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Determination of Moisture Content in Mortar at Near Relaxation Frequency 17 GHz

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The knowledge of moisture content in cement based material is important especially for the safety in field work. In this paper, a non-destructive and contactless free space method is used for measurement of moisture content in cement based materials (mortar) at microwave frequencies. The measurement system consists of a 17 GHz dielectric resonator oscillator (DRO) as a microwave source, a Power Meter as the detector, and a pair of lens horn antennas to transmit and receive the microwave signal. An empirical formula of moisture content was obtained by using a relationship between attenuation and moisture content. This model is best for prediction of moisture content greater than 2% with percentage mean error of 3%.

Keywords: Mortar, attenuation, moisture content, nondestructive technique (NDT), free space, transmission

1. INTRODUCTION

CEMENT-BASED MATERIALS (cement paste, mortar, concrete, etc.) are widely used in many structures of the construction industry. Together with the cement, main content of the materials is water and sand [1]. The quality and strength of the material is commonly characterized based on its water-to-cement (w/c) ratio. Therefore, accurate determination of water or moisture content in such material is important, especially in the field construction work, to assure that the building structure is safe for workers.

Microwave is known to be sensitive to moisture content. Since it offers non-destructive testing, many applications regarding moisture determination use the method. In the microwave technique, valuable information of permittivity of sample is known. As water has high permittivity at microwave frequency compared to dry materials, it is easily measured using the technique. Accordingly, highly accurate prediction of the water content is possible. Due to that reason, many researchers have proposed the technique in terms of moisture measurement such as in wheat [2], grain [3] and also in cement-based material [4]. Modern literature related to moisture content determination was discussed by Kaatze and Hubner [5]. Their paper discusses the current electromagnetic techniques for moisture content determination of material.

In mortar microwave measurement, many investigations found that the free-space technique offers more flexibility than contact measurement. [6-8]. Some of the reasons are possibility of large area coverage and ease of remote sensing. In the free-space method, transmission measurement surpasses performance of reflection measurement. Transmission measurement considers the sample as a whole while reflection measurement indicates most of the signals which are reflected from the surface of the material. It was also found that transmission measurement has advantage over reflection measurement in terms of curing investigation [9]. The transmission free-space method for investigation of mortar sample was found in terms of hardened mortar structure [10] and young mortar specimen [11] in terms of w/c ratio. Transmission technique, likewise the reflection technique, takes account of the attenuation data of the microwave to characterize the sample. However, most of the microwave attenuation measurement works related to moisture content of the mortar sample is only given in terms of empirical results. Hasar et al. [6] proposed the ANN technique to predict the attenuation of microwave signal due to different w/c ratio. This method, however, needs the network to be trained to operate. Also the process is time consuming, since it requires an amount of measurement data sets of the experiment. Therefore, it is important to model the water content of mortar due to attenuation at microwave frequencies.

Moisture content of mortar is very important in the knowledge of compressive strength. The conventional process to determine the moisture content of the samples is by using the oven drying method. The advantage of the oven drying method is precision 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 has also been used to measure the moisture content. In the microwave method, the weakness of the conventional oven method can be overcome. Using this method, it takes shorter time compared to the conventional method and also not a certain shape is needed or the sample can be formed in arbitrary shape. Besides, measurement can be done using the free space technique. In other words, sample and detector are contactless.

In this paper, the prediction technique for determination of moisture content of mortar is proposed. The operating frequency used is 17 GHz, which coincides with the relaxation frequency of water at 20 °C [12]. This will result in higher dielectric losses and thus greater attenuation due to the moisture content in mortar.

2. SUBJECT & METHODS

The materials used for measurement of attenuation for mortar sample consist of sand and cement beside water as a binding agent. The sand was sieved with a strainer of cross sectional area 2 mm x 2 mm to get only the small uniform size sand so as to reduce the scattering of EM wave on the sample. The type of cement used in this study is Ordinary Portland Cement (OPC) manufactured by Lafarge Malayan Cement Berhad and exceeding the quality requirements specified in the Malaysian Standard MS 522 : Part 1: 1989 Specifications for Ordinary Portland Cement. The sample is placed between two antennas (transmitter and receiver). The powers received with and without sample are recorded in order to get the attenuation. The sample is dried in a forced convection oven for more than 5 minutes before weighing. The moisture content in each sample is calculated from the ratio of water volume related to the specimen data. The water volume was calculated as the difference in weight of the specimen before and after oven drying. In general, the correct reading of moisture content is obtained only when the weight of the measured material is kept constant. The amount of moisture content inside the sample was calculated using wet basis measurement as follows:

$$moisture\ content(\%) = \frac{m_w - m_d}{m_w} \times 100 \tag{1}$$

where m_w is the mass before drying and m_d is the mass after drying. The values of m_d are obtained after one to two days in the oven until the readings of mass are constant. The average value of received power is used to calculate the attenuation. The attenuation of sample is obtained by using the ratio of received power with and without sample.

$$Attenuation\ (dB) = 10\log_{10}\left(\frac{\text{Power Received}\ \textit{(With Sample)}}{\text{Received Power}\ \textit{(Without Sample)}}\right) \tag{2}$$

The measurement system for determination of moisture content of mortar was set up as shown in Fig.1. In this set up, the sample is sandwiched between a pair of antennas. The antenna is a device for radiating and receiving electromagnetic waves. The antenna used in this study is a lens horn antenna. For this measurement, a pair of lens horn antennas is used to measure the transmission power.

One of them is used as a transmitter, while the other one as a receiver. The model of this antenna is 18820-FA with frequency range from 13.0 GHz to 18.0 GHz and nominal gain is 25 dBi and diameter of aperture 150 mm and VSWR less than 1.5. This antenna was designed and manufactured by Flann Microwave Limited. The advantage of lens horn antenna is the ability to convert a spherical wavefront into a plane wavefront that will provide greater directivity compared to other antennas. The sample holder is located in the middle of two antennas with 12 cm gap from the transmitter and 13.2 cm from the receiver. The gap between receiver and top surface of sample is similar to the gap between transmitter and the lower surface of the container.

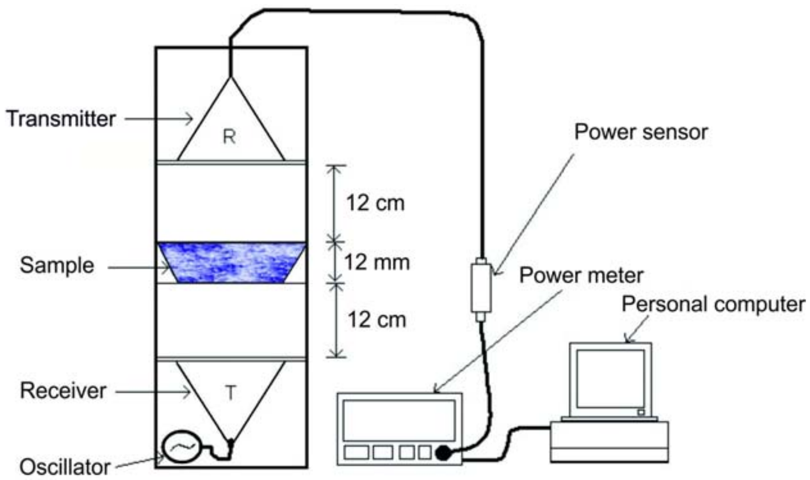

Fig.1. Measurement set up for moisture content measurement of cement sample.

3. RESULTS AND DISCUSSION

In determination of moisture content inside the mortar sample, the data of all samples was plotted in a graph and the best fitted line was obtained and the equation of fitted line was used as empirical formula. The scatter diagram and calibration line of the data, as shown in Fig.2, suggests that the relationship between attenuation and moisture content of the samples is in quadratic form. The results clearly show that the attenuation and moisture content are strongly correlated with regression coefficient between attenuation and moisture content of about 0.9837 and are related by the formula

$$A = -0.071\ MC^2 + 3.7\ MC + 3.5 \tag{3}$$

and

$$MC = 0.00334\ A^2 + 0.208 A - 0.629 \tag{4}$$

where *MC* is the fitted moisture content as a function of attenuation, *A*. In this work, Eq. (4) has been used successfully to determine the moisture content inside the mortar sample. This model is applicable only at frequency 17 GHz by assuming a constant density of the sample. The relative error was calculated using

$$Relative\ error = \left| \frac{Predicted\ MC - True\ MC}{True\ MC} \right| \qquad (5)$$

where predicted and true moisture were found using Eq. (4) and the conventional oven method. The equation can be used as an empirical formula where the values of moisture content can be read out directly once the attenuation values are known.

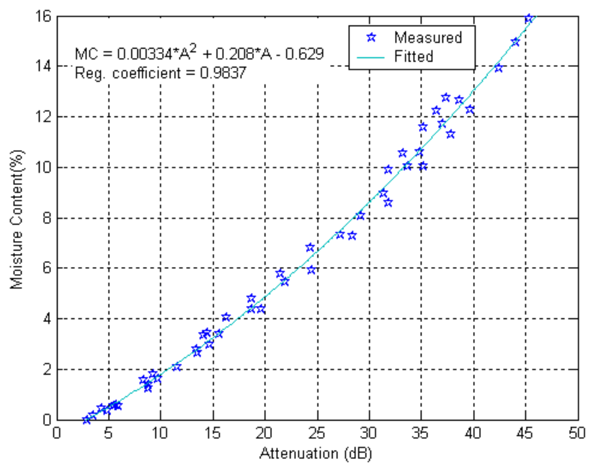

Fig.2. Relationship between moisture content and attenuation.

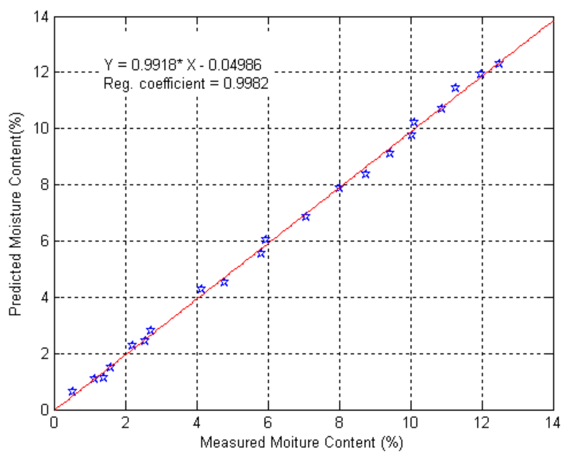

Fig.3. Direct comparison between predicted and measured moisture content.

Fig.3 shows the correlation between the measured and predicted values of moisture content for five sets of new sample. The correlation between the measured and predicted values is good whereby the regression coefficient is 0.9982. Instead, the mean relative error between measured and predicted moisture content is 0.05. That means, the mean relative error between measured and predicted moisture content is within 5%.

Fig.4 shows the relative error of predicted moisture content by using Eq. (4) based on the measurement result. As expected, the graphs on Fig.4 show the inconsistency of relative errors for moisture content less than 2 %. For moisture contents more than 2 %, however, the relative errors are lower than 0.3. The inconsistency of relative errors iss due to the non-uniformity of moisture content inside the sample. This figure also shows that the relative error from 2% of moisture content onwards gives a uniform value and this shows that there was no systematic error for this validation.

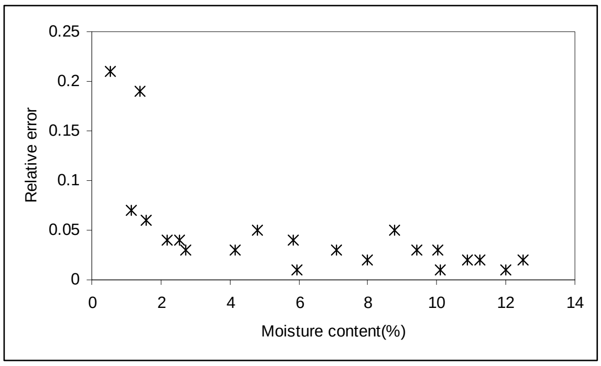

Fig.4. Relationship between relative error and moisture content

4. CONCLUSION

The microwave model has been successfully developed to determine the moisture content inside mortar. The work consists of attenuation measurement using the transmission technique for mortar sample. This model is best suited for prediction of moisture content greater than 2% with percentage mean error of 3%. This model is applicable only at frequency 17 GHz by assuming a constant density of the sample.

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