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PRELIMINARY DETERMINATION OF ASPHALT PROPERTIES USING MICROWAVE TECHNIQUES

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ABSTRACT

An accurate, contactless and nondestructive method has been developed to characterize the rheological properties of asphalt (bitumen) by applying microwave techniques. The measured microwave parameters can be related to material parameters because microwaves are affected by means of wave transmission through the asphalt medium. In lossless and lossy dielectrics, diverse properties such as porosity, material composition, uniformity of the material, delamination of layers, moisture and contamination content and many other properties can be measured by suitable modeling and calibration of the measuring techniques. Microwave parameters can be correlated with conventional testing and the Strategic Highway and Research Program (SHRP) standard. Preliminary test results indicate a good correlation with material properties. Conventional methods, which are time consuming, costly and empirical, could be replaced by this new microwave method. This would bring about a revolutionary change in the highways and transportation sector worldwide.

Keywords: asphalt, rheology, microwave, permittivity, dielectric constant, non-destructive, environment.

INTRODUCTION

Asphalt and cement are binding materials used for road construction. Asphalt is used in bituminous (flexible pavement) construction and cement is used in the construction of rigid pavements. In the United States, 94% of roads are surfaced with asphalt; only 6% are rigid pavements. In Malaysia and other developing countries, asphalt is used on more than 94% of road surfaces. In many countries only asphalt roads are in service and there are no rigid pavements at all. On average, 6% of asphalt is used for the construction of flexible pavement in the world's highways. To meet the need for the high volume of asphalt pavement construction, the demand for asphalt is increasing at 2.3% per year and would reach 114 million tons in 2009 (Freedonia, 2006). Moreover, the price of asphalt increases with the price of crude oil. The price of crude oil has increased by over 725% (from USD14.47 in 1993 to USD105.00 in 2008 (Asian Electronic Trading on the New York Stock Exchange, 2008). Simultaneously, the price of bitumen has also increased over the last 15 years, also by 725%.

The research on asphalt primarily focuses on quality and precision. Asphalt is a visco-elastic material produced as a by-product in oil refineries or in natural deposits. It is a rheological material because its deformation characteristics vary with load together with the rate of load application. It is also a thermoplastic material; it liquefies when heated and becomes semi-solid when cooled.

Generally, asphalt is heated to about 160–165^{0}C prior to mixing with stone aggregates, fillers, additives etc. in the batching plant to produce a mixture for paving in flexible pavement construction. At this mixing temperature, the visco-elastic properties of the asphalt change. This change plays an important role in the quality and durability of the flexible pavement produced. In order to ensure the quality of the asphalt material, accurate testing procedures are important.

However, the conventional testing method currently used on asphalt is more than 110 years old (in 1888, H. C. Bowen invented the Bowen Penetration Machine to determine the consistency of asphalt) (Roberts *et al.*, 1996). In addition, most specifications and design methods for asphalt and asphalt mixtures are empirical and over 50 years old.

In most asphalt mixtures, the quality of asphalt interaction (adhesion) is the main factor in pavement deterioration (Colvin and Moore, 2004). The time delay incurred in road construction programs due to testing bitumen and bitumen-related products is quite substantial and can adversely affect construction works. As such, a new procedure other than the conventional testing of highway materials is required. Usage of electromagnetic waves may provide a new way of analyzing bitumens.

The current asphalt testing methods are associated with the following problems, as outlined below:

- i Many standards such as ASTM, AASHTO, SHRP, NIST, EN (European Norms), BS are applied;
- ii Many variables are involved in testing such as temperature, local environment;
- iii Many researchers are mainly focused on solving the problems involved in meeting their own country's demand first rather than on other countries' environmental conditions;
- iv Different sources of crude oil mean that the properties of bitumen vary from source to source;
- v Conventional testing is neither precise nor reliable;
- vi Conventional testing is tedious, expensive and time consuming.

In view of these problems, it is desirable that an alternative, fast test method be developed that can ascertain the precise properties of asphalt. The Strategic

Highway and Research Program (SHRP) has spent about USD50 million on asphalt research, to address and quantify the properties of asphalt binders. However, these testing are very expensive.

In Malaysia, the cost of maintaining roads was RM8.9 billion as on RMK 8 (EPU, 2001), and RM5.1 billion has been spent on the development of new roads. Thus, the Malaysian maintenance budget is 174.5% higher than the budget provided for development of new roads. If one looks at the worldwide situation, an estimated USD90 billion is spent annually on the up-keep of roads. Moreover, billions of dollars are spent annually on the repair of roads and vehicles because of potholes (Highways, 2001). Globally, the repair costs associated with potholes is more than USD1 billion per annum.

The benefit from the research presented here is expected reduction in highway maintenance costs incurred as a result of pavement defects, pavement deformation, cracks, stripping, rutting, and shoving. The application of this research is expected to prolong the design life of pavement. It may also reduce the cost and time expenses in laboratory testing leading to a time saving in construction. The research is also expected to help improve the quality of roads in terms of riding. Consequently, this research will benefit road authorities and users alike.

A proper and reliable testing method is necessary for asphalt to eliminate the variability of the asphalt binder. The electromagnetic wave may have the potential to be used in the testing of asphalt and presents a unique, reliable testing method that could be both fast and precise.

PERMITTIVITY AND PERMEABILITY OF MATERIALS BY MICROWAVES

Each material has a unique set of electrical characteristics that are dependent on its dielectric properties (Agilent Technologies, 2005). Electromagnetic waves are suitable to measure the dielectric properties with proper selection of frequency band.

The velocity of light is only a function of the permittivity and permeability of a medium. The velocity of light in a medium (Nyfors and Vainikainen, 1989) is $v_{light} = 1/\sqrt{\mu\varepsilon}$.

In free-space, (Stratton, 2007) $v_{light} = c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = \frac{1}{\sqrt{4\pi * 10^{-7} * 8.854 * 10^{-12}}} = 2.9979\text{x}10^8$ m/sec

Equation [1]

$$V_p = V_{light} = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}}$$

Where V_p is the velocity of light in a medium

$$n = \frac{\text{Velocity of light in free space}}{\text{Velocity of light in medium}} = \frac{c}{V_p} = \frac{c}{\frac{c}{\sqrt{\mu_r \varepsilon_r}}}$$

$=\sqrt{\mu_r \varepsilon_r}$ Equation [2]

where

n = refractive index

For non-magnetic materials, (Nyfors and Vainikainen, 1989) $\mu_r = 1$, $n = \sqrt{\varepsilon_r}$

Permittivity and permeability are the major dielectric properties of materials. They are important properties of an engineering material which determine a material's electromagnetic characteristics. It is important to note that permittivity and permeability are not constant. They can change with frequency, temperature, orientation, mixture, pressure, and molecular structure of the material. The permittivity, ε, and magnetic permeability, μ, of a medium together determine the phase velocity, *v*, of electromagnetic radiation through that medium (Nyfors and Vainikainen, 1989): $\varepsilon\mu = \frac{1}{v^2}$

During the passing of an electromagnetic wave through any sample, the following changes occur:

i Velocity decreases ($V_d < c$)
ii Wavelength shortens ($\lambda_d < \lambda_0$)
iii Impedance is lower in the sample ($Z < Z_0$)
iv Magnitude is attenuated (insertion loss)

Figure-1 shows a reflected and transmitted signal of an electromagnetic wave (Agilent Technologies, 2005).

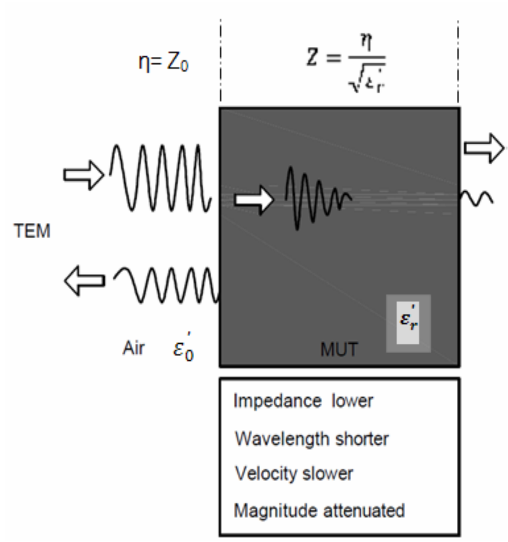

Figure-1. Reflected and transmitted signals of electromagnetic wave.

The following formulae show the above relation:

$V = c/\sqrt{\varepsilon_r'}$ Equation [3]

where, V = velocity in the sample under test and c = speed of light in free-space.

$\lambda_d = \frac{\lambda_0}{\varepsilon_r'}$ Equation [4]

where, $\lambda_0 =$ free-space wavelength

$\lambda_d =$ wavelength in the sample under test

$$Z = Z_0 / \sqrt{\varepsilon_r'} \qquad \text{Equation [5]}$$

where, Z =impedance in the sample, and
Z_0 = free-space impedance

$$Z_0 = \sqrt{\mu_0/\varepsilon_0} = 120\pi = 377.99\Omega \qquad \text{Equation [6]}$$

MATERIALS AND METHODS

Microwave free-space method (MWFSM)

James Clerk Maxwell, R. M. Redheffer and Harold L. Bassett worked on the free-space method by contributing their efforts in the various stages (Ghodgaonkar *et al.*, 2000) of research. The electromagnetic properties of material are closely related to the microparameters of the material, such as electron density, electron temperature, and collision frequency of the particles in the case of plasmas or concentration of charge carriers, their mobility and relaxation time in semiconductors (Musil and Zacek, 1986a).

From the permittivity measurements, the microparameters of the material medium can be evaluated from the relation between complex permittivity, loss factor, loss tangent, and many other material parameters. Permittivity is a fundamental property of materials. It is independent of measuring techniques, but is dependent on the frequency of microwave tested and the temperature of the tested material (Bartley and Begley, 2005).

The microwave parameters of bitumen such as permittivity and other measured parameters, and their correlation with conventional and SHRP tests, may become important for use in highway materials testing and also commercial applications in the pavement industry.

Currently, asphalt is tested by conventional testing such as penetration, softening point and viscosity. The SHRP developed a new set of testing procedures. The measurement of the microwave properties of bitumen by the free-space method has the potential to be very cost effective, fruitful and reliable. It is contactless and nondestructive and, for this reason, this method may be suitable for high and low temperatures, in strong magnetic and electric fields, and in hostile environments (Musil and Zacek, 1986a).

To achieve a good, accurate measurement with the MWFSM, some general guidelines were followed in this research:

- The wave incident to the sample from the antenna should be a plane wave;
- To determine the far-field, a reasonable formula should be taken into account in this process. Far-field (FF) begins at $2D^2/\lambda$ for antennas D » λ (Alabaster and Dahele, 2003; Bartley and Begley, 2005; Field, 2001);
- The sample size should be considered carefully as it is very important;
- The wall thickness of the sample container should be in order; and
- The placement of the sample holder should be in between the common focal plane for a pair of spot-focusing horn lens antennas.

The solution of 'Maxwell' equations determines how the microwave energy propagates through a material.

Antenna and sample size

The antenna system transmits a plain electromagnetic wave into a strictly limited volume and guarantees that the plain electromagnetic wave goes completely through the measured sample with negligible diffraction of incident energy on the specimen edges. An attenuation of 10 dB through the sample layer was maintained to avoid disturbances due to multiple reflections between the sample and the antennas (Kraszewski *et al.*, 1996). The free-space LRL (Line-Reflect-Line) calibration techniques, along with the smoothing or time domain gating feature of the VNA, can eliminate multiple reflections also (Ghodgaonkar *et al.*, 2000).

Measurement method

A proper and appropriate measuring system was developed taking into account the sample thickness, container wall thickness, spot-focusing horn lens antenna system and calibration techniques in order to eliminate or minimize the three main problems associated with MWFSM, namely, i) diffraction, ii) multiple reflections, and iii) impedance mismatch.

Calibration in the free-space method was chosen based on type of antenna and VNA. Many calibration methods are available for use in the free-space method. They are Open, Short, TRL (Thru-Reflect-Line), TRM (Thru-Reflect-Match), and LRL (Line-Reflect-Line). Choosing of calibration techniques depends mainly on material measurement software and VNA.

Experimental model for determining permittivity

In this study, the microwave free-space techniques was used to calculate the dielectric properties of bitumen from measured scattering parameters by a suitable arrangement of the testing procedure. In order to do this, a new protocol for the sample preparation was developed.

Sample container and sample thickness

Due to the testing requirement being at high temperature, a high temperature-resistant Teflon material was used as the sample container with a proper thickness based on the knowledge of complex permittivity and availability of sheet thickness. Preparation of a rectangular Teflon holder was made by using a Computer Numerical Control (CNC) machine in the Mechanical Engineering laboratory of University Putra Malaysia (UPM).

The term "permittivity" relates to whether the medium permits the electrical lines of force or not and if

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so, to what extent. This depends on the material's ability to transmit or permit an electrical field. Permittivity describes the interaction of a material with an electric field. On the other hand, the term "permeability" relates to whether the medium permits the magnetic lines of force or not and if so, to what extent.

The permittivity and permeability of a material were normalized to relative permittivity and relative permeability with respect to free-space. In the frequency domain, the complex relative permittivity (Nyfors and Vainikainen, 1989) is

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$ Equation [7]

Complex relative permittivity = $\varepsilon_r^* = \frac{\varepsilon^*}{\varepsilon_0} = \varepsilon_r' - j\varepsilon_r'' = \left(\frac{\varepsilon'}{\varepsilon_0}\right) - j\left(\frac{\varepsilon''}{\varepsilon_0}\right)$ Equation [8]

ε_r^* = complex relative permittivity
ε^* = complex permittivity
ε_0 = vacuum permittivity i.e. permittivity of the free-space

Permittivity of the vacuum, ε_0 = permittivity of the free-space is equal to (Stratton, 2007): $\frac{1}{C^2 \cdot \mu_0}$ =8.854 x 12^{-12} F/m or (C^2/ ($N.m^2$)
where c = velocity of light in free-space = 2.998x10^{-12} m/s
μ_0 = permeability in vacuum = 4πx10^{-7} H/m.

Complex relative permittivity is a combination of a real part and an imaginary part. The real part is known as the dielectric constant (DC). The real part of permittivity (ε_r') is a measure of how much energy from an external electric field is stored in a material. The imaginary part of permittivity (ε_r'') is called the loss factor and is a measure of how dissipative or lossy a material is to an external electric field. The linear permittivity of a homogeneous material is usually given relative to that of vacuum, as a relative permittivity. The dielectric constant (ε_r') is equivalent to relative permittivity (ε_r) or the absolute permittivity (ε) relative to the permittivity of free-space (ε_0). The imaginary part of permittivity (ε_r'') is always greater than zero and is usually much smaller than (ε_r') for lowloss material (Zoughi and Bakhtiari, 1990).

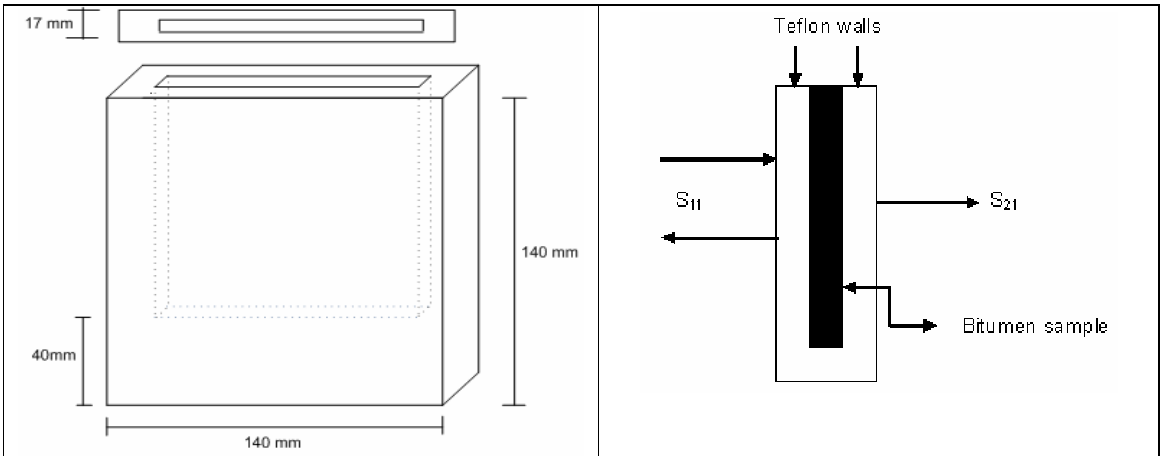
Thickness of container wall

Teflon is to be used as a material for container wall for its loss factor nearly zero (0.0002 @ 1 MHz) (Golio, 2001). Since Teflon is able to endure a high temperature, (melting point 327^{0}C), a bitumen sample holder was manufactured from Teflon using the CNC procedure. The dimensions are deemed to be appropriate in line with the free-space testing procedure. The following analysis was used in calculating the container wall thickness and the sample thickness.

Thickness of sample or container wall is evaluated from the following formula, (Musil and Zacek, 1986c): $\lambda_0 / 4\sqrt{\varepsilon_r'}$. For Teflon or asphalt is as follow:

$$\lambda_0 / 4\sqrt{\varepsilon_{Teflon\ or\ asphalt}}$$ Equation [9]

Quarter wavelength is taken as the maximum value of a cycle of wavelength is at ¼ and ¾ of a cycle wave. Sample thickness, d_3 < ¼ λ_0. Thickness of the material must be small compared with the wavelength if absolute measurements are used (Ida, 1992). Thickness of the container wall, $d_1 = s\,\lambda_0 / 2\sqrt{\varepsilon_r'}$ is suitable, if the measurement is carried out in one frequency. In such cases, it accommodates exactly an integer number of half waves (Musil and Zacek, 1986b). The quarter wavelength is that called "electric thickness". The characteristics a quarter wavelength is that it generates maximum power at $\varphi^c/2$. The highest (max. or min.) intensity is at the point of quarter wavelength. The material and the dimensions used are shown in Figure-2.



(a) Fabricated Teflon container (b) Cross-section of Teflon container with sample

Figure-2. Fabricated container of Teflon and sample.

It was known that the uncertainties in S_{11} measurements using VNA are low for the high values of S_{11} and that $|S_{11}|$ has its maximum when d = (2n+1) λ_m, where d is the thickness, λ_m is the wavelength in the medium, and n = an integer. This is due to the quarter wave transformer effect (Il Sung Seo, 2004). Table-1 shows the electric thickness of the sample and container walls of Teflon.

Table-1. Electric thickness of the sample and container walls of Teflon.

Microwave frequency band (GHz)	**Center frequency** (GHz)	**Thickness** (mm)	
		Teflon wall	**Asphalt**
		$\frac{\lambda_0}{4\sqrt{\varepsilon_{teflon}}}$	$\frac{\lambda_0}{4\sqrt{\varepsilon_{asphalt}}}$
X-band (8 – 12)	10	5.175 ≈5.0	4.749 ≈5.0
K-band (18 – 26)	22	2.352	2.158

The permittivity of asphalt binder (ε_r') is 2.494 as calculated from the coaxial probe method. The permittivity of Teflon (ε_r') $\varepsilon_1 r^{1r}$) is taken as 2.1 from the data sheet of the manufacturer, Dupont.

The thickness of the sample is d= (2n+1) $\lambda_m/4$, where $\lambda_m/4$, is electric thickness and λ_m is the wavelength in the medium. To minimize the errors caused by the measurement `uncertainties, the specimen thickness was chosen to be close to an odd multiple of electric thickness $\lambda_m/4$, (Il Sung Seo, 2004; Musil and Zacek, 1986a).

The K_u-band can be chosen for smaller thicknesses of sample and container wall, but due to the viscous behavior of asphalt, and the pouring problem inside the Teflon container, the X-band frequency was chosen for microwave testing.

- Asphalt sample thickness was set so that the attenuation within the sample would be at least 10 dB, to reduce the multiple reflections (Kraszewski *et al*., 1996).
- Sample thickness should be less than a quarter wavelength.

Two types of penetration graded asphalt 80-100 and 60-70 and a third performance graded asphalt PG 76 were selected for this research as these are widely used in Malaysia and other countries. The bitumen for this study was supplied by Shell Singapore with the collaboration of Shell Malaysia.

Sample preparation

The three types of neat bitumens, 80-100, 60-70 and PG 76, were blended with three types of additives in different percentages. The additives were cellulose oil palm fibers (COPF), ethylene vinyl acetate (EVA), and tire rubber powder (TRP). They were blended at their mixing temperatures, as determined by SHRP specifications. The blending of three types of additives with three types of bitumen at five proportions of additives was carried out by proportion of weight of asphalt and there were also three control samples of bitumen 80-100, bitumen 60-70 and bitumen PG 76. Samples 1 to 16 contain bitumen 80-100. Sample 1 is the control sample of bitumen 80-100, i.e., no additives were added, samples 2 to 6 contained cellulose oil palm fiber (COPF), at an increment of 0.2% of COPF (0.2% to 1.0%). Samples 7 to 11 contained EVA polymer at an increment of 2.0%, starting from 2.0% to 10.0% by weight of asphalt. Samples 12 to 16 contained TRP at an increment of 2.0%, from 2.0% to 10% by weight of asphalt.

Samples 17 to 32 were blended with bitumen 60-70; sample 17 was the control sample, samples 18 to 22 contained COPF, at an increment of 0.2% of COPF. Samples 23 to 27 contained EVA polymer at an increment of 2.0%, starting from 2.0% to 10.0% by weight of asphalt. Samples 28 to 32 contained TRP at an increment of 2.0%, from 2.0% to 10% by weight of asphalt.

Samples 33 to 48 were blended with bitumen PG 76; sample 33 was the control sample of bitumen PG 76. Samples 34 to 38 contained COPF, at an increment of 0.2% of COPF. Samples 39 to 43 contained EVA polymer at an increment of 2.0%, starting from 2.0% to 10.0% by weight of asphalt. Samples 44 to 48 contained TRP at an increment of 2.0%, from 2.0% to 10% by weight of asphalt.

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Table-2. Details of blended samples of bitumen with different percentages of additives.

80-100 Bitumen					
Sample No.	**Cellulose**	**Sample No.**	**EVA**	**Sample No.**	**TRP**
1	**0 %, Control**	**1**	**0 %, Control**	**1**	**0 %, Control**
2	0.2%	7	2%	12	2%
3	0.4%	8	4%	13	4%
4	0.6%	9	6%	14	6%
5	0.8%	10	8%	15	8%
6	1.0%	11	10%	16	10%
60-70 Bitumen					
Sample No.	**Cellulose**	**Sample No.**	**EVA**	**Sample No.**	**TRP**
17	**0 %, Control**	**17**	**0 %, Control**	**17**	**0 %, Control**
18	0.2%	23	2%	28	2%
19	0.4%	24	4%	29	4%
20	0.6%	25	6%	30	6%
21	0.8%	26	8%	31	8%
22	1.0%	27	10%	32	10%
PG 76 Bitumen					
Sample No.	**Cellulose**	**Sample No.**	**EVA**	**Sample No.**	**TRP**
33	**0 %, Control**	**33**	**0 %, Control**	**33**	**0 %, Control**
34	0.2%	39	2%	44	2%
35	0.4%	40	4%	45	4%
36	0.6%	41	6%	46	6%
37	0.8%	42	8%	47	8%
38	1.0%	43	10%	48	10%

Figure-3 shows the testing of bitumen sample by microwave non-destructive test including the asphalt containers in laboratory at microwave frequency of X-band.

(a) Bitumen PG 76, samples in Teflon containers

(b) Spot-focusing horn lens antennas, sample and VNA

Figure-3. Samples and Non-destructive Testing by Spot-focusing Horn Lens Antennas.

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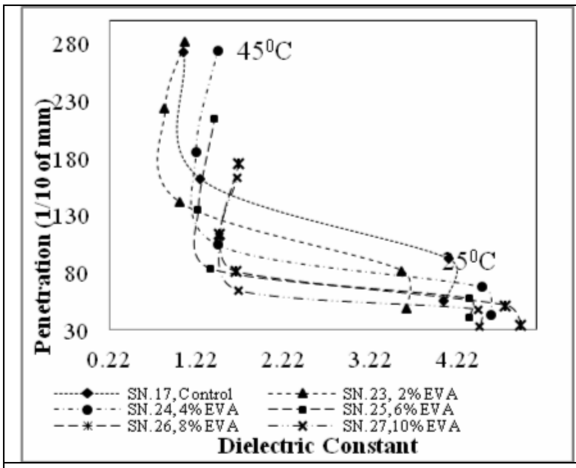
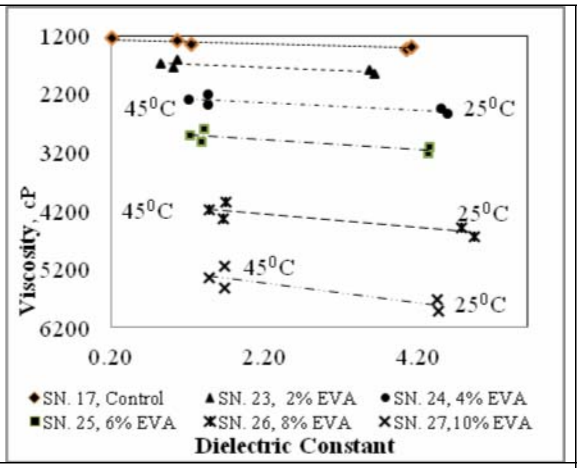
RESULTS AND DISCUSSIONS

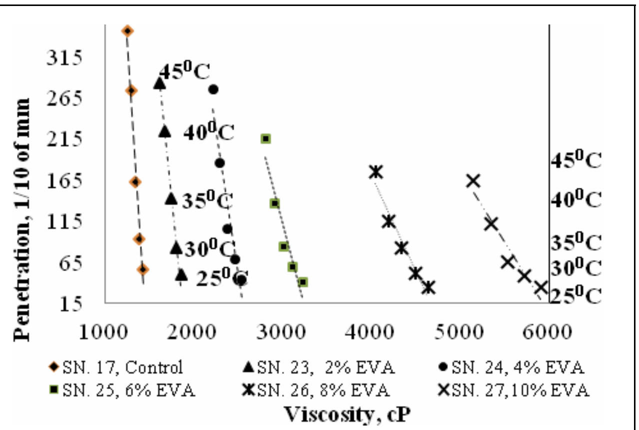
The 48 samples were tested at five different temperatures (25, 30, 35, 40, and 45 degree Celsius), generating 240 items of data for each test. The 240 data items from each test, namely, penetration and viscosity, were plotted against dielectric constant of each sample. Preliminary test results from a microwave free-space method indicated a good correlation of material properties in terms of penetration and viscosity of asphalt. The results discussed here suggest that classical methods, which are time consuming, costly and empirical could be replaced by this new concept of using microwaves. Some of the results of penetration and viscosity were plotted against dielectric constant at a frequency of 10 GHz to find the correlation of the 48 samples. As an example, Figure-4 explains the (a) Penetration versus Dielectric Constant for 60-70 grade bitumen, (b) Viscosity vs. Dielectric Constant, (c) Penetration vs. Viscosity for samples 17, 23-27.



(a) Penetration vs. Dielectric Constant (SN. 17, 23-27), 10 GHz



(b) Viscosity versus Dielectric Constant (SN. 17, 23-27), 10 GHz



(c) Penetration vs Viscosity (SN.17, 23-27)

Figure-4. (a) Penetration vs. Permittivity, (b) Viscosity vs. Permittivity, (c) Penetration vs. Viscosity for samples 17, 23-27.

Effect of glass transition temperature (Tg) on polymers

In this experiment, the polymers used were: polytetrafluoroethylene (PTFE), i.e., the Teflon plate which was used for the container, and EVA and TRP, which were used as additives to the asphalt. The glass transition temperature (Tg) is the temperature at which the polymer changes from a hard glass state to a rubber-like state. There are two methods for the determination of the glass transition temperature. i) Differential Scanning Calorimetry (DSC) defines Tg as the change in the heat capacity when the polymer matrix goes from the glass state to the rubber state. ii) Thermo-Mechanical Analysis (TMA) defines the glass transition in terms of the change in the coefficient of thermal expansion (CTE) (Arlon). The techniques DSC and TMA measure a different result of the change from glass to rubber: DSC measures a heat effect; TMA measures a physical effect, the coefficient of thermal expansion. Teflon (PTFE) has a minor second order crystalline transition at about 19^0C, which results in a minor hiccup in the curve of the dielectric constant vs. temperature, but it is neither a

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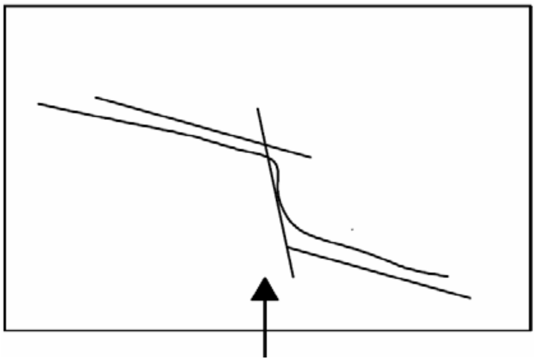
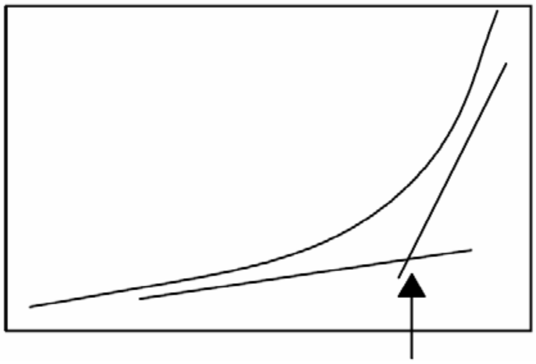
melt point nor a real glass transition. The glass transition temperature determined by both the methods differed by 5–10^{0}C during a test of the polymers. So, for the Teflon plate, and as well as for the polymers EVA and TRP used in this experiment, there is definitely a strong possibility of the effect of glass transition temperature, as all tested data at 30^{0}C nearer to the glass transition temperature. Changes occur for relative density in PTFE for temperatures from 17^{0}C to 32.35^{0}C (Figure-5(c)) and changes occur in a combined effect of PTFE at 31^{0}C (Figure-5(d)), (measured by scaling from plot).

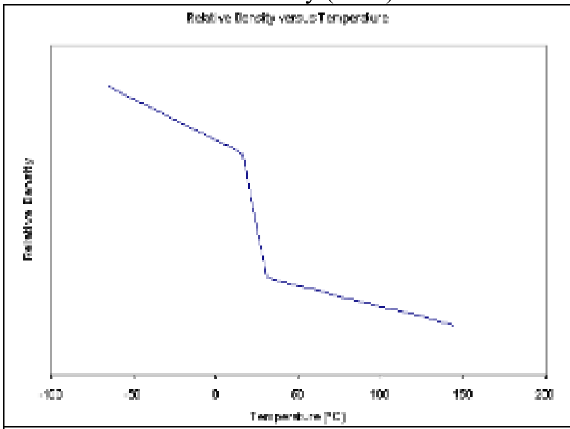
Figure-5 explains the glass transition temperature (Tg), measured by two methods and also the effect of glass transition temperature (Tg) on PTFE.



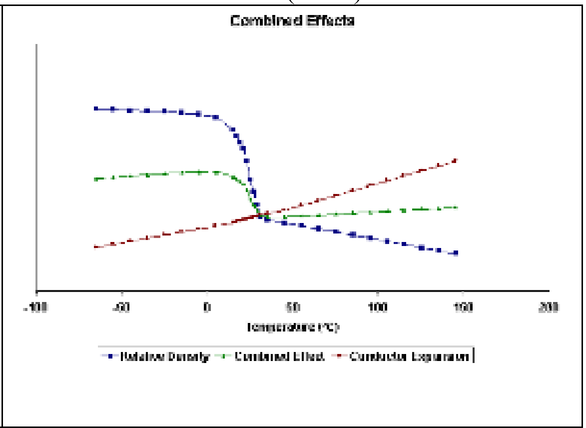
(a) Tg determination by differential scanning calorimetry (DSC)



(b) Tg determination by thermo mechanical analysis (TMA)



(c) Relative Density vs. temperature curve for PTFE dielectric (Micro-coax, Application note # 27)



(d) Combined effects of PTFE density change and conductor thermal expansion (# 27)

Figure-5. The effect of glass transition temperature (Tg) on PTFE.

Scanning electron microscopy (SEM)

The elementary analysis of 48 samples was done by Energy Dispersive X-ray (EDX) and Scanning Electron Microscopy (SEM). Only the three control samples of bitumen 80-100, bitumen 60-70 and bitumen PG 76 are mentioned here. The percentages are in atomic percentages. Hydrogen molecules cannot be detected in the images because they are so light; the lightest element which can be detected is Beryllium. Figure-6 explains the Spectrum images on neat asphalts for 80-100, 60-70 and PG 76 grade bitumen.

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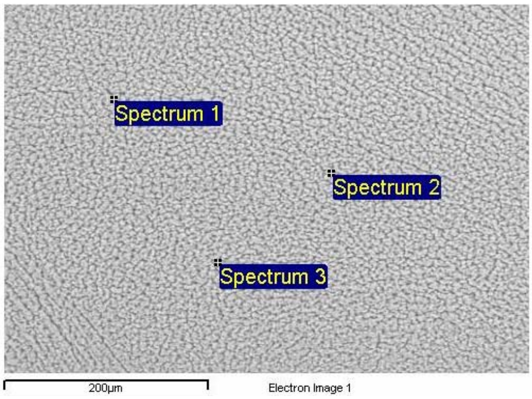
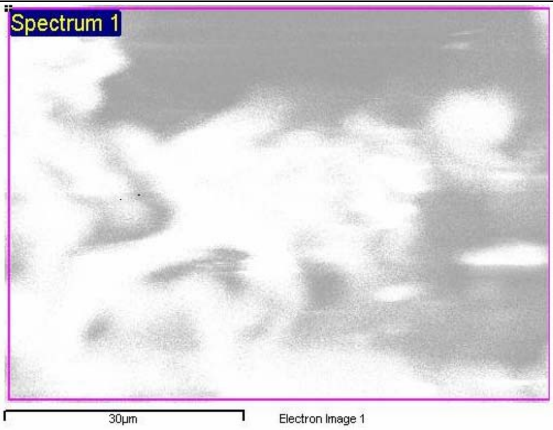
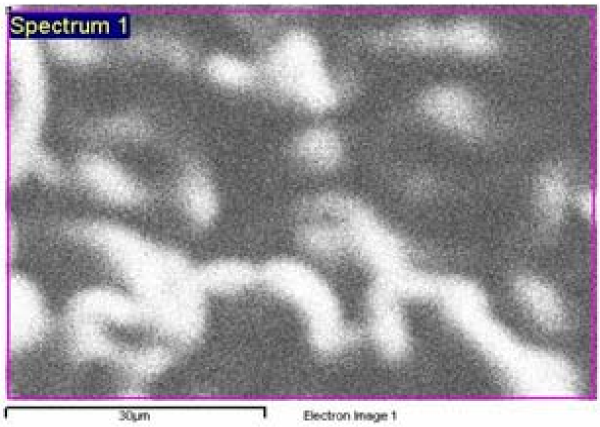




(a) Bitumen 80-100, Control sample (0.0%), SN. 1	(b) Bitumen 60-70, Control sample (0.0%), SN. 17



(c) Spectrum Images of PG 76 performance grade bitumen

Figure-6. Spectrum images for (a) Bitumen 80-100, (b) Bitumen 60-70, and (c) Bitumen PG 76.

Figure 7 explains the elementary analysis of the three control samples: (a) Bitumen 80-100, (b) Bitumen 60-70 and (c) Bitumen PG 76. All results are atomic percentages and for the processing option all elements are normalized.

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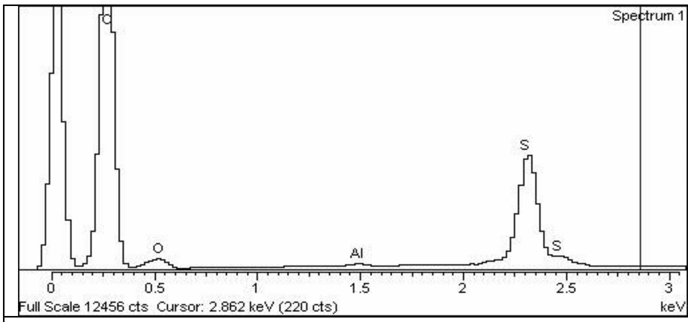
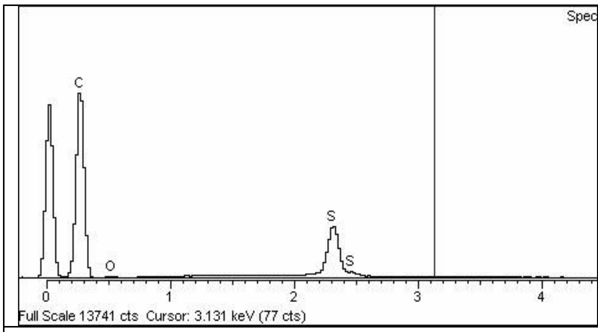


Spectrum 1, 2, 3	C	O	S	Total	Remarks
Mean	95.89	1.99	2.12	100.00	
S. D.	0.28	0.71	0.43		
Max.	96.14	2.77	2.48		
Min.	95.59	1.38	1.94		

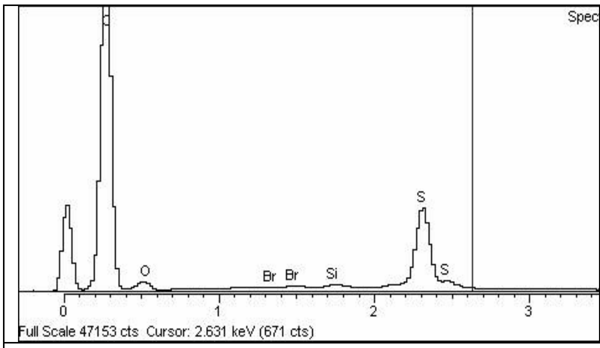
(a) Bitumen 80-100, Control sample (0.0%), SN. 1



Spectrum	C	O	Al	S	Total
1	93.80	3.62	0.05	2.53	100.0

Remarks

(b) Bitumen 60-70, Control sample (0.0%), SN. 17



Spectrum	C	O	Si	S	Br	Total
Spectrum 1	93.88	3.91	0.06	2.12	0.02	100.0

Remarks

(c) Bitumen PG 76, Control sample (0.0%), SN. 33

Figure-7. Elementary analysis of the control samples for bitumen: (a) 80-100, (b) 60-70 and (c) PG 76.

Environmental effects

Open burning of asphalt is common all over the world. Asphalt is a highly viscous material, and it requires heating for mixing with aggregates for road construction. In classical tests, performance graded asphalt is tested at temperatures as high as 182^0C and viscosity tests are carried out around 165^0C. The flash and fire points of bitumen are tested at their flash and fire temperatures, which are above 230^0C. This heating involves huge fume emissions in asphalt mixing quarries as well as in highway laboratories undertaking conventional tests. Fumes have some vigorous environmental effects and have associated health and safety issues (Rodrı´guez-Valverde *et al.*, 2003).

In contrast, the newly developed testing method is environmentally friendly because the maximum testing temperature is 45^0C.

CONCLUSIONS

There is a current need in world highways research for a fast and precise bitumen testing method to obtain a better asphalt selection which may solve the major pavement problems associated with asphalts. The approach of the microwave free-space method could be a very cost effective and precise alternative method.

From the plotted graphs, it can be concluded that the gradual decrease of permittivity occurs with increasing penetration because higher penetration relates to higher temperature. On the other hand, it can be concluded that there is a gradual increase in permittivity with increasing viscosity. Viscosity decreases with increasing temperature. This paper is the first attempt to make a model of the permittivities of asphalt binder. Asphalt is very complex in its composition and rheological properties as asphalt's rheological properties vary with temperature, flow load and also rate of load application.

Researchers Nelson and Bartley, with USDA and USDD (United States Department of Agriculture and

United States Department of Defense), investigated the many attempts that were made to make a model of the permittivities of food materials and achieved varying degrees of success and found the following:

a) The gradual decrease of in the dielectric constant with increasing temperature appears reasonable for a food material containing this much water (Nelson *et al.*, 2002);
b) The dielectric constant is reduced by increasing temperature in much in the same way as it is with water (Nelson *et al.*, 2002);
c) The dielectric constant (DC) decreases with increase of frequency;
d) The dielectric constant presents a slight decrease with increase of frequency (Kraszewski *et al.*, 1996); and
e) These results compare satisfactorily with data reported earlier and obtained with other measurement techniques (Nelson, 1984; Nelson and Stetson, 1976).

They also commented that food materials are very complex in their composition and also in their dielectric properties. This means that it is necessary to measure the permittivities under the particular condition of interest to obtain reliable data (Nelson *et al.*, 2002).

Asphalt is more complex compared to food materials. A lot of research is therefore also required to obtain a model of the permittivities of asphalt.

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