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DIELECTRIC, ULTRASONIC AND VISCOELASTIC PROPERTIES OF RUBBER WOOD

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DIELECTRIC, ULTRASONIC AND VISCOELASTIC PROPERTIES OF RUBBER WOOD

By

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Dissertation Submitted in Fulfilment of the Requirements for the Degree of Doctor of Philosophy in the Faculty of Science and Environmental Studies
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Dedicated to

My Wife, Daughter, Parents, Father-in-law,

Mother-in-law and Uncle

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ε^*	complex permittivity
ε'	dielectric constant
ε''	dielectric loss factor
ε_0	free space permittivity
ε_s	static dielectric permittivity
ε_∞	dielectric permittivity at very high frequency
$\varepsilon(\omega)$	dielectric permittivity as function of angular frequency
χ^*	complex susceptibility
χ'	real part of susceptibility
χ	imaginary part of susceptibility
ρ	density
θ	angle in degree
σ	conductivity
τ	relaxation time (sec)
ω	angular frequency
ω_p	peak angular frequency
ω_c	characteristics angular frequency
f	frequency (Hz)
i	$=\sqrt{-1}$
eV	electron volt
r	Correlation coefficients
r^2	Co-efficients of determination
Hz	Hertz

kHz	kilohertz
GHz	gigahertz
ln	natural logarithm
log	logarithm
A	cross-sectional area
C*	complex capacitance
C’	real part of capacitance
C”	imaginary part of capacitance
d	thickness
DC	Direct Current
E	Electric field strength
E*	Complex dynamic modulus
E’	Storage modulus
E”	Loss modulus
FSP	Fiber Saturation Point
MC	Moisture Content
L	Longitudinal
R	Radial
T	Tangential
v	Velocity
Γ	Christofel stiffness
C	elastic constant
S	elastic compliance
N	ultrasonic property at an angle θ
P	ultrasonic property parallel to grain

Q	ultrasonic property perpendicular to grain
tanδ	loss tangent

Abstract of dissertation submitted to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy.

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MD. FIROZ KABIR

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Chairman : Associate Prof. Dr. W. Mohamad Daud W. Yusoff

Faculty : Science and Environmental Studies

Dielectric, ultrasonic and viscoelastic properties of rubber wood were studied with various physical parameters, such as moisture contents (MC), grain directions and temperatures. Three anisotropic directions, namely longitudinal, radial and tangential to the growth ring were considered for the measurement of these properties. Dielectric properties were measured at low frequencies from 10^{-2} to 10^{5} Hz and at microwave frequencies from 1 to 18 GHz. Ultrasonic properties were determined with a commercial ultrasonic tester at 45 kHz. Viscoelastic properties were carried out with the Dynamic Mechanical Thermal Analyzer at frequency ranging from 0.01 to 100 Hz.

At low frequencies, five types of dielectric mechanism were observed for different MC such as 1) less than 5%, 2) 5-10%, 3) 11-17%, 4) 18-25% and 5) more than 25%. Dielectric constant increased with temperature for these frequencies while dielectric loss factor showed minimum value in oven-dry condition. Dielectric constant and dielectric loss factor varied in the order of longitudinal > radial ≥ tangential directions. Dielectric data at low frequency are

in well agreement with those calculated from equivalent circuit using the concept of universal capacitor. Three equivalent circuits fitted well for data at very low MC or for oven-dried wood, MC below fiber saturation point and MC above fiber saturation point. Activation energies were 0.27eV, 0.34eV and 0.41eV for longitudinal, radial and tangential directions respectively.

At microwave frequencies, dielectric constant and dielectric loss factor were found to increase with MC ranging from oven-dry up to saturation point. Dielectric constant also decreased with temperature and dielectric loss factor exhibited peaks at 10 GHz. Dielectric constants are predicted well by Winner, Lichteneker and generalized equations with lower value of the exponents. Above 3 GHz, dielectric loss factor fitted well with the predicted values using Winner, Kraszewski, Looyenga or with generalized equations with lower values of the exponents. Below 3 GHz, dielectric loss factor are unpredictable by these mixture equations.

The ultrasonic velocity and elastic stiffness constant vary in the order of longitudinal > radial > tangential. Any deviation from longitudinal axis reduced ultrasonic velocities and elastic stiffness constant for all MC. Ultrasonic velocities were well predicted by Hankinson and Osgood formula for all rotational directions and angles. This method are also capable to detect of wood defects, such as cross grain, knot and split.

The storage modulus (E') decreased with MC up to 30% and it remains almost constant above this point. The loss tangent (tan δ) showed peaks at lower frequencies. The E' increased with frequency and temperature while tan δ decreased with frequency and showed peaks at 50°C. The highest value of E' and tan δ were observed in longitudinal direction.

Abstrak dissertasi yang dikemukakan kepada Senat Universiti Puta Malaysia sebagi memenuhi keperluan untuk ijazah Doktor Falsafah.

SIFAT DIELEKTRIK, ULTRASONIK DAN VISKOELASTIK KAYU GETAH

Oleh

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Sifat dielektrik, ultrasonik dan keanjalan visko terhadap kayu getah telah dikaji dengan menggunakan pelbagai parameter fizikal, seperti kandungan wap air (KWA), arah butiran dan suhu. Tiga arah anisotropik, iaitu arah membujur, jejari dan tangen kepada gelang pertumbuhan telah dipertimbangkan untuk pengukuran terhadap sifat-sifat di atas. Sifat dielektrik telah diukur pada frekuensi rendah, dari 10^{-2} kepada 10^{5} Hz dan pada frekuensi gelombang mikro dari 1 hingga 18 GHz. Sifat ultrasonik telah diperolehi dengan menggunakan penguji ultrasonik komersial pada 45 kHz. Sifat viskoelastik telah dijalankan dengan menggunakan Alat Analisis Dinamik Mekanikal Terma pada julat frekuensi antara 0.01 hingga 100 Hz.

Pada frekuensi-frekuensi rendah, lima jenis mekanisma dielektrik diperhatikan untuk KWA yang berlainan iaitu 1) kurang daripada 5%, 2) 5-10%, 3) 11-17%, 4) 18-25% dan 5) lebih daripada 25%. Pemalar dielektrik meningkat dengan suhu untuk frekuensi-frekuensi tersebut sementara faktor kehilangan dielektrik menunjukkan nilai minimum dalam pengeringan-ketuhar. Pemalar dielektrik dan faktor kehilangan dielektrik berubah seperti susunan

berikut: arah membujur > jejari ≥ tangen. Data-data dielektrik pada frekuensi rendah adalah sepadan dengan pengiraan yang dibuat daripada litar setara dengan berkonsepkan kapasitor universal. Tiga litar setara sepadan dengan data-data pada KWA yang amat rendah atau pada kayu getah yang telah dikering-ketuharkan, KWA dibawah paras gentian tepu dan KWA diatas takad gentian tepu. Tenaga pengaktifan adalah masing-masing 0.27 eV, 0.34 eV dan 0.41 eV untuk arah membujur, jejari dan tangen.

Pada frekuensi gelombang mikro, pemalar dielektrik dan faktor kehilangan dielektrik didapati telah meningkat dengan KWA dari julat pengeringan-ketuhar hingga takat tepu. Pemalar dielektrik juga menurun dengan suhu dan faktor kehilangan dielektrik mempamerkan puncak-puncak pada 10 GHz. Pemalar dielektrik dianggarkan dengan baik menggunakan persamaan Winner, Lichteneker dan persamaan am dengan nilai eksponen yang rendah. Di atas 3 GHz, faktor kehilangen dielektrik berpadanan dengan nilai-nilai anggaran mengunakan persamaan Winner, Kraszewski, Looyenga atau dengan persamaan am dengan nilai-nilai eksponen yang rendah. Pada frekuensi 3 GHz kebawah, faktor kehilangen dielektrik tidak boleh diramalkan dengan gabungan persamaan-persamaan ini.

Halaju ultrasonik dan pemalar ketegangan elastik berbeza mengikut susunan membujur > jejari > tangen. Sebarang lencongan daripada paksi membujur mengurangkan halaju ultrasonik dan pemalar ketegangan elastik untuk semua KWA. Halaju ultrasonik telah dianggarkan dengan baik menggunakan formula-formula Hankinson dan Osgood untuk semua arah putaran dan sudut. Kaedah ini juga berupaya untuk mengesan kecacatan-kecacatan pada kayu, seperti butiran silang, buku dan belahan.

Modulus simpan (E’) berkurangan dengan KWA hingga 30% dan kandungan ini berkekalan secara berterusan diatas takad ini. Kehilangan tangen (tan δ) menunjukkan puncak-puncak pada frekuensi dan yang lebih rendah. E’ meningkat dengan frekuensi dan suhu sementara tan δ berkurangan dengan frekuensi dan menunjukkan puncak-puncak pada 50° C. Nilai E’ dan tan δ yang tertinggi diperhatikan pada arah membujur.