecrator and subjected to saturation under a vacuum pressure of 3.74 kPa for ten minutes. The specimens were removed from the water chamber and stored in a deep freezer for 16 hours at (-18) °C. Specimens were withdrawn from the deep freezer and allowed for thawing for 120 minutes in the air then were transferred into a water bath and stored for 120 minutes at 60 ºC. Specimens were denoted as conditioned specimens then stored at 25 °C for 120 minutes before testing for ITS**. Plate 4** exhibits the specimens under the moisture damage process in the water bath.

Plate 4. Specimens under moisture damage process.

7. RESULTS AND DISCUSSION.

7.1 Influence of volumetric Properties on ultrasonic pulse velocity

As explained in **Fig.1**, increasing the volume of voids filled with asphalt VFA leads to an increase in the pulse velocity. This could be attributed to the reduced total available air voids percentages by blocking, voids with asphalt cement, and allowing the ultrasonic pulse to traverse the specimen quickly**. Fig.2** shows the increase in pulse velocity with the reduction in the specimen's total volume of voids. Similar actions can be observed regarding considerably better propagation of pulse through the specimen as the voids reduce.

Fig.3 shows the increase in ultrasonic pulse velocity with the asphalt cement increase. The asphalt cement will overlay the aggregates with a thin film and fill some of the voids, which increase the propagation of the ultrasonic pulse through the asphalt concrete specimen.

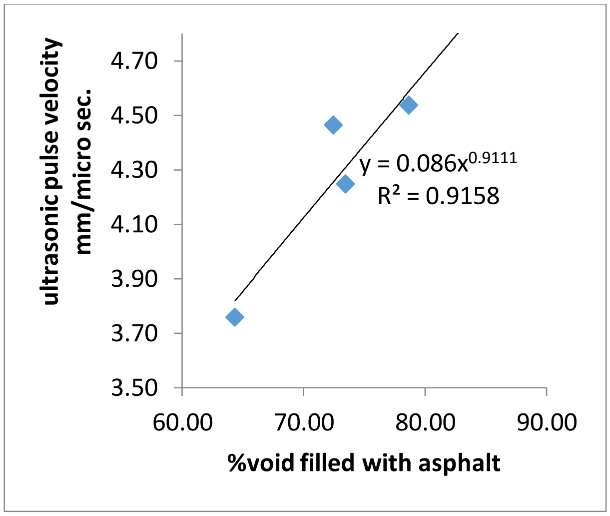


Figure 1. Ultrasonic pulse velocity -VFA relationship.

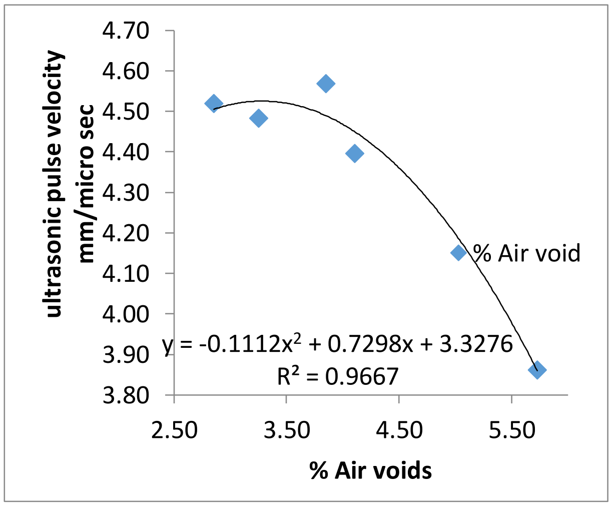


Figure 2. Ultrasonic pulse velocity - Total Voids relationship.

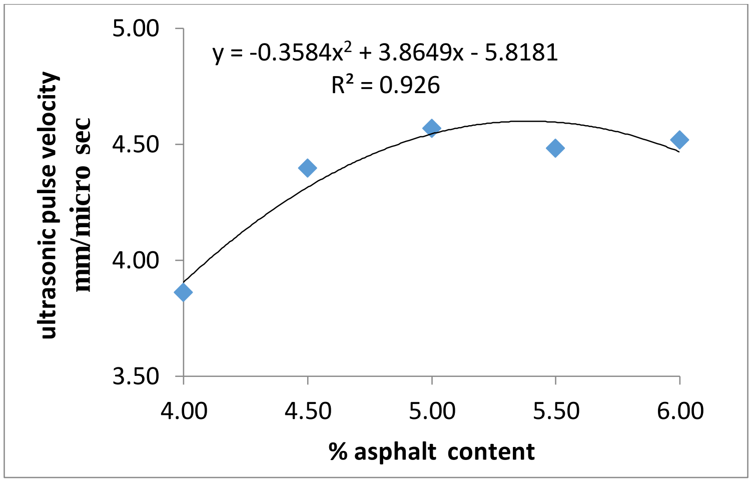
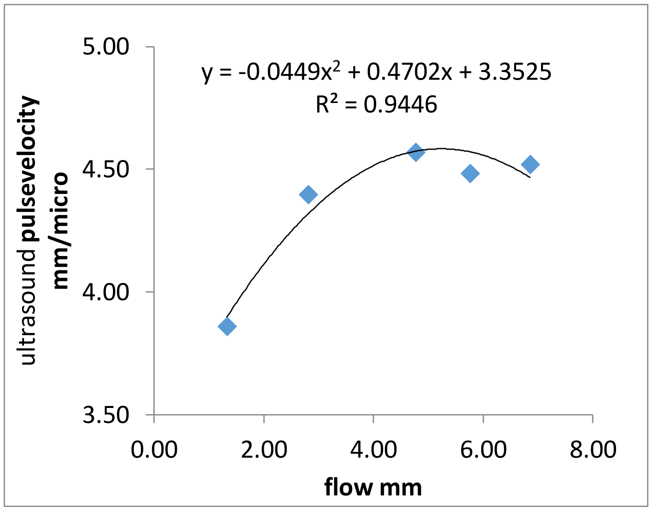


Figure3. Ultrasonic pulse velocity, asphalt content relationship.

7.2 Influence strength properties on ultrasonic pulse velocity.

Fig.4 shows the increase in pulse velocity when the Marshall stability increases. This could be attributed to the fact that the Marshall stability increases as the density of asphalt concrete increases. **Fig. 5** shows that the ultrasonic pulse velocity increase as flow value increase; this could be related to the fact that the increase in asphalt content could increase the flow values causes increase the pulse velocity.

Fig. 6 exhibits the influence of shear strength on the ultrasonic pulse velocity. It can be observed that, as the punching shear increases, the pulse velocity increases. This may be attributed to the fact that shear strength is mainly dependent on the adhesion of the binder with aggregate, and particle interlock. Such adhesion requires more asphalt cement, which will block the voids and facilitates the propagation of the ultrasonic pulse through the asphalt concrete specimen.



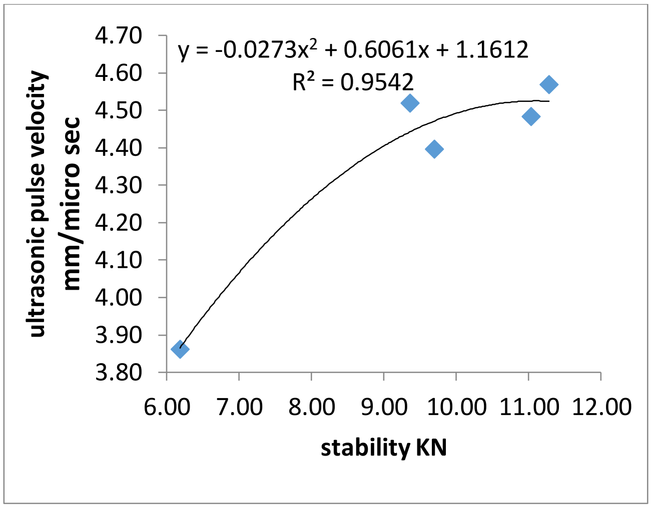


Figure 4. Ultrasonic pulse Velocity-Marshal Stability relationship.

Figure 5. Ultrasonic pulse velocity- flow relationship.

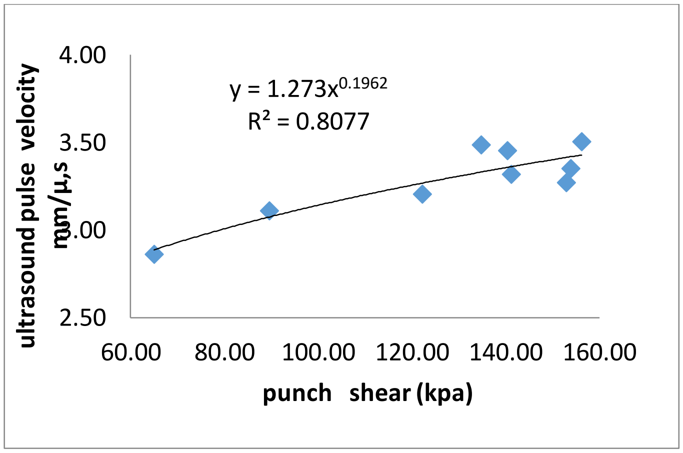


Figure 6. Punching shear – ultrasonic pulse velocity relationship.

7.3 Influence of Testing Temperature and Indirect Tensile Strength on ultrasonic pulse Velocity

In **Fig.7**, asphalt concrete specimens have also been tested for ITS indirect tensile strength. Two test temperatures were considered (25 and 40) °C. It can be observed that higher test temperatures exhibit higher ultrasonic pulse velocity. The testing temperature in general, although the lower testing temperature of 25 °C, exhibits lower ultrasonic pulse velocity as compared to that at 40 °C; this could be attributed to the reduction in voids as the asphalt expand of higher temperature.

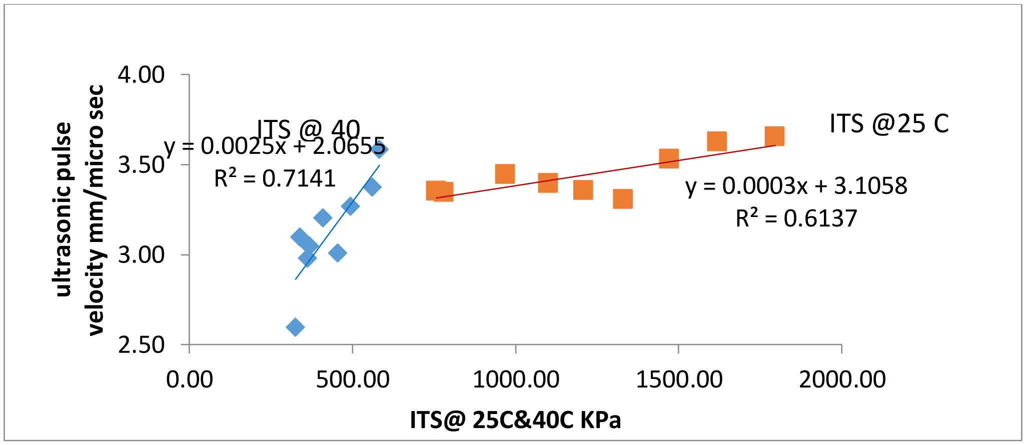


Figure 7. Tensile Strength-Pulse velocity relationship.

7.4 Influence of Moisture Damage on ultrasonic pulse velocity

Fig.8 shows the relation of moisture damage on pulse velocity. It can be noted that asphalt concrete specimens after practicing the moisture damage cycle (conditioned), shows lower pulse velocity by 13% than that of (unconditioned) case. This could be attributed to the possible micro-cracks initiated during the freezing stage of the test and, the possible stripping occurred during the thawing stage of the test.

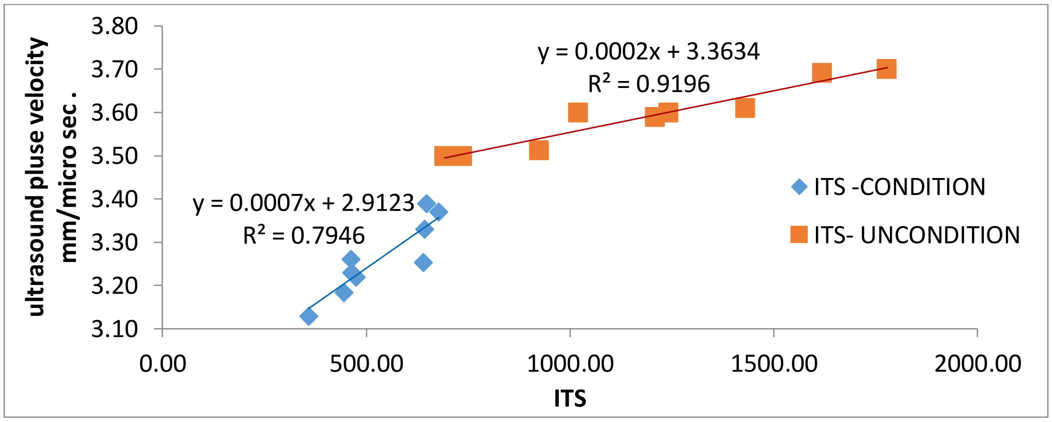


Figure 8. Influence of moisture damage on ultrasonic pulse velocity.

8. CONCLUSIONS.

The following conclusions are drawn on the basis of the testing program:

1. The wave velocity increases as bulk density, asphalt content, and volume of voids filled with asphalt VFA, increase.
2. The wave velocity increases as flow, Marshal Stability, shear, and tensile strengths increase.
3. Moisture damage exhibit negative influence on wave velocity by 13%, influence on pulse velocity
4. The testing temperature shows a significant influence on pulse velocity by 4%when testing at 40°C.

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