Faculty of Engineering

CONCRETE STRENGTH DETERMINATION USING MICROSTRIP PATCH ANTENNA VIA VECTOR NETWORK ANALYZER

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Final Year Project Report	√
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CONCRETE STRENGTH DETERMINATION USING MICROSTRIP PATCH ANTENNA VIA VECTOR NETWORK ANALYZER

BENJAMIN BIN EMIN

A dissertation submitted in partial fulfilment
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ABSTRACT

Compressive strength of concrete is very important to provide good quality of concrete, ensuring public safety and increase the lifespan of concretes. One of the most important parameters influencing the concrete strength is moisture content. This project proposed a portable microwave non-destructive method by designing a microstrip patch antenna operating at 2.4 GHz using Computer Simulation Technology (CST) Studio Suite. The microstrip patch antenna is connected to Vector Network Analyzer (VNA) via coaxial cable to obtain the reflection coefficient. The reflection coefficient will be correlated with moisture content and compressive strength of concrete cubes. The microstrip antenna will be investigated on the reliability of concrete strength determination. The initial results of antenna when projecting the signal into open air yields a -33.38 dB and frequency of 2.566 GHz which is within the acceptable range of planned frequency. Two experiments are conducted which are concrete cubes cured for 28 days and concrete cubes with various moisture content. Relationship of reflection coefficient with curing time and compressive strength are obtained in this first experiment while relationship between reflection coefficient and moisture content are obtained from the second experiment. The value of moisture content varies from 0% to 45% are tested and measured using the microstrip patch antenna. Two equations are obtained from the relationship between reflection coefficient with moisture content and compressive strength. From the equations, the accuracy in prediction of moisture content and compressive strength is 93.37% and 97.43% respectively. Hence the equations show great potential of the microwave method in determination of compressive strength of concrete cubes.

ABSTRAK

Kekuatan mampatan konkrit adalah sangat penting untuk menyediakan kualiti konkrit yang baik, memastikan keselamatan awam dan meningkatkan jangka hayat konkrit. Salah satu parameter terpenting yang mempengaruhi kekuatan konkrit ialah kandungan lembapan. Projek ini mencadangkan kaedah tidak merosakkan gelombang mikro mudah alih dengan mereka bentuk antena tampalan jalur mikro yang beroperasi pada 2.4 GHz menggunakan Suite Studio Teknologi Simulasi Komputer (CST). Antena tampalan jalur mikro disambungkan kepada Penganalisis Rangkaian Vektor (VNA) melalui kabel sepaksi untuk mendapatkan pekali pantulan. Pekali pantulan akan dikaitkan dengan kandungan lembapan dan kekuatan mampatan kiub konkrit. Antena jalur mikro akan disiasat mengenai kebolehpercayaan penentuan kekuatan konkrit. Keputusan awal antena apabila menayangkan isyarat ke udara terbuka menghasilkan -33.38 dB dan frekuensi 2.566 GHz yang berada dalam julat frekuensi yang dirancang. Dua eksperimen dijalankan iaitu kiub konkrit diawet selama 28 hari dan kiub konkrit dengan pelbagai kandungan lembapan. Hubungan pekali pantulan dengan masa pengawetan dan kekuatan mampatan diperoleh dalam eksperimen pertama ini manakala hubungan antara pekali pantulan dan kandungan lembapan diperoleh daripada eksperimen kedua. Nilai kandungan lembapan berbeza dari 0% hingga 45% diuji dan diukur menggunakan antena tampalan jalur mikro. Dua persamaan diperoleh daripada hubungan antara pekali pantulan dengan kandungan lembapan dan kekuatan mampatan. Daripada persamaan, ketepatan dalam ramalan kandungan lembapan dan kekuatan mampatan masing-masing ialah 93.37% dan 97.43%. Oleh itu persamaan menunjukkan potensi besar kaedah gelombang mikro dalam penentuan kekuatan mampatan kiub konkrit.

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LIST OF ABBREVIATIONS

CST	-	Computer Simulation Technology
DT	-	Destructive Testing
NDT	-	Non-Destructive Testing
NDE	-	Non-Destructive Evaluation
MNDT	-	Microwave Non-Destructive Testing
UPV	-	Ultrasonic Pulse Velocity
VNA	-	Vector Network Analyzer
w/c	-	Water to cement

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is the most frequently used material in the construction of civil structures. Concrete, a heterogeneous material, is composed of air, water, cement powder, fine aggregate, and coarse aggregate. The aggregates serve as inert filler materials whereas cement powder and water undergo a chemical reaction to form into cement paste binder. Compressive strength of concrete is one of the most crucial factors to determine the life-service and quality of the concrete. Destructive testing (DT) and non-destructive testing (NDT) are two methods in determination the compressive strength of concrete. Because of the effects on the durability and lifespan of concrete, DT of concrete is not always the viable method to determine the concrete strength. Therefore, the NDT approaches is the promising method to determine the compressive strength of existing or freshly made concretes as well as assess the condition of concrete [1]. Rebound hammer test, pull-out test, ultrasonic pulse velocity test, penetration resistance test, and microwave test are the NDT methods.

The most critical parameter influencing concrete strength is the moisture content of concrete. There is no test that can accurately assess the content of cement and water-to-cement ratios of cured concrete. Radio and microwave non-destructive testing (MNDT) are crucial method for determination of voids, flaws, defects, cracks, and moisture content by means of microwave [2]. These approaches have more benefits compared to other non-destructive evaluation (NDE) approaches (ultrasonic, radiography) due to less expensive, quality resolution, reliable and easier to apply on [3]. These MNDT techniques play a significant role in construction application as these techniques are fast, precise, and reliable. The concrete strength, which is highly impacted by water-to-cement ratio and coarse-to-cement ratios of concretes was researched by studying microwave near field reflection characteristic evaluation of concrete. In the study, cement paste samples with various water-to-cement ratios are evaluated under different microwave frequency ranges. The findings show a relationship between water-to-cement ratios and reflection coefficients. Hence a connection of concrete strength and the reflection coefficient are also achieved [4].

The microwave non-destructive technique that used in this research is a microstrip patch antenna that operates at 2.4 GHz. A microstrip patch antenna consist of a radiating patch on top of a substrate. a ground plane at the bottom which acts as a base and a feed line. Microstrip patch antenna is used in this research due to its small size, light weight, cheap, ease of fabrication and simplicity.

The report describes the concrete strength determination using a rectangular microstrip patch antenna to obtain the reflection coefficient via Vector Network Analyser (VNA). Concrete specimens with different water/cement ratio will be prepared and the reflection coefficient are measured by using a VNA. Concrete cubes cured for 28 days period will also be prepared to obtain the compressive strength using compressive strength test and tested to obtain reflection coefficient via VNA. The relationship of reflection coefficient with moisture content and compressive strength will be analysed. Two quadratic equations will be acquired from the relationship and used in determining the compressive strength and moisture content. A rectangular microstrip patch antenna with an operating frequency of 2.4 GHz will be designed and simulated by using Computer Simulation Technology (CST) software.

1.2 Problem Statement

Together with the rapidly increase of population over the years in Malaysia, the development of construction buildings is increasing due to the demand of the population. Furthermore, Malaysia is a tropical country, where the humidity of air, hot weather surroundings, and rainy season can damage and reduce the life service of the buildings. Flooding cases in Malaysia has been increased drastically especially during the rainy season over the past few years. These situation leads to concern on the quality and durability of concrete strength. In current days, the commonly used test to determine concrete strength in civil industry is compressive strength test which is a destructive method and damages the existing building constructions. Hence an NDT method is proposed in this research, which is portable, cheaper in cost and easier of implementation compared to other NDT methods.

Second issues concerning on the reliability of microstrip patch antenna as moisture sensor. A moisture sensor determines the moisture content of a concrete and correlated with reflection coefficient. The challenge lies in designing the microstrip patch antenna to function as a dependable moisture detection sensor. Parameters of antenna such as radiation pattern, resonant frequency, bandwidth and return loss, also known as reflection coefficient, are vital for the performance of the microstrip patch antenna. The shape of the microstrip patch antenna must also be considered in the designing process. Optimization and parameter sweep are usually used to improve the performance of the microstrip patch antenna.

1.3 Objectives

I. To design a rectangular microstrip patch antenna operatable at 2.4 GHz by using CST Studio Suite

II. To investigate the reliability of microstrip patch antenna on concrete strength determination.

III. To analyse the correlation between reflection coefficient displayed by the Vector Network Analyzer (VNA) and moisture content of the concrete cubes.

1.4 Summary

The purpose of this study is to investigate and determine the concrete strength using a rectangular microstrip patch antenna via Network Vector Analyser (VNA). Hence a rectangular microstrip patch antenna that operates at 2.4 GHz will be designed and simulated by using Computer Simulation Technology (CST) software. This investigation will focus the reflection coefficient obtained and displayed through the VNA. The correlation between the reflection coefficient and moisture content will be analysed and relate it to the concrete strength.

Each part of the thesis is divided into five chapters which are introduction, literature review, methodology, results and discussion, and conclusion. The first chapter presents an outline of the study's background, aims, problem statement, and scope.

The research in literature review is detailed in depth in Chapter 2 of the report. It all begins with DT and NDT methods in determining concrete strength. Information regarding the shape of microstrip patch antenna, advantages, and disadvantages of microstrip patch antenna and feeding techniques are mentioned. The parameters of antenna include return loss also known as reflection coefficient, resonant frequency, bandwidth, efficiency, gain, and radiation pattern.

In chapter 3, flowcharts, Gantt charts, and design specification are presented to illustrate the research methodology. The chapter also discussed the calculation of the microstrip patch antenna. Additionally, the two experiments which are concrete cubes with various moisture content and concrete cubes cured for 28 days period will be briefed.

Chapter 4 presented the simulation results of parameter sweep on proposed designs which are inset feed, curved edge, slot and mixture of both curved edge and slot. Two experiments will be conducted which are concrete cubes with various moisture content and concrete cubes cured for 28 days period. From the experiments, analysis will be carried out on the relationship of reflection coefficient with curing time, compressive strength, and moisture content. Quadratic equations are obtained from the relationship to measure the accuracy in predicting the moisture content and compressive strength of the concrete cubes.

The goal of Chapter 5 is to present the conclusion of the results gathered to determine the success ability of the objectives of this study. In addition, the recommendation for the future work is drawn from this study.

Chapter 2

LITERATURE REVIEW

2.1 Overview

The aim of this chapter is to deliver the fundamental overview of the methods in determining concrete strength. DT methods and NDT methods are the two methods to determine the concrete strength of concrete structures. Hence these two methods will be discussed in this chapter. In this research, microstrip patch antenna will be introduced for the concrete strength determination. Following that, the properties of a microstrip patch antenna are further discussed including its bandwidth, frequency, gain, efficiency, pattern, and return loss, also known as reflection coefficient. Furthermore, the next section gives a brief overview of several feeding methods, including aperture couple feed, transmission line feed, proximity coupled feed, and coaxial probe feed. To further assist readers, previous research regarding on methods of concrete strength determination and antenna design will be provided.

2.2 Destructive Testing (DT) Methods

Destructive testing (DT) for compressive strength is comprised of making a cement cube, curing it under ideal pressure and temperature conditions, breaking the cement cube and finally measuring the force needed to shatter the cube. This is considered as a destructive test because the force is increased gradually until the cement breaks in compression. The destructive testing method is suitable and provides economically advantageous for the concrete specimens that are manufactured on a larger scale. The main goal of destructive testing is to identify the lifespan of the concrete and detect the flaws of the design that might not be obvious under normal working conditions. The DT methods include compressive strength test, drilled core test, and cast-in-placed cylinders test.

The compressive strength test can be done on either cube or cylinder specimens and generally carried out at 7 days and 28 days. Research was done on the compressive strength test with three cylindrical specimens [5]. Based on study, the compressive strength of the three cylindrical specimens is 31, 28, and 30 MPa respectively, averaging the compressive strength of the concrete at 30 MPa. The result obtained proved that the compressive strength test is reliable for the determination the actual compressive strength of concretes. However, compressive strength test is a destructive method which damage the existing concrete structures. Figure 2.1 shows the conical rupture of the cylindrical specimen after the compressive strength test.

Figure 2.1: Conical rupture of the cylindrical specimen [5]

Drilling core of a concrete slab is also one of the DT methods as it damages the structure of concrete slab. After the test, the location of the drilled core of the concrete slab requires to be repair and replace. Based on research [6], the compressive strength obtained from the cores has been discovered less than the compressive strength obtained from the cylindrical specimens. Thie result obtained might be due to drilling as a destructive method which produce microcracking in the cement matrix and impair the link between the aggregate particles and the wet cement [7].

2.3 Non-destructive Testing (NDT) Methods

Non-destructive testing (NDT) is a analytical method used by various industries to assess the characteristics of a material, component, structure, or system without harming and damaging the serviceability of the part or system. The demand of industry to achieve both short-term needs and long-term goals have been the primary driving factor behind the countless improvement of NDT methods. The depth of penetration, vertical and lateral resolution, contrast in physical properties, sign-to-noise ratio and existing information about the structure are the major factors of a non-destructive survey's success [8]. In the industry of civil, NDT methods are used to evaluate the compressive strength of concretes. The combination of non-destructive and destructive testing provides an interesting option to evaluate the concrete strength in existing structural concretes [9][10]. The most popular NDT techniques for the evaluation of concrete strength is rebound hammer and ultrasonic pulse velocity.

2.3.1 Rebound Hammer Test

Rebound hammer, which also known as Schmidt hammer, is developed in 1948 by Swiss engineer Ernst Schmidt. The popularity of rebound hammer test is due to being one of the economical, easiest, and simplest method for non-destructive testing. The purpose of the rebound hammer test of concrete is normally to correlate the relationship between surface hardness of the concrete and compressive strength within an allowable error. The device uses a spring and measure the hardness of concrete surfaces using the rebound principle. Figure 2.2 shows the Silver Schmidt Hammer used in rebound hammer test [11].

Figure 2.2 Silver Schmidt Hammer [11]

A low rebound number demonstrates that the surface of the concrete is soft, implying as the concrete is weak, whereas a high rebound number denotes that the concrete is robust and firm. However, studies have shown that there are limitations on the accuracy of the test in estimating the concrete strength in using rebound hammer test. Various factors such as surface smoothness, type of cement, rigidity of specimen, specimen age, type of coarse aggregate, and carbonation of surface affect the result [11].

Research was conducted to examine the precision of result obtained from the rebound hammer test in comparison to the real compressive strength of concrete. According to Co [12], the result of compressive strength obtained by using rebound hammer test has an error of 15.32% with the actual compressive strength. The actual compressive strength of the samples for both upper and lower region of the concrete are also underestimated. Sanchez et al. [13] also observed that the results obtained from the rebound hammer is lower compared to the actual compressive strength. Research was done to identify the effects of surface and moisture content on the result of rebound hammer test. Based on the study, a fresh concrete with a wet surface has a softer surface, resulting in less rebound than normal rebound. A cured and dry concrete has a harder surface with less moisture content gives a higher rebound number than normal [11]. This proved that moisture content of a concrete effects the result of rebound hammer test. Hence, rebound hammer does not provide an accurate result of actual compressive strength but still a reliable if its calibrated and combined with other NDT methods.

2.3.2 Ultrasonic Pulse Velocity (UPV) Test

Another commonly used NDT methods in measuring the concrete strength is ultrasonic pulse velocity (UPV) test. Ultrasonic pulse velocity test is a non-destructive testing method which calculate how long it takes a longitudinal wave to travel a given distance. To assess the concrete quality in constructions, ultrasonic waves are used for the measurement of ultrasonic pulse velocity (UPV). As opposed to other types of electromagnetic radiation, which can easily pass-through vacuum, ultrasonic waves are electromagnetic waves that can only exist in mass media. A generating transducer, a receiving transducer and a device that shows the amount of time it takes for an ultrasonic pulse to travel from a transmitter to a receiver are the components make up the pulse velocity equipment [14]. The velocity can be calculated by using the equation (1) below [15]:

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

where:

$V = Velocity\ (m/s)$
$L = Length\ (m)$
$T = Effective\ Time\ (s)$

Research was conducted to determine the correlation between concrete strength and UPV values by using result obtained from different existing reinforced concrete structures with having different ages and unknown ratio of concrete mixtures [16]. Based on the result obtained, the value of UPV increase as the concrete strength increase. Rajagopalan et al. [17] also obtained a correlation between UPV and compressive strength of concrete for some common mixtures. The research assessed simultaneous measurement of compressive strength and pulse velocity on 150 mm cubes at various age, from 1 day to 28 days. The research proved the linear relationship between the strength and velocity. However, the accuracy of actual compressive strength is also affected by other factors. An experimental study was done on ultrasonic pulse velocity evaluation of the microstructure of cementitious material at early age. The results shows that UPV values increase as compressive strength and solid phase volume increase while UPV decrease when the water/cement ratio increase. The result also stated that the relationship between UPV and compressive strength is almost linear at early stage [18]. Based on these studies, the correlation of compressive strength and UPV is not accurate due to other factors affecting the results.

2.3.3 Pull Out Test

Another DT methods is the pull-out test. According to [19], the underlying idea behind pull-out testing is since the peak force (pull-out force) closely correlates to the strength of cylindrical and cubic concretes that was evaluated in the laboratory, a precise assessment of the in-situ strength may be achieved. Any available area can be utilized to conduct the pull-out test in an existing structural concrete. For the preparation of the insert in this instance, a unique technique is needed and used. Recently, a modified version of pull-out test has been proposed, which is known as post-installed screw pull-out test. The test is partially destructive method where a large screw is insert into a hole that has already been drilled in the cured concrete and subsequently pulling out the screw to cause the