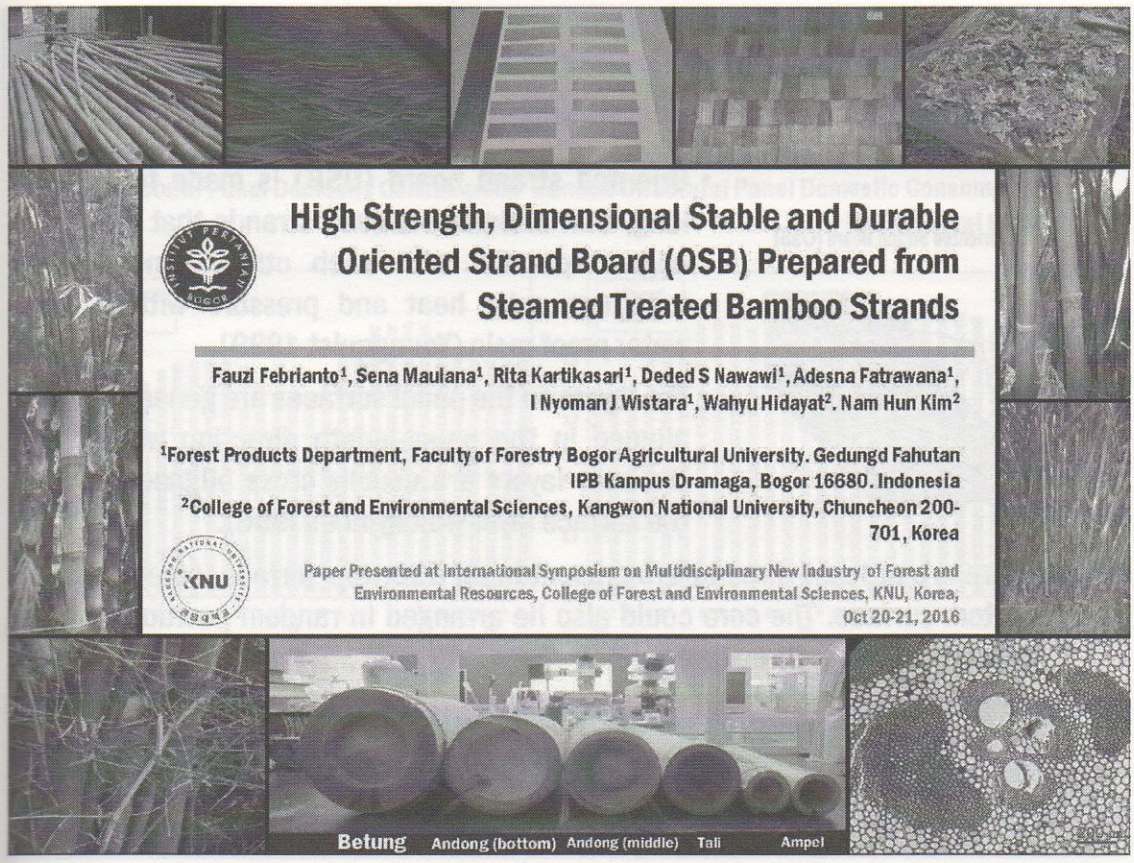
International Symposium
of the Institute of Forest Science

# New Multidisciplinary Perspectives of Forest and Environmental Resources

**Date**
October 20 (Thu), 2016
**Venue**
College of Forest and Environmental Sciences at Kangwon National University
**Organizer**
The Institute of Forest Science at Kangwon National University
College of Forest and Environmental Sciences at Kangwon National University
**Sponsor**
Korean Federation of Science and Technology Societies

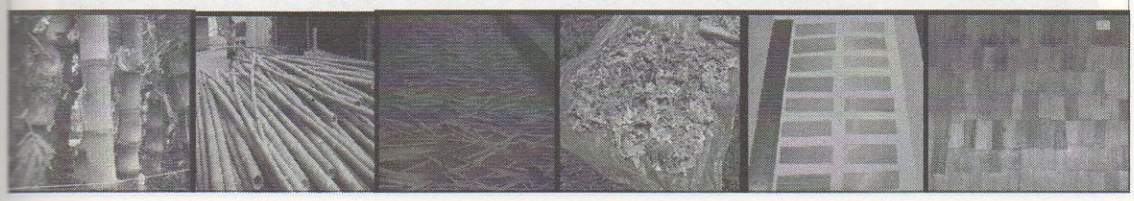
KNU

## Session 2.
## Forest Bio-materials as Future Advanced Materials

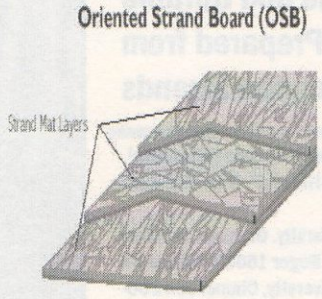



## Presentation Outline

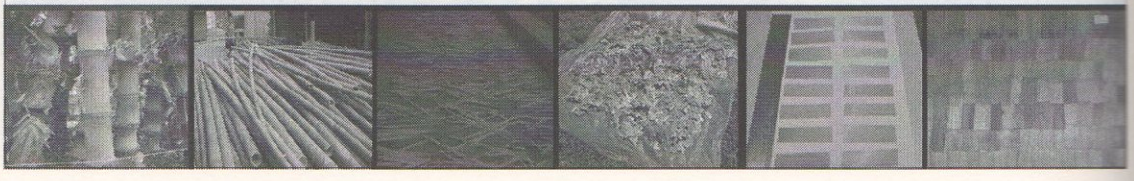
1. What is OSB
2. OSB Applications
3. Bamboo OSB
4. Research Activities and Results
5. Conclussion
6. Publications etc



# What is OSB?

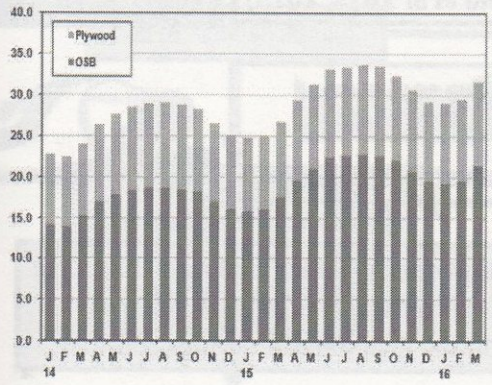



- Oriented strand board (OSB) is made from long, thin and narrow wood strands that are aligned parallel with each other, bonded together under heat and pressure with a water proof resin (Youngquist 1999).
- The layers on the panel surfaces are generally aligned in the panel-length direction while the core layers are usually cross aligned to the surface layer (Anonymous 1996).
- There are at least three layers present in an OSB; top surface, core and bottom surface. The core could also he arranged in random position or consists of two or three layers.

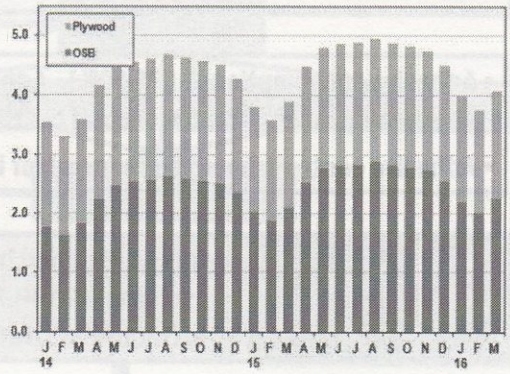


# OSB Consumption in USA and Canada

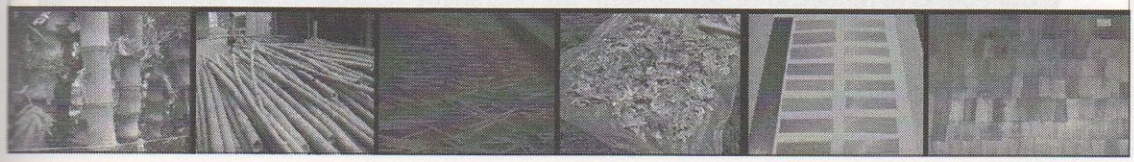
US Structural Panel Domestic Consumption BSF (Annual Rate)




Canada Structural Panel Domestic Consumption BSF (Annual Rate)




Source: RISI, 2015



# Bamboo OSB

- Bamboo is one of the most important non wood forest products in Indonesia and is abundantly available.
- Bamboo has gained increasing interest as an alternative material for wood substitution due to its very fast growth rate, short rotation age, easily cultivated, and high tensile strength.

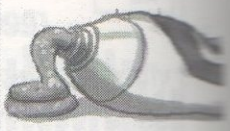
- Naturally bamboo is succeptible to wood destroying organisms (i.e. termite, beetle, fungi and bacteria)
- Preserved bamboo using chemicals; Durability (+); strength (-); cost (-); environment (-) (Hunt and Garrat 1976)

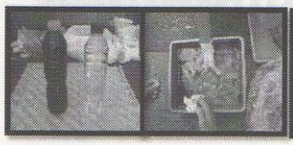
Studies about OSB made from bamboo have been done by Lee *et al* (1996), Sumardi *et al*( 2008), Febrianto *et al* (2015, 2012, 2010). The mat-formed panel products could be effectively manufactured in an industrial scale using bamboo.

## Bamboo OSB (continued)

Steamed treatment on bamboo strands prior to be used for OSB: durability (+); strength (+); cost (+); environment (+) (Febrianto *et al* 2013; 2015)

- Adhesive consumption⇑ (PF 10%). Adhesive cost in wood based composite ~ 40-60% of total cost.
- Adhesive content should be reduced for industrial applications

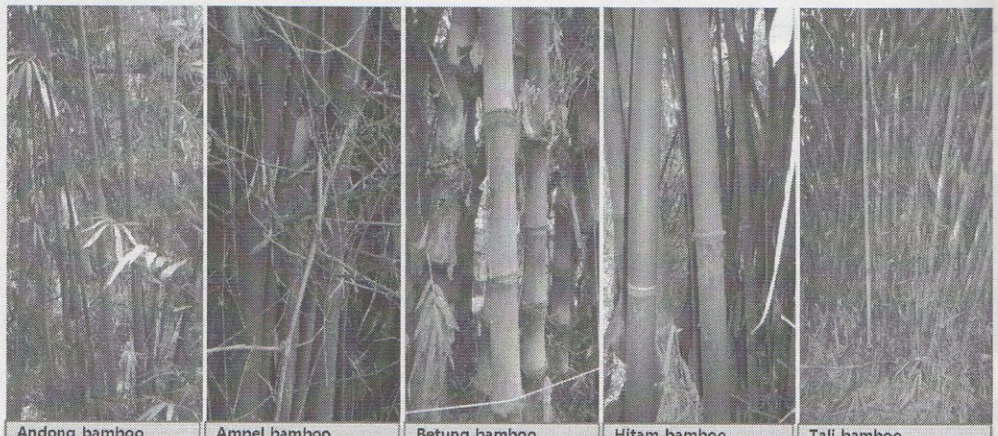




Modified steamed treatments: Washing with water and base solution (NaOH 1%) after steam treatment to remove extractive in strands and to optimalize curing condition

Our goal is to reduce adhesive content with excellent physical, mechanical and durability properties of OSB prepared from modified steamed treated bamboo strands

## 5 bamboos species mostly used for housing etc



| Andong bamboo (*G.verticillata*) SG = 0,47; ρ= 0,60 g/cm³ | Ampel bamboo (*B. vulgaris*) SG = 0,47; ρ= 0,55 g/cm³ | Betung bamboo (*D. asper*) SG = 0,63; ρ= 0,73 g/cm³ | Hitam bamboo (*G. Atroviolacea*) SG = 0,63; ρ= 0,73 g/cm³ | Tali bamboo (*G.apus*) SG = 0,63; ρ= 0,73 g/cm³ |
|---|---|---|---|---|

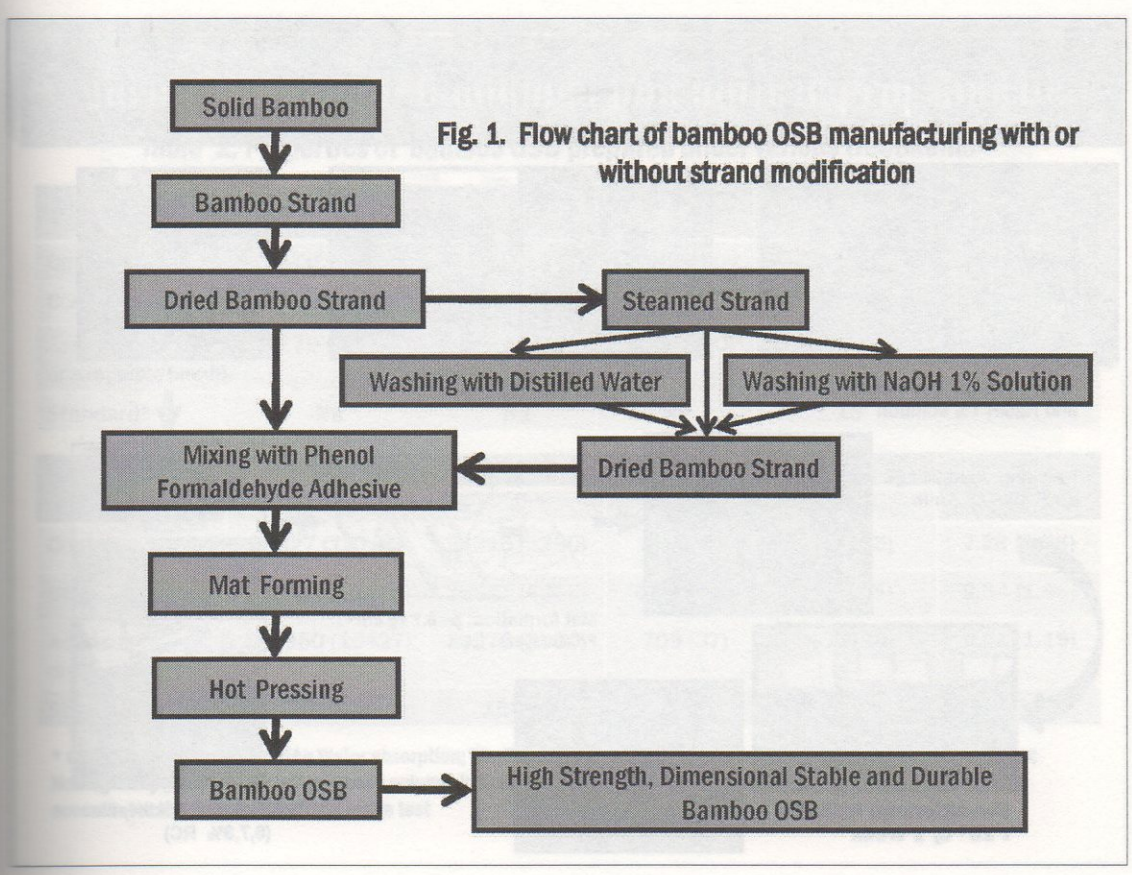
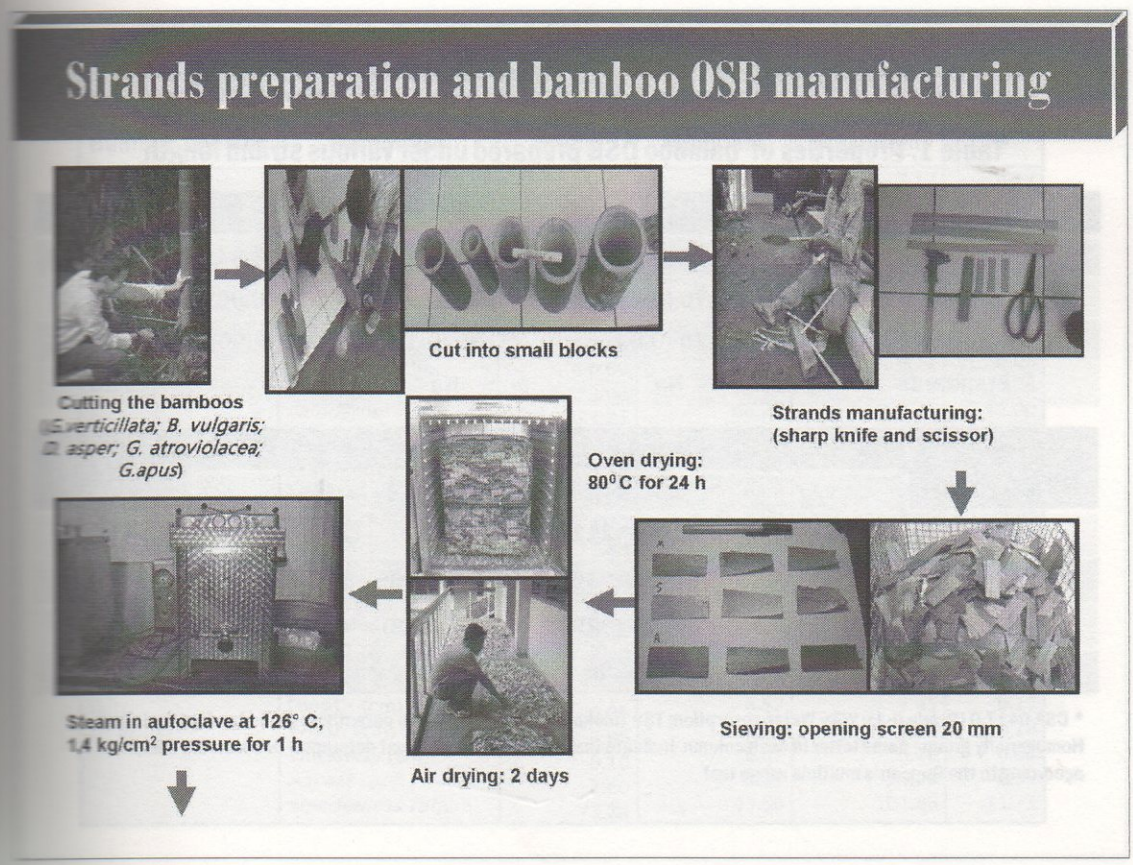
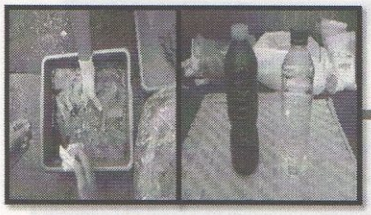



**Fig. 1. Flow chart of bamboo OSB manufacturing with or without strand modification**



# Strands preparation and bamboo OSB manufacturing

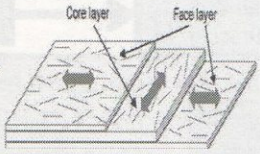


Washing/dipping in water and NaOH 1% solution

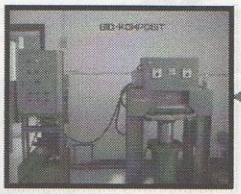
Re-drying MC target 5%

Strand storage

Gluing: PF adhesive (6,7,8% RC)

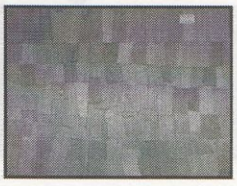



Mat formation: ρ= 0.7 kg.cm$^{-3}$ F/C/B layers: 1:1:1



Pressing: load 25 kgf. cm$^{-2}$, 180$^{0}$ C, 7 min

Conditioning: RH65%, t 25$^{0}$ C, 1 week



# Results I

**Table 1. Properties of bamboo OSB prepared under various strand length**

| Strand length (mm) | Density (kg/cm$^3$) | MC (%) | WA(%) | TS (%) |
|---|---|---|---|---|
| 50 | 0.71 (0.02) | 5.45 (0.12) | 48.49 (3.84) | 13.43 (1.10) |
| 60 | 0.70 (0.02) | 5.75 (0.20) | 46.03 (8.09) | 14.94 (2.24) |
| 70 | 0.70 (0.02) | 5.35 (0.10) | 47.80 (2.96) | 12.92 (1.18) |
| Standard* | Na | Na | Na | ≤ 15 |

| Strand length (mm) | MOE (kg/cm$^2$) | | MOR (kg/cm$^2$) | | IB (kg/cm$^2$) |
|---|---|---|---|---|---|
| | // | ⊥ | // | ⊥ | |
| 50 | 80958 (9213) | 19649 (2113)$^{b}$ | 581 (31 | 324 (31.99)$^{a}$ | 5.41 (1.06) |
| 60 | 83050 (12435) | 31432 (3307)$^{a}$ | 579 (81.06) | 383 (54.62)$^{ab}$ | 7.01 (0.52) |
| 70 | 90627 (13785) | 34915 (3290)$^{a}$ | 581 (30.88) | 417 (55.21)$^{b}$ | 7.28 (1.28) |
| Standard* | 56084 | 15296 | 296 | 196 | 3.52 |

* CSA 0437.0 (Grade 0-1); WA= Water absorption; TS= Thickness swelling; Value in parentheses are standard deviation; Homogeneity group ; Same letter in each column indicate that there is no significant deference between the samples according to the Duncan's multiple range test

# Results II

**Table 2. Properties of bamboo OSB prepared under various treatments**

| Treatment | Density (kg/cm³) | MC (%) | WA(%) | TS (%) | Durability |
|---|---|---|---|---|---|
| Control | 0.70 (0.02) | 5.35 (0.04) | 47.80 (2.96)[b] | 12.92 (0.68)[b] | Not resistance |
| Cold water | 0.70 (0.03) | 5.54 (0.44) | 37.12 (2.22)[a] | 14.45 (1.24)[b] | Medium |
| Acetic anhy-- drade solution | 0.70 (0.02) | 5.10 (0.11) | 35.59 (3.30)[a] | 10.40 (1.44)[a] | Medium |
| Standard* | Na | Na | Na | ≤ 15 | Na |

| Treatment | MOE (kg/cm²) | | MOR (kg/cm²) | | IB (kg/cm²) |
|---|---|---|---|---|---|
| | // | ⊥ | // | ⊥ | |
| Control | 90627 (13785) | 34915 (3290) | 581 (31) | 417 (65) | 7.28 (1.28) |
| Cold water | 108694 (11213) | 36817 (4965) | 655 (134) | 492 (74) | 9.34 (1.46) |
| Acetic anhy-- drade solution | 112960 (10427) | 33276 (3000) | 709 (37) | 438 (18) | 9.61 (1.19) |
| Standard* | 56084 | 15296 | 296 | 196 | 3.52 |

* CSA 0437.0 (Grade 0-1); WA= Water absorption; TS= Thickness swelling; Value in parentheses are standard deviation; Homogeneity group ; Same letter in each column indicate that there is no significant deference between the samples according to the Duncan's multiple range test

# Strand Dimention, aspect ratio and slenderness ratio

| Bamboo species | Parameter | Mean | Minimum | Maximum | SD |
|---|---|---|---|---|---|
| Andong (*G.verticillata*) | Length (cm) | 6.96 | 6.79 | 7.12 | 0.17 |
| | Width (cm) | 2.07 | 1.93 | 2.20 | 0.13 |
| | Thickness (cm) | 0.10 | 0.08 | 0.12 | 0.02 |
| | *Aspect ratio* | 3.38 | 3.15 | 3.61 | 0.36 |
| | *Slenderness ratio* | 73.59 | 59.66 | 87.51 | 13.93 |
| Ampel (*B. vulgaris*) | Length (cm) | 7.15 | 6.97 | 7.33 | 0.18 |
| | Width (cm) | 1.96 | 1.83 | 2.10 | 0.14 |
| | Thickness (cm) | 0.09 | 0.07 | 0.11 | 0.02 |
| | *Aspect ratio* | 3.66 | 3.39 | 3.94 | 0.28 |
| | *Slenderness ratio* | 83.21 | 66.21 | 100.21 | 17.00 |
| Betung (*D. asper*) | Length (cm) | 7.00 | 6.84 | 7.17 | 0.16 |
| | Width (cm) | 2.18 | 2.04 | 2.32 | 0.14 |
| | Thickness (cm) | 0.09 | 0.08 | 0.11 | 0.02 |
| | *Aspect ratio* | 3.23 | 3.00 | 3.46 | 0.23 |
| | *Slenderness ratio* | 77.83 | 65.26 | 90.40 | 12.57 |
| Hitam (*G. Atroviolacea*) | Length (cm) | 6.97 | 6.35 | 7.60 | 0.13 |
| | Width (cm) | 2.05 | 1.62 | 2.50 | 0.21 |
| | Thickness (cm) | 0.11 | 0.06 | 0.20 | 0.02 |
| | *Aspect ratio* | 3.44 | 2.69 | 4.36 | 0.36 |
| | *Slenderness ratio* | 67.74 | 35.55 | 126.67 | 11.46 |
| Tali (*G.apus*) | Length (cm) | 6.99 | 6.57 | 7.45 | 0.17 |
| | Width (cm) | 1.96 | 1.53 | 2.31 | 0,18 |
| | Thickness (cm) | 0.10 | 0.07 | 0.16 | 0.02 |
| | *Aspect ratio* | 3.60 | 3.02 | 4.56 | 0.36 |
| | *Slenderness ratio* | 73.24 | 43.50 | 101.86 | 11.73 |

# Results III

**Table 3. Physical properties of OSB prepared from various bamboo species with or without steam treatment**

| Bamboo species | Strands Treatment | Physical Properties | | | |
|---|---|---|---|---|---|
| | | Density (g/cm$^3$) | MC (%) | WA (%) | TS (%) |
| Tali | Non steam | 0.82 (0.02) | 10.12 (0.17) | 20.35 (1.34) | 6.08 (1.35) |
| | Steam | 0.79 (0.04) | 9.64 (0.19) | 27.30 (1.88) | 4.50 (0.51) |
| Hitam | Non steam | 0.78 (0.01) | 9.82 (0.19) | 24.86 (2.13) | 5.26 (0.51) |
| | Steam | 0.76 (0.01) | 9.70 (0.13) | 24.27 (0.12) | 5.27 (1.51) |
| Andong | Non steam | 0.78 (0.02) | 9.79 (0.17) | 27.29 (0.88) | 4.64 (0.47) |
| | Steam | 0.77 (0.03) | 8.35 (0.63) | 29.46 (4.74) | 8.69 (1.23) |
| Ampel | Non steam | 0.77 (0.04) | 8.44 (0.28) | 31.99 (4.65) | 4.79 (0.31) |
| | Steam | 0.74 (0.01) | 7.75 (0.27) | 32.36 (3.97) | 9.06 (1.65) |
| Betung | Non steam | 0.78 (0.03) | 6.69 (0.27) | 30.07 (2.15) | 4.03 (0.65) |
| | Steam | 0.80 (0.02) | 10.07 (0.24) | 24.23 (4.11) | 4.87 (0.92) |
| CSA 0437.0 ( *Grade O-1*) Standard* | | na | na | na | ≤15 |

*Structural Board Association (2005); Adhesive (PF) content 10 % ; MC (Moisture content); WA (Water absorption); TS (Thickness swelling)

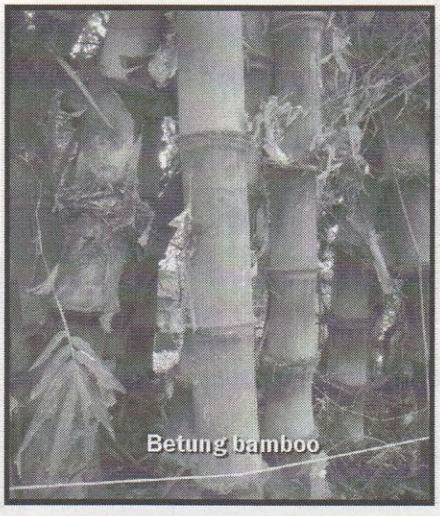
# Results III

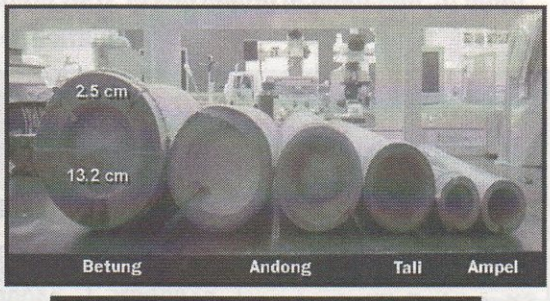
**Table 4. Mechanical properties of OSB prepared from various bamboo species with or without steam treatment**

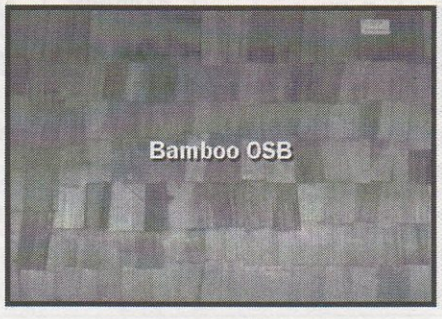
| Bamboo Species | Strand Treatment | Mechanical Properties | | | | |
|---|---|---|---|---|---|---|
| | | MOE (kg/cm$^2$) | | MOR (kg/cm$^2$) | | IB ( kg/cm$^2$) |
| | | // | ⊥ | // | ⊥ | |
| Tali | Non steam | 96411 (5417) | 14043 (2620) | 702 (60) | 177 (19) | 6.31 (0.15) |
| | Steam | 119935 (14605) | 15349 (2479) | 735 (118) | 230 (44) | 9.98 (0.30) |
| Hitam | Non steam | 102177 (24908) | 16071 (2381) | 718 (234) | 168 (25) | 5.40 (1.36) |
| | Steam | 100517 (7515) | 16113 (3093) | 729 (123) | 246 (70) | 6.31 (0.14) |
| Andong | Non steam | 107120 (4706) | 13677 (2081) | 758 (29) | 197 (33) | 7.90 (2.66) |
| | Steam | 119796 (10776) | 17683 (2055) | 792 (16) | 257 (54) | 8.38 (2.06) |
| Ampel | Non steam | 80599 (7688) | 12586 (1042) | 687 (36) | 184 (24) | 7.52 (2.00) |
| | Steam | 103245 (5972) | 17129 (3060) | 762 (63) | 255 (47) | 8.30 (2.54) |
| Betung | Non steam | 83383 (4598) | 12369 (4332) | 645 (86) | 196 (59) | 6.82 (2.19) |
| | Steam | 104941 (7276) | 16780 (3210) | 667 (87) | 223(78) | 9.75 (2.78) |
| CSA 0437.0 ( *Grade O-1*) Standard* | | ≥56 084 | ≥13256 | ≥234 | ≥98 | ≥3.52 |

*Structural Board Association (2005); Adhesive (PF) content 10%

## Betung Bamboo and Bamboo OSB




## Results IV

**Table 5. Physical properties of OSB prepared from various bamboo strands modification**

| No | Strands Treatments | Density (g/cm$^3$) | MC (%) | WA (%) | TS (%) |
|---|---|---|---|---|---|
| 1 | Control | 0.72$^a$ | 10.92$^b$ | 45.06$^d$ | 7.31$^d$ |
| 2 | Steamed | 0.72$^a$ | 9.67$^a$ | 36.25$^c$ | 6.14$^c$ |
| 3 | Steamed+distilled water | 0.72$^a$ | 8.78$^a$ | 32.96$^b$ | 5.30$^b$ |
| 4 | Steamed+NaOH 1% solution | 0.72$^a$ | 8.84$^a$ | 26.70$^a$ | 4.00$^a$ |
| 5 | Immersed in borax 3% preservative solution | 0.73$^a$ | 11.19$^b$ | 45.29$^d$ | 8.90$^e$ |
| 6 | Steamed + borax 3% preservative solution | 0.72$^a$ | 11.68$^b$ | 46.74$^d$ | 9.8$^f$ |
| 7 | CSA 0437 (Grade O-1) | - | - | - | ≤15% |

*Structural Board Association (2005); MC (Moisture content); WA (Water absorption); TS (Thickness swelling); Adhesive (PF) content 8%

# Results IV

**Table 6. Mechanical properties of OSB prepared from various bamboo strands modification**

| Strand Treatment | Mechanical Properties | | | | |
|---|---|---|---|---|---|
| | MOE (kg/cm²) | | MOR (kg/cm²) | | IB ( kg/cm²) |
| | // | ⊥ | // | ⊥ | |
| Control | 86523[a] | 11965[b] | 519[c] | 146[a] | 3.81[a] |
| Steamed | 106700[b] | 12171[b] | 658[d] | 182[b] | 4.69[b] |
| Steamed+distilled water | 118988[bc] | 14090[c] | 740[e] | 206[c] | 5.06[bc] |
| Steamed+NaOH 1% solution | 124403[c] | 14247[c] | 820[f] | 231[d] | 5.79[d] |
| Immersed in borax 3% preservative solution | 85402[a] | 10394[a] | 430[b] | 135[a] | 3.62[a] |
| Steamed + borax 3% preservative solution | 86018[a] | 10316[a] | 400[a] | 131[a] | 3.30[a] |
| CSA 0437 (Grade 0-1) | ≥56 084 | ≥13256 | ≥234 | ≥98 | ≥3.52 |

*Structural Board Asociation (2005); Adhesive (PF) content 8 %

# Results IV

**Table 7. Durability properties of OSB prepared from various bamboo strands modification**

| Strands Treatment | Durability Against*..... | | | | | |
|---|---|---|---|---|---|---|
| | Subterranean Termite | | | Dry Wood termite | | |
| | WL (%) | MORT | Class | WL (%) | MORT | Class |
| Solid bamboo | 12.22[e] | 61.33[a] | IV | 9.18[e] | 60.00[a] | IV |
| Control | 9.31[d] | 89.33[b] | III | 4.33[d] | 88.00[bc] | II |
| Steamed | 6.72[c] | 97.67[c] | II | 2.19[c] | 84.67[b] | II |
| Steamed+distilled water | 4.87[b] | 96.50[c] | II | 1.26[b] | 94.67[bc] | I |
| Steamed+NaOH 1% solution | 4.32[b] | 98.67[c] | II | 0.85[ab] | 94.67[bc] | I |
| Immersed in borax 3% preservative solution | 4.86[b] | 100.00[c] | II | 1.17[ab] | 100.00[c] | I |
| Steamed + borax 3% preservative solution | 2.05[a] | 100.00[c] | I | 0.73[a] | 100.00[c] | I |

*SNI 01-7207-2014 Standard (BSN 2014); Adhesive (PF) content 8 %; WL (Weight loss); MORT (Mortality); Class (Durability class)

# Results IV

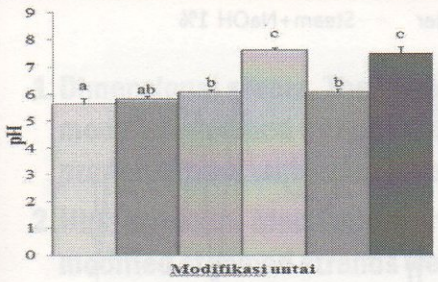
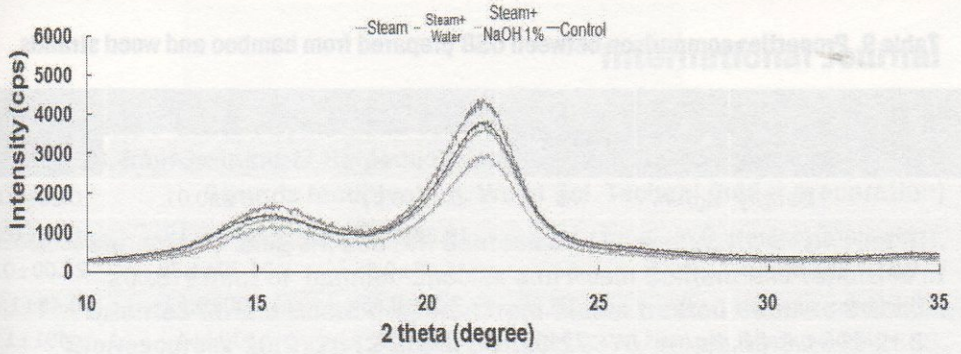



**Fig.2. pH bamboo strands under various conditions**

**Table 8. Chemical component bamboo under various conditions**

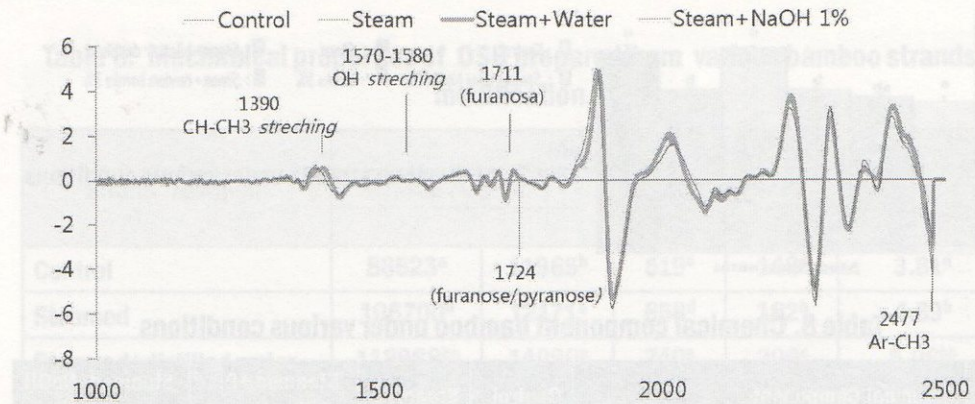
| No | Chemical Component | Control | Steamed | Steamed +Distilled water | Steamed+NaOH 1% solution |
|---|---|---|---|---|---|
| 1 | Hollocellulose (%) | 70.73 | 67.74 | 67.38 | 67.49 |
| 2 | Alpha cellulose (%) | 56.57 | 58.40 | 59.14 | 60.55 |
| 3 | Lignin (%) | 27.35 | 26.80 | 26.88 | 23.23 |
| 4 | Acid soluble lignin (%) | 1.43 | 1.36 | 1.38 | 1.49 |
| 5 | Extractive dissolved in cold water (%) | 7.75 | 6.91 | 6.83 | 6.80 |
| 6 | Extractive dissolved in hot water (%) | 9.87 | 9.73 | 9.28 | 8.87 |
| 7 | Extractive dissolved in al-ben (%) | 5.72 | 5.75 | 4.72 | 4.49 |

# Results IV




| Species | Treatment | k | λ | left | right | β | peak | θ | lam | I200 | Crystalinity (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Betung | Control | 0.9 | 0.15 | 20.24 | 20.70 | 0.0429 | 21.46 | 10.73 | 1.8 | 7.1 | 75.4 |
| | Steam | 0.9 | 0.15 | 20.28 | 20.70 | 0.0422 | 21.42 | 10.71 | 1.7 | 6.7 | 74.4 |
| | Steam+Water | 0.9 | 0.15 | 20.24 | 20.60 | 0.0412 | 21.48 | 10.74 | 1.9 | 8.1 | 77.2 |
| | Steam+NaOH1% | 0.9 | 0.15 | 20.20 | 20.76 | 0.0446 | 21.56 | 10.78 | 1.4 | 5.3 | 73.6 |

# Results IV




| Wave Length | 2477 | 1916 | 1724 | 1711.16 | 1580 | 1570 | 1390 |
|---|---|---|---|---|---|---|---|
| Functional Group | Ar-CH3 | O-H *strec* | furanose/pyranose Hemicellulose | C-H Hemicellulose | O-H *strec* | O-H *strec* | C-H, CH3 Hemicellulose |
| Control Strands | -4.38 | -5.33 | -0.98 | 0.47 | -0.20 | -0.01245537 | 0.55 |
| Steamed Strands | -4.38 | -5.33 | -0.89 | 0.44 | -0.19 | -0.01252272 | 0.48 |
| Steamed+ NaOH 1% Strands | -2.69 | -5.3 | -0.62 | 0.37 | -0.19 | -0.01249499 | 0.45 |

**Fig.3. NIR spectra of untreated and treated betung bamboo strands**

# Results V

**Table 9. Properties comparison between OSB prepared from bamboo and wood strands**

| Parameter | Unit | Standard[1] | Bamboo OSB[2] | | Wood OSB[3] |
|---|---|---|---|---|---|
| | | | Control | Steam+NaOH 1% | |
| Density | $Kg/cm^3$ | na | 0.72±0.02 | 0.72±0.01 | 0.60±0.01 |
| Moisture content | % | na | 10.92±0.78 | 8.84±0.19 | 8.09±0.33 |
| Water absorption | % | na | 45.06±0.85 | 26.70±1.30 | 24.00±0.51 |
| Thickness swelling | % | 15 | 7.31±0.65 | 4.00±0.62 | 8.48±1.36 |
| MOR parallel | $Kg/cm^2$ | 234 | 519±21 | 820±14 | 491±11 |
| MOR perpendicular | $Kg/cm^2$ | 96 | 146±9 | 231±15 | 268±18 |
| MOE parallel | $Kg/cm^2$ | 45000 | 86523±10735 | 124403±3095 | 57330±979 |
| MOE perpendicular | $Kg/cm^2$ | 13000 | 11965±238 | 14247±165 | 18088±156 |
| Internal bond | $Kg/cm^2$ | 3.45 | 3.81±0.31 | 5.79±0.68 | 9.10±2.35 |
| [4]Durability Against: Subterranean termite | Class | I to IV | III-IV | II | Na |
| Dry wood termite | | | II | I | Na |

[1]Standar: CSA0437.0 (grade-1); na: not available; [2]Betung bamboo; Adhesive (Fenol Formaldehida 8%); [3]Mangium wood; Adhesive (*Methylene diphenyl diisocyanate* 7%); [4]SNI 01-7207-2014 Standard (BSN 2014).

## 5. Conclussion

1. **Dimensional stable.** The WA and TS of bamboo OSB produced from modified steamed strands were much lower compared to bamboo OSB prepared from untreated strands.
2. **High strength.** Mechanical properties of bamboo OSB produced from modified steamed strands were much higher compared to bamboo OSB prepared from untreated strands. MOR and MOE of bamboo OSB were more than 2 times higher compared to OSB prepared from wood strands.
3. **Durable.** Natural durability of bamboo OSB produced from modified steamed strands against subterranean termite and dry wood termite were one to two level higher compared to bamboo OSB prepared from untreated strands. The resistance of bamboo OSB against subterranean termite and dry wood termite produced in this research was equal to bamboo OSB preserved with 3% borax preservative solution.

## 6. Publications

### International Journal


1. Febrianto F, Lestari D, Maulana S, Sari RK, Wistara INJ, Hidayat W, Kim NH. 2016. Improvement of Bamboo Oriented Strand Board Properties through Strands Modification. Wood Sci. Technol (under preparation)
2. Febrianto F, Jang JH, Lee SH, Santosa IA, Hidayat W, Kwon JH, Kim NH. 2015. Effect of bamboo Species and Resin Content on Properties of Oriented Strand Board Prepared from Steam treated Bamboo Strands. *BioResources* 10(2):2642-2655. DOI:10.15376/biores.10.2.2642-2655. ISSN: 1930-2126. Department of Forest Biomaterials, NC State University, Raleigh, NC. Impact factor 1,43. URL: http://www.bioresources.com; http://www.bioresourcesjournal.com; http://ncsu.edu/bioresources
3. Febrianto F, Sahroni, Hidayat W, Bakar ES, Kwon GJ, Kwon JH, Kim NH. 2012. Properties of oriented strand board made from betung bamboo (*Dendrocalamus asper* (Schultes.f) Backer ex Heyne). Wood Sci. Technol 46:53-62. DOI 10.1007/s00226-010-0385-8. Impact factor 1,920 (2014). Muenchen. p-ISSN 0043- 7719; e-ISSN 1432- 5225. Springer. URL: http://link.springer.com/journal/226