

สารบัญ

	หน้า
บทคัดย่อ	(3)
Abstract	(5)
กิตติกรรมประกาศ	(7)
ผลงานตีพิมพ์เผยแพร่จากวิทยานิพนธ์	(8)
สารบัญ	(9)
รายการตาราง	(11)
รายการภาพประกอบ	(13)
ตัวย่อและสัญลักษณ์	
บทที่	
1 บทนำ	
1.1 บทนำต้นเรื่อง	1
1.2 กรรมวิธีการทำไม้แปรรูปแถบไม้อัดเรียงเส้นในโรงงานอุตสาหกรรม	4
1.3 การสำรวจเอกสาร	6
1.4 วัตถุประสงค์	12
1.5 สรุป	12
2 การหามุมเรียงแถบไม้ที่เหมาะสม	
2.1 บทนำ	13
2.2 การคำนวณความเค้นในโอเอสแอล	14
2.3 ขอบเขตที่ใช้กำหนดการวิจัย	22
2.4 การหาแบบการเรียงแถบไม้ที่เหมาะสมของโอเอสแอล	23
2.5 ผลการคำนวณ	29
2.6 สรุป	68
3 การทำขึ้นทดสอบและวิธีการทดสอบ	
3.1 บทนำ	69
3.2 การทำโอเอสแอลในห้องปฏิบัติการ	69
3.3 การวางแผนการทดลอง	74
3.4 การเตรียมขึ้นทดสอบ	76
3.5 การทดสอบ	77
3.6 สรุป	80

สารบัญ (ต่อ)

	หน้า
4 ผลและอภิปรายผล	
4.1 บทนำ	81
4.2 การคำนวณสมบัติต่างๆในผลการทดลอง	81
4.3 ผลการทดลอง	84
4.4 การปรับปรุงแบบจำลอง	108
4.5 ผลการเปรียบเทียบการทดลองและค่าจากแบบจำลอง	112
4.6 สรุป	120
5 บทสรุป	121
บรรณานุกรม	125
ภาคผนวก	
ภาคผนวก ก โปรแกรมการคำนวณแบบการเรียงแถบไม้ที่ดีที่สุด	128
ภาคผนวก ข โมดูลัสเฉือนและอัตราส่วนพัทธ์ของของไม้จริงบางชนิด	175
ภาคผนวก ค การหาแบบการเรียงแถบไม้ที่ให้ค่าความแข็งแรงสูงสุด	176
ภาคผนวก ง การกระจายความเค้น ณ จุดออกแบบ	189
ภาคผนวก จ ผลการทดสอบเบื้องต้น	190
ภาคผนวก ฉ สมบัติเชิงกลของโอเอสแอล	197
ผลงานตีพิมพ์เผยแพร่จากวิทยานิพนธ์	
ผลกระทบของขนาด รูปร่าง และทิศทางของเส้นของชิ้นไม้ย่อยต่อความแข็งแรง ของโอเอสแอล	199
Mechanical Properties of Rubberwood Oriented Strand Lumber (OSL): The Effect of Strand Length	206
ประวัติผู้เขียน	224

รายการตาราง

ตาราง	หน้า
1.1 Import of logs and timber from 1988 to 2001	3
2.1 Mechanical properties of rubberwood	29
2.2 Angle sensitivity analysis of OSL Type I (MSC) when the angle of a layer changed to $\pm 5^\circ$ and compared with the optimum orientation [31° , 28° , 25° , 21° , 16° , 10° , 1° , -8° , -11° , -27°] _A , optimum moment of $3,244 \text{ N}\cdot\text{m}/\text{m}$	55
2.3 Angle sensitivity analysis of OSL Type I (MSC) when the angle of a layer changed to $\pm 5^\circ$ and compared with the optimum orientation [29° , 25° , 21° , 16° , 9° , 0° , -6° , -8° , -6° , -11°] _A , optimum moment of $2,877.50 \text{ N}\cdot\text{m}/\text{m}$	61
3.1 Mass fraction of OSL consisted of dried strand, water, and glue	70
3.2 Experimental design for bending test	74
3.3 Experimental design for tension and compression test	75
4.1 Average coefficients of variation for some properties of clear wood	84
4.2 Results of OSL Type 0 in tension test	85
4.3 ANOVA of tension test	86
4.4 Results of OSL type 0 in compression test	90
4.5 ANOVA of compression test	
4.6 Strength of rubber wood (solid wood) and average strength of OSL with different strand lengths (SG = 0.7)	98
4.7 Results of static bending test	101
4.8 ANOVA of static bending test	102
4.9 Regression analysis of MOR and MOE in bending	104
4.10 Bending strength (MOR) comparison of OSL Type 0 between test and calculation	112
4.11 MOR comparison of OSL Type I between experiment and calculation	115
4.12 MOR comparison of OSL Type II between experiment and calculation	117
B.1 Ratios of elastic for some species of softwoods and Hardwoods at 12% moisture content	175
D.1 Stress in each layer at optimum orientation [31° , 28° , 25° , 21° , 16° , 10° , 1° , -8° , -11° , -27°] _A by Maximum Stress Criterion (MSC)	189
D.2 Stress in each layer at optimum orientation [29° , 25° , 21° , 16° , 9° , 0° , -6° , -8° , -6° , -11°] _A by Tsai-Hill Criterion (THC)	189

รายการตาราง (ต่อ)

ตาราง		หน้า
E.1	Specific gravity determination of specimen in tensile test along grain direction	191
E.2	Results from tensile test along grain direction	191
E.3	Specific gravity determination of specimen in tensile test perpendicular to grain direction	192
E.4	Results from tensile test perpendicular to grain direction	192
E.5	Specific gravity determination of specimen in compressive test along grain direction	193
E.6	Results from compressive test along grain direction	193
E.7	Specific gravity determination of specimen in compressive test perpendicular to grain direction	194
E.8	Results from compressive test perpendicular to grain direction	194
E.9	Specific gravity determination of specimen in bending test	195
E.10	Results from bending test	196
F.1	Mechanical properties of OSL and solids wood used for initial value in programming calculation	197

รายการภาพประกอบ

ภาพประกอบ	หน้า
1.1 Composition and usage of rubberwood	2
1.2 Typical manufacturing processes of OSB and OSL	4
1.3 Principal axes and principal planes of wood	7
1.4 Strength-angle curve of rubberwood according to Hankinson's formula	8
2.1 Principal stresses following principal axes and principal planes	14
2.2 Principal axes (1-direction, 2-direction) and arbitrary axes (x-direction, y-direction) with angle θ	16
2.3 Layer k of distance z from center line datum	18
2.4 Principal stresses determination diagram	21
2.5 Optimized function by Univariate Search method	24
2.6 Optimized function by Exhaustive Search method	25
2.7 Flowchart of optimizing strand orientation by Univariate Search method	27
2.8 Stress profiles of OSL Type 0 (strand alignment with angle 0°)	30
2.9 Stress profiles of OSL Type I oriented according to MSC [$31^\circ, 28^\circ, 25^\circ, 21^\circ, 16^\circ, 10^\circ, 1^\circ, -8^\circ, -11^\circ, -27^\circ$] _A	31
2.10 Stress profiles of OSL Type I oriented according to THC [$29^\circ, 25^\circ, 21^\circ, 16^\circ, 9^\circ, 0^\circ, -6^\circ, -8^\circ, -6^\circ, -11^\circ$] _A	32
2.11 Stress profiles along x-direction of OSL Type 0 (dash line) and OSL Type I (continuous line)	33
2.12 Sensitivity of OSL on tensile strength parallel to grain	34
2.13 Sensitivity of OSL on tensile strength perpendicular to grain	35
2.14 Sensitivity of OSL on compressive strength parallel to grain	36
2.15 Sensitivity of OSL on compressive strength perpendicular to grain	37
2.16 Sensitivity of OSL on shear strength	38
2.17 Sensitivity of OSL on modulus of elasticity parallel to grain	39
2.18 Stress profiles of OSL with $E_1 = 22.4$ GPa (continuous line) and with $E_1 = 28.05$ GPa (dash line) according to MSC	40
2.19 Stress profiles of OSL with $E_1 = 35.06$ GPa (continuous line) and with $E_1 = 28.05$ GPa (dash line) according to MSC	41
2.20 Stress profiles of OSL with $E_1 = 22.4$ GPa (continuous line) and with $E_1 = 28.05$ GPa (dash line) according to THC	42

รายการภาพประกอบ (ต่อ)

ภาพประกอบ	หน้า
2.21 Stress profiles of OSL with $E_1 = 35.06$ GPa (continuous line) and with $E_1 = 28.05$ GPa (dash line) according to THC	43
2.22 Sensitivity of OSL on modulus of elasticity perpendicular to grain	44
2.23 Stress profiles of OSL with $E_2 = 2.60$ GPa (continuous line) and with $E_2 = 2.08$ GPa (dash line) according to MSC	45
2.24 Stress profiles of OSL with $E_2 = 2.60$ GPa (continuous line) and with $E_2 = 2.08$ GPa (dash line) according to THC	46
2.25 Sensitivity of OSL on shear modulus	47
2.26 Stress profiles of OSL with $G_{12} = 1.80$ GPa (continuous line) and with $G_{12} = 2.24$ GPa (dash line) according to MSC	48
2.27 Stress profiles of OSL with $G_{12} = 2.60$ GPa (continuous line) and with $G_{12} = 2.24$ GPa (dash line) according to MSC	49
2.28 Stress profiles of OSL with $G_{12} = 1.80$ GPa (continuous line) and with $G_{12} = 2.24$ GPa (dash line) according to THC	50
2.29 Stress profiles of OSL with $G_{12} = 2.81$ GPa (continuous line) and with $G_{12} = 2.24$ GPa (dash line) according to THC	51
2.30 Sensitivity of OSL on Poisson's ratio	52
2.31 Stress profiles of OSL with $\nu_{12} = 0.28$ (continuous line) and with $\nu_{12} = 0.35$ (dash line) according to MSC	53
2.32 Stress profiles of OSL with $\nu_{12} = 0.28$ (continuous line) and with $\nu_{12} = 0.35$ (dash line) according to THC	54
2.33 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 1 changed 5° (continuous line)	56
2.34 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 2 changed 5° (continuous line)	56
2.35 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 3 changed 5° (continuous line)	57
2.36 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 4 changed 5° (continuous line)	57
2.37 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 5 changed 5° (continuous line)	58
2.38 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 6 changed 5° (continuous line)	58
2.39 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 7 changed 5° (continuous line)	59
2.40 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 8 changed 5° (continuous line)	59

รายการภาพประกอบ (ต่อ)

ภาพประกอบ	หน้า
2.41 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 9 changed 5° (continuous line)	60
2.42 Stress profiles comparison of optimum OSL (dash line) and of OSL Type I (MSC) with layer 10 changed 5° (continuous line)	60
2.43 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 1 changed 5° (continuous line)	61
2.44 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 2 changed 5° (continuous line)	62
2.45 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 3 changed 5° (continuous line)	62
2.46 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 4 changed 5° (continuous line)	63
2.47 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 5 changed 5° (continuous line)	63
2.48 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 6 changed 5° (continuous line)	64
2.49 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 7 changed 5° (continuous line)	64
2.50 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 8 changed 5° (continuous line)	65
2.51 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 9 changed 5° (continuous line)	65
2.52 Stress profiles comparison of optimum OSL (dash line) and of OSL Type II (THC) with layer 10 changed 5° (continuous line)	66
3.1 (a) 5 cm, 10 cm, 15 cm of strand ordered from left to right respectively (b) strand thickness distribution	70
3.2 (a) Rotary drum for glue blending (b) Spray gun	71
3.3 Apparatus for strand orienting by hand	72
3.4 Temperature at the core of OSL mat during hot pressing process	73
3.5 Pressure steps during hot pressing process	73
3.6 Dimension of specimen in tension test	76
3.7 Bending testing machine	77
3.8 Tension testing machine	78
3.9 Compression testing machine	79
4.1 Typical load-deflection curve.	83

รายการภาพประกอบ (ต่อ)

ภาพประกอบ	หน้า
4.2 Failure mode of tension test (a) parallel to grain (b) perpendicular to grain	87
4.3 Specific tensile strength parallel to grain vs. strand length	88
4.4 Specific tensile strength perpendicular to grain vs. strand length	88
4.5 Specific tensile modulus of elasticity parallel to grain vs. strand length	89
4.6 Specific tensile modulus of elasticity perpendicular to grain vs. strand length	89
4.7 Failure mode in compression test a) parallel to grain b)perpendicular to grain	92
4.8 Specific compressive strength parallel to grain vs. strand length	93
4.9 Specific compressive strength perpendicular to grain vs. strand length	93
4.10 Specific compressive modulus of elasticity parallel to grain vs. strand length	94
4.11 Specific compressive modulus of elasticity perpendicular to grain vs. strand length	94
4.12 Comparison of stress transfer angles of 2 strand length of OSL when stress is on longitudinal direction of strand	95
4.13 Stress transfer angle with 90° to grain direction when stress is in transverse direction	96
4.14 Model of voids in OSL as difference strand length	97
4.15 Model of voids in OSL as strand overlap between layers	97
4.16 Voids in OSL manufactured in laboratory	97
4.17 Numbers of voids in OSL (shown in black points) comparing between 3 strand length (a) 15 cm (b) 10 cm (c) 5 cm	97
4.18 Modified Hankinson’s formula as different order “n” for predicting tensile strength parallel to grain of OSL made from rubber wood with SG = 0.7, 1 mm of strand length	100
4.19 Modified Hankinson’s formula as different order “n” for predicting compressive strength parallel to grain of OSL made from rubber wood with SG = 0.7, 1 mm of strand length	100
4.20 Specific MOR vs. strand length for different orientation of OSL	103
4.21 Specific bending MOE vs. strand length for different orientation of OSL	103
4.22 Modulus of rupture (MOR) vs. Modulus of elasticity (MOE) in bending	104

รายการภาพประกอบ (ต่อ)

ภาพประกอบ	หน้า
4.23 Tension failure mode on the bottom surface of OSL in static bending test.	105
4.24 Tension failure mode on the bottom surface and shear failure mode in the middle of OSL in static bending test	105
4.25 Modified Hankinson's formula as different order "n" for predicting bending MOE parallel to grain of OSL from rubberwood with SG = 0.7, 1 mm of strand thickness	107
4.26 Modified Hankinson's formula as different order "n" for predicting bending MOR parallel to grain of OSL from rubberwood with SG = 0.7, 1 mm of strand thickness	107
4.27 Flowchart for modification in determining principal stresses as N.A. does not coincide with the centroidal axis of the cross section because $E^T \neq E^C$	109
4.28 Maximum moment as a function of shear modulus (G_{12}) and Poisson's ratio (ν_{12})	110
4.29 Maximum moment as a function of shear modulus (G_{12}) and Poisson's ratio (ν_{12}) in 3D-surface	110
4.30 Average bending strength (MOR) comparison of OSL Type 0	113
4.31 A "Σ-shape" vertical density profile through thickness (Wang, <i>et al.</i> , 2000)	114
4.32 Stress profile in bending of OSL (a) with uniform VDP and (b) with "Σ-shape" VDP	114
4.33 MOR of OSL Type I comparing between experiment and calculation	116
4.34 MOR of OSL Type II comparing between experiment and calculation	117
4.35 Overlap between layers in OSL	118

ตัวย่อและสัญลักษณ์

ϵ_1	Normal strain in 1-direction
ϵ_2	Normal strain in 2-direction
ϵ_3	Normal strain in 3-direction
$\{\epsilon\}_{12}$	Strain vector in plane 12
ϵ_x	Normal strain in x-direction
ϵ_y	Normal strain in y-direction
$\{\epsilon\}_{xy}$	Strain vector in plane xy
ϵ_x^o	Normal strain of center line datum in x-direction
ϵ_y^o	Normal strain of center line datum in y-direction
$\{\epsilon\}^o$	Normal strain vector of center line datum
γ_{12}	Shearing strain in plane 12
γ_{13}	Shearing strain in plane 13
γ_{23}	Shearing strain in plane 23
γ_{xy}	Shearing strain in plane xy
γ_{xy}^o	Shearing strain of center line datum in plane xy
κ_x	Curvature of center line datum in x-direction
κ_y	Curvature of center line datum in y-direction
κ_{xy}	Curvature of center line datum in plane xy
$\{\kappa\}$	Curvature vector of center line datum
ν_{12}	Poisson's ratio for deformation along 2-direction caused by stress along 1-direction
ν_{21}	Poisson's ratio for deformation along 1-direction caused by stress along 2-direction
θ	Angle θ against 1-direction
σ_1	Normal stress in 1-direction
σ_2	Normal stress in 2-direction
σ_3	Normal stress in 3-direction
σ_4	Shearing stress in plane 13
σ_5	Shearing stress in plane 23
σ_6	Shearing stress in plane 12
$\{\sigma\}_{12}$	Stress vector in plane 12
$\sigma(\theta)$	Strength of wood with angle θ against 1-direction
σ_x	Normal stress in x-direction
σ_y	Normal stress in y-direction
$\{\sigma\}_{xy}$	Stress vector in plane xy
τ_{12}	Shearing stress in plane 12
τ_{13}	Shearing stress in plane 13
τ_{23}	Shearing stress in plane 23
τ_{xy}	Shearing stress in plane xy
ζ	Slenderness ratio

ตัวย่อและสัญลักษณ์ (ต่อ)

$[\bar{A}]$	Anti-symmetry Laminate
$[\bar{s}]$	Symmetry Laminate
$[\bar{T}]$	Non-symmetry Laminate
$[A]$	Extensional stiffness matrix
$[B]$	Coupling Stiffness matrix
$[D]$	Bending stiffness matrix
$\{M\}$	Resultant moments vector
$\{N\}$	Resultant Forces vector
$[Q]$	Stiffness matrix
$\overline{[Q]}$	Overall stiffness matrix
$\overline{[Q]}_k$	Overall stiffness matrix of layer k
$[T]$	Transformation matrix
%MC	Moisture content in percentage
C_1	Compressive strength in 1-direction
C_2	Compressive strength in 2-direction
C_{OSL}	Compressive strength of OSL
C_{SW}	Compressive strength of solid wood
C.V.	Coefficient of variation
d	Strand thickness
DMRT	Duncan 's new multiple range test
e	Natural logarithm constant that equals to 2.718282...
E_1	Modulus of elasticity in 1-direction
E_2	Modulus of elasticity in 2-direction
E_1^C	Compressive Modulus of elasticity in 1-direction
E_2^C	Compressive Modulus of elasticity in 2-direction
E_1^T	Tensile Modulus of elasticity in 1-direction
E_2^T	Tensile Modulus of elasticity in 2-direction
G_{12}	Modulus of rigidity or shear modulus in plane 12
LVL	Laminated veneer lumber
l	Strand length
M_x	Moment per length along x-direction
M_y	Moment per length along y-direction
M_{xy}	Moment per length in plane xy
MOR	Modulus of rupture
MOE	Modulus of elasticity
MOE_{OSL}	Modulus of elasticity of OSL
MOE_{SW}	Modulus of elasticity of solid wood
MOR_{OSL}	Modulus of rupture of OSL
MOR_{SW}	Modulus of rupture of solid wood
MSC	Maximum stress criterion
m_1	Weight before drying
m_0	Weight after drying
N	Bending strength at slenderness ratio

ตัวย่อและสัญลักษณ์ (ต่อ)

n	An empirically determined exponent constant
N.A.	Neutral axis
N_x	Force per length along x-direction
N_y	Force per length along y-direction
N_{xy}	Force per length in plane xy
OSB	Oriented strand board
OSL	Oriented strand lumber
P	Bending strength parallel to grain
Pa	Parallel to grain direction
Pe	Perpendicular to grain direction
pMDI	Polymeric Diphenylmethane Diisocyanate
PSL	Parallel strand lumber
Q	Bending Strength perpendicular to grain
Q_{ij}	Member ij in stiffness matrix
\bar{Q}_{ij}	Member of overall stiffness matrix
\bar{Q}_{ijk}	Member ij of overall stiffness matrix of layer k
S_{12}	Shearing strength in plane 12
S_{ij}	Member ij of compliance matrix
S.D.	Standard deviation
SG	Specific gravity
sC ₁	Specific compressive strength along 1-direction
sC ₂	Specific compressive strength along 2-direction
sE ₁ ^C	Specific compressive Modulus of elasticity in 1-direction
sE ₂ ^C	Specific compressive Modulus of elasticity in 2-direction
sE ₁ ^T	Specific tensile Modulus of elasticity in 1-direction
sE ₂ ^T	Specific tensile Modulus of elasticity in 2-direction
sMOR	Specific modulus of rupture
sMOE	Specific modulus of elasticity
SSTr	Sum of square of treatment
SSE	Sum of square of error
SST	Sum of square of total
sT ₁	Specific tensile strength along 1-direction
sT ₂	Specific tensile strength along 2-direction
T ₁	Tensile strength in 1-direction
T ₂	Tensile strength in 2-direction
THC	Tsai-Hill Criterion
T _{OSL}	Tensile strength of OSL
T _{SW}	Tensile strength of solid wood
Type 0	OSL oriented with [0°, 0°, 0°, 0°, 0°, 0°, 0°, 0°, 0°, 0°, 0°] _A
Type I	OSL oriented with [29°, 25°, 21°, 16°, 9°, 0°, 0°, -6°, -8°, -6°, -11°] _A
Type II	OSL oriented with [26°, 22°, 18°, 12°, 5°, 0°, 0°, 0°, 0°, 0°, 0°] _A
VDP	Vertical density profile
V	5 cm. of strand length

ตัวอย่างและสัญลักษณ์ (ต่อ)

X	10 cm. of strand length
XV	15 cm. of strand length
X _C	Compressive strength in 1-direction
X _T	Tensile strength in 1-direction
Y _C	Compressive strength in 2-direction
Y _T	Tensile strength in 2-direction
z	Distance from center line datum
z _k	Distance of layer k from center line datum