UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A MICROWAVE TECHNIQUE TO PREDICT MOISTURE CONTENT IN MORTAR

MOHAMAD ASHRY BIN JUSOH

To My Lovely Mother, Brother and Sister……

And

In memorial: Father

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DEVELOPMENT OF A MICROWAVE TECHNIQUE TO PREDICT MOISTURE CONTENT IN MORTAR

By

MOHAMAD ASHRY BIN JUSOH

April 2007

Chairman : Zulkifly Abbas, PhD

Faculty : Science

This thesis describes a simple microwave nondestructive free space method at 17.2 GHz to determine the moisture content of mortar cement. The method is simple, fast, contactless and accurate way to determine the moisture content in mortar. The measurement system consists of a 17.2 GHz dielectric resonator oscillator (DRO) as a microwave source, Power Meter as the detector, a pair of lens horn antenna to transmit and receive microwave signal. The 17.2 GHz frequency was chosen since the sensitivity to the moisture content is higher at this frequency compared to the low frequency. The Agilent Visual Engineering Environment software was used to control and retrieve data from the Power Meter. The microwave part of the measurement system is setup to determine the amplitude of transmitted wave (received powers). A comparison of the two received powers (with sample and without sample) gives an estimate of the attenuation of the sample. The actual moisture content was found by applying standard oven drying method. The calculation and selection of mixture model were discussed thoroughly and only the best performance of mixture model was selected. The dielectric mixture equation (Lichtenecker Mixture Model) has been chosen to calculate the complex permittivity of sample and also predicted the attenuation of sample due to the smallest mean error compared to other models like Kraszewski and Landau. An optimization technique was used to improve the Lichtenecker model so that the mean error between measured and predicted can be reduced. A calibration equation relating the measured attenuation and moisture content was established and the sensitivity of the sensor is 2.8147 dB/ % moisture content. An empirical model of moisture content was obtained from improved attenuation formula and was tested to the sample. The measured and predicted attenuation were found in good agreement within ±5% of mean relative error.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master sains

PEMBANGUNAN TEKNIK GELOMBANG MIKRO UNTUK MERAMAL KANDUNGAN KELENGASAN DALAM MORTAR

Oleh

MOHAMAD ASHRY BIN JUSOH

April 2007

Pengerusi : Zulkifly Abbas, PhD

Fakulti : Sains

Tesis ini memperihalkan kaedah ruang terbuka ringkas gelombang mikro tanpa musnah pada 17.2 GHz untuk menentukan kandungan kelengasan dalam simen mortar. Teknik ini adalah ringkas, cepat, tanpa sentuh, dan cara yang tepat untuk menentukan kandungan kelengasan dalam mortar. Sistem pengukuran terdiri daripada 17.2 GHz Pengayun Resonator Dielektrik sebagai punca gelombang mikro, Meter Kuasa sebagai pengesan isyarat dan sepasang Lens Horn Antenna untuk menghantar dan menerima isyarat gelombang mikro. Frekuensi 17.2 GHz dipilih kerana sensitiviti yang tinggi terhadap kandungan kelengasan berbanding dengan frequensi rendah. Perisian Agilent Visual Engineering Environment digunakan untuk mengawal dan memperoleh data daripada Meter Kuasa. Bahagian gelombang mikro pada sistem pengukuran diatur untuk menentukan amplitud kuasa yang diterima. Perbandingan dua kuasa yang diterima (dengan sampel dan tanpa sampel) memberikan anggaran pengecilan pada sampel. Nilai sebenar kandungan kelengasan dicari dengan pelaksanaan kaedah piawai pengeringan oven. Pengiraan dan pemilihan model campuran telah dibincangkan dengan sepenuhnya dan model campuran yang prestasi terbaik telah dipilih. Persamaan campuran dielektrik (Model campuran Lichtenecker) telah dipilih untuk mengira ketelusan kompleks pada sampel dan meramalkan pengecilan pada sampel kerana min ralat terkecil dibandingkan dengan model lain seperti Kraszewski dan Landau. Teknik optimum digunakan untuk memperbaiki model Lichtenecker supaya min ralat antara diukur dan diramal dapat dikurangkan. Persamaan penentukuran yang mengaitkan antara pengecilan dan kandungan kelengasan telah dihasilkan dan kesensitifan pengesan adalah 2.8147 dB/ % kandungan kelengasan. Model empirikal bagi kandungan kelengasan telah diperolehi daripada formula pengecilan yang ditingkatkan dan telah diuji pada sampel. Pengecilan yang diukur dan diramal masing-masing didapati dalam persefahaman yang baik dengan min ralat bandingan ±5%

ACKNOWLEDGEMENTS

The author wishes to thank his family members for their love, support and encouragement as well as for always being there for him.

The author extends his deepest gratitude to the chairman of supervisory committee, Dr. Zulkifly B Abbas for his kindness, guidance, suggestion and his willingness to help.

The author also wishes to thank the member of the supervisory committee, Prof. Dr. Kaida B Khalid for their advice, supervision and guidance.

Appreciation also given to my colleagues, Mr Cheng Ee Meng and my senior, Mr Lee Kim Yee and all members in the RF & Microwave Lab, past and present, for their guidance, help and support.

I certify that an Examination Committee has met on 12 April 2007 to conduct the final examination of Mohamad Ashry Bin Jusoh on his Master of Science thesis entitled "Development of a Microwave Technique To Predict Moisture Content in Mortar" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Noorhana Yahya, PhD
Assoc. Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Jumiah Hassan, PhD
Assoc. Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Husaini Omar, PhD
Assoc. Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Kaharudin Dimyati, PhD
Assoc. Professor
Faculty of Engineering
Universiti of Malaya
Malaysia
(External Examiner)

HASANAH MOHD. GHAZALI, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

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

Zulkifly Abbas, PhD
Lecturer
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Kaida Khalid, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 17TH JULY 2007

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

MOHAMAD ASHRY BIN JUSOH

Date: 20^{TH} JUNE 2007

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

α	attenuation constant
c	velocity of light
ε^{*}, $\varepsilon^{'}$, $\varepsilon^{''}$	complex permittivity, dielectric constant (or real part of permittivity) and loss factor (or imaginary part of permittivity)
m.c	moisture content
m_w	mass before drying
m_d	mass after dried
P_i	power measured with the material inserted
P_o	power measured without material inserted
S_{11}, S_{12}, S_{21}, S_{22}	scattering parameters
E	the electric field intensity
H	the magnetic field intensity
D	the electric flux density
B	the magnetic flux density
P	the electric charge density
J	the current density
μ	permeability
σ	conductivity
γ	propagation constant
β	phase constant
∇	Laplacian vector
k	wave number
TE	Transverse Electric

TM	Transverse Magnetic
TEM	Transverse Electromagnetic Modes
$\tan\delta$	loss tangent
d	sample thickness
η	impedance
η_0	impedance in free space
ω	angular frequency
f	frequency
OPC	Ordinary Portland Cement
dB	decibels
Agilent VEE	Agilent Visual Engineering Environment
ASTM	American Society for Testing and Material Standards
AASHTO	American Association of State Highway and Transportation Officials
MATLAB	Matrix Laboratory

CHAPTER 1

INTRODUCTION

1.1 An overview of Microwave Non-Destructive Technique

Microwave Non-Destructive Technique (MNDT) has been applied successfully to specific testing problems for more than 50 years. The first few papers describing such techniques appeared in the early 1950's but the bulk of papers being published where after 1960's. Before this time, equipment was not generally available for the generation and measurement of such short electromagnetic waves. It is likely that the exploitation of their full potential in this field will have to await the development of affordable robust generators operating at the higher microwave frequencies.

The term MNDT refers to electromagnetic testing conducted at frequencies in the microwave region. Most electromagnetic book identifies that the microwave region is roughly between 300 MHz to 300 GHz and wavelength are between 10^{-3} and 10^{-1}m (Table 1.1). Testing with microwave is dominated by the basic properties of microwaves. Since their penetration in good conducting materials in minimal, they are mainly used to test the nonconducting materials.

On the other hand, microwaves are affected by a large number of material properties. In lossless or lossy dielectrics, material composition, uniformity of the material, moisture and contamination content and such diverse properties as porosity are some of the properties that can be measured.

Table 1.1: The electromagnetic spectrum (Liao, 1990)

Wavelength (m)	Frequency (Hz)	Usual division of radiation
10^{-14}	3×10^{22}	Cosmic radiation
10^{-13}	3×10^{21}	
10^{-12}	3×10^{20}	
10^{-11}	3×10^{19}	X and Gamma radiation
10^{-10}	3×10^{18}	
10^{-9}	3×10^{17}	
10^{-8}	3×10^{16}	Ultraviolet
10^{-7}	3×10^{15}	
10^{-6}	3×10^{14}	Visible light
10^{-5}	3×10^{13}	Infrared
10-^{4}	3×10^{12}	
10^{-3}	3×10^{11}	
10^{-2}	3×10^{10}	Microwaves
10^{-1}	3×10^{9}	
1	3×10^{8}	Radiowaves

The interest in this work is the interaction of microwaves with materials. This takes the forms of absorption in materials, scattering, attenuation and transmission. These effects are exploited in various testing arrangements to allow for quantitative measurements in materials.

Nowadays, several techniques have been proposed to determine the moisture content inside the sample. In this study, the microwave technique is used due to the sensitivity of the wave to the moisture content. Interaction between moisture content and wave will be discussed on the next chapter.

1.2 Problem statement

Mortar is the most common material used in many structures. It is a heterogeneous material composed of cement powder, sand and water. The conventional process to determine the moisture content of the samples is by using the oven drying method. The advantage of oven drying method is precise but it takes a long time to analyze the sample. Furthermore, this technique is not practical for in-situ measurement or field work measurement.

Recently, microwave technique is also used to measure the moisture content. In microwave method, the weakness of conventional oven method can be overcome. Using this method, it takes a shorter time to determine the moisture content compared to the conventional method and also the sample can be measured as it is. Besides that, measurement can be done using free space technique. In other words, sample and detector are contactless.

Many researchers like Kharkovsky (2002), Kraszewski (1977), Okamura (1981) and Ma (1999) have published about moisture content determination at low frequency. The operating frequency in this work is 17.2 GHz which coincide with the relaxation frequency of water at 20^{o}C (Kaatze and Uhlendorf 1981). This will result in higher dielectric losses and thus greater attenuation due to the moisture content in mortar.

1.3 Microwave technique

Microwave behave much like light wave in that travel in straight lines, refract, reflect, diffract, scatter, and interfere according to the same physical length. However they (microwave and optical wave) are difference in behavior because of the difference in wavelength. Microwave wavelengths are typically 10^5 larger than optical wavelengths. Thus microwave tend to interact with materials and structures on a macroscopic scale. For example, microwaves are capable of penetrating most nonmetallic materials, reflecting and scattering from internal boundaries and interacting with molecules (Bahr, 1982).

Ultrasound (elastic wave) and microwave are two types of wave which have the ability to penetrate into some materials. However, they are also major differences between them. Ultrasound/ultrasonic wave can penetrate metal (conductor) but microwave cannot. As well known, metal is a good conductor and exhibit skin depth of a few micrometers or less (Bahr, 1982). Thus, microwaves are essentially totally reflected at the surface of a metal. Ultrasound transducer usually requires direct contact to the object under test. However microwave technique is contactless. Ultrasound velocities are typically five orders of magnitude (10^5) less than the electromagnet wave velocities. An advantage of high velocity microwave propagation is that it permits rapid inspection, limited only by mechanical considerations.

In this study, the measurement of attenuation can be performed using microwave technique. This measurement is also known as Microwave Non-Destructive Technique (MNDT). There are two classes of MNDT: free space methods and openended waveguide methods (Tamyis et al., 2002). However, the free space method is the more commonly used method as it does not require surface contact during measurement. In this study, a free space method is used to measure the attenuation of mortar at 17.2 GHz. This thesis also presents the correlation between attenuation of received signal and moisture content. By using the characteristics of water containing in the material, a microwave passing through the moistened material is absorbed by the water and the quantity of attenuation changes according to the moisture content.

Determination of attenuation using free space method can be measured using reflection or transmission technique. In transmission/reflection technique, the materials under test are inserted in a piece of transmission line and the properties of the material are deduce from the basis of the reflection from the material or the transmission through the material.

The general consideration of this thesis is to use only the amplitudes of the transmission power to determine the attenuation of. According to the analysis, the permittivity of the sample can be determined uniquely from the measurement values of the amplitudes in the case which the sample has large enough attenuation. Thus, this method can be used for the dynamic measurement of permittivity.

1.4 Objective

The main objectives of this work are

- To compare measured attenuation results with available predicted models.
- To improve the performance of the best predicted model.
- To develop a model to predict moisture content in mortar based on microwave attenuation measurements.

1.5 Scope of Thesis

This thesis describes the method of microwave in determination of moisture content of mortar material. The transmission modes in microwave method are used in this measurement. Chapter 2 describes about raw material and the microwave measurement techniques that will be used in this measurement.

Chapter 3 is about Electromagnetic theory. The attenuation equation was derived from Maxwell equation and was used to predict the attenuation of sample. This chapter also described about wave and interaction with matter. The signal flow graph and Mason Non-Touching Loop (Appendix A) method was used to calculate the attenuation of sample which is multiple reflections was considered inside the sample.

Chapter 4 presents about methodology whereby this chapter was discussed about sample that was used in attenuation measurement and the preparation of that sample.

This chapter also described about measurement set up and followed by microwave instrumentation and control for attenuation measurement.

The simulation and measurement results were discussed in chapter 5. The analysis of parameter for attenuation equation such as thickness, frequency and moisture content was shown in this chapter. The result was shown in relationship between attenuation versus that parameters and attenuation versus moisture content as well. This chapter also presents the optimization technique to improve the attenuation formula and to get the calibration line of moisture content to predict the moisture content of the sample. The validation of new model (improved Lichtenecker Model) has been done and shown in this chapter. The sensitivity of sensor was found to be 2.8147 dB/ % moisture content.

Finally, the conclusion and suggestion for future work were presented in chapter 6.