



UNIVERSITI PUTRA MALAYSIA

**DEVELOPMENT OF MICROWAVE REFLECTED TYPE
MOISTURE METER FOR WOODEN CROSS-ARMS**

NG KOK CHEONG

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**DEVELOPMENT OF MICROWAVE REFLECTED TYPE
MOISTURE METER FOR WOODEN CROSS-ARMS**

By

NG KOK CHEONG

**Thesis Submitted in Fulfilment of the Requirements for the
Degree of Master of Science in the Faculty of
Science and Environmental Studies
Universiti Putra Malaysia**

May 2000



Dedicated to My Father and Mother ...



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirements for the degree of Master of Science.

DEVELOPMENT OF MICROWAVE REFLECTED TYPE MOISTURE METER FOR WOODEN CROSS ARMS

By

NG KOK CHEONG

May 2000

Chairman : Associate Professor Dr. Kaida bin Khalid

Faculty : Science and Environmental Studies

A simple, cheap, accurate, portable and easy to operate microwave reflected type moisture meter has been developed to determine the moisture content and consequently to assess the quality of the in service wooden cross-arms. The investigation shows that the dielectric properties of the Chengal wood are dependent on the moisture content (MC) at microwave frequencies. The moisture in wood contributes in two different forms, one below fiber saturation point (FSP) and the other above FSP. Both dielectric constant and dielectric loss factor for Chengal wood increases slowly when the MC increases from zero up to FSP and increases rapidly with MC above FSP.

Investigation was made to find the optimum conditions for the sensor design. The optimum condition for best sensitivity of the sensor was determined through experimental and theoretical methods. It was found out that the sensitivity can be controlled by thickness of protective cover and the optimum thickness is about 1 mm. The investigation to find out the minimum thickness of the cross-arms section to avoid interference was discussed. It was found that the minimum thickness for the



cross-arms to reach a semi-infinite length was about 50mm. The operating principles of the sensor are based on the plane wave propagation theory and the dielectric mixture theory. The details of Weiner's mixture model were discussed and it was used as the theoretical model to predict and convince the experimental results.

In the actual service condition, moisture content of Chengal wooden cross-arms varied within certain range. For decayed wood, its MC varying between Equilibrium moisture content (EMC) to about 45% of dry basis and the sound wood MC between EMC to about 30% of dry basis. It was quite hard for the cross-arms to achieve higher level of MC. Once the cross-arms achieve a higher level of MC, it may take about 20 hours to return to EMC level. The densities of severely decayed, partly decayed and sound wood were different from each other even from the same species of wood. The densities were found to vary between 680kgm^{-3} to 820kgm^{-3} . The reflected power signal for severely decayed, partly decay and sound wood at EMC were less than 0.05, 0.05 to 0.10 and 0.13 to 0.15 respectively. It was found that the microwave reflected type sensor can determine the decay stage of the wooden cross arms at EMC.

A HP-basic program was written to develop the meter scale for microwave moisture meter. The meter scale contains two types of reading. They are MC reading and stage of decay reading. The mean error were 2.3% and 1.1% for severely decayed and sound wood respectively and the maximum error were found to be 5.4% and 3.9% respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

**PEMBINAAN METER KELENGASAN JENIS
PANTULAN MIKROGELOMBANG UNTUK PALANG LENGAN KAYU**

Oleh

NG KOK CHEONG

Mei 2000

Pengerusi : Profesor Madya Dr. Kaida bin Khalid

Fakulti : Sains dan Pengajian Alam Sekitar

Sebuah meter kelengasan jenis pantulan mikrogelombang yang ringkas, murah, tepat, mudah alih serta mudah digunakan telah dibina untuk mengukur kandungan air dan juga paras pereputan bagi kayu palang yang sedang digunakan. Menurut kajian, didapati bahawa sifat dielektrik kayu Chengal bergantung kepada kandungan kelengasan (KK) pada frekuensi mikrogelombang. Kelengasan kayu menyumbang kepada dua keadaan yang berbeza iaitu pada keadaan di mana KK kurang daripada takat tepu gentian (TTG) dan melebihi TTG. Pemalar dielektrik dan faktor kehilangan dielektrik kayu Chengal menunjukkan peningkatan secara perlahan apabila KKnya kurang daripada TTG sementara peningkatan sifat dielektrik adalah lebih cepat apabila KWanya melebihi TTG. Kajian telah dibuat untuk menentukan syarat optimum bagi pembinaan sesebuah pengesan. Syarat optimum untuk kepekaan terbaik bagi pengesan telah ditentukan secara ujikaji dan teori. Kajian telah menentukan bahawa kepekaan pengesan boleh dikawal dengan ketebalan pelindung dan didapati ketebalan optimum bagi pelindung perspek adalah lebih kurang 1mm.

Perbincangan juga telah dibuat di atas kajian untuk menentukan ketebalan minimum bagi kayu palang supaya tidak berlaku interferens. Ketebalan minimum bagi sesebuah kayu palang untuk mencapai panjang semi-infinit telah ditentukan lebih kurang 50mm. Prinsip pengoperasian pengesan adalah berdasarkan kepada teori perambatan gelombang satah serta teori dielektrik campuran (*dielectric mixture theory*). Model Weiner telah dibincangkan secara mendalam dan ia digunakan untuk meramal dan menyakinkan lagi keputusan ujikaji.

Dalam keadaan sebenar, KK bagi kayu palang jenis Chengal berubah dalam sesuatu julat tertentu. KK untuk kayu reput berubah dalam julat antara KK seimbang (*equilibrium moisture content*) ke lebih kurang 45% (asas kering), sementara KK untuk kayu sempurna berubah dalam julat antara KK seimbang ke lebih kurang 30% (asas kering). Didapati bahawa adalah sukar bagi sesebuah kayu palang untuk mencapai tahap KK yang tinggi. Apabila kayu palang mencapai tahap KK yang tinggi, ia memerlukan masa lebih kurang 20 jam untuk menurun ke tahap KK seimbang. Ketumpatan bagi kayu reput, kayu separa reput dan kayu kukoh adalah berbeza antara satu sama lain walaupun berasal dari spesies kayu yang sama. Ketumpatannya masing-masing didapati berubah di antara julat 680kgm^{-3} hingga 820kgm^{-3} . Isyarat bagi kuasa pantulan (*reflected power*) kayu reput, separa reput dan kayu kukoh adalah masing-masing kurang daripada 0.05, 0.05 ke 0.10 and 0.13 ke 0.15. Menurut kajian ini, didapati bahawa meter kelengasan jenis pantulan mikrogelombang dapat menentukan tahap pereputan bagi sesebuah kayu palang pada keadaan KK seimbang.

Sebuah pengaturcaraan berdasarkan bahasa HP-basic telah ditulis untuk membina skala rujukan bagi meter kelengasan mikrogelombang. Skala rujukan yang dibina mengandungi dua jenis bacaan iaitu skala berdasarkan peratusan KK and skala berdasarkan tahap kereputan kayu. Ralat purata bagi kayu reput dan kayu sempurna masing-masing ialah 2.3% and 1.1% sementara ralat maksimum adalah masing-masing 5.4% and 3.9%.

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I certify that an Examination Committee met on 4 May 2000 to conduct the final examination of Ng Kok Cheong on his Master of Science thesis entitled “Development of Microwave Reflected Type Moisture Meter for Wooden Cross-Arms” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Yusof Sulaiman, Ph.D.
Professor,
Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Chairman)

Kaida Khalid, Ph.D.
Associate Professor,
Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Member)

Hamami Sabri, Ph.D.
Associate Professor,
Faculty of Forestry
Universiti Putra Malaysia
(Member)

Jumiah Hassan, Ph.D.
Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Member)



MOHD. GHAZALI MOHAYIDIN, Ph.D.
Professor/Deputy Dean of Graduate School,
Universiti Putra Malaysia

Date : 17 MAY 2000



This thesis was submitted to the Senate of Universiti Putra Malaysia and was accepted as fulfilment of the requirements for the degree of Master of Science.

KAMIS AWANG, Ph.D.
Associate Professor,
Dean of Graduate School,
Universiti Putra Malaysia

Date :  **8 JUN 2000**



DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



(NG KOK CHEONG)

Date : 18/5/2000

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	viii
APPROVAL SHEETS	ix
DECLARATION FORM	xi
LIST OF FIGURES	xv
LIST OF TABLES	xx
LIST OF PLATES	xxi
LIST OF SYMBOLS AND ABBREVIATIONS	xxii

CHAPTER

I	GENERAL INTRODUCTION	1
	Introduction	1
	Objectives	5
II	DIELECTRIC PROPERTIES OF WOOD	7
	Introduction	7
	Microwave Aquametry	7
	The Principle of Microwave Aquametry	8
	Microwave Sensor	9
	Basic Definition	10
	Microwave	10
	Moisture Content	11
	Dielectric Properties of Material	13
	Literature Review	14
	Water in Paste Material	15
	Grain Direction of Wood	17
	Samples Used in the Studies	17
	Sample Description	18
	Severely Decayed Wood Samples (Type A)	18
	Incipient (Partly) Decay Wood Samples (Type B)	19
	Sound Wood Samples (Type C)	20
	Features and Advantages of Microwave Methods	21
	Unique Features of Microwave Radiation	22
	Dielectric Mixture Theory	23
	Model of Water Suspension by Wiener's	25
	Measurement Principles	35
	Summary	36



III	REFLECTION TYPE SYSTEM FOR MICROWAVE AQUAMETRY	37
	Introduction	37
	A Reflection Type System for Microwave Aquametry	37
	Summary	49
IV	METHODOLOGY FOR DEVELOPMENT OF MICROWAVE MOISTURE METER	50
	Introduction	50
	Standard Method for Moisture Measurement	50
	Empirical Measurement	51
	Measurement of Dielectric Properties	51
	Experimental Measurement	55
	Measurement of Reflected Power	55
	Calibration of Microwave Moisture Meter	60
	Apparatus Arrangement for Microwave Moisture Meter	60
	Initial Calibration Procedures of Microwave Moisture Meter	61
	Determination of Calibration Curve for Microwave Moisture Meter	62
	Summary	62
V	RESULTS AND DISCUSSION	63
	Introduction	63
	Effect of Soaking	64
	Dielectric Properties of Chengal Wood Specimens	65
	Variation with Frequency	65
	Variation with Moisture Content (MC)	66
	Attenuation of Microwave Power in Wood Medium	69
	Variation with Sample Thickness for Various Thickness of Protective Layer	69
	Variation with Sample Thickness for Various MC of Samples	70
	Optimum Conditions in Moisture Sensor Design	71
	Empirical Results	71
	Theoretical Results	73
	Experimental Results	73
	Comparison of Empirical, Theoretical and Experimental Results..	75
	Moisture Content of Chengal Cross Arms	76
	Variation of MC with Exposure Times to Artificial Rain	76
	Variation of MC with Drying Times	76
	Variation of Microwave Reflected Signal with Drying Times	77
	Density of Chengal Cross-Arms	78
	Variation with Reflected power	78
	Calibration of Microwave Moisture Meter for Wooden Cross-Arms	80
	Summary	82



VI FURTHER WORK AND CONCLUSION	122
Introduction	122
Development of Portable Type Microwave Moisture Meter	122
Field Test ..	125
General Conclusion	126
Recommendation for Future Work	129
REFERENCES	132
APPENDICES	135
Appendix I	136
Appendix II	141
Appendix III	159
Appendix IV	163
VITA	165



LIST OF FIGURES

Figures	Page
2.1	The Basic Concept for Measuring Moisture Content by Microwave Absorption..... 9
2.2	Classification of Microwave Sensors Being Used for Moisture Content Measurement..... 10
2.3	Loss Angle of a Lossy Medium..... 14
2.4	Material Permittivity as a Function of Moisture Content..... 16
2.5	Principal Axis of Wood Anisotropy : L, Longitudinal Axis; R, Radial Axis; T, Tangential Axis..... 17
2.6	The simple model of a biphasic water suspension in layer of thickness t 24
2.7	Model of Oven-Dry Wood Specimen..... 26
2.8	Model of Wood Specimen with Moisture Content Below FSP..... 26
2.9 (a)	Model of Wood Specimen with Moisture Content at FSP (i)..... 28
2.9 (b)	Model of Wood Specimen with Moisture Content at FSP (ii)... 29
2.10 (a)	Model of Wood Specimen with Moisture Content Above FSP (i).... 30
2.10 (b)	Model of Wood Specimen with Moisture Content Above FSP (ii)... 30
2.11 (a)	Model of Fully Saturated Wood Specimen (i)..... 32
2.11 (b)	Model of Fully Saturated Wood Specimen (ii)..... 32
2.12	Dielectric Properties of Oven Dry Woods at Room Temperature and Frequencies of 130 MHz to 20 GHz..... 36
3.1	Reflection and Transmission Phenomena in the Reflection Type Moisture Meter..... 38
3.2	Plane Wave Incident Normally on an Interface of Two Dielectric Mediums..... 39
3.3	A Signal Flow-Graph of the Sensor Structure..... 42



3.4	A Simplified Signal Flow Graph.....	42
3.5	An Illustration of Complex Reflection Coefficient, R	49
4.1	Coaxial open-ended reflection method using HP-85070A Dielectric Probe.....	54
4.2	Basic Operation of RS 8960.....	57
4.3	Experimental Set-Up for Optimum Conditions in Sensor Design.....	58
4.4	Experimental Set-Up for Microwave Moisture Meter.....	61
5.1	Variation of Dielectric Properties with Microwave Frequencies for Oven Dried Wood Specimens Type A, B and C.....	84
5.2	Variation of Dielectric Properties with Microwave Frequencies for Wood Specimens Type A, B and C at FSP.....	85
5.3	Variation of Dielectric Properties with Microwave Frequencies for Higher Moisture Level of Wood Specimens Type A, B and C.....	86
5.4	Variation of Dielectric Properties Against MC at Various Microwave Frequencies for Wood Specimen Type A.....	87
5.5	Variation of Dielectric Properties Against MC at Various Microwave Frequencies for Wood Specimen Type B.....	88
5.6	Variation of Dielectric Properties Against MC at Various Microwave Frequencies for Wood Specimen Type C.....	89
5.7	Empirical Results of Dielectric Properties Against MC at 10.7GHz for Wood Specimen Type A.....	90
5.8	Empirical Results of Dielectric Properties Against MC at 10.7GHz for Wood Specimen Type B.....	90
5.9	Empirical Results of Dielectric Properties Against MC at 10.7GHz for Wood Specimen Type C.....	91
5.10	Comparison of Empirical and Wiener Mixture Model Results : Dielectric Properties Against MC for Wood Specimen Type A at 10.7GHz.....	92
5.11	Comparison of Empirical and Wiener Mixture Model Results : Dielectric Properties Against MC for Wood Specimen Type B at 10.7GHz.....	93



5.12	Comparison of Empirical and Wiener Mixture Model Results : Dielectric Properties Against MC for Wood Specimen Type C at 10.7GHz.....	94
5.13	Variation of Reflected Power Against Sample Thickness with Various MC of Wood Specimens Type A, B and C Respectively at 10.7GHz.....	95
5.14	Variation of Reflected Power Against Sample Thickness with Various Protective Layer Thickness for Wood Specimens Type A, B and C Respectively at 10.7GHz.....	96
5.15	Empirical Results of Reflected Power Against MC with Various Protective Layer Thickness for Wood Specimens Type A at 10.7GHz.....	97
5.16	Empirical Results of Sensitivity Against Protective Layer Thickness for Wood Specimens Type A with Various Range of MC at 10.7GHz.....	97
5.17	Empirical Results of Reflected Power Against MC with Various Protective Layer Thickness for Wood Specimens Type B at 10.7GHz.....	98
5.18	Empirical Results of Sensitivity Against Protective Layer Thickness for Wood Specimens Type B with Various Range of MC at 10.7GHz.....	98
5.19	Empirical Results of Reflected Power Against MC with Various Protective Layer Thickness for Wood Specimens Type C at 10.7GHz.....	99
5.20	Empirical Results of Sensitivity Against Protective Layer Thickness for Wood Specimens Type C with Various Range of MC at 10.7GHz.....	99
5.21	Theoretical Results of Reflected Power Against MC with Various Protective Layer Thickness for Wood Specimens Type A at 10.7GHz.....	100
5.22	Theoretical Results of Sensitivity Against Protective Layer Thickness for Wood Specimens Type A with Various Range of MC at 10.7GHz.....	100
5.23	Theoretical Results of Reflected Power Against MC with Various Protective Layer Thickness for Wood Specimens Type B at 10.7GHz.....	101



5.24	Theoretical Results of Sensitivity Against Protective Layer Thickness for Wood Specimens Type B with Various Range of MC at 10.7GHz.....	101
5.25	Theoretical Results of Reflected Power Against MC with Various Protective Layer Thickness for Wood Specimens Type C at 10.7GHz.....	102
5.26	Theoretical Results of Sensitivity Against Protective Layer Thickness for Wood Specimens Type C with Various Range of MC at 10.7GHz.....	102
5.27	Experimental Results of Reflected Power Against MC for Wood Specimens Type A with Protective Layer Thickness from 1mm to 9mm	103 to 105
5.28	Experimental Results of Reflected Power Against MC for Wood Specimens Type B with Protective Layer Thickness from 1mm to 9mm	106 to 108
5.29	Experimental Results of Reflected Power Against MC for Wood Specimens Type C with Protective Layer Thickness from 1mm to 9mm	109 to 111
5.30	Experimental Results of Sensitivity Against Protective Layer Thickness with Various Range of MC for Wood Specimens Type A, B and C	112
5.31	Comparison between Experimental, Results of Reflected Power Against MC with Various Protective Layer Thicknesses for Wood Specimens Type A.....	113
5.32	Comparison between Experimental, Results of Reflected Power Against MC with Various Protective Layer Thicknesses for Wood Specimens Type B.....	114
5.33	Comparison between Experimental, Results of Reflected Power Against MC with Various Protective Layer Thicknesses for Wood Specimens Type C.....	115
5.34	Comparison between Experimental, Results of Sensitivity Against Protective Layer Thickness for Wood Specimens Type A,	116
5.35	Increases of MC Against Exposure Times to Dropping Water for Wood Specimens Type A,	117
5.36	Decreases of MC Against Drying Times at Surrounding Atmosphere for Wood Specimens Type A, B and C	117



5.37	Variation of Reflected Power Against Drying Times at Surrounding Atmosphere for Wood Specimens Type A,	118
5.38	Variation of Reflected Power and Density Against Various Types of Wood Specimens at EMC level.....	119
5.39	Calibration Curves of Microwave Moisture Meter for Wood Specimens Type A and C.....	120
5.40	Comparison of Measured MC by Microwave Moisture Meter and Oven MC for Wood Specimen Type A.....	121
5.41	Comparison of Measured MC by Microwave Moisture Meter and Oven MC for Wood Specimen Type C.....	121
6.1	Block Diagram of MMM-WCA	123
6.2	Function Selector and Calibration Setting	124



LIST OF TABLES

Table		Page
2.1	IEEE Microwave Frequency Bands.....	11
2.2	Summary of Equations for Wiener Mixture Model.....	33
2.3	Initial Experimental or Calculated Data for Wiener Mixture Model...	34
4.1	Operating Conditions and Rating of Doppler Module RS 8960.....	56
5.1	Moisture Content of Fully Saturated Chengal Wood Specimens.....	64
5.2	Constants of the Equations for Curve Fitting of Dielectric Properties for Specimens Type A, B and C at Frequency 10.7GHz.....	68
5.3	Constants of the Equations for Curve Fitting of Calibration Results for Sample Type A and C.....	81
6.1	Technical Data of MMM-WCA	125



LIST OF PLATES

Plate		Page
1.1	The Power Lines that Constructed with Wood Poles in Malaysia.....	4
1.2	Weathered Cross-Arm with Decayed on the Surface.....	4
1.3	Comparison between Severely Decayed, Incipient Decay and Sound Wood Sample.....	4
2.1	Samples of Severely Decayed Wood (Type A).....	18
2.2	Samples of Incipient (Partly) Decay Wood (Type B).....	19
2.3	Samples of Normal Sound Wood (Type C).....	20
4.1	Equipment Set-up for Dielectric Properties Measurement.....	51
4.2	A Good Contact between Dielectric Probe (HP-85070A) and a Wood Specimen.....	53
4.3	Physical Model of Doppler Module RS 8960.....	55
5.1	Meter Scale of Microwave Moisture Meter for Wooden Cross-Arms.....	80
6.1	Microwave Reflected Type Moisture Meter for Wooden Cross-Arms (MMM-WCA).....	123
6.2	Operating of MMM-WCA	123
6.3	MC-meter Scale for MMM-WCA	124
6.4	Field Test for MMM-WCA on 9/8/1999 at Bagan Serai (Ipoh, Perak)	131
6.5	Field Test for MMM-WCA on 21/9/1999 at Kahang (Kluang, Johore)	131

LIST OF SYMBOLS AND ABBREVIATIONS

ϵ^*	Relative permittivity
ϵ'	Dielectric constant
ϵ''	Dielectric loss factor
ϵ_m	Complex material permittivity
ϵ_0	Free air permittivity
μ^*	Relative permeability
t	Transmission coefficient
Γ	Reflection coefficient
R^2	Reflected power
R_∞^2	Reflected power at semi-infinite length
d_∞	Semi-infinite length
P	Power
I	Current
D	Relative density
ρ	Density
σ	Conductivity
f	Frequency
ω	Angular frequency
η	Intrinsic impedance
γ	Propagation constant
α	Attenuation constant
β	Phase constant
E	Electric field strength
H	Magnetic field strength
$\tan\theta$	Loss tangent
θ	Loss angle
S_{11}	Scattering parameter (port 1 to port 1)
S_{12}	Scattering parameter (port 2 to port 1)
S_{21}	Scattering parameter (port 1 to port 2)
S_{22}	Scattering parameter (port 2 to port 2)



V	Volume
v	Volume fraction
MC or MC _{db}	Moisture content (dry basis)
MC _{wb}	Moisture content (wet basis)
m _d	Mass of dry material
m _m	Mass of moist material
m _w	Mass of water
EMC	Equilibrium moisture content
FSP	Fiber saturation point
KWA	Kandungan wap air
TTG	Takat tepu gentian
l, x, d	Material thicknesses
r	Correlation coefficient
r ²	Coefficient of determination
AC	Alternating current
DC	Direct current
L	Longitudinal
R	Radial
T	Tangential
RF	Radio frequencies
%	Percentage
π	=3.141592654
j	= $\sqrt{-1}$
Type A	Severely decayed wood
Type B	Partly (Incipient) decay wood
Type C	Sound wood
MMM-WCA	Microwave Moisture Meter for Wooden Cross-Arms
IEEE	Institute of Electrical and Electronic Engineering
TNB	Tenaga Nasional Berhad

CHAPTER I

GENERAL INTRODUCTION

Introduction

Generally, wood consists of many different elements and substances. Oven-dry wood consists of two main components: cell wall substance and air in the cell lumen. In moist wood with the moisture level below fiber saturation point (FSP), an additional component exists. This additional component is the bound water. When moisture level exceeds the saturation point, there exists a fourth component, namely free water. The moisture content at which a given cell has lose all of its cavity water and contains only water vapor in the cavities but the cell wall is fully saturated by water vapor is referred as the FSP. Generally, FSP range from 18% to 35% dry basis.

In Malaysia, some of the power lines are constructed with wooden poles and wood cross-arms. Normally Chengal woods are used extensively for this purpose (Plate 1.1). When wood is exposed to weather, not only its surface undergoes changes also its cell wall substances tend to be continuously exposed to chemical and biological changes. Therefore, the weathered and normal sound woods have their own different dielectric properties values although they originate from the same wood species. Plates 1.2 and 1.3 show the samples of weathered and normal sound wooden cross-arms respectively. As a result of weathering, the wood surfaces tend to absorb more moisture as compared to the normal sound wood. The moisture will sustain in the weathered wood for some time before reaching equilibrium moisture