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Research paper

Development and Characterization of Microwave Absorber Composite Material

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Abstract

The rapid development of electronic systems and telecommunications has resulted in a growing and intense interest in microwave electromagnetic absorber technology and microwave absorbing composite material. This research was conducted to develop microwave absorber composites called thermoplastic natural rubber barium ferrite (TPNR-BF). The composite was characterized by determination of its physical, mechanical, magnetic and microwave properties. TPNR-BF with the fine particles barium ferrite filler content of 0-20% by weight were prepared using melt blending method. The microwave electromagnetic properties were measured using free-space microwave non-destructive testing system (MNDTS) in the frequency range of 7-13 GHz. The mechanical and Magnetic properties of the thermoplastic natural rubber-barium ferrite were also measured using Magnetometer. The effects of the different percentage of filler content on the mechanical and microwave properties of the composites have been evaluated. Both microwave dielectric constant and the reflection coefficient of TPNR-BF increase with increasing frequency and filler content while transmission coefficient decreases with increasing filler content which indicates that the composite absorbs more microwave energy by the filler. Barium ferrite contents show an inverse relation with the mechanical properties such as tensile strength and stiffness. MNDTS shows excellent capability for advanced characterization of a microwave composite material.

Keywords: *Microwave; Natural rubber; Permeability; Permittivity; Thermoplastic.*

1. Introduction

The rapid development of electronic systems and telecommunications has resulted in a growing and intense interest in microwave electromagnetic absorber technology and microwave absorber materials. Recently, extensive research conducted to develop efficient microwave absorbing composite material [1]. Microwave absorber material could be produced using a non-magnetic polymeric matrix as hosting material and inclusion of magnetic material as filler and the resulting material called polymer-bonded magnet (PBM). Both hosting and filler material could be varied for each specific application, and the performance of the performance new PBD material depends on properties of both inclusion and filler and the volume fraction, shape, size and dispersion of the magnetic filler material [2]. The advantages of PBMs over their metallic and ceramic counterparts are their ability to be molded into complex shapes and sizes, lightweight and comparably low cost. The microwave absorber can be used to minimize the electromagnetic reflection from the metal plate such as aircraft, ships, tanks and the walls of anechoic chambers and electronic equipment. [3]. Recently intensive research conducted to develop microwave absorber composite using polymers and incorporated magnetic filler in micro and Nanoscale [4-5].

Barium ferrite type-M, $BaFe_{12}O_{19}$, is one of the several hexaferrites. Barium ferrite is essential components in permanent magnets, magnetic recording media, microwave and high-frequency devices. The use of barium ferrite as a magnetic filler in microwave composite because it possesses superior and attractive properties such as high magnetization, remanence, coercivity and electrical resistivity. One of the vital polymer hosting material in microwave absorber composite is the thermoplastic natural rubber (TPNR) and high-density polyethylene (HDPE). Several studied conducted to develop microwave absorber used TPNR and HDPE [6-9].

The demand for the development of reliable non-destructive testing (NDT) techniques for characterization of composite materials is ever increasing. Among the few available methods, microwave technique seems promising for non-destructive testing of composite materials and structures. The term microwaves refer to alternating current signals/electromagnetic waves with frequencies between (3×10^8 Hz) and (3×10^{11} Hz). Since the penetration of microwaves in the right conducting materials is minimal, Microwave NDT techniques are mainly used for non-metallic materials (dielectric materials). Intensive studied conducted to develop and use microwave nondestructive method, an electromagnetic testing method for characterization of material and determine the electromagnetic properties of material [10-18].

This study was conducted to develop a thermoplastic natural rubber composite incorporated different barium ferrite content to for a microwave absorber composite. The composite developed in this study was characterized to determine the physical, mechanical, magnetic and microwave properties. Microwave properties of the composite were determined using the microwave nondestructive testing system developed for advanced electromagnetic characterization of materials.

2. Microwave Theory

Most of the magnetic composite materials such as thermoplastic natural rubber-barium ferrite composites are dielectric materials.

A dielectric material can be characterized by two independent electromagnetic properties namely, complex permittivity ε* and complex permeability μ*. However, the complex permittivity ε* and complex permeability μ* of these composite materials can be defined by[19-20]:

$$\varepsilon^{*} = \varepsilon^{'} - j\varepsilon^{''} \tag{1}$$

$$\mu^{*} = \mu^{'} - j\mu^{''} \tag{2}$$

Where ε' is the real part of the complex permittivity, ε'' is the imaginary part of the complex permittivity. Dividing equation one by permittivity of free space (ε_o) the property becomes dimensionless and relative to free space;

$$\varepsilon_r^{*} = \frac{\varepsilon^{*}}{\varepsilon_0} = \varepsilon_r^{'} - j\varepsilon_r^{''} \tag{3}$$

$$\mu_r^{*} = \frac{\mu^{*}}{\mu_0} = \mu_r^{'} - j\mu_r^{''} \tag{4}$$

Where ε'_r is the real part of the relative permittivity called dielectric constant and ε''_r is the imaginary part of the relative permittivity called loss factor. The dielectric constant is a measure of how much energy from the external electric field is stored in a material. The loss factor is a measure of how the dissipative or lossy material is to an external electric field due to current conduction.

3. Microwave Nondestructive Testing System

In free-space measurement system, the free-space reflection and transmission coefficients S_{11} and S_{21} of a planner sample are measured for normally incident plane wave. The complex constitutive parameters ε* are calculated from the measured S_{11} or S_{21}. Figure 1 gives a schematic diagram of the MDS, which was developed for microwave non-destructive evaluation of composite materials. The system consists of a pair of spot-focusing horn lens antennas (model no. 857012X-950/C) were manufactured by Alpha Industries, Woburn, MA (USA). These antennas have two identical 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.
This measurement set up covers a frequency range of 7-13 GHz. However, the same setup can be used in the frequency range of 7.5 -40 GHz by an appropriate change of mode transitions. 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. This network analyzer is used to make accurate S-parameter (reflection and transmission) measurements in free-space using line-reflect line calibration model. A personal computer along with appropriate measurement software can be used for overall automation of the free-space measurement system.

4. Material and tests

This section provides the all raw material used to develop the microwave absorber composite. The procedures used to develop the composite and all test conducted to characterize the composite.

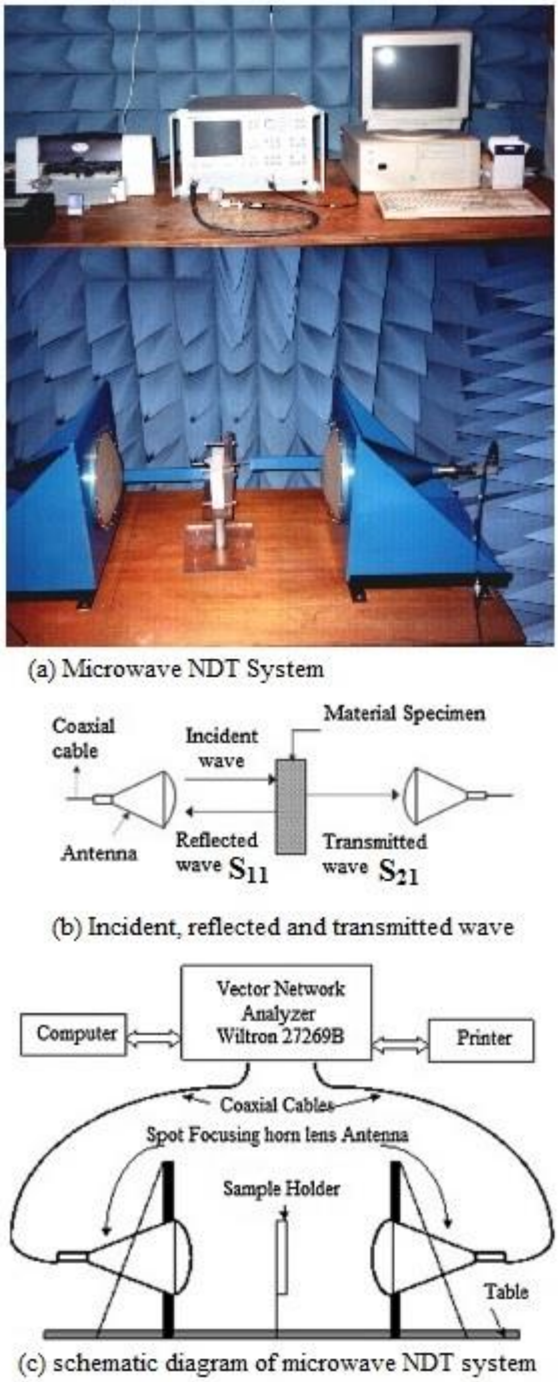

Fig. 1: Microwave nondestructive testing system (MDS).

4.1. Material and Preparation

Materials used to develop the thermoplastic natural rubber barium ferrite composite were natural rubber (NR) provided by Malaysian Rubber Board (LGM), HDPE supplied by Mobile (M) Sdn. Bhd., liquid natural rubber (LNR) were prepared in the laboratory of applied physics and engineering using photodegradation method, barium ferrite ($BaFe_{12}O_{19}$) with an average diameter of 3 μm and purity of 99.9% as filler provided by Johnson Matthey USA.
NR, LNR, and HDPE as raw materials are used as the thermoplastic natural rubber matrix composite (TPNR). Mixing NR, LNR, and HDPE with the following percentage respectively 20:10:70 makes the TPNR matrix. TPNR matrix will be grounded to small pieces then mixing with the prepared dry powder filler (barium ferrite). The composite mixture will be prepared using different filler content 0,5,10,15 and 20 percentage by mass. The

composite will be melted using Plasticorder Brabender PL2000 at 140°C, the speed of wheel rotation will be 135 rpm for a period. NR, LNR, and HDPE as raw materials are used as the thermoplastic natural rubber matrix composite (TPNR).

4.2. Characterization Tests

The physical properties of the microwave composite developed in this study were examined by scanning electron micrographs (Phillips SEM XL 30). Measurements of the magnetic properties of the developed composite were performed. Testing for magnetic properties of the composite was done using Magnetometer Vibrating Sample (VSM) model LDJ 9500. Performing the tensile test does a characterization of the mechanical properties of the composite. From the tensile tests, Young's modulus stress and strain at break were deduced and recorded. Microwave properties of the composites such as reflection coefficients, transmission coefficients and complex permittivity (dielectric constant) were performed using the microwave NDT system recently developed by the researcher and presented in the previous section.

5. Result and Discussion

The characteristic of the composite material is presented in the following sub-section. The first section provides the physical properties; the second section presents the mechanical properties including tensile stress and strain. The third and fourth sections provide the magnetic and microwave properties of the composite respectively.

5.1. Physical Properties

Scanning electron micrographs (SEM) of the microwave absorber composite is given in Figure 2 for 0%, 10% and 20% BF filler. The image shows that the barium ferrite well dispersed in the TPNR matrix. Increasing BF content indicates that the particle of BF accumulates and may lead to significant decrease of mechanical properties of the composite. This may attribute to the larger weak interfacial zone and very weak bond between the filler and polymer matrix.

The density of TPNR-BF was evaluated at each BF filler content. The density of the composite increases slightly with the increasing filler content. The density of 0, 5, 10, 15 and 20% of BF content were 0.89, 0.93, 1.01,1.19 and 1.35 gram/cm^3 respectively.

The surface hardness of TPNR-BF composite was measured using durometer hardness after 3 seconds after the pressure foot is in firm contact with the specimen. The hardness increased from 40 to 41 for 0% and 20% respectively. The melting point decreased with increasing filler content were also observed. This may result from increasing thermal conductivity of the composite with increasing filler content.

5.2. Mechanical Properties

The mechanical properties of the TPNR-BF at different filler content are shown in Figure 3. All mechanical properties of the composite decrease with increasing BF content. This is expected as the interfacial zone between the hosting polymer, and the metal particles are the weaker zone in the material. This weak zone increase with increasing filler content and reduce the tensile stress, tensile strain, and young modulus of the composite. It is recommended to improve the bonding between BF filler and polymer matrix using available treating processes such as heating, epoxy or ultrasound method. It is also noted that the metal filler cold pulls out from the polymer matrix near the surface. This is due to weak bond between BF filler and matrix.

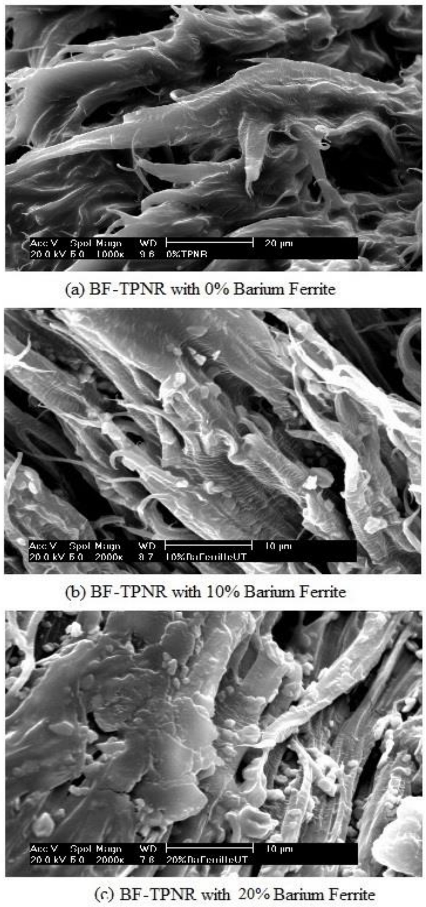

Fig. 2: Scanning electron micrographs (SEM) of the microwave absorber composite. (a) 0% BF, (b) 10% BF and (c) 20% BF.

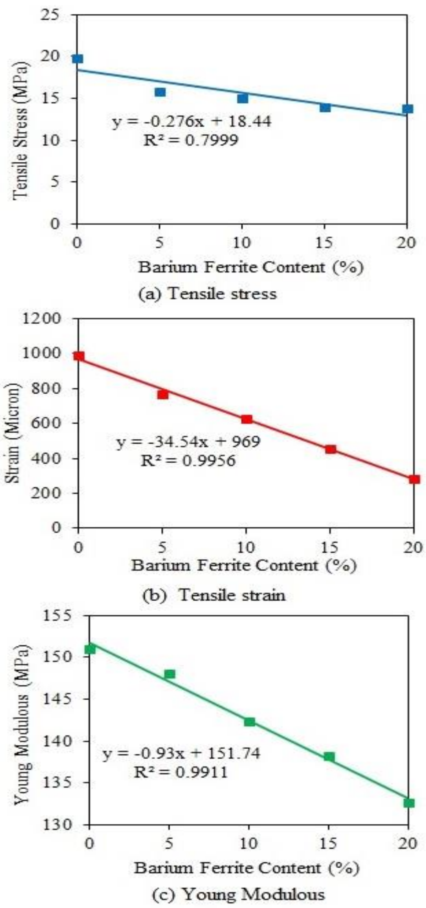

Fig. 3: The mechanical properties of the TPNR-BF at different filler content. (a) tensile stress, (b) tensile strain, and (c) Young modulus.

5.3. Magnetic Properties

The magnetic properties of the TPNR-BF at different filler content is given in Figure 4. The results show that magnetic permeability of barium ferrite composite is positive proportional with the weight fraction of the barium ferrite filler and it is a coefficient dependent on magnetic properties, geometry, size, dispersion and volume of the filler. Further improvement of the magnetic properties could be performed using nanoparticle barium ferrite filler which could improve the dispersion in the hosting matrix and further improve the mechanical properties of the composite. The inclusion of small amount converts the polymer matrix from non-magnetic material to magnetic composite. Also, Magnetic properties such as M_s and M_r increase with increasing BF content. The magnetic hysteresis curve also indicates that H_c decrease with increasing BF content.

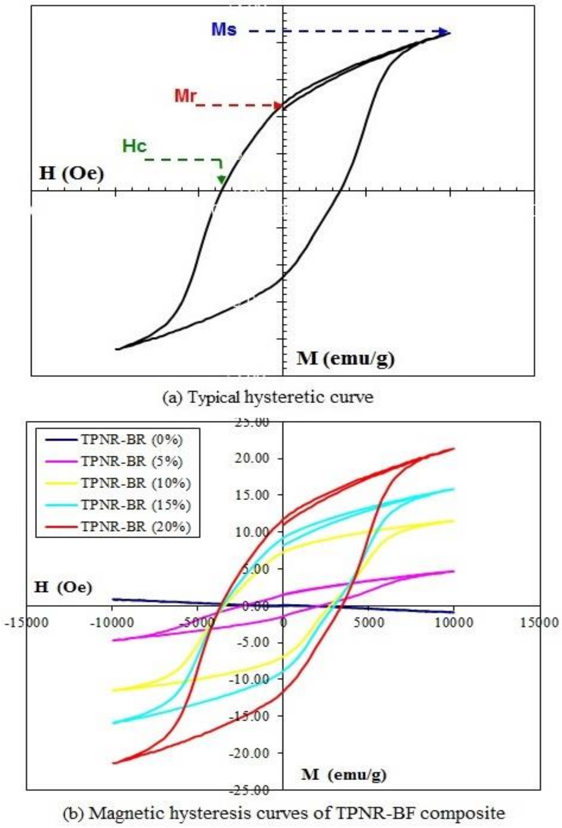

Fig. 4: Magnetic properties (H vs M curve) of TPNR-BF composite.

5.4. Microwave Properties

The microwave properties of the TPNR-BF such as scattering parameters (reflection coefficients and transmission coefficients) and complex permittivity (dielectric constant and loss factor) at different barium ferrite filler content are shown in Figures 5 and 6. The material shows excellent ability to absorb microwave signal. The amount of absorption is directly proportional to the amount of barium ferrite filler content. This can be read from increasing dielectric constant with increasing BF content which may lead to more signal energy absorbed by BF filler and reduce the transmission of the wave after passing the composite. The loss factor increase with increasing BF content and frequency. This may attribute to the increase of the current conductance of the composite with increasing metal BF filler. The results also show that the reflection of the microwave signal increase with BF filler content because the metal BF block the signal from transmit the composite.

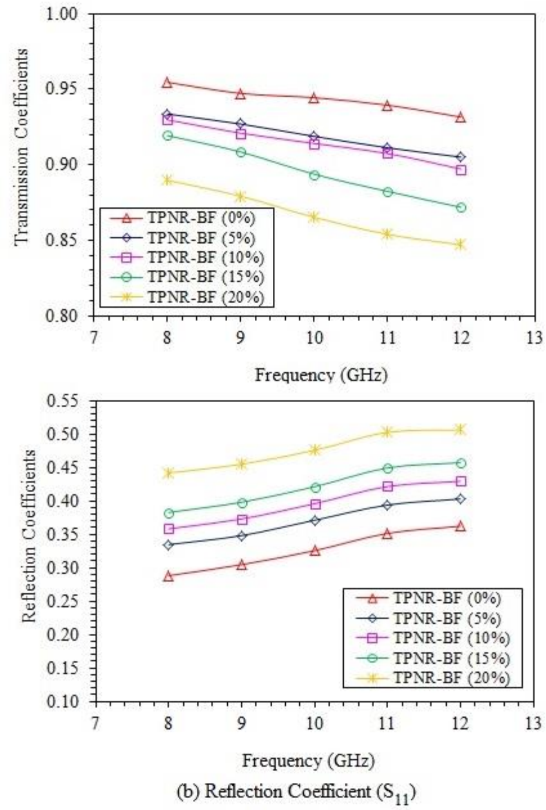

Fig. 5: Scattering parameters (reflection and transmission coefficient) of TPNR-BF.

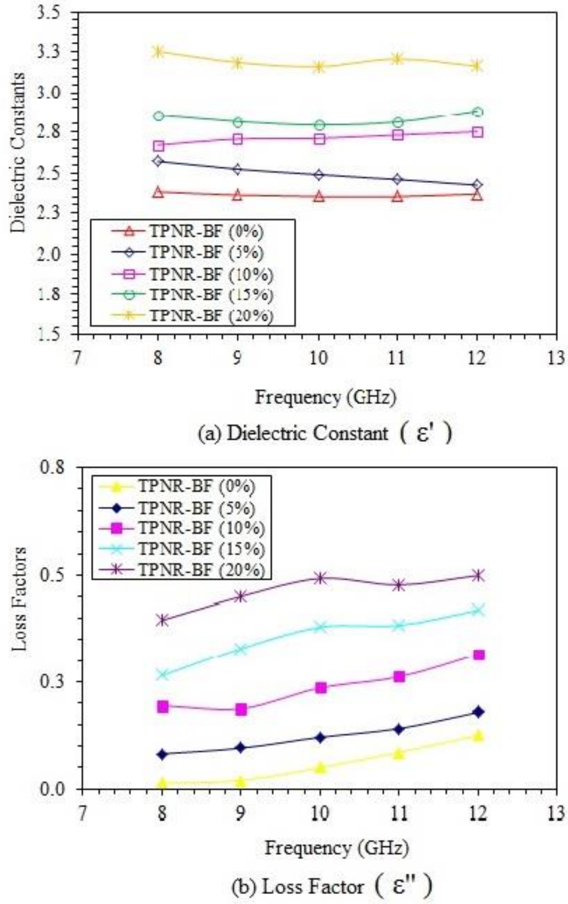

Fig. 6: Complex permittivity (Dielectric constant and loss factor) of TPNR-BF.

6. Conclusion

This study has successfully produced a microwave absorber composite material called thermoplastic natural rubber barium ferrite TPNR-BF utilizing barium ferrite type-M, $BaFe_{12}O_{19}$ itself to be the filler while the TPNR forms the hosting material. The proposed material has attractive properties such as high magnetization, remanence, coercivity and electrical resistivity. The materials also have exceptional resistance to high temperature, humidity, chemicals, and corrosion. The proposed material has been characterized to determine its mechanical, physical, microwave properties using relevant standard methods. The mechanical properties decline with the increasing BF content. This trend could be enhanced by treatment processes such as using epoxy, ultrasound treatment, and thermal treatment.

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References

[1] Bregar VB, (2004), Advantages of ferromagnetic nanoparticle composites in microwave absorbers, *IEEE Transactions on Magnetics*, 40 (3), 1679 - 1684
[2] Mokhtar N, Abdullah M & Ahmad S, (2012), Structural and Magnetic Properties of Type-M Barium Ferrite – Thermoplastic Natural Rubber Nanocomposites, *Sains Malaysiana* 41(9), 1125–1131.
[3] Feng YB, Qiu T, & Shen CY, (2007), Absorbing properties and structural design of microwave absorbers based on carbonyl iron and barium ferrite, *Journal of Magnetism and Magnetic Materials* 318, 8–13.
[4] Kong I, Ahmad S, Abdullah M, Hui D, Yusoff AN & Puryanti D., (2010), Magnetic and microwave absorbing properties of magnetite–thermoplastic natural rubber nanocomposites, *Journal of Magnetism and Magnetic Materials* 322, 3401–3409.
[5] Flaifel MH, Ahmad S, Abdullah M, Shaari RRAH, Ayman A & El-Saleh, SA, (2014), Preparation, thermal, magnetic and microwave absorption properties of thermoplastic natural rubber matrix impregnated with NiZn ferrite nanoparticles, *Composites Science and Technology* 96, 103–108.
[6] Abdullah MH, Ahmad M, Ibrahim NB & Yusoff AN, (2008). Microwave magnetic, dielectric and absorption properties of some cerium yttrium iron garnets. *Sains Malaysiana* 37(2), 205-201.
[7] Kong I, Ahmad SH, Abdullah MH, Hue D, Yusoff AN & Puryanti D, (2010), Magnetic and microwave absorbing properties of magnetite – thermoplastic natural rubber nanocomposites. *Journal of Magnetism and Magnetic Materials* 322, 3401- 3409.
[8] Yusoff AN, Abdullah MH, Ahmad SH, Jusoh SF, Mansor AA & Hamid SAA, (2002), Electromagnetic and absorption properties of some microwave absorbers. *Journal of Applied Physics* 92, 876-882.
[9] Puryanti D, Ahmad SH, Abdullah MH & Yusoff AN (2007), Effect of nickel-cobalt-zinc ferrite filler on magnetic and thermal properties of thermoplastic natural rubber composites, *International Journal of Polymeric Materials* 56, 1-12.
[10] Al-Qadi IL, Riad SM, Mostaf R & Su W, (1997), Design and evaluation of a coaxial transmission line fixture to characterize Portland cement concrete, *Construction and Building Mater*ial 11 (3), 163–173.
[11] Jamil M, Hassan MK, Al-Mattarneh HMA & Zain MFM, (2013), Concrete dielectric properties investigation using microwave non-destructive techniques, *Material, and Struct*ure 46, 77–87.
[12] Al-Mattarneh H, (2016), Determination of chloride content in concrete using near- and far-field microwave non-destructive methods, Corrosion Science, *Corrosion Science* 105, 133–140.
[13] Al-Mattarneh H, (2014), Electromagnetic quality control of steel fiber concrete, *Construction and Building Materials* 73, 350–356.
[14] Al-Mattarneh HMA, Ghodgaonkar DK. & Majid WMBWA, (2001), Microwave nondestructive testing for classification of Malaysian timber using free-space techniques, *Proceedings of the* Sixth International, Symposium on Signal Processing and its Applications, Sixth International, *IEEE Xplore*, 2, 450-453.
[15] Al-Mattarneh HMA, Ghodgaonkar DK, & Majid WMWA, (2001), Microwave sensing of moisture content in concrete using open-ended rectangular waveguide, *Subsurface Sensing Technologies, and Applications*, 2 (4), 377-390.
[16] Al-Mattarneh H, Ghodgaonkar DK, Abdul Hamid H, Al-Fugara A & Abu Bakar SH, (2002), Microwave Reflectometer System for Continuous Monitoring of Water Quality, IEEE Proceedings of the 2002 Student Conference on Research and Development, *IEEE Xplore*, July 16-17, 430-433.
[17] Al-Mattarneh HMA, Ghodgaonkar DK,. Wan Mahmood Majid B.W.A, (2001), Determination of Compressive Strength of Concrete Using Free-Space Reflection Measurements in the Frequency Range of 8–12.5 GHz, *Asia-Pacific Microwave Conference, Microwave for New Century*, December 3–6, National Taiwan University, Taipei, Taiwan, R.O.C.
[18] Ghodgaonkar DK, Varadan VV & Varadan VK, (1989), Free-space method for measurement of dielectric constants and loss tangents at microwave frequencies, *IEEE Trans. Instrumentation and Measurement* 38, 789–793.
[19] Kim SS, Jo SB, Gueon KI, Choi KK, Kim JM & Churn KS, (1991). Complex permittivity and microwave absorption of ferrite-rubber composite in X-band frequencies., *IEEE Transaction on Magnetics*. 27 (6), 54-62.
[20] Shinb JY & Oh JH (1993). The Microwave absorbing phenomina of Ferrite Microwave absorbers, *IEEE Transaction on Magnetics*. 29 (6), 3437-3439.