Microwave Nondestructive Evaluation of Textile Composites for Comparison Between Electrical and Physical Properties

Aidil Saifan Abu Bakar[1], Mohd Iqbal Misnon[2], Deepak Kumar Ghodgaonkar[1], Norasimah Khadri[1], Jamil Hj Salleh[2], Wan Yunus Wan Ahmad[2], Mohamed Dahalan Mohamed Ramli[3]

Microwave Technology Center
[1]Faculty of Electrical Engineering, [2]Faculty of Applied Science, [3]Faculty of Mechanical Engineering
MARA University of Technology (UiTM), 40450 Shah Alam, Selangor, Malaysia
deep27@gmail.com

ABSTRACT

Composites are expensive and destructive test methods are applied to determine their physical properties. For textile composites, a nondestructive test could save time and cost if the physical properties such as moisture content, weave architecture, void content and fiber volume fraction can be deduced from electrical properties. Microwave nondestructive testing techniques such as measurement of complex permittivity will be used for correlation with physical properties of composites. For textile composites made from E-Glass and Kevlar fibers, dielectric properties are measured using free-space microwave measurement system. Experimental results are reported for dielectric constants and loss factors of textile composites with their physical properties.

INTRODUCTION

In this paper, microwave nondestructive testing (MNDT) techniques such as reflection, transmission and dielectric measurements will be applied to characterize some of the properties of textile composites. The above parameters can be correlated with physical properties such as volume fraction, voids content and moisture content by suitable modeling and calibration. MNDT of composite materials is an important science which involve development of sensors and probes, methods and calibration technique for detection of flaws, cracks, defects, voids, inhomogeinities, moisture content, etc, by means of microwaves. MNDT techniques have advantages over other NDT methods regarding low cost, good penetration in nonmetallic materials, good resolution and contactless feature of the microwave sensor (antenna). MNDT techniques are increasing being used in quality control and condition assessment of concrete structures and timber grading [1-2].

There has been a growing awareness of the importance of textile-reinforced composites. It plays an important role in the advancement of the aeronautics and aerospace industries. Composites have been proven as weight saving materials. The new microwave testing techniques for detection of damage, defect and delamination of textile composites will be useful to aerospace and other industries manufacturing commercial products such as high performance cars, boats and sporting goods.

Composites are very expensive and destructive test methods are normally applied to determine their physical properties. A nondestructive test could save time and cost on some of the measured properties such as moisture content, fiber characterization, fiber orientation, weave architecture, voids defects and fiber volume fraction.

In this study, free-space techniques are used to calculate dielectric properties from measured S-parameters using free-space microwave measurement system. The free-space microwave measurement system consists of a pair of spot-focusing horn lens antennas, coaxial cables, mode transitions and a vector network analyzer. Diffraction effects at the edges of the samples are minimized by using spot-focusing horn lens antennas. Errors due to multiple reflections between antennas via the surface of the sample are corrected by using free-space LRL (Line, Reflect, Line) calibration technique. Results are reported for textile composites made from E-Glass and Kevlar fibers. Epoxy has been used as the resin.

SAMPLE PREPARATION

High performance fabrics (HPF): E-glass (G7628), Kevlar (K151) and Kevlar (K141) were used to fabricate composites using epoxy (Morcrete BJC 39) resin. Several layers of HPF were laid and then impregnated with epoxy resin (ratio of epoxy resin with hardener is 70:30). The ratio of HPF to epoxy resin is 50:50. The impregnated HPF was then compressed under a pair of aluminum plates and 2 mm or 4 mm thickness spacers were inserted between the plates. The assembly was pre-cured at room temperature for 30 minutes and then cured in an oven for one hour at 100°C. It was then left for 24 hours to cool down.

Each specimen that has been fabricated was cut into 20.5 cm by 20.5 cm size. Part of this specimen will be used to measure physical properties such as thickness, fabric sett, aerial density, and fiber volume fraction. Fiber orientation and weave architecture were also noted. For microwave measurements of dielectric properties, specimens of size 10.2 cm by 10.2 cm were used.

Three types of composites sample have been fabricated which were E-Glass 7628, Kevlar K141 and Kevlar K151. Thickness of these composites is 2 mm or 4 mm.

PHYSICAL PROPERTIES

Table 1 shows the data of HPF used to fabricate textile composites. Thickness of fabric has been determined using MS ISO 5084:2003; ASTM D 1777-1996 standard method, fabric sett was examined using MS ISO 7211/2:2003; BS 2865:1984, while aerial density was measured in g m^{-2} unit using MS ISO 3801:2003; ASTM D 3779-1996.

Table 2 and 3 show the density and fiber volume fraction (FVF) of textile composites of thickness 2 mm and 4 mm, respectively. Fiber volume fractions of composites were assessed using CRAG (Composite Research Advisory Group) method 1000 by resin burn-off [3].

DIELECTRIC PROPERTIES

For calculation of dielectric properties, S-parameters are measured using free-space microwave measurement system (FSMM) [4]. It consists of a pair of spot-focusing horn lens antennas, coaxial cables, a vector analyzer, mode transitions and a computer. Diffraction effects at the edges of the samples are minimized by using spot-focusing horn lens antennas. Errors due to multiple reflections between antennas via the surface of the sample are corrected by using free-space LRL (Line, Reflect, Line) calibration technique [5]. Results are reported for textile composites made from E-Glass and Kevlar fibers. Epoxy has been used as the resin.

After performing the free space LRL calibration, the complex permittivity (ε^*) is calculated from the measured values of S_{21} by using transmission (S_{21}) only method given by Mohd Aziz et al [6]. Due to measurement errors, loss tangent less than 0.025 can not be measured accurately by transmission only method. Dielectric properties of textile composites are given in tables 4 and 5 at 10 GHz and 21 GHz, respectively.

In order to test for delamination in textile composites, a cardboard (thickness = 0.5mm) was sandwiched between two Teflon plates (thickness = 6.25 mm) of size 10.2 cm by 10.2 cm. One-fourth of the cardboard of dimension 4.5 cm x 4.5 cm was removed to simulate air gap in textile composites. Then, measurements were made at the center of four quadrants of the Teflon-cardboard-Teflon composite. Table 6 gives dielectric measurements at 24.7 GHz.

CONCLUSIONS

From tables 2 and 3, it is observed that there is no difference in fiber volume fractions and densities for 2 mm and 4 mm composites. From tables 4 and 5, dielectric constants of Kevlar K141 and Kevlar K151 composites are lower than E-glass 7628 composites due to lower density. For composites having thickness 2 mm, dielectric constants of E-Glass G7628 and Kevlar K141 are lower at 21 GHz as compared with 10 GHz. But, there is no effect of the frequency on Kevlar K151 composites having a thickness of 2 mm. This is due to twill weave structure of K151 fabrics in K151 composites. For composites having thickness of 4 mm, there is insignificant difference in dielectric constant values at 10 and 21 GHz.

From Table 6, it is found that dielectric constant of quadrant with air gap is significanly different than other quadrants . So, the FSMM system can be used to detect the presence of air gap. Also, this technique can be used to detect the delamination in textile composites.

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Table 1: Data of High Performance Textile Fabrics

Fabric Types	Thread (count)	Thickness (mm)	End/2cm	Pick/ 2cm	Fabric Weight (g/m^2)	Weave Structure
E-Glass G7628	44 x 32	0.210	35	25	203.44	Plain
Kevlar K141	17 x 17	0.254	14	13	271.16	Plain
Kevlar K151	17 x 17	0.254	10	10	169.45	Twill 3/1

Table 2: Density and Fiber Volume Fraction of High Performance Fabrics for 2 mm Composites

Sample	No. of layers/ Composite	Density of Composite (g/cc)	Density of fibre (g/cc)	FVF (%)
E-Glass G7628	12	1.76	2.54	48.94
Kevlar K141	9	1.24	1.44	44.58
Kevlar K151	9	1.21	1.44	44.95

Table 3: Density and Fiber Volume Fraction of High Performance Fabrics for 4 mm Composites

Sample	No. of layers/ Composite	Density of Composite (g/cc)	Density of fibre (g/cc)	FVF (%)
E-Glass G7628	24	1.77	2.54	46.87
Kevlar K141	18	1.28	1.44	48.40
Kevlar K151	18	1.29	1.44	54.48

Table 4: Dielectric Properties of textile composites at 10GHz

	Thickness 2mm		Thickness 4 mm	
Sample	Dielectric Constant	Loss Factor	Dielectric Constant	Loss Factor
E- Glass G7628	4.92	0.07	4.56	0.29
Kevlar 141	4.00	0.35	3.75	0.34
Kevlar 151	3.95	0.37	3.72	0.43

Table 5: Dielectric Properties of Samples at 21GHz

	Thickness 2mm		Thickness 4 mm	
Sample	Dielectric Constant	Loss Factor	Dielectric Constant	Loss Factor
E- Glass G7628	4.59	0.37	4.50	0.23
Kevlar 141	3.62	0.56	3.65	0.26
Kevlar 151	3.96	0.32	3.68	0.32

Table 6: Air gap effect at 24.7 GHz

Quadrant	**Dielectric Constant**	**Loss Factor**
1 with air gap	2.04	-0.01
2	2.12	-0.02
3	2.10	-0.02
4	2.10	-0.02