UNIVERSITI PUTRA MALAYSIA

# *MICROWAVE CHARACTERIZATION TECHNIQUE OF MORTAR, CONCRETE REINFORCEMENT WIRE MESH, AND MORTAR FILLED WITH PVC TUBES*

MOHAMMED ABDULKAREEM JAWAD

FS 2014 25

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By

MOHAMMED ABDULKAREEM JAWAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

June 2014

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**DEDICATION**

***This thesis is especially dedicated to my beloved parents, brothers and sister***

***And***

***In memorial***

***My beloved grandfather***

***(Jawad)***

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia, in fulfillment of the requirement for the Degree of Master of Science

# MICROWAVE CHARACTERIZATION TECHNIQUE OF MORTAR, CONCRETE REINFORCEMENT WIRE MESH, AND MORTAR FILLED WITH PVC TUBES

By

**MOHAMMED ABDULKAREEM JAWAD**

**June 2014**

**Chairman: Associate Professor Zulkifly Abbas, PhD**

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This thesis describes a simple non-destructive free space technique to characterize Mortar, concrete reinforcement wire mesh (CRWM) and mortar filled with PVC tubes from 12 to 18 $GH_Z$ (Ku-band). This technique is simple, non-contact and precise method based on transmission and reflection properties of the samples. The measurement setup consists of a pair of transmitting and receiving lens horn antennas connected respectively to port 1 and port 2 of the Agilent N5230A PNA-L Vector Network Analyzer (VNA). The dielectric properties of the mentioned samples were measured using open ended coaxial probe. The minimum thickness of mortar structure to have a static value of dielectric constant and loss factor was found to be as 4.4 cm instead of 1.89 cm based on the manufacturers equation. The samples were placed in between the two horn antennas for the reflection and transmission coefficient measurements. The highest values of $S_{11}$ and lowest $S_{21}$ were found to be true for pure mortar structure whilst the opposites were found to be true for mortar filled with PVC tube. The mean $S_{11}$ for a mortar, CRWM and mortar filled with tubes were 0.31, 0.27 and 0.25 whilst the mean $S_{21}$ were 0.00008, 0.005 and 0.05, respectively. The curing time conditions were investigated for mortar structure at various thicknesses (1.1, 2.2, 3.3 and 4.4 cm). The transmission coefficients of all frequencies for a 1.1 cm thick sample are almost similar except for 17.5 $GH_Z$. Reduction in $S_{21}$ values at 17.5 $GH_Z$ were due to high absorption of water which coincides with its relaxation frequency. The measured results were compared with the Finite Element Method (FEM). The calculation was implemented using HFSS (High Frequency Structure Simulator). The measured dielectric constant and loss factor values were considered to be input values for the simulation to calculate ($S_{11}$ and $S_{21}$). Generally, the errors were found to be 0.99 for the calculated reflection coefficient ($S_{11}$) and 0.013 for the calculated transmission coefficient ($S_{21}$).

Abstrak tesis dikemukakan kepada Senat Universiti Putra Malaysia, sebagai memenuhi keperluan bagi mendapat Ijazah Sarjana Sains

**TEKNIK PENCIRIAN MIKROGELOMBANG UNTUK MORTAR, KONKRIT TETULANG BESI DAN MORTAR DENGAN TIUB PVC TERBENAM**

Oleh

**MOHAMMED ABDULKAREEM JAWAD**

**Jun 2014**

**Pengerusi: Professor Madya Zulkifly Abbas, PhD**

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Tesis ini menerangkan teknik tak memusnah udara lapang untuk memperciri mortar, konkrit yang diperkuat dengan jaringan wayar (CRWM) dan mortar yang diisi dengan tiub PVC daripada 12 hingga 18 GHz (jalur Ku). Teknik mudah, tanpa sentuh dan tepat ini adalah berdasarkan sifat hantaran dan pantulan sampel. Persediaan pengukuran terdiri daripada sepasang antena tanduk tranmissi dan penerima yang disambung ke port 1 and port 2 Agilent N5230A PNA-L Vector Network Analyzer (VNA). Sifat dielektrik sampel tersebut diukur dengan menggunakan penderi hujung sepaksi terbuka. Ketebalan minima bagi struktur mortar untuk mendapat nilai statik bagi dielektrik tetap dan faktor hilang didapati pada 4.4 sm dan bukannya 1.89 sm berdasarkan persamaan daripada pengeluar. Sample tersebut diletakkan di antara dua antena tersebut untuk pengukuran pekali pantulan dan hantaran. Nilai $S_{11}$ dan $S_{21}$ tertinggi dicatatkan pada struktur mortar asli manakali nilai sebaliknya dicatatkan pada mortar yang diisi dengan tibu PVC. Nilai purata $S_{11}$ bagi mortar, CRWM dan mortar yang diisi dengan tibu PVC adalah 0.31, 0.27 dan 0.25 manakala nilai purata $S_{21}$ masing-masing adalah 00008, 0.005 and 0.05. Tempoh pengeringan mortar telah diselidiki bagi ketebalan yang berbeza (1.1, 2.2, 3.3 and 4.4 sm). Nilai pekali hantaran bagi semua frekuensi untuk ketebalan 1.1 sm adalah sama kecuali 17.5 GHz. Pengurangan nilai $S_{21}$ pada 17.5 GHz adalah disebabkan oleh penyerapan yang tinggi oleh air berbetulan dengan frekuensi pengenduran. Hasil pengukuran telah dibandingkan dengan kaedah elemen hingga (FEM). Pengiraan dibuat denagn HFSS (High Frequency Structure Simulator). Pengukuran nilai tetap dielektrik dan faktor hilang digunakan untuk mengira ($S_{11}$ and $S_{21}$). Secara umumnya, ralat yang dicatatkan adalah sebanyak 0.99 untuk pengiraan pekali pantulan ($S_{11}$) dan 0.013 untul pekali hantaran ($S_{21}$).

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Mohammed Abdulkareem Jawad
2014


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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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# DECLARATION

**Declaration by Graduate Student**

I hereby confirm that:

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## LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| CRWM | - | Concrete Reinforcement Wire Mesh |
| PVC | - | Polyvinyl Chloride |
| PNA-L | - | Precision Network Analyzer |
| VNA | - | Vector Network Analyzer |
| cm | - | Centimeter |
| GHz | - | Giga Hertz |
| FEM | - | Finite Element Method |
| HFSS | - | High Frequency Structure Simulator |
| $S_{11}$, $S_{22}$ | - | Reflection coefficient |
| $S_{21}$, $S_{12}$ | - | Transmission coefficient |
| NDT | - | Non-Destructive Technique |
| ASTM | - | American Society for Testing and Material Standards |
| PCA | - | Portland Cement Association |
| PCC | - | Portland Cement Concrete |
| OPC | - | Ordinary Portland Cement |
| EM | - | Electromagnetic |
| DC | - | Direct current |
| AC | - | Alternating current |
| PTFE | - | Polytetrafluoroethylene |
| $\lambda$ | - | Wavelength |
| MOM | - | Method of Moment |
| FDM | - | Finite Difference Method |

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| | | |
|---|---|---|
| PDE | - | Partial Differential Equations |
| E | - | The electric field intensity |
| H | - | The magnetic field intensity |
| D | - | The electric flux density |
| B | - | The magnetic flux density |
| J | - | The current density |
| P | - | The electric charge density |
| E | - | Permittivity |
| $\mu$ | - | Permeability |
| $\omega$ | - | Angular frequency |
| f | - | Frequency |
| $\gamma$ | - | Propagation constant |
| $\alpha$ | - | Attenuation constant |
| $\beta$ | - | Phase constant |
| $\nabla$ | - | Laplacian vector |
| $tan\ \delta$ | - | Loss tangent |
| $\sigma$ | - | Conductivity |
| $\varepsilon'$ | - | Dielectric constant |
| $\varepsilon''$ | - | Loss factor |
| c | - | Velocity of light |
| VSWR | - | Voltage Standard Wave Ratio |
| dB | - | Decibels |
| PECs | - | Perfect Electric Conductor |

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| | | |
|---|---|---|
| PMCs | - | Perfect Magnetic Conductor |
| 3D | - | Three- Dimensional |
| *d* | - | Thickness |
| *L* | - | Location |
| PC | - | Portland Cement |

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# CHAPTER 1

# INTRODUCTION

## 1.1 A Brief Historical Description of Cement and Concrete

Concrete, which is compounded of hard and solid special materials, is often made by different types of gravel and sand. Also, water as well as cement is used to bond the sand and the gravel together. Furthermore, concrete is one of the materials that can be utilized in construction field.

The clay was used by the Assyrians and Babylonians as bonding materials. In contrast, gypsum and lime cement was utilized by the Egyptians. After that, the hydraulic cement, which is the modern cement, was firstly created by a British engineer called John Smeaton in 1756. The process of making this cement was achieved by adding pebbles as a coarse aggregate and then mixing powered brick into the cement. Posteriorly, Portland cement was invented by Joseph Aspdin, who was an English inventor, in 1824. From that time, the Portland cement has been the popular cement that is used in concrete production. The first actual artificial cement, which resulted from burning of the clay as well as ground limestone together, was made by Joseph Aspdin. Due to this burning process, several changes in the chemical characteristics of materials were achieved. Furthermore, stronger cement was acquired rather than the cement would be achieved from plain crushed limestone (Bellis, 2011).

Aggregate is considered another important part in addition to cement. Basically, Aggregates consist of gravel, slag, sand, burned shale, crushed stone, ashes, and burned clay. For making enormous section or structures of cement, the coarse aggregate can be used. While, for making the smooth surfaces and the concrete slabs, fine aggregate (in reference to size) is utilized. Concrete, which comprises of embedded metal, namely, usually steel, is known as reinforced concrete or ferroconcrete. In 1849, Joseph Monier, who was honored a patent in 1867, invented the reinforced concrete. Joseph Monier, who was a Parisian gardener, made garden concrete pots and tubes that were reinforced with iron mesh. Either bendable or tensile metal strength are combined by reinforced concrete with the compressional concrete strength in order to with stand heavy loads. This invention was exhibited in Paris Exposition in 1867. In addition to aforementioned, the reinforced concrete promoted to be used in bridges, floors, ties of railway, pipes, as well as arches.

In Mesopotamia, the early cement version consisted of gravel, sand and lime in the $3^{rd}$ millennium B.C, after that, in Egypt. It was uncertain by which a hydraulic mixture was resulted from the combination of the Pozzolan and hydrated non-hydraulic lime. However, the first usage of cement, which was resulted from such materials, was by Ancient Macedonians. Also, it was used after three centuries in a large degree by

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Roman engineers (Hill and Donald, 1984). Moreover, artificial pozzolans (pottery or ground brick) and natural pozzolans (pumice or trass) were used in these concretes.
The most notably examples of the structures that created from theses concretes are the enormous dome of the Pantheon in Rome and the huge Baths of Caracalla. An extensive use of hydraulic cement was created for large system of Roman aqueducts.

An active tradition of using the hydraulic cement in structures, for example, shipbuilding facilities, fortresses, canals, and harbors were maintained by several military engineers medieval masons. However, this knowledge preservation in the literary sources, which is from Middle Ages, is unknown. In the 18th, the French and the British engineers formalized the technical knowledge of making hydraulic cement (Sismondo and Sergio, 2009).

## 1.2 Modern Cements

Due to three main necessities, the development of the modern hydraulic cements initiated, which was around 1800, from the starting of the industrial revelation:

- Hydraulic cement render (stucco) for finishing brick buildings in wet climates.
- Hydraulic mortars for masonry construction of harbor works, etc., in contact with sea water.
- Development of strong concretes.

An important contribution for developing the cement was achieved by John Smeaton; in England, the third Eddystone Lighthouse construction of (1755–9) was planned by him. For the purpose of setting as well as developing some strength in the period of twelve hour between successive high tides, a hydraulic mortar was necessary.

After that, an intensive implementation of market research on the availability of hydraulic limes was accomplished by him. Then, the "hydraulicity" of the lime was noted to be correlating to limestone clay content. Smeaton, who was a civil engineer by vocation, took the idea no further. In the first nineteenth century decade, apparently unaware, Louis Vicat identified the same principles of Smeaton's work. In 1817, Vicat carried on inventing a combine of burning clay as well as chalking method into an intimate mixture; therefore, an "artificial cement" was produced (Mukerji and Chandra, 2009). Around the same time, "British cement" was produced by James Frost, who was working in Britain, in a similar manner (Francis, 1977). However, he did receive a patent until 1822. In 1824, Joseph Aspdin received a patent for a similar material, which he called Portland cement, since the render, which made from it, was in the same color of prestigious Portland stone. From 1850 onward, the concrete use in construction field grew quickly. Soon, it was considered the principal usage for cements; thus, Portland cement started playing a predominant role.

There are two types of cement, which can be categorized as hydraulic and non-hydraulic. Either constantly exposed to wet weather or under water cab be hardened. This is attributed to the chemical reaction between the water and the powder of



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anhydrous cement (hydration). Hydrates, which resulted from the chemical reaction, are not considered very durable in water and so water-soluble. Whilst, the underwater is not hardened by the non-hydraulic cements such as the reaction with atmospheric carbon dioxide can harden the slaked limes. Cement plays an important role as a material in the mortar and the concrete production in masonry, aggregate in order to form a material of a strong building.

When cement is mixed with water, which leads to a hydration series of chemical reactions, it is set or cured. The constituents slowly hydrate and crystallize; the cement is obtained its strength by the interlocking of the crystals. Also, the final strength and the speed of curing resulted from maintaining the high moisture content in cement, which is during curing time. The addition of the Gypsum is done to Portland cement in order to prevent a longer time of working and early hardening or "flash setting". The time of curing of cement is usually different and depending on the environmental as well as mixed conditions; the total cure can occur over a month, while the first hardening takes as little as twenty minutes. Within 24 hours to a week, the cement typically can cure to the extent where it can be used into service.

### 1.3 An Overview of Microwave Non-destructive Technique

The microwave signals can be easily penetrating into the dielectric media. The operation frequency as well as the loss factor of the dielectric material, which is the ability of absorption of the microwave energy, can dictate the depth penetration. Measurements can be carried on either a contact or non-contact mode whilst operating on either both sides or one side of the material (transmission or reflection techniques). Techniques of microwave NDT are considered sensitive to dimensional and geometrical variations of a medium or a defect. For the purpose of the increment of measurement sensitivity to certain orientation defects, the polarization properties of microwave signals can be utilized. By evaluating the properties and composition of mixtures comprising the curing influence, chemically produced composites can be also achievable. It cannot be essentially true that since the microwave signals in the centimeter range have wavelengths, the resolution, which acquired using these signals, is not considered to be better than a large fraction of the operating wavelength. For instance, in terms of monitoring variation of thickness in dielectric coatings and slabs, the illustration of the measurement resolutions of some microns at 10 GHz (wavelength of 3 cm in free space) is achieved by the techniques of the microwave NDT when the resolution is the smallest variation of thickness, which is probable to be detected. The better resolution of a wavelength has been provided by either techniques of a millimeter wave or the near-field microwave when the resolution, which in a given application, is the smallest spatial distance between two defects; therefore, they are separately detected. The resolution of the measurement in any way is not necessarily rendered better in terms of increasing the frequency (Zoughi and Ganchev, 1995).

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Also, at around cracks of 12 GHz fatigue, which is on metal surfaces with widths of a few microns, have been detected. Furthermore, spatial resolution is considered to be a microwave sensor function that used (e.g., open-ended coaxial lines, cavity resonators and open-ended waveguides, etc.). Statements that made in conjunction with resolutions of radar cannot be always applied to techniques of microwave NDT although both use microwaves because most of applications of NDT are conducted in the near-field of a probe, as opposed to its far-field. Furthermore, compared to the far field, changes in properties of the reflection coefficient in terms of defect as well as a given microwave sensor are different in the near-field.

A long history of microwave nondestructive techniques (MNDT) can be traced to the early 1950s, a well-built flurry of activities in1960s and 1990s. Nonetheless, these techniques are usually due to as "emerging techniques" and not popularly distinguished in the community of nondestructive testing (NDT). Developing the techniques of the millimeter as well as microwave NDT is considered to be interesting for those who appreciated the advantages and the importance of such techniques. Moreover, this increased visibility can be encouraging and a welcome change. In general, unlike the community of NDT, the microwave community is generally more aware of the applications of microwaves; to avoid inspecting structures and materials intrusively. Nonetheless, articles usually are considered to having the attention of the practitioners when published in microwave oriented journals, which is not NDT. In addition to that, even though the developing approaches can be expanded in order to comprise the problems of practical NDT, the majority of these scientific investigations might not attack a problem of NDT straightly. The variation of theoretical development of antenna admittance, which is in layered plasma, is a good example for that. The layered plasma can be very similar to a layered dielectric composite even though majority of such problems have dealt with understanding the characteristics of an antenna that is at a spacecraft while re-entering the atmosphere. There are several experimental and theoretical developments of millimeter as well as microwave (besides to research in the 1970s and early 1980s), especially in terms of NDT purposes, that occurred in the last few years. An example of a significant potential application area for microwave and millimeter wave NDT can be represented by the new dielectric material inspection of such as composites.

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### 1.4 Problem Statement

Defects in concrete structure are usually traceable to construction or concreting procedures used. The type of defect must be identified accurately to ensure an effective repair method. Visual examination is insufficient to provide enough information to locate the defect. In some cases, visual examination could not even identify defects such as pores or wire mesh in a concrete. Several measurement techniques have been proposed as solutions. However, many of these techniques as described in Chapter 2 are too expensive, sophisticated, inaccurate or impractical for in-situ measurements. In recent years, microwave techniques are gaining increasing interest as the preferable technique to evaluate defect in concretes. However, many of these techniques were applied at frequencies lower than 12 GHz. The effect of ionic conductivity at frequencies below 3 GHz remained a problem in defect evaluation to discriminate between trapped water and wired mesh or other lossy materials. Measurements in the X-band frequency between 8 GHz and 12 GHz, however, were limited to reflection measurement and no attempts were made to classify between pure mortar, concrete reinforcement wire mesh (CRWM) and mortar filled with tubes.

This thesis discriminates mortar, concrete reinforcement wire mesh and mortar filled with PVC tubes in frequency range from 12 to 18 $GH_Z$ (Ku-band) as well as detects the locations of wire mesh and tubes inside the mortar structure using non-destructive free space technique. In addition, monitors the minimum thickness for the mortar structure to obtain a static value of dielectric constant and loss factor. The higher the measurement frequency, the lower the wavelength and thus the higher will be the microwave probing resolution. Also effect of moisture content on the curing time can be easily observed at frequencies close to 17 GHz which is the relaxation frequency of water. Also this thesis employs a Finite Element Method (FEM) to calculate both the reflection and transmission coefficients ($S_{11}$, $S_{21}$) of pure mortar (1.1, 2.2, 3.3 and 4.4 cm), CRWM and mortar filled with tubes. The FEM results will be compared to the measurement data. The FEM calculation can then be used to assess the accuracy of the permittivity data and to predict the transmission and reflection properties before performing the real measurements.

### 1.5 Research Objectives

The main objectives of this research are:

1) To determine the dielctric properties (dielectic constant and loss factor) and S-parameters (reflection and transmission coefficients) of pure mortar, concrete reinforcment wire mesh (CRWM) and mortar filled with PVC tubes in (Ku-band) from 12 to 18 $GH_Z$. The effect of sample thickness as well as the inclusion of wire mesh and tube shall be consedired.

2) To examine the variation in both the transmission and reflection coefficents and permittivity with curing time of pure mortar. The effect of sample thickness and operating frequency shall also be considered.

3) To compare the measured transmission and refelction coefficents with the calculated results using Finite Element Method (FEM).

### 1.6 Scope of Thesis

This thesis has six chapters. Chapter 2 gives a brief description on cement technology. Some of the techniques to evaluate defects of cement are presented. Also included in the state of the art of microwave technique that are applicable for evaluating defects in cement as well as a survey of numerical electromagnetic technique. The electromagnetic theory with special emphasis on the finite element theory are described in detail in Chapter 3. The sample preparation, measurement setup and the software implementation of the Finite Element Method procedure are explained in Chapter 4. All the results related to the research objectives are presented and analyzed critically in Chapter 5. Finally, the contributions and suggestions for future work are summarized in Chapter 6.

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