Correlation Study of Microwave Non Destructive Testing (MNDT) and Ultrasonic Pulse Velocity (UPV) on Concrete Block

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***Abstract*- The main objective of this project is to study the relationship of the electrical properties by using microwave non destructive testing (MNDT) and ultrasonic pulse velocity (UPV). In this project, ten sample of concrete block are use. The electrical properties of interest in microwave non destructive testing (MNDT) are dielectric constant, loss factor and loss tangent, but for ultrasonic pulse velocity (UPV) the properties that involved are path length, velocity and also the transit time that the wave propagate from transmitter to the receiver. In order to know this relationship, five stages of process are involved which is collecting the sample of the concrete block, measure by using microwave non destructive testing (MNDT) , finding the electrical properties by using FORTRAN software based on S_{11} and S_{21} parameters, measure the properties of concrete block using ultrasonic pulse velocity (UPV) and correlation process. In this project, firstly the concrete block sample was measured the concrete block by using Free Space Measurement System (FSMM) via the method of microwave non destructive testing (MNDT) at X-band which is 8 GHz to 12 GHz. The FSMM system consists of WILTRON 37269 Vector Network Analyzer (VNA), a pair of spot focusing antenna, mode transitions, coaxial cables, sample holder and computer. Each of the concrete blocks has a different of electrical properties. After done the measurement by using microwave non destructive testing (MNDT) the same sample was remeasured by using Pundit Plus Ultrasonic Tester via the method of ultrasonic pulse velocity (UPV) in order to know its path length, velocity and transit time. From the result obtained, clearly the relationship by using microwave non destructive testing (MNDT) and ultrasonic pulse velocity (UPV) can be made.**

***Keywords*-Vector Network Analyzer (VNA), Ultrasonic Pulse Velocity (UPV), Microwave Nondestructive Testing (MNDT), Free Space Microwave Measurement (FSMM).**

I. INTRODUCTION

Cement-based materials which are concrete block that using in this project are widely used in construction industry, domestic, commercial, recreational, rural and educational construction. Communities around the world rely on concrete as a safe, strong and simple building material. It is used in all types of construction; from domestic work to multi-storey office blocks and shopping complexes. Despite the common usage of concrete, few people are aware of the considerations involved in designing strong, durable, high quality concrete [1]. Knowledge of physical properties of such materials is important for determination of their quality [1]. Actually concrete block is made by mixing cement, water, coarse and fine aggregates. Each concrete block that was used in this project has different compositions. So, that differences in these compositions will be differentiates each concretes block from one to another from the electrical properties by using Microwave Nondestructive Testing (MNDT) and Ultrasonic Pulse Velocity (UPV).

Microwave Nondestructive Testing (MNDT)

Free Space Microwave Measurement (FSMM) using Microwave non-destructive techniques have shown great potential for the determination of properties which is to determine its dielectric constant, loss factor and also loss tangent of different block concrete. The main advantage of this Free Space Microwave Measurement (FSMM) system is that with suitable modifications, it is possible to make precise, accurate and reproducible Microwave Nondestructive Testing (MNDT)) measurements on materials under high or low temperature conditions and complex electromagnetic environmental conditions due to contactless feature of free-space measurements. Another significant advantage of free-space methods is that the measurements can be made when incident, reflected and transmitted signals are circularly/elliptically polarized electromagnetic waves. This Free Space Microwave Measurement (FSMM) system consists of a pair of spot-focusing horn lens antennas, mode transitions, coaxial cables and a vector network analyzer (VNA).

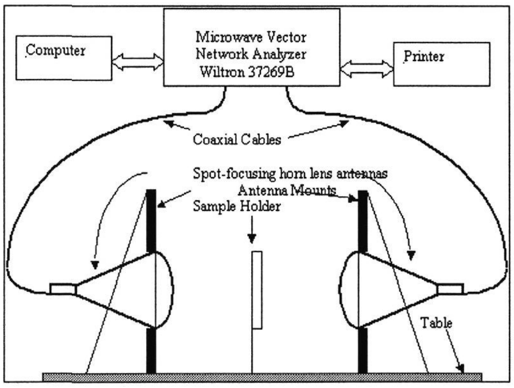

Figure 1: Schematic diagram of free space microwave measurement system

Ultrasonic Pulse Velocity (UPV)

Ultrasonic Pulse Velocity (UPV), involve one or more of the following measurement which is, time of transit of the wave, path length, frequency and velocity. The method of measurement make use either pulsed or continuous waves [2]. The pulse technique is the simplest of all ultrasonic testing methods and it is commonly used. It consists basically of measuring the time taken for a short train of sound waves to move through a given distance. This distance can be determined if the speed of sound in the material is known or, if the distance be known; the speed of sound can be readily calculated. Pulse methods have advantages of being able to provide readily defined and accurately located reference points for transit time [2]. By measuring the relative amplitude of pulses which have travelled different distance, one can determine attenuation coefficients. Observing the patterns of the received pulses can provide valuable information about the nature of a defect at which the pulses have been reflected and, perhaps, of the structure of the material being tested [3]. Actually pulse-echo method is the most commonly used ultrasonic pulse technique [4]. In this project, transit time means the time taken when the wave propagates in this concrete block from the transmitter transducer to the receiver transducer and velocity regarding to this project is the speed of that wave. Besides that path length means that the length of the wave that propagates in this concrete block. Actually each concrete block have different of this properties but all of this properties have the relationships between one and another.

II. THEORY

Every material has a unique set of electrical characteristics that are dependent on its dielectric properties. Permittivity is a quantity used to describe dielectric properties of material under the influence of electromagnetic waves with reflection at interfaces and the attenuation of wave energy within those materials [5]. Below the formula of complex relative permittivity (ε*) of a material in a frequency domain which is expressed in equation (1).

$$\varepsilon^* = \varepsilon' - j\,\varepsilon'' = \frac{D}{E} \text{ and } \varepsilon'' = \frac{\sigma}{\varepsilon_o\,\omega} \qquad (1)$$

Where;

ε^* = relative permittivity of the material
ε'= dielectric constant
ε'' = loss factor
ε_o = permittivity of free space
σ = conductivity of the material
ω = angular frequency of the field
D = electric flux density or displacement
E = electric field intensity

The real part actually referred to the dielectric constant (ε'), while the imaginary parts are referred to the loss factor which is (ε"). Actually the dielectric constant is ratio of the permittivity of a substance to the permittivity of free space. It is an expression of the extent to which a material concentrates electric flux, and is the electrical equivalent of relative magnetic permeability [5]. In this project the dielectric constant are referred the stored of energy when the material is exposed to an electric field while dielectric loss factor which is can be determine by energy absorption and attenuation.

When a linearly polarized, uniform plane wave is normally incident on the sample of thickness (d_s) and this incident wave actually transmitted, reflected and absorbed by the sample [5]. The S_{11} actually refereed to the reflected signal and S_{21} referred to the transmitted signal. The formula of S_{11} and S_{21} are shown in the equation (2) and equation (3) below.

$$S_{11} = \frac{\Gamma - \Gamma \exp(-2\gamma_s d_s)}{1 - \Gamma^2 \exp(-2\gamma_s d_s)} \quad (2)$$

$$S_{21} = \frac{(1 - \Gamma^2) \exp(-\gamma_s d_s)}{1 - \Gamma^2 \exp(-2\gamma_s d_s)} \quad (3)$$

Where;

γ_s = propagation constant in the sample

Γ = reflection coefficient of the sample /air interface

Both are functions of the complex permittivity of the sample (ε^*) and given by Equation (4):-

$$\varepsilon^* = \frac{\gamma_s}{\gamma_0}\left(\frac{1-\Gamma}{1+\Gamma}\right) \quad (4)$$

Where, $\gamma_o = (\frac{j2\pi}{\lambda_o})$ represents the propagation constant of free space and λ_o is the free-space wavelength. Equations (1) to (4) will be the basis to the calculation of complex permittivity of concrete block.

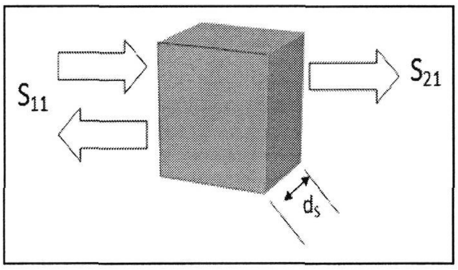

Figure 2: Schematic diagram of concrete block.

III. METHODOLOGY

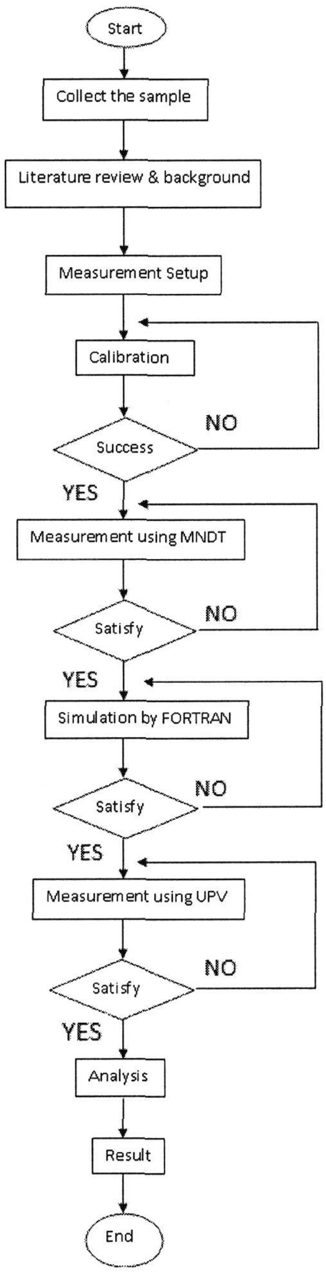

Figure 3: Methodology Process

IV. MEASUREMENT SYSTEM

Microwave Nondestructive Testing (MNDT)

The measurement system of Microwave Non Destructive Testing is consists of coaxial cables and

WILTRON 37269B Vector Network Analyzer (VNA). This network analyzer is used to make accurate reflection and transmission (S-parameters) measurements in free-space using line-reflect-line calibration model. This WILTRON 37269B Vector Network Analyzer (VNA) actually are connected to a pair of spot focusing antenna by using circular to rectangular waveguide analyzers. The focused antennas are connected to the two ports of the WILTRON 37269B vector network analyzer by using precision coaxial cables, rectangular-to-circular waveguide adapters and coaxial-to-rectangular waveguide adapters. These antennas have two-equal plano-convex lenses mounted back to back in a conical horn antenna. One plano-convex lens gives an electromagnetic plane wave and the other plano-convex lens focuses the electromagnetic radiation at the focus. For these antennas, the ratio of focal distance to antenna diameter (F/D) of the lens is equal to one and D is approximately 30.5 cm. The distance between these antennas can be change and a sample holder placed at the common focal plane for holding concrete block sample is mounted on a micrometer- driven carriage.

The inaccuracies in dielectric measurement using free space method are mainly due to the diffraction effects at the edge of the sample and due to multiple reflections between coaxial-to-rectangular waveguide adapters, rectangular-to-circular waveguide transitions. Actually, the spot-focusing horn lens antennas were used for minimizing diffraction effects due to the edge of the sample. The thru, reflect, and line which is TRL calibration technique and time domain gating feature of the network analyzer were used to eliminate errors due to multiple reflection. This setup operates in the frequency range 8 GHz to 12 GHz because in this project are used X-band. The TRL technique requires three standards, which is through connection, a short circuit connected to each port, and a transmission line connected between the tests ports [6]. These calibrations standard are easier to implement in free space as compared with discrete impedance standards required in other calibration techniques.

For this calibration concept actually involves the mid band frequency which is 10 GHz, the devices of the micrometer are set to be 0.00 mm. That means, no samples are located in the middle of the sample holder. The distance of the antenna is changed to changing the gauge meter to 7.5mm from the center of the middle reference plates. The thickness of the metal plate that already using for this calibration technique is 3.18mm, so the distance must be moved behind depends on thickness of this metal plate. After TRL calibration, the thru connection was measured for S11 readings and the reflect connection was measured for S21 readings. The amplitude and phase of S11 were 0.0±0.2dB and 180°±1° while the amplitude and phase for S21 were 0.0±0.1dB dB and 0°±1° respectively. After calibration process has been done, the concrete blocks was placed between the spot focusing antennas and then do the measurement of S_{11} and S_{21}. The ε' and ε" of the concrete blocks sample can be extracted by S_{21} using FORTRAN software.

Figure 4: FSMM system

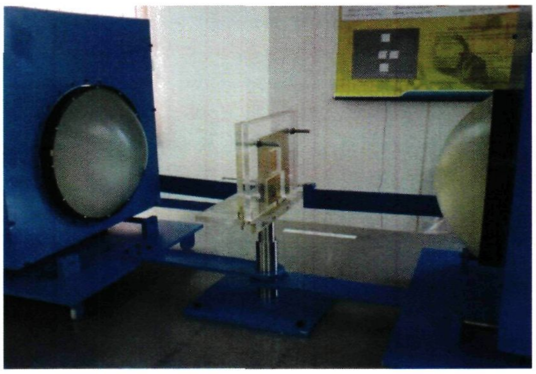

Figure 5: Calibration using TRL

Figure 6: Sample of concrete block

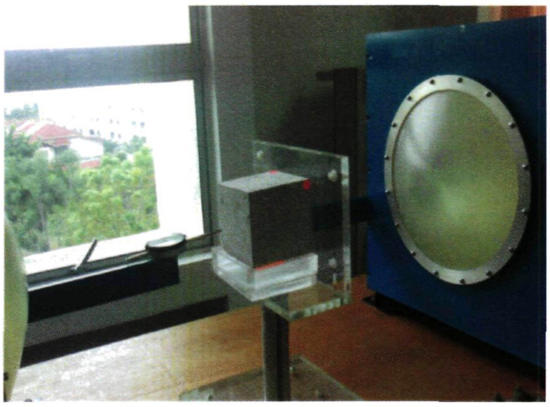

Figure 7: Measurement progress

Ultrasonic Pulse Velocity (UPV)

The measurement of the velocity, path length and transit time of ultrasonic pulses as a means of testing materials was originally developed for assessing the quality and condition of concrete and the PUNDIT will undoubtedly be used predominately for this purpose. Figure 8 shows the picture of this equipment. In most of the applications it is necessary to measure the pulse velocity to a high degree of accuracy since relatively small changes in pulse velocity usually reflect relatively large changes in the condition of the concrete. For this reason it is important that care be taken to obtain the highest possible accuracy of both the transit time and the path length measurements since the pulse velocity measurement depends on both of these. Accuracy of transit time measurement can only be assured if good acoustic coupling between the transducer face and the concrete surface can be achieved. For a concrete surface formed by casting against steel or smooth timber shuttering, good coupling can readily be obtained if the surface is free from dust and grit and covered with a light or medium grease or suitable couplant. A wet surface presents no problem. If the surface is moderately rough, stiffer grease should be used but very rough surfaces require more elaborate preparation [7].

Direct method

When an ultrasonic pulse traveling through concrete meets a concrete-air interface, there is a negligible transmission of energy across this interface so that any air-filled crack or void lying directly between the transducers will obstruct the direct beam of ultrasound when the void has a projected area larger than the area of the transducer faces. The first pulse to arrive at the receiving transducer will have been diffracted around the periphery of the defect and the transit time will be longer than in similar concrete with no defect [7].

The arrangement for direct method is as shown in Figure 9, where it requires access to two surfaces. The transmitting and receiving transducers are placed on opposite surfaces of the concrete slab. This will give maximum sensitivity and provide a well-defined path length.

Figure 8: Pundit Plus Ultrasonic Tester

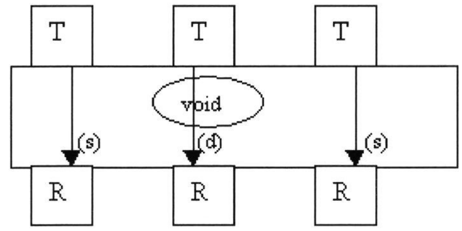

Figure 9: Direct Method

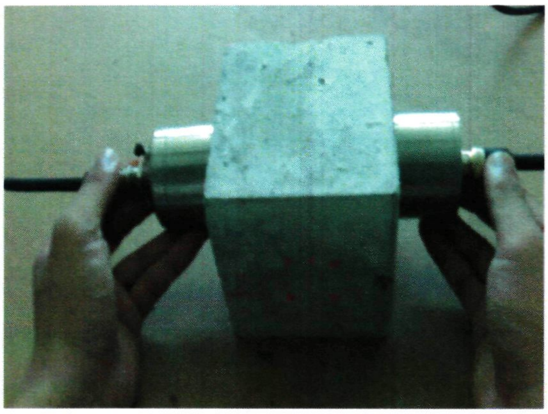

Figure 10: Measurement Progress

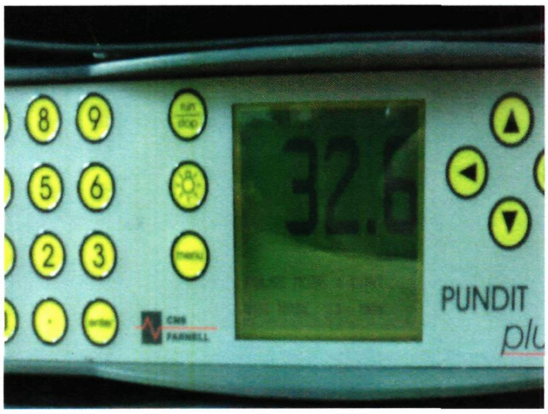

Figure 11: Reading of measurement progress

V. RESULTS & DISCUSSION

The electrical properties which are dielectric constant, loss factor and loss tangent were obtained from S_{11} and S_{21} parameters after extracted it by using FORTRAN software. The results at mid band of X-band which is 10 GHz were taken into account for every concrete block that has been measured. From the calibration results in this project the magnitude and phase of S11 are 0.089 dB and 179.03° of the theoretical value of 0dB and 180° for the reflect calibration. For the thru calibration technique, magnitude and phase of S21 are 0.009 dB and 0.22° of the theoretical values of 0dB and 0°.

Each concrete block that was used in this project has different compositions. So, that differences in these compositions will be differentiates each concretes block from one to another from the electrical properties by using Microwave Non destructive Testing (MNDT) and Ultrasonic Pulse Velocity (UPV) instead that the ideal dielectric constant of concrete block is 2.2

Table 1 shows the average value for dielectric constant, loss factor and loss tangent from 10 samples of concrete block at 10 GHz mid band frequency. For the Table 2, shows the transit time, velocity and path length by using Pundit Plus Ultrasonic Tester via the method of ultrasonic pulse velocity (UPV) that the wave propagate from the transmitter to the receiver. For table 3 shows the combination of MNDT and UPV after the value of dielectric constant are arranged from the highest of dielectric constant to the lowest of the dielectric constant.

Table 1: Dielectric Constant, Loss Factor and Loss Tangent for every concrete block by Using MNDT

Name of concrete block	Dielectric Constant	Loss factor	Loss Tangent
A	2.6199	-0.5426	-0.2071
B	2.6699	-0.2345	-0.0878
C	2.5335	-0.2227	-0.0879
D	2.5763	-0.2233	-0.0867
E	2.437	-0.2151	-0.0883
F	2.6056	-0.2357	-0.0904
G	2.5793	-0.616	-0.2388
H	2.6466	-0.6024	-0.2276
I	2.5937	-0.653	-0.2518
J	2.5892	-0.6671	-0.2576

Table 2: Transit time, Velocity and Path Length for every concrete block by Using UPV

Name of concrete block	Transit Time (us)	Velocity (ms)	Path Length (mm)
A	28	3.8929	109
B	29.2	3.87	113
C	31.2	3.6859	115
D	34	3.5294	120
E	30.2	3.7086	112
F	26.8	3.9179	105
G	34.5	3.5072	121
H	28.6	3.8811	111
I	25.5	3.9216	100
J	36.3	3.4986	127

Table 3: Combination of MNDT and UPV after the dielectric constant already arranged

Name of concrete block	Dielectric Constant	Loss factor	Loss Tangent	Transit Time (us)	Velocity (ms)	Path Length (mm)
B	2.6699	-0.2345	-0.0878	29.2	3.87	113
H	2.6466	-0.6024	-0.2276	28.6	3.8811	111
A	2.6199	-0.5426	-0.2071	28	3.8929	109
F	2.6056	-0.2357	-0.0904	26.8	3.9179	105
I	2.5937	-0.653	-0.2518	25.5	3.9216	100
J	2.5892	-0.6671	-0.2576	36.3	3.4986	127
G	2.5793	-0.616	-0.2388	34.5	3.5072	121
D	2.5763	-0.2233	-0.0867	34	3.5294	120
C	2.5335	-0.2227	-0.0879	31.2	3.6859	115
E	2.437	-0.2151	-0.0883	30.2	3.7086	112

Figure 12 shows that, the data measurement of dielectric constant at 10 GHz versus transit time for 10 sample of concrete block. From that figure, it shows that the higher the dielectric constant the higher the transit time will be. It means that, the higher the dielectric constant, the longer the time for the wave to propagate from the transmitter to the receiver by using Pundit Plus Ultrasonic Tester via the method of ultrasonic pulse velocity (UPV).

From figure 12 obviously, all ten concrete block can be divided into 2 groups which are Group I and Group II as shown in the Table 4. The Group I consists of concrete block B, H, A, F and I and Group II consists of concrete block J, G, D, C and E.

Figure 13 and Figure 14 shows clearly the relationships of dielectric constant with transit time for concrete block from group I and group II respectively. It can be conclude that the highest of the dielectric constant, the highest the transit time will be.

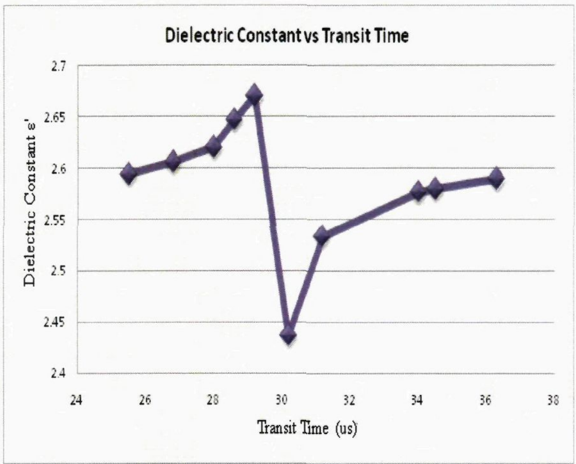

Figure 12: Dielectric Constant vs. Transit Time

Table 4: Group I and Group II of the sample concrete block

Group	Name of concrete block	Dielectric Constant	Loss factor	Loss Tangent	Transit Time (us)	Velocity (ms)	Path Length (mm)
I	B	2.6699	-0.2345	-0.0878	29.2	3.87	113
	H	2.6466	-0.6024	-0.2276	28.6	3.8811	111
	A	2.6199	-0.5426	-0.2071	28	3.8929	109
	F	2.6056	-0.2357	-0.0904	26.8	3.9179	105
	I	2.5937	-0.653	-0.2518	25.5	3.9216	100
II	J	2.5892	-0.6671	-0.2576	36.3	3.4986	127
	G	2.5793	-0.616	-0.2388	34.5	3.5072	121
	D	2.5763	-0.2233	-0.0867	34	3.5294	120
	C	2.5335	-0.2227	-0.0879	31.2	3.6859	115
	E	2.437	-0.2151	-0.0883	30.2	3.7086	112

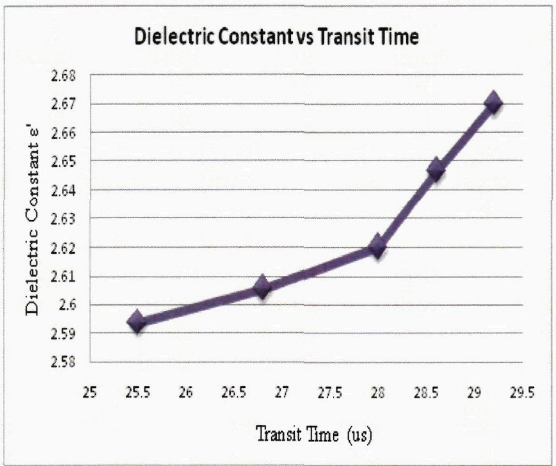

Figure 13: Dielectric Constant vs. Transit Time for concrete block of Group I

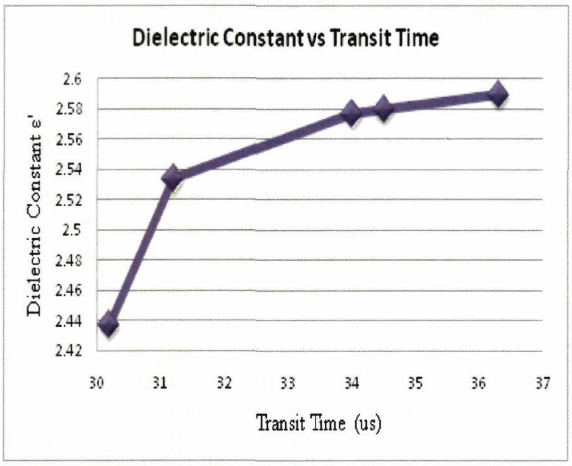

Figure 14: Dielectric Constant vs. Transit Time for concrete block of Group II

Figure 15 were illustrated the plot of loss factor and loss tangent of the several of concrete sample at X-band which is 10 GHZ mid band frequency versus transit time. From the graph, it was shown that no relationship can be made between loss factor or loss tangent with transit time because not much loss factor or loss tangent changing with transit time.

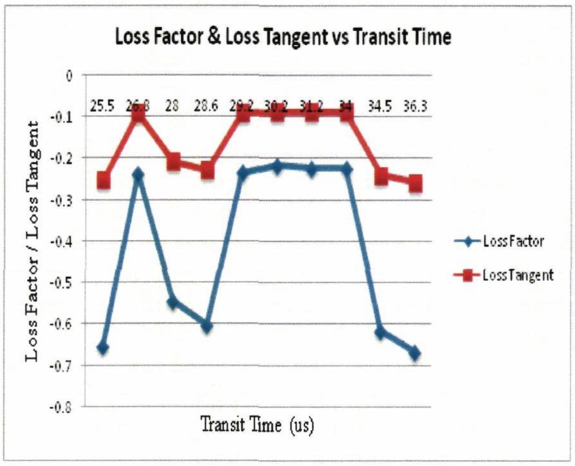

Figure 15: Loss Factor & Loss Tangent vs. Transit Time

Figure 16 shows, the dielectric constant of 10 concrete blocks versus velocity. This velocity means the velocity of the wave that propagated from transmitter transducer to the receiver transducer by using Pundit Plus Ultrasonic Tester via the method of ultrasonic pulse velocity (UPV) when doing the measurement at that concrete block. From that figure, it shows that the lower the dielectric constants, the faster the velocity of that wave propagate. From Figure 16 also, the entire ten concrete blocks can be divided into two groups as before. Figure 17 and Figure 18 shows the relationship between dielectric constant and velocity for group I and group II respectively. According to the graph, the lower dielectric constant, the higher the velocity will be.

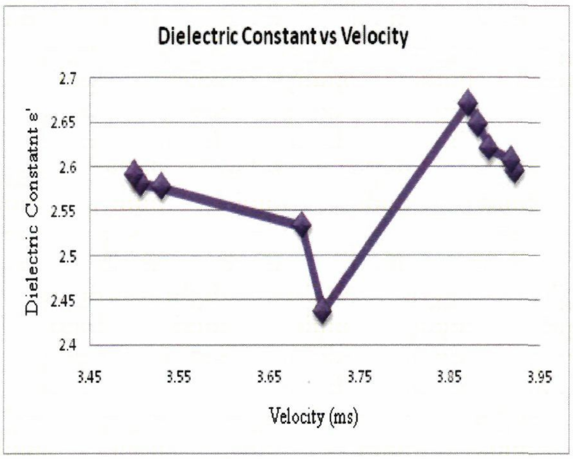

Figure 16: Dielectric Constant vs. Velocity

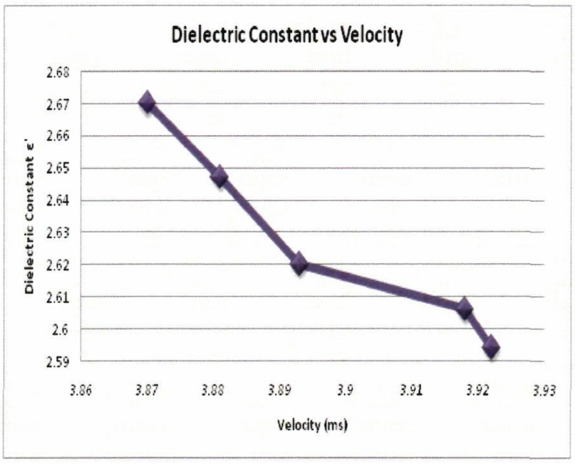

Figure 17: Dielectric Constant vs. Velocity for concrete block of Group I

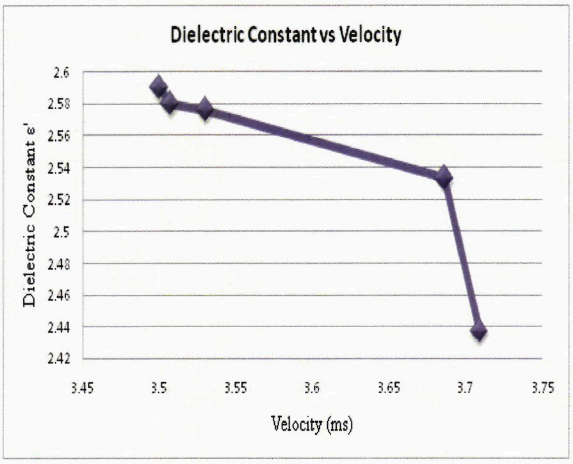

Figure 18: Dielectric Constant vs. Velocity for concrete block of Group II

Figure 19 are shown the loss factor and loss tangent versus the velocity of the ultrasonic wave. In this figure too, the data that tabulated are not having the consistency. These situations actually are same with the loss factor and the loss tangent versus transit time. The plotted of the loss factor versus velocity actually quite similarly with loss tangent versus velocity. From the graph, it was shown that no relationship can be made between loss factor or loss tangent with velocity because not much loss factor or loss tangent changing with velocity. Actually, each concrete block has a unique loss factor and loss tangent respectively.

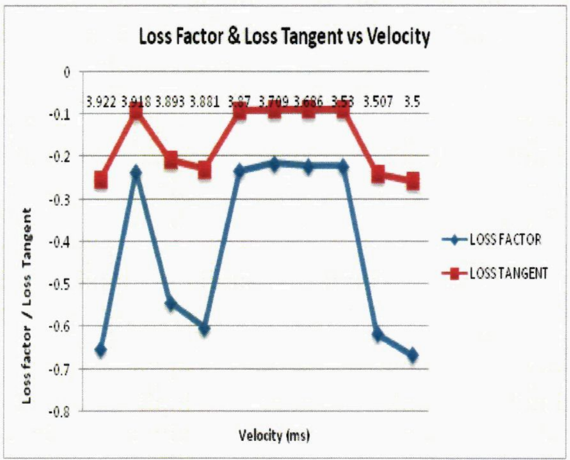

Figure 19: Loss Factor & Loss Tangent vs. Velocity

Figure 20 shows, the dielectric constant versus path length for 10 samples of the concrete block. Path length means that the length of the wave that propagates from the transmitter transducer to the receiver transducer when that wave propagates in the concrete block. From that figure, the higher the dielectric constant, the higher the path length, meaning that the higher the dielectric constant the longer the wave propagates from the transmitter to the receiver. If a certain concrete block having a many bubble inside it, the path length of that wave will be longer.

Figure 20, all the concrete block sample also can be divided into two group which is, in Figure 21 and Figure 22. This of two figures shown clearly about the relationship between dielectric constant with path length.

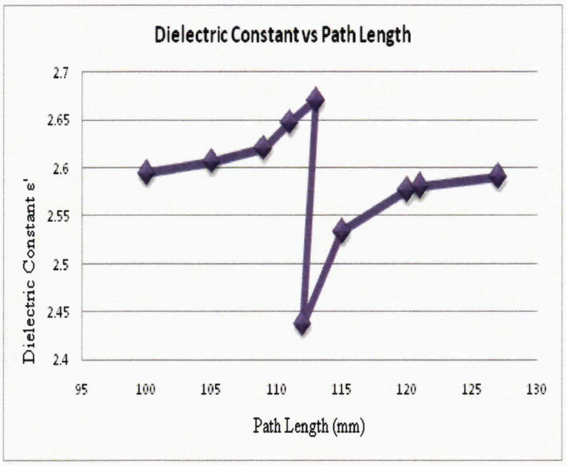

Figure 20: Dielectric Constant vs. Path Length

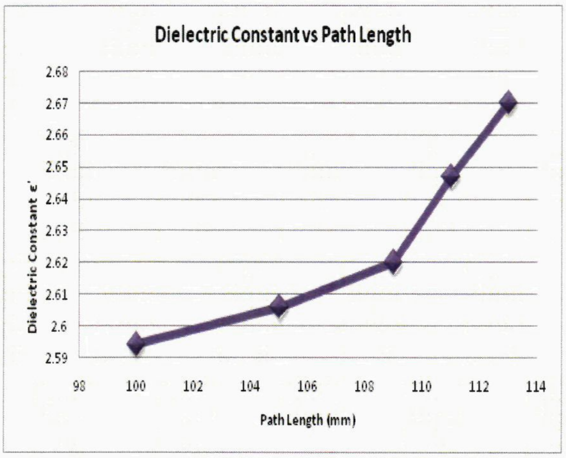

Figure 21: Dielectric Constant vs. Path Length for concrete block of Group I

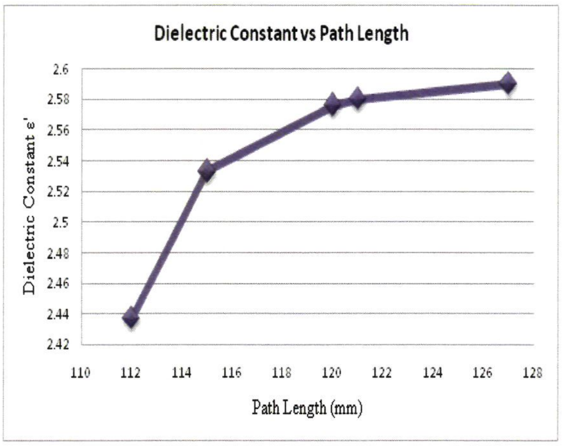

Figure 22: Dielectric Constant vs. Path Length for concrete block of Group II

Figure 23 observed that, the loss factor and the loss tangent versus path length. In this case also, the plotted graph of loss factor quite similarly with the loss tangent and this of two properties actually not having a great relationship with path length because not much loss factor or loss tangent changing with path lengths of that wave propagate.

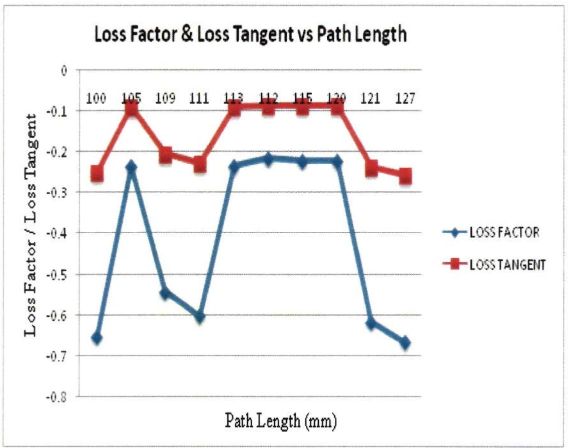

Figure 23: Loss Factor & Loss Tangent vs. Path Length

All the properties of the concrete block by using Ultrasonic Pulse Velocity which is transit time; velocity of the wave and also the path length actually is an important element to determine the strength of the concrete. But by using Ultrasonic Pulse Velocity, all of these properties do play a major role in determine the strength since dielectric constant has to be measured using Microwave Non Destructive Testing (MNDT). So, there is no significant relation between the strength of the concrete and the dielectric constant when using Non Destructive Testing (MNDT).

In this project the concrete block sample size is 10cm x 10cm x 10cm, so by measuring this sample by using Free Space Microwave Measurement (FSMM) via the method of Microwave Non Destructive Testing (MNDT) the wave can penetrate and also propagate through this material since its size 10cm x 10cm x10cm. It is because the penetration depth actually is between 38 mm and 102 mm which are 1.5 inch and 4 inch. In this project are using $\lambda/4$ and using X-Band which is 8 to 12 GHz so the mid band frequency is 10 GHz.

VI. CONCLUSION

Free Space Microwave Measurement (FSMM) using Microwave non-destructive techniques having a great potential for the determination properties of dielectric constant, loss factor and also loss tangent of different concrete block.

It was observed that when the dielectric constant of concrete block is high the transit time is also high, and the longer of the path length taken when the dielectric constants of concrete block is high. But, the velocity of that wave becomes slow when dielectric constant of the concrete block is high. Besides that, the value of the loss factor and the loss tangent are not much changing with any UPV parameters. Each concrete block sample actually has unique electrical properties.

Table 5: The relationship dielectric constant, transit time, path length and velocity

Dielectric Constant	Transit Time (us)	Path Length (mm)	Velocity (ms)
High	High (Longer)	High (Longer)	Low (slow)
Low	Low (Less)	Low (short)	High (faster)

VII. FUTURE DEVELOPTMENT

For the future study, research on dielectric constant for different grade of concrete block can be applied using Microwave Nondestructive Testing (MNDT) at higher frequency range.

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