

Material Characterization of Timber Utility Poles using Experimental Approaches

by

Roman Elsener

A thesis presented to the

University of Technology Sydney

in fulfilment of the
thesis requirement for the
degree

Master of Engineering

Sydney, Australia in March 2014

Course: C03017
Principal Supervisor: A/Prof Dr Jianchun Li
Second Supervisor: Dr Ulrike Dackermann

University of Technology Sydney
Faculty of Engineering
Centre for Built Infrastructure Research
15 Broadway
Ultimo, NSW 2007
Australia

Certificate of Original Authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

22/03/2014 Production Note:
Signature removed prior to publication.

Date and Signature of Student

ACKNOWLEDGMENT

I would like to express my appreciation to my principal supervisor A/Professor Jianchun Li who was very supportive and motivating throughout my degree. He was an excellent advisor in technical questions and always inspired me in achieving my goals.

I would like to express my gratitude to my second supervisor Dr. Ulrike Dackermann who was a great support in technical as well as practical matters. She always assisted very professionally with words and deeds and it was a pleasure working with her.

The laboratory staff, notably Peter Brown, David Hooper, Mulgheta Hailu, David Dick-er, Rami Haddad, Laurence Stonard and Scott Graham were extremely helpful and sup-
portive, everyone in their particular area. I would like to thank them all very much; it was fantastic working with you.

I would also like to thank my fellow students and colleagues, Saad Subhani, Ning Yan and Bahram Jozi. Working together with you was a great pleasure for me since we were a real team in supporting and helping each other in many aspects of our work.

I gratefully acknowledge the collaboration with our industrial partner Ausgrid, in par-
ticular Terry Westlake and Bob White whom it was a pleasure working with. They were very supportive in helping us preparing and conducting field tests.

Sincere thanks also to the various academic staff members from UTS and BUAS who assisted with their knowledge in specific questions. Many thanks Keith Crews, Chris-
tophe Sigrist, Bijan Samali and Christof Wüthrich.

ABSTRACT

Utility poles made of timber are a significant part of Australia's infrastructure for power distribution and communication networks. Wood as a natural material deteriorates under the influence of environmental conditions such as weathering, fungus and insect attack which results in a reduction of the strength of the poles. Determining soundness and the remaining strength of timber utility poles in service is crucial in order to maintain a reliable and secure power network.

This thesis presents an investigation of using static and dynamic material testing approaches to determine material properties and detecting internal damage of timber utility poles from two hardwood eucalyptus tree species, i.e. Spotted Gum and Tallowwood. The comparative study of static and dynamic tests based on the wave transmission time or time of flight (TOF) is necessary for the development of novel non-destructive testing (NDT) techniques for the health assessment of in-situ utility poles. In order to develop accurate non-destructive models, knowledge of the orthotropic material properties is necessary.

In open literatures, comparative studies on orthotropic material properties are scarce to find for most eucalyptus species used for utility poles. Typically, material properties are only available in the longitudinal (i.e. along main wood fibre) direction, and most international standards cover only details on material testing in such direction with no coherent or comprehensive guidelines being given for the testing of the other two secondary directions (radial and tangential) of timber. TOF measurements were conducted by several researchers for a number of timber species, however non on high density woods

such as the investigated eucalyptus species.

Based the full set of material properties (Modulus of Elasticity and Poisson's ratios) of two new utility poles determined with static tests in all three orthotropic directions (longitudinally, radially and tangentially), the dynamic tests were calibrated and used for the non-destructive material characterization and internal damage detection. The tests were also conducted taking into account varying moisture contents and different grain angles as they occur in the field. Ultimately, an orthotropic numerical model was created to simulate the experimental damage detection case which could be used to simulate further damage cases. The results revealed that the formulas used for the dynamic material characterization must be adjusted for the investigated species. The numerical model was capable of simulating the experimental case and predicting the TOF for damaged poles. The method has potential for the prediction of internal damage of eucalyptus timber poles in the field.

Keywords: Timber Properties, Material Testing, Damage Detection, Eucalyptus

TABLE OF CONTENTS

1	INTRODUCTION	1
1.1	Problem Statement	1
1.2	Aim and Scope	2
1.3	Thesis Overview	4
1.3.1	Published Work	4
2	BACKGROUND AND LITERATURE REVIEW	6
2.1	Chapter Overview.....	6
2.2	Characteristics of Wood.....	6
2.2.1	Anisotropy	7
2.2.2	Heterogeneity.....	7
2.2.3	Hygroscopicity.....	11
2.2.4	Wood Pests	12
2.2.5	Treatment of Wood.....	14
2.2.6	Specific Eucalyptus Characteristics.....	15
2.3	Mechanical Properties of Wood	16
2.3.1	Elastic Properties	17
2.3.2	Strength Properties.....	20
2.4	Non-Destructive Testing.....	21
2.4.1	Background.....	21
2.4.2	Current Practice	30
2.5	Conclusions.....	33
3	RESEARCH METHODOLOGY	35
3.1	Chapter Overview.....	35

3.2	Project Framework.....	35
3.2.1	Project Organization	35
3.2.2	Research Goals	36
3.2.3	Innovations and Merits	38
3.2.4	Challenges.....	39
3.3	Overview of Tests.....	39
3.4	Conclusions.....	41
4	STATIC MATERIAL TESTS	43
4.1	Chapter Overview.....	43
4.2	Introduction.....	43
4.3	Material Testing Methodology	44
4.3.1	Testing Specimens	44
4.3.2	Testing Machines.....	46
4.3.3	4-Point Bending Tests.....	46
4.3.4	Tension Tests	48
4.3.5	Compression Tests.....	49
4.3.6	Poisson’s Ratio Test	50
4.4	Results and Discussion	51
4.4.1	Modulus of Elasticity.....	51
4.4.2	Poisson’s Ratio	54
4.4.3	Mechanical Properties	57
4.5	Conclusions.....	59
4.5.1	Comparison of Standards.....	59
4.5.2	Testing Recommendations.....	60
5	ULTRASONIC MATERIAL TESTS	61
5.1	Chapter Overview.....	61
5.2	Introduction.....	61
5.3	Ultrasonic Testing Methodology	63
5.3.1	Testing Specimens	64
5.3.2	Testing Instrumentation	65
5.3.3	Time of Flight Measurements.....	67
5.3.4	Time of Flight Calculations	69
5.3.5	Ultrasonic Material Characterization.....	70
5.3.6	Moisture Content Tests.....	74
5.3.7	Grain Angle Tests	76
5.3.8	Calculation of the Elastic Constants	77
5.4	Results and Discussion	82

5.4.1	Moduli of Elasticity	82
5.4.2	Shear Moduli	86
5.4.3	Poisson's Ratios.....	91
5.4.4	Practical Testing Consideration: Moisture Content.....	92
5.4.5	Practical Testing Consideration: Grain Angle.....	94
5.4.6	Comparison E/G Ratios	101
5.5	Conclusions.....	102
6	DAMAGE DETECTION.....	103
6.1	Chapter Overview.....	103
6.2	Introduction	103
6.2.1	Acoustic Tomography	107
6.3	Damage Detection Methodology.....	109
6.3.1	Testing Specimens	109
6.3.2	Small Clear Specimens – Longitudinal	110
6.3.3	Small Clear Specimens – Transversal	111
6.3.4	Pole Sections – Transversal.....	113
6.3.5	Numerical Modelling.....	114
6.4	Results and Discussion	116
6.4.1	Damage Detection – Longitudinal.....	116
6.4.2	Damage Detection – Transversal.....	117
6.4.3	Acoustic Tomography	126
6.5	Conclusions.....	128
7	SYNTHESIS.....	130
7.1	Discussion	130
7.1.1	Static Results	131
7.1.2	Ultrasonic Results.....	131
7.2	Conclusions and Outlook	132
8	BIBLIOGRAPHY.....	134
	INDICES	142
	Index of Figures	142
	Index of Tables.....	147
	Index of Equations.....	149

9	APPENDICES	151
9.1	Appendix A.....	152
9.2	Appendix B.....	153
9.3	Appendix C.....	154

NOMENCLATURE

<i>AT</i>	Acoustic tomography
<i>CS</i>	Compression strength
<i>COV</i>	Coefficient of variation
<i>FE</i>	Finite element
<i>FSP</i>	Fibre saturation point
<i>LVDT</i>	Linear variable differential transducer
<i>MAE</i>	Mean absolute error
<i>MAPE</i>	Mean absolute percentage error
<i>MC</i>	Moisture content
<i>MFA</i>	Micro fibril angle
<i>MOE_l</i>	Modulus of elasticity in longitudinal direction
<i>MOE_r</i>	Modulus of elasticity in radial direction
<i>MOE_t</i>	Modulus of elasticity in tangential direction
<i>MOR</i>	Modulus of rupture
<i>NDE</i>	Non-destructive evaluation
<i>NDT</i>	Non-destructive testing
<i>P-wave</i>	Compressional or longitudinal wave
<i>S-wave</i>	Shear or transversal wave
<i>TOF</i>	Time of flight
<i>TS</i>	Tensile strength

WTT	Wave transmission time
WSP	Water saturation point

Symbols

c_{LL}	P-wave in longitudinal direction
c_{RR}	P-wave in radial direction
c_{TT}	P-wave in tangential direction
$c_{LR,RL}$	S-wave in longitudinal radial plane
$c_{LT,TL}$	S-wave in longitudinal tangential plane
$c_{RT,TR}$	S-wave in radial tangential plane
ε	Strain
σ	Stress
f	Frequency
G	Shear modulus
λ	Wavelength
\bar{x}	Mean value
ν	Poisson's ratio
V	Wave velocity
V_L	Longitudinal wave velocity

