# Mechanical properties of Tropical Woods


## By TAKASHI NAKAI

**Wood Utilization Division, Forestry and Forest Products Research Institute**
(Kukizaki, Ibaraki, 305 Japan)


## Introduction

Since 1948, various kinds of tropical woods have been imported to Japan from Southeast Asia and Pacific regions, mainly as a raw material for producing plywood and also for sawn timber.

For the most effective utilization of these valuable woods, the Forestry and Forest Products Research Institute (formerly called the Government Forest Experiment Station) has conducted a series of comprehensive studies on the properties and processing suitabilities of them.[1~8), 12~16)]

The results obtained by employing the standard small clear specimen are of useful for practical purposes and especially important to deepen our understanding of wood.

Many reports on the mechanical properties of tropical woods have been published by various authorities, but almost all reports have tabulated neither the tensile strength parallel to grain nor the comparisons of Young's moduli and strength properties among three mutually perpendicular axes.

In this paper, the mechanical properties, including the tensile strength, of 56 imported tropical woods are presented with the comparisons of Young's moduli and strength properties among three mutually perpendicular axes. Where a particular species from the same origin has been tested twice or more times, the results are combined.

Then the theoretical equations developed by Sawada[11)] for predecting the modulus of rupture in rectangular cross section are compared with the test results. Finally, some mechanical properties of the three year old *Acacia mangium* planted in Sabah are presented. As the faster growing species have become a subject of world attention, *Acacia mangium* is believed one of them. But its mechanical properties have not yet published. This part was presented by the author at the Wood Engineering Group Meeting of the IUFRO All-Division 5 Conference held at Madison, U.S.A., in July, 1983 as a prompt report.[10)]

## Materials and testing procedure

### *1) The preparation of the test specimen*

The species tested are tabulated in Table 1 in order of family name. To avoid getting test specimens from core part and sap wood part of logs, mainly due to the presence of brittle heart and the initial stage of decay which was sometimes observed when logs were transported into the laboratory, side matched specimens were cut. For the longitudinal tests, tension, static bending and impact bending specimens were cut side by side at the same growing portion in a log. For the perpendicular tests, the same growing portion as used for the longitudinal test specimens was carefully cut.

The test specimens for compression parallel to grain, shear, and local bearing, which is called "the partial compression" in JIS Z 2111, but may be called as above, were cut at the not-destructive part after the static bending test had finished.

The test specimens for hardness were not prepared according to the JIS Z 2117. The both cross sections of the compression parallel to grain test specimen and the radial surface of local bearing test specimen were used to measure the hardness.

The number of test specimens were ten each for a longitudinal test and five to six for a perpendicular test per one log. Because of cracks

Table 1. List of timbers tested

| | Comon name | Scientific name (Family) | Origin | Number of log |
|---|---|---|---|---|
| | **Hardwood** (broad-leaved) | | | |
| 1. | Campnosperma | *Campnosperma brevipetiolata* (Anacardiaceae) | Sol. | 1 |
| 2. | Spondias | *Spondias* sp. (Anacardiaceae) | N.G. | 1 |
| 3. | Alstonia | *Alstonia* sp. (Apocynaceae) | N.G. | 1 |
| 4. | Jelutong | *Dyera* sp. (Apocynaceae) | Kal. | 1 |
| 5. | Canarium | *Canarium* sp. (Burseraceae) | N.G. | 1 |
| 6. | Terminalia | *Terminalia* sp. (Combretaceae) | N.G. | 2 |
| 7. | Erima | *Octomeles sumatrana* (Datiscaceae) | N.G. | 1 |
| 8. | Phdiek | *Anisoptera glabra* (Dipterocarpaceae) | Cam. | 2 |
| 9. | Giam | *Cotylelobium* sp. (Dipterocarpaceae) | Kal. | 1 |
| 10. | Apitong | *Dipterocarpus* sp. (Dipterocarpaceae) | Phi. | 4 |
| 11. | Chhoeuteal Sar | *Dipterocarpus alatus* (Dipterocarpaceae) | Cam. | 3 |
| 12. | Chhoeuteal Fangkuoi | *Dipterocarpus insularis* (Dipterocarpaceae) | Cam. | 3 |
| 13. | Keruing | *Dipterocarpus* sp. (Dipterocarpaceae) | Kal. | 4 |
| 14. | Keruing | *Dipterocarpus* sp. (Dipterocarpaceae) | Mly. | 3 |
| 15. | Kapur | *Dryobalanops* sp. (Dipterocarpaceae) | Sab. | 6 |
| 16. | Koki Khsach | *Hopea pierrei* (Dipterocarpaceae) | Cam. | 1 |
| 17. | Sengawan | *Shorea albida* (Dipterocarpaceae) | Swk. | 1 |
| 18. | Red Lauan | *Shorea negrosensis* (Dipterocarpaceae) | Phi. | 3 |
| 19. | Red Meranti | *Shorea (Rubroshorea)* sp. (Dipterocarpaceae) | Swk. | 4 |
| 20. | Light Red Meranti | *Shorea (Rubroshorea)* sp. (Dipterocarpaceae) | Kal. | 1 |
| 21. | White Meranti | *Shorea (Anthoshorea)* sp. (Dipterocarpaceae) | Kal. | 1 |
| 22. | Komnhan | *Shorea hypochra* (Dipterocarpaceae) | Cam. | 2 |
| 23. | Yellow Meranti | *Shorea (Richetioides)* sp. (Dipterocarpaceae) | Kal. | 1 |
| 24. | Bangkirai | *Shorea (Shorea)* sp. (Dipterocarpaceae) | Kal. | 4 |
| 25. | Balau | *Shorea (Shorea)* sp. (Dipterocarpaceae) | Kal. | 3 |
| 26. | Resak | *Vatica* sp. (Dipterocarpaceae) | Kal. | 1 |
| 27. | New Guinea Basswood | *Endospermum medullosum* (Euphorbiaceae) | N.G. | 1 |
| 28. | Borneo Oak | *Quercus* sp. (Fagaceae) | Kal. | 1 |
| 29. | Malas | *Homalium foetidum* (Flacourtiaceae) | N.G. | 1 |
| 30. | Ramin | *Gonystylus bancanus* (Gonystylaceae) | Kal. | 2 |
| 31. | Calophyllum | *Calophyllum* sp. (Guttiferae) | Sol. | 1 |
| 32. | Geronggang | *Cratoxylon arborescens* (Guttiferae) | Smt. | 1 |
| 33. | Ulin | *Eusideroxylon zwageri* (Lauraceae) | Kal. | 1 |
| 34. | Litsea | *Litsea* sp. (Lauraceae) | N.G. | 1 |
| 35. | Intsia | *Intsia* sp. (Leguminosae) | N.G. | 1 |
| 36. | Menggeris | *Koompassia excelsa* (Leguminosae) | Kal. | 1 |
| 37. | Ro Yong | *Parkia streptocarpa* (Leguminosae) | Cam. | 1 |
| 38. | Sepetir Paya | *Pseudosindora palustris* (Leguminosae) | Swk. | 2 |
| 39. | Champaca | *Michelia* sp. (Magnoliaceae) | Kal. | 1 |
| 40. | Jong Kong | *Dactylocladus stenostachys* (Melastomataceae) | Swk. | 2 |
| 41. | Keledang | *Artocarpus* sp. (Moraceae) | Kal. | 1 |
| 42. | Kamerere | *Eucalyptus deglupta* (Myrtaceae) | N.G. | 1 |
| 43. | Kelat | *Eugenia* sp. (Myrtaceae) | Kal. | 1 |
| 44. | Rong Leang | *Tristania* sp. (Myrtaceae) | Cam. | 1 |
| 45. | Labula | *Anthocephalus cadamba* (Rubiaceae) | N.G. | 1 |
| 46. | Taun | *Pometia pinnata* (Sapindaceae) | N.G. | 1 |
| 47. | Nato | *Palaquium* sp. (Sapotaceae) | Sol. | 1 |
| 48. | Planchonella | *Planchonella* sp. (Sapotaceae) | N.G. | 1 |
| 49. | White Siris | *Ailanthus* sp. (Simaroubaceae) | N.G. | 1 |
| 50. | Amberoi | *Pterocymbium beccarii* (Sterculiaceae) | N.G. | 1 |
| 51. | Teraling | *Tarrietia* sp. (Sterculiaceae) | Kal. | 1 |
| 52. | Karas | *Aquilaria malaccensis* (Thymelaeaceae) | Kal. | 1 |
| 53. | Celtis | *Celtis* sp. (Ulmaceae) | N.G. | 1 |
| 54. | Gmelina | *Gmelina* sp. (Verbenaceae) | N.G. | 1 |
| 55. | Teak | *Tectona grandis* (Verbenaceae) | Bma. | 1 |
| | **Softwood** (conifer) | | | |
| 56. | Agathis | *Agathis* sp. (Araucariaceae) | Kal. | 1 |
| 57. | Srol Kraham | *Dacrydium elatum* (Podocarpaceae) | Cam. | 1 |

Note:

Bma.: Burma, Cam.: Cambodia, Kal.: Kalimantan, Mly.: Malaysia, N.G.: Papua New Guinea
Phil.: Philippines, Sab.: Sabah, Sol.: Solomon Islands, Swk.: Sarawak, Smt.: Sumatora.

occurred during the natural drying procedure, it was impossible to prepare the perpendicular test specimen for some species.

The moisture condition of the test specimens was the air dry condition (15±2%) and all tests were carried out in a room controlled at temperature of 20±1°C and relative humidity of 75±5%.

*2) The methods of test*

The test methods were based on the Japan Industrial Standards, JIS Z 2101–2117. A detailed description of this procedure is not given in this paper, but brief descriptions of each of the strength tests are as follows:

(1) Static bending test

In the static bending test a specimen of 25×25×400 mm was supported over a span of 350 mm, which is 14 times of the height of the specimen. The load was applied at midspan on the radial surface (tangential direction).

(2) Compression parallel to grain test

For the compression parallel to grain test a 25×25×50 mm specimen was employed and load was applied using a special equipment which ensures a uniform distribution of load over the cross-section. A mirror-type extensometer was used to measure the axial strain (deformation). This extensometer was used in compression perpendicular to grain test and also in tension test both parallel and perpendicular to grain for measuring the elongation with 25 mm gauge length.

(3) Compression perpendicular to grain test

The size of a test specimen was the same as that for the compression parallel to grain test. The load directions were the radial and tangential directions.

(4) Local bearing test (Partial compression test)

The test specimen was of prism with a square cross section having 25 mm height and 125 mm length, which is five times of the height. Arrangement for this test is shown in Fig. 1. Load was applied on the radial surface.

(5) Tension parallel and perpendicular to grain test

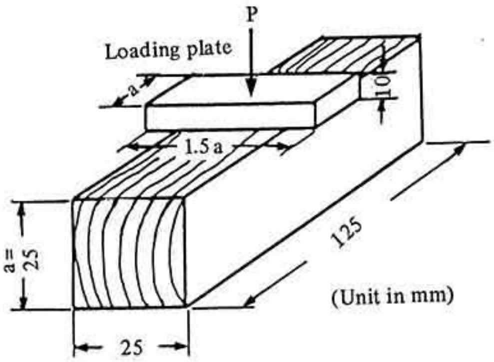


Fig. 1. Test arrangement of local bearing test (partial compression test in JIS Z 2111)

The shape and dimension of these test specimen were shown in JIS Z 2112.

(6) Shear parallel to grain test

The shear parallel to grain test was made on a "chair type" specimen. Shear test was conducted in both the radial and tangential plane on end matched pairs of specimens.

(7) Hardness test

For the hardness test a 10 mm diameter steel ball was embedded in $1/\pi$ mm depth on the specimen surface. The load P(kg) at the $1/\pi$ mm indentation was recorded. Hardness was expressed as the value of P/10 (kg/mm$^2$).

(8) Impact bending test

The size of test specimen was 20×20×300 mm. Taking the span of 240 mm, a hammer with 10 kg·m energy struck the mid span on edge grain. Absorbed energy in impact bending was calculated as below:

$$a = q/bh \ (\mathrm{kg \cdot m/cm^2})$$

a: absorbed energy (kg·m/cm$^2$)
q: impact work (kg·m)
b: width of specimen (cm)
h: height of specimen (cm)

## Results and discussions

*1) Relationship between specific gravity and mechanical properties*

The test results on mechanical properties of 56 tropical woods are tabulated in Table 2

Table 2. Mechanical properties of 56 tropical woods (Air dry condition)

| No. | Species | Origin | Specific gravity | Compression parallel to grain | | | Tension parallel to grain | | | Static bending | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hardwood (broad-leaved) | | $R_u$ | $E_c$ ($10^3$kg/cm²) | $\sigma_p$ (kg/cm²) | $\sigma_c$ (kg/cm²) | $E_t$ ($10^3$kg/cm²) | $\sigma_p$ (kg/cm²) | $\sigma_t$ (kg/cm²) | $E_b$ ($10^3$kg/cm²) | $\sigma_p$ (kg/cm²) | $\sigma_b$ (kg/cm²) |
| 1 | Campnosperma | Sol. | 0.50 | 128 | 250 | 381 | 118 | 873 | 1356 | 101 | 500 | 805 |
| 2 | Spondias | N.G. | 0.39 | 83.0 | 207 | 288 | 80.2 | 592 | 851 | 70.2 | 308 | 534 |
| 3 | Alstonia | N.G. | 0.45 | 92.0 | 259 | 309 | 80.9 | 594 | 750 | 81.4 | 300 | 572 |
| 4 | Jelutong | Kal. | 0.43 | 102 | 297 | 361 | 98.6 | 731 | 961 | 81.2 | 307 | 540 |
| 5 | Canarium | N.G. | 0.48 | 141 | 236 | 342 | 144 | 800 | 1309 | 110 | 351 | 648 |
| 6 | Terminalia | N.G. | 0.53 | 108 | 300 | 390 | 102 | 748 | 976 | 92.1 | 499 | 774 |
| 7 | Erima | N.G. | 0.37 | 81.6 | 180 | 268 | 78.9 | 406 | 609 | 60.5 | 298 | 478 |
| 8 | Phdiek | Cam. | 0.67 | 130 | 334 | 475 | 116 | — | 1194 | 101 | 480 | 856 |
| 9 | Giam | Kal. | 1.00 | 263 | 639 | 804 | 229 | 1726 | 2240 | 199 | 860 | 1515 |
| 10 | Apitong | Phi. | 0.73 | 155 | 359 | 534 | 128 | 967 | 1457 | 129 | 622 | 1191 |
| 11 | Chhoeuteal Sar | Cam. | 0.76 | 168 | 452 | 596 | 155 | — | 1352 | 127 | 622 | 1062 |
| 12 | Chhoeuteal Bangkuoi | Cam. | 0.82 | 172 | 504 | 645 | 143 | — | 1530 | 140 | 715 | 1255 |
| 13 | Keruing | Kal. | 0.83 | 230 | 561 | 710 | 197 | 1521 | 1962 | 180 | 767 | 1285 |
| 14 | Keruing | Mly. | 0.85 | 256 | 571 | 761 | 235 | 1042 | 1656 | 201 | 739 | 1384 |
| 15 | Kapur | Sab. | 0.67 | 185 | 413 | 555 | 158 | 1066 | 1426 | 137 | 695 | 1074 |
| 16 | Koki Khsach | Cam. | 0.84 | 193 | 470 | 695 | 210 | — | 2616 | 157 | 985 | 1653 |
| 17 | Sengawan | Swk. | 0.67 | 246 | 392 | 594 | 195 | 1430 | 2184 | 158 | 648 | 1079 |
| 18 | Red Lauan | Phi. | 0.58 | 141 | 320 | 478 | 140 | 999 | 1596 | 111 | 475 | 905 |
| 19 | Red Meranti | Swk. | 0.55 | 104 | 381 | 476 | — | — | — | 107 | 559 | 876 |
| 20 | Light Red Meranti | Kal. | 0.48 | 98.8 | 316 | 365 | 106 | 843 | 1046 | 80.1 | 378 | 632 |
| 21 | White Meranti | Kal. | 0.56 | 165 | 325 | 423 | 143 | 1099 | 1368 | 128 | 501 | 919 |
| 22 | Komnhan | Cam. | 0.74 | 171 | 507 | 654 | 152 | — | 1448 | 145 | 724 | 1206 |
| 23 | Yellow Meranti | Kal. | 0.49 | 135 | 384 | 420 | 105 | 1063 | 1193 | 106 | 497 | 789 |
| 24 | Bangkirai | Kal. | 0.89 | 221 | 540 | 691 | 217 | 1474 | 1870 | 177 | 873 | 1505 |
| 25 | Balau | Kal. | 0.93 | 212 | 566 | 762 | 197 | 1362 | 1847 | 180 | 859 | 1447 |
| 26 | Resak | Kal. | 0.80 | 156 | 554 | 678 | 153 | 1277 | 1729 | 134 | 676 | 1257 |
| 27 | New Guinea Basswood | N.G. | 0.36 | 108 | 213 | 305 | 105 | 736 | 1189 | 86.1 | 359 | 592 |
| 28 | Borneo Oak | Kal. | 1.05 | 262 | 638 | 874 | 219 | 1606 | 1938 | 203 | 907 | 1561 |
| 29 | Malas | N.G. | 0.84 | 189 | 587 | 723 | 171 | 1711 | 2022 | 162 | 757 | 1411 |
| 30 | Ramin | Kal. | 0.68 | 197 | 479 | 678 | 190 | 1236 | 1971 | 158 | 742 | 1244 |

| No. | Species | Origin | Shear parallel to grain | | Local bearing | Hardnnes | | | Impact bending |
|---|---|---|---|---|---|---|---|---|---|
| | Hardwood (broad-leaved) | | $\tau_R$ (kg/cm²) | $\tau_T$ (kg/cm²) | $\sigma_p$ (kg/cm²) | $H_l$ (kg/mm²) | $H_r$ (kg/mm²) | $H_t$ (kg/mm²) | $a$ (kg·m/cm²) |
| 1 | Campnosperma | Sol. | 88 | 114 | 40.7 | 4.0 | 1.5 | 1.0 | 0.54 |
| 2 | Spondias | N.G. | 64 | 82 | 27.8 | 3.7 | 0.9 | 0.8 | 0.31 |
| 3 | Alstonia | N.G. | 58 | 77 | 34.7 | 3.1 | 1.2 | 0.8 | 0.28 |
| 4 | Jelutong | Kal. | 71 | 78 | 28.6 | 3.5 | 0.9 | 0.7 | 0.45 |
| 5 | Canarium | N.G. | 78 | 101 | 26.3 | 4.0 | 1.1 | 0.8 | 0.63 |
| 6 | Terminalia | N.G. | 96 | 96 | 54.6 | 4.7 | 1.5 | 1.4 | 0.56 |
| 7 | Erima | N.G. | 47 | 52 | 17.4 | 2.8 | 0.7 | 0.5 | 0.33 |
| 8 | Phdiek | Cam. | 99 | 107 | 50.6 | 5.7 | 2.1 | 1.7 | 0.73 |
| 9 | Giam | Kal. | 180 | 196 | 121 | 10.3 | 4.3 | 3.9 | 1.38 |
| 10 | Apitong | Phi. | 136 | 149 | 68.1 | 5.7 | 2.2 | 2.0 | 1.01 |
| 11 | Chhoeuteal Sar | Cam. | 116 | 128 | 47.3 | 6.8 | 2.5 | 2.0 | 0.82 |
| 12 | Chhoeuteal Bangkuoi | Cam. | 131 | 141 | 58.2 | 7.5 | 2.7 | 2.1 | 0.91 |
| 13 | Keruing | Kal. | 134 | 149 | 78.7 | 7.1 | 2.4 | 2.2 | 0.86 |
| 14 | Keruing | Mly. | 147 | 154 | 84.0 | 8.5 | 2.5 | 2.1 | 1.15 |
| 15 | Kapur | Sab. | 109 | 120 | 56.1 | 6.5 | 1.9 | 1.7 | 0.74 |
| 16 | Koki Khsach | Cam. | 173 | 194 | 83.0 | 9.7 | 4.0 | 3.0 | 1.44 |
| 17 | Sengawan | Swk. | 104 | 116 | 54.2 | 6.6 | 1.8 | 1.6 | 0.91 |
| 18 | Red Lauan | Phi. | 84 | 102 | 42.9 | 4.2 | 1.4 | 1.0 | 1.13 |
| 19 | Red Meranti | Swk. | 104 | 103 | 51.4 | 5.6 | 1.4 | 1.2 | 0.60 |
| 20 | Light Red Meranti | Kal. | 87 | 99 | 47.2 | 3.5 | 1.2 | 1.0 | 0.52 |
| 21 | White Meranti | Kal. | 104 | 97 | 46.6 | 5.4 | 1.3 | 1.0 | 0.85 |
| 22 | Komnhan | Cam. | 135 | 117 | 71.8 | 7.2 | 2.7 | 2.5 | 1.08 |
| 23 | Yellow Meranti | Kal. | 82 | 102 | 47.5 | 4.3 | 1.6 | 1.1 | 0.58 |
| 24 | Bangkirai | Kal. | 156 | 191 | 107 | 8.3 | 3.5 | 3.1 | 1.28 |
| 25 | Balau | Kal. | 167 | 198 | 125 | 9.3 | 3.8 | 3.3 | 1.47 |
| 26 | Resak | Kal. | 142 | 178 | 82.1 | 7.9 | 2.3 | 1.8 | 0.69 |
| 27 | New Guinea Basswood | N.G. | 56.7 | 45.8 | 30.5 | 3.4 | 0.8 | 0.7 | 0.30 |
| 28 | Borneo Oak | Kal. | 213 | 185 | — | 10.5 | 5.6 | 4.3 | 2.08 |
| 29 | Malas | N.G. | 141 | 215 | 91.1 | 9.3 | 4.3 | 3.1 | 0.99 |
| 30 | Ramin | Kal. | 119 | 116 | 66.5 | 7.9 | 2.6 | 2.1 | 0.73 |

Table 2 (Continued)

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | Calophyllum | Sol. | 0.65 | 114 | 297 | 450 | 111 | 548 | 862 | 102 | 611 | 955 | 119 | 135 | 68.7 | 5.2 | 2.2 | 1.8 | 0.67 |
| 32 | Geronggang | Smt. | 0.44 | 119 | 210 | 337 | 108 | 906 | 1284 | 93.5 | 396 | 692 | 86 | 110 | 34.0 | 3.9 | 1.2 | 0.9 | 0.45 |
| 33 | Ulin | Kal. | 1.04 | 209 | 736 | 911 | 185 | 1671 | 2538 | 187 | 1048 | 1886 | 185 | 233 | 221 | 9.6 | 6.1 | 5.3 | 0.84 |
| 34 | Litsea | N.G. | 0.43 | 95.7 | 225 | 322 | 87.8 | 672 | 1193 | 75.5 | 325 | 545 | 59 | 72 | 27.0 | 3.5 | 1.0 | 0.8 | 0.49 |
| 35 | Intsia | N.G. | 0.76 | 175 | 458 | 671 | 191 | 1298 | 1911 | 155 | 829 | 1350 | 174 | 179 | 112 | 9.0 | 3.8 | 3.2 | 1.12 |
| 36 | Menggeris | Kal. | 0.81 | 174 | 514 | 622 | 171 | 971 | 1458 | 159 | 750 | 1260 | 169 | 140 | 104 | 6.3 | 2.2 | 2.0 | 0.92 |
| 37 | Ro Yong | Cam. | 0.56 | 113 | 311 | 443 | 93.5 | — | 1156 | 102 | 561 | 927 | 130 | 125 | 69.6 | 5.6 | 1.7 | 1.5 | 0.68 |
| 38 | Sepetir Paya | Swk. | 0.60 | 141 | 326 | 501 | 144 | 906 | 1396 | 116 | 547 | 888 | 92 | 123 | 59.4 | 5.9 | 2.2 | 1.6 | 0.36 |
| 39 | Champaca | Kal. | 0.54 | 126 | 389 | 481 | 123 | 990 | 1355 | 113 | 513 | 890 | 118 | 144 | 73.9 | 5.1 | 1.7 | 1.3 | 0.58 |
| 40 | Jong Kong | Swk. | 0.52 | 141 | 302 | 442 | 140 | 819 | 1288 | 110 | 501 | 808 | 83 | 74 | 41.3 | 5.3 | 1.5 | 1.3 | 0.49 |
| 41 | Keledang | Kal. | 0.57 | 162 | 451 | 518 | 139 | 1225 | 1587 | 121 | 513 | 854 | 111 | 102 | 50.1 | 4.7 | 1.4 | 1.1 | 0.77 |
| 42 | Kamerere | N.G. | 0.65 | 140 | 413 | 493 | 106 | 1017 | 1262 | 113 | 484 | 857 | 86 | 97 | 51.6 | 4.8 | 1.7 | 1.3 | 1.01 |
| 43 | Kelat | Kal. | 0.76 | 152 | 438 | 572 | 128 | 958 | 1197 | 134 | 592 | 1039 | 129 | 140 | — | 6.2 | 1.8 | 1.6 | 0.86 |
| 44 | Rong Leang | Cam. | 1.18 | 238 | 607 | 901 | 230 | — | 2640 | 203 | 1346 | 2240 | 273 | 310 | — | 13.6 | 6.6 | 6.4 | 1.91 |
| 45 | Labula | N.G. | 0.44 | 106 | 312 | 347 | 75.4 | 735 | 1057 | 87.4 | 377 | 659 | 67 | 104 | 42.9 | 3.8 | 1.5 | 0.9 | 0.45 |
| 46 | Taun | N.G. | 0.61 | 164 | 314 | 458 | 150 | 1163 | 1766 | 127 | 601 | 1027 | 106 | 126 | 55.9 | 5.2 | 1.7 | 1.5 | 0.67 |
| 47 | Nato | Sol. | 0.71 | 169 | 314 | 481 | 148 | 1135 | 1755 | 125 | 592 | 1125 | 109 | 144 | 59.1 | 6.0 | 2.4 | 1.7 | 0.93 |
| 48 | Planchonella | N.G. | 0.48 | 140 | 291 | 407 | 137 | 1032 | 1648 | 114 | 464 | 779 | 79 | 95 | 37.7 | 4.9 | 1.6 | 1.0 | 0.69 |
| 49 | White Siris | N.G. | 0.42 | 131 | 237 | 346 | 124 | 754 | 1148 | 89.8 | 374 | 639 | 70 | 51 | 25.2 | 3.5 | 1.1 | 0.7 | 0.41 |
| 50 | Amberoi | N.G. | 0.43 | 132 | 220 | 313 | 113 | 759 | 1047 | 75.9 | 249 | 494 | 43 | 66 | 17.8 | 3.9 | 1.0 | 0.7 | 0.40 |
| 51 | Teraling | Kal. | 0.80 | 169 | 528 | 657 | 174 | 1213 | 1725 | 146 | 678 | 1200 | 153 | 156 | 99.2 | 7.0 | 2.8 | 2.5 | 1.04 |
| 52 | Karas | Kal. | 0.44 | 92.1 | 269 | 321 | 95.9 | 640 | 898 | 77.0 | 313 | 542 | 83 | 63 | 31.3 | 3.0 | 0.8 | 0.8 | 0.51 |
| 53 | Celtis | N.G. | 0.66 | 154 | 413 | 494 | 140 | 1069 | 1324 | 133 | 598 | 991 | 129 | 154 | 69.3 | 5.6 | 2.6 | 1.7 | 0.63 |
| 54 | Gmelina | N.G. | 0.56 | 126 | 324 | 434 | 127 | 697 | 1133 | 107 | 441 | 782 | 89 | 98 | 51.8 | 5.6 | 1.7 | 1.4 | 0.57 |
| 55 | Teak | Bma. | 0.52 | 70.1 | 213 | 356 | 68.7 | 586 | 870 | 66.4 | 380 | 673 | 97 | 111 | 77.5 | 4.8 | 1.7 | 1.5 | — |
| **Soft wood** (conifar) | | | | | | | | | | | | | | | | | | | |
| 56 | Agathis | Kal. | 0.46 | 118 | 348 | 373 | 108 | 1028 | 1504 | 114 | 426 | 737 | 78 | 79 | 40.2 | 3.6 | 1.0 | 0.9 | 0.43 |
| 57 | Srol Kraham | Cam. | 0.53 | 84.5 | 327 | 438 | 65.5 | — | 884 | 77.8 | 467 | 853 | 116 | 138 | 61.9 | 5.2 | 1.7 | 1.5 | 0.32 |

Note:
$E_c$ : Young's modulus in compression parallel to grain.
$\sigma_p$ : Stress at proportional limit.
$\sigma_c$ : Maximum crushing strength in compression parallel to grain.
$E_t$ : Young's modulus in tension parallel to grain.
$\sigma_t$ : Tensile strength.
$E_b$ : Young's modulus in static bending.
$\sigma_b$ : Modulus of rupture in static bending.
$\tau_R$ : Shearing strength (Radial plane).
$\tau_T$ : End hardness.
$H_l$ : Shearing strength (Tangential plane).
$H_r$ : Side hardness (Tangential surface).
$H_t$ : Side hardness (Radial surface).
$a$ : Absorbed energy in impact bending.

under the two main classes, hardwood and softwood. As Kuruing has two origins, namely Kalimantan and Malaysia, two sets of data are tabulated separately.

Table 2 gives the common name of species, its origin, specific gravity, the results of compression parallel to grain, tension parallel to grain, static bending, shear parallel to grain, local bearing, hardness and impact bending.

The value of the specific gravity was based on the volume of the test specimen and its weight at the time of the test, i.e. air dry condition.

The specific gravity ranged from 0.36 of New Guinea Basswood to 1.18 of Rong Leang in hardwood. The close relationship observed between the specific gravity and mechanical properties was the same as shown in a previous report.[9] The linear regression analysis between the specific gravity and mechanical properties is presented in Table 3.

**Table 3. Results of linear regression analysis on tropical hardwood**

| Linear regression equation | ( r ) |
|---|---|
| $\sigma_c=-32.0+852$ Ru | (0.97) |
| $\sigma_t=223+1903$ Ru | (0.79) |
| $\sigma_b=-205+1870$ Ru | (0.96) |
| $E_b=5.92\times10^3+183\times10^3$ Ru | (0.93) |
| $H_l=-1.28+11.3$ Ru | (0.95) |
| $\tau_R=-24.8+215$ Ru | (0.94) |
| $\sigma_b=-126+9.08\times10^{-3}\ E_b$ | (0.93) |
| $\sigma_c=95.9+70.4\ H_l$ | (0.95) |

See footnote in Table 2.
r: correlation coefficient

Table 3 also includes the relationship between Young's modulus of elasticity and modulus of rupture and that between end hardness and compressive strength.

The relationship between specific gravity (Ru) and absorbed energy (a) was expressed as

$$a=1.38\ \mathrm{Ru}^{1.37} \qquad (r^2=0.78)$$

for tropical hardwood.

## 2) *Comparison of estimated modulus of rupture with results obtained*

According to the theory developed by Sawada,[11] the modulus of rupture will be estimated by following equation under the condition of rectangle beam with the ratio of beam depth to span less than 1/6.

$$\sigma_b=\frac{3r-1}{r+1}\sigma_c \qquad (1)$$

where $r=\sigma_t/\sigma_c$

The results obtained in this series of tests confirmed the theory as shown in Fig. 2. The mean value of the ratio of the observed modulus of rupture to the estimated one was 0.99 with the range from 0.76 of Amberoi to 1.30 of Calophyllum. In the case of Calophyllum, it should be pointed out that the tensile strength value was smaller than expected due to the cross grain, and Amberoi showed smaller modulus of rupture than expected. When the modulus of rupture and compressive strength of some specific species are known, tensile strength parallel to grain can be calculated using the equation (1) if needed.

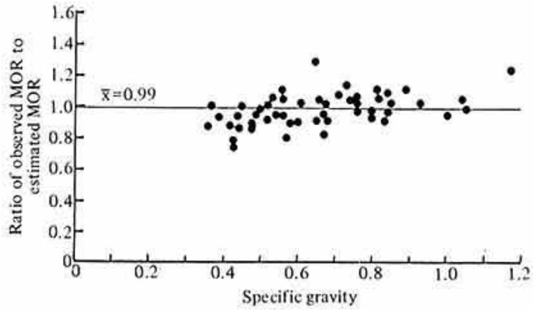


Fig. 2. Relationship between the ratio of observed MOR to estimated MOR and specific gravity

The ratios of $\sigma_b/\sigma_c$, and $\sigma_t/\sigma_c$ were 1.9 and 2.8, respectively, according to this series of tests with tropical hardwood.

## 3) *Comparisons of Young's moduli and strength properties among three mutually perpendicular axes*

In Table 4, the comparisons of Young's moduli and strength properties among three mutually perpendicular axes are shown.

The Young's moduli in compression and ten-

**Table 4. Comparisons of Young's moduli and strength properties among three mutually perpendicular axes**

| Species | Young's moduli in compression $E_c$ | | | Young's moduli in tension $E_t$ | | | Proportional limit in compression $\sigma_p$ | | | Tensile strength $\sigma_t$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hardwood** (broad-leaved) | L | R | T | L | R | T | L | R | T | L | R | T |
| 1. Campnosperma | 100 | 8.5 | 4.3 | 100 | 9.7 | 4.4 | 100 | 10.2 | 6.5 | 100 | 9.1 | 5.1 |
| 2. Spondias | 100 | 8.7 | 5.3 | 100 | 8.7 | 5.0 | 100 | 13.5 | 5.7 | 100 | 8.6 | 4.9 |
| 3. Alstonia | 100 | 8.0 | 2.7 | 100 | 8.4 | 2.3 | 100 | 9.2 | 3.0 | 100 | 11.0 | 3.9 |
| 4. Jelutong | 100 | 8.9 | 3.7 | 100 | 9.0 | 3.9 | 100 | 10.5 | 5.4 | 100 | 12.1 | 4.6 |
| 5. Canarium | 100 | 5.1 | 2.2 | 100 | 5.3 | 2.2 | 100 | 8.5 | 5.6 | 100 | 5.5 | 3.7 |
| 6. Terminalia | 100 | 9.8 | 5.8 | 100 | 10.1 | 4.8 | 100 | 9.1 | 6.5 | 100 | 9.3 | 6.8 |
| 7. Erima | 100 | 5.5 | — | 100 | 6.3 | — | 100 | 8.0 | — | 100 | 8.1 | — |
| 8. Phdiek | 100 | 9.1 | 5.6 | 100 | — | 4.6 | 100 | 8.7 | 5.6 | 100 | — | 4.2 |
| 9. Giam | 100 | 7.0 | 4.3 | 100 | 7.5 | 4.6 | 100 | 10.8 | 7.2 | 100 | 4.1 | 3.2 |
| 10. Apitong | 100 | 8.3 | 5.3 | 100 | 9.7 | 6.2 | 100 | 9.0 | 6.7 | 100 | 8.8 | 5.5 |
| 11. Chhoeuteal Sar | 100 | 9.3 | 4.8 | 100 | 10.9 | 5.0 | 100 | 9.5 | 5.8 | 100 | 9.5 | 5.5 |
| 12. Chhoeuteal Bangkuoi | 100 | 8.9 | 5.4 | 100 | 9.6 | 5.9 | 100 | 8.1 | 5.5 | 100 | 8.5 | 5.2 |
| 13. Keruing | 100 | 6.2 | 3.9 | 100 | 7.3 | 4.1 | 100 | 8.3 | 5.2 | 100 | 5.5 | 3.6 |
| 14. Keruing | 100 | 6.1 | 3.2 | — | — | — | 100 | 6.6 | 5.2 | — | — | — |
| 15. Kapur | 100 | 7.2 | 3.3 | 100 | 7.6 | 3.2 | 100 | 9.8 | 5.3 | 100 | 7.3 | 4.3 |
| 16. Koki Khsach | 100 | 10.6 | 5.3 | — | — | — | 100 | 17.9 | 9.2 | — | — | — |
| 17. Sengawan | 100 | 5.2 | 2.6 | 100 | 4.9 | 2.7 | 100 | 6.0 | 3.9 | 100 | 3.7 | 2.3 |
| 18. Red Lauan | 100 | 8.5 | 3.5 | 100 | 7.2 | 3.2 | 100 | 10.0 | 4.7 | 100 | 5.6 | 3.5 |
| 19. Red Meranti | 100 | 10.4 | 3.5 | 100 | 13.3 | 4.7 | 100 | 11.3 | 5.1 | 100 | 9.1 | 5.8 |
| 20. Light Red Meranti | 100 | 9.2 | 3.4 | 100 | 7.9 | 3.2 | 100 | 9.3 | 5.5 | 100 | 4.6 | 2.7 |
| 21. White Meranti | 100 | 6.0 | 2.9 | 100 | 7.1 | 3.1 | 100 | 10.1 | 5.8 | 100 | 6.3 | 3.5 |
| 22. Komnhan | 100 | 8.9 | 5.4 | 100 | — | 6.2 | 100 | 8.1 | 5.6 | 100 | — | 4.2 |
| 23. Yellow Meranti | 100 | 7.6 | 3.8 | 100 | 9.0 | 3.6 | 100 | 7.3 | 3.6 | 100 | 7.3 | 5.2 |
| 24. Bangkirai | 100 | 10.0 | 6.3 | — | — | — | 100 | 14.7 | 9.1 | — | — | — |
| 25. Balau | 100 | 10.9 | 6.5 | — | — | — | 100 | 14.1 | 8.8 | — | — | — |
| 26. Resak | 100 | — | 3.9 | — | — | — | 100 | — | 7.3 | — | — | — |
| 27. New Guinea Basswood | 100 | 6.1 | 4.5 | 100 | 7.0 | 4.1 | 100 | 10.9 | 6.0 | 100 | 6.0 | 3.8 |
| 28. Borneo Oak | 100 | 7.2 | 4.7 | 100 | — | 5.9 | 100 | 8.3 | 7.0 | 100 | — | 3.4 |
| 29. Malas | 100 | 11.6 | 6.2 | 100 | 12.5 | 5.3 | 100 | 13.1 | 5.3 | 100 | 8.2 | 4.6 |
| 30. Ramin | 100 | 8.8 | 3.9 | 100 | 8.7 | 4.0 | 100 | 11.9 | 6.3 | 100 | 6.5 | 3.3 |
| 31. Calophyllum | — | — | — | 100 | 10.1 | 6.0 | — | — | — | 100 | 13.3 | 8.0 |
| 32. Geronggang | 100 | 7.3 | 3.6 | 100 | 7.0 | 3.5 | 100 | 12.8 | 6.0 | 100 | 7.0 | 3.8 |
| 33. Ulin | — | — | — | — | — | — | — | — | — | — | — | — |
| 34. Litsea | 100 | 9.2 | 3.6 | 100 | 10.2 | 3.5 | 100 | 10.9 | 4.7 | 100 | 6.4 | 3.6 |
| 35. Intsia | 100 | 9.5 | 7.7 | 100 | 8.8 | 6.1 | 100 | 14.1 | 11.4 | 100 | 7.3 | 4.6 |
| 36. Menggeris | 100 | 8.2 | 5.7 | 100 | 6.4 | 4.7 | 100 | 11.3 | 8.7 | 100 | 8.6 | 5.5 |
| 37. Ro Yong | 100 | 9.7 | 4.6 | 100 | 11.8 | 6.1 | 100 | 13.3 | 8.4 | 100 | 10.3 | 5.5 |
| 38. Sepetir Paya | 100 | 7.1 | — | 100 | 7.5 | — | 100 | 14.3 | — | 100 | 6.9 | — |
| 39. Champaca | 100 | 9.6 | 5.6 | 100 | 6.6 | 5.6 | 100 | 11.8 | 8.6 | 100 | 8.7 | 5.6 |
| 40. Jong Kong | 100 | 8.0 | 2.5 | 100 | 8.4 | 2.4 | 100 | 11.2 | 4.9 | 100 | 6.8 | 3.2 |
| 41. Keledang | 100 | 7.7 | 3.3 | 100 | 7.1 | 3.8 | 100 | 8.4 | 5.0 | 100 | 5.4 | 2.9 |
| 42. Kamerere | 100 | 7.3 | 3.5 | 100 | 9.5 | 4.0 | 100 | 7.2 | 3.1 | 100 | 6.3 | 4.1 |
| 43. Kelat | 100 | 8.2 | 4.6 | — | — | — | 100 | 7.5 | 4.8 | — | — | — |
| 44. Rong Leang | 100 | 11.4 | — | — | — | — | 100 | 18.0 | — | — | — | — |
| 45. Labula | 100 | 9.5 | 4.3 | 100 | 12.2 | 5.4 | 100 | 10.3 | 5.7 | 100 | 11.2 | 5.2 |
| 46. Taun | 100 | 6.0 | 4.5 | 100 | 6.2 | 4.3 | 100 | 8.3 | 4.7 | 100 | 5.2 | 4.2 |
| 47. Nato | 100 | 9.2 | 4.7 | 100 | — | 4.7 | 100 | 10.0 | 5.5 | 100 | — | 4.5 |
| 48. Planchonella | 100 | 6.9 | 3.4 | 100 | 5.5 | 3.5 | 100 | 10.8 | 5.4 | 100 | 5.8 | 3.7 |
| 49. White Siris | 100 | 5.6 | 2.9 | 100 | 6.5 | 3.0 | 100 | 11.0 | 4.3 | 100 | 6.1 | 3.3 |
| 50. Amberoi | 100 | 5.3 | — | 100 | 5.8 | — | 100 | 9.7 | — | 100 | 4.5 | — |
| 51. Teraling | 100 | 10.5 | 4.7 | 100 | 7.9 | 4.4 | 100 | 9.9 | 9.1 | 100 | 6.3 | 4.5 |
| 52. Karas | 100 | — | 2.3 | 100 | — | 3.0 | 100 | — | 3.7 | 100 | — | 3.7 |
| 53. Celtis | 100 | 6.4 | 4.7 | 100 | 8.0 | 3.7 | 100 | 13.1 | 5.8 | 100 | 8.8 | 5.5 |
| 54. Gmelina | 100 | 7.0 | 4.9 | 100 | 6.5 | 4.5 | 100 | 8.2 | 5.0 | 100 | 5.5 | 5.1 |
| 55. Teak | 100 | 17.1 | 12.5 | 100 | 15.6 | 11.0 | 100 | 23.6 | 18.2 | 100 | 14.3 | 8.4 |
| Hardwood all over mean | **100** | **8.3** | **4.5** | **100** | **8.5** | **4.4** | **100** | **10.8** | **6.2** | **100** | **7.6** | **4.5** |
| **Soft wood** (conifer) | | | | | | | | | | | | |
| 56. Agathis | 100 | 5.6 | 2.9 | 100 | 6.7 | 2.6 | 100 | 6.5 | 2.7 | 100 | 4.9 | 2.2 |
| 57. Srol Kraham | 100 | 14.1 | 6.5 | 100 | 15.1 | 7.1 | 100 | 15.5 | 6.6 | 100 | 9.1 | 6.0 |

Table 5. Some mechanical properties of *A. mangium*

| | A<br>Pith excluded | B<br>Pith included | Ratio<br>B/A |
|---|---|---|---|
| Number of static bending specimen | 67 | 6 | |
| Speciffic gravity at test | 0.365-0.481-0.560 | 0.267-0.309-0.365 | 0.64 |
| Modulus of rupture (kg/cm²) | 443-756-1021 | 196-350-486 | 0.46 |
| Stress at proportional limit (kg/cm²) | 308-448-571 | 120-204-272 | 0.46 |
| Young's modulus in static bending (10³kg/cm²) | 82.2-103-121 | 43.1-52.5-71.9 | 0.51 |
| Number of compression specimen | 73 | 7 | |
| Maximum crushing strength (kg/cm²) | 328-427-533 | 192-214-259 | 0.50 |
| Stress at proportinal limit (kg/cm²) | 222-283-414 | 112-128-159 | 0.45 |
| Young's modulus in compression (10³kg/cm²) | 69.1-104-159 | 33.4-41.9-49.4 | 0.40 |
| Number of shear specimen | 73 | 12 | |
| Shearing strength (radial plane) (kg/cm²) | 62.3-90.1-130 | 33.8-48.1-73.6 | 0.53 |
| Number of impact bending specimen | 67 | 3 | |
| Specific gravity at test | 0.362-0.477-0.587 | 0.250-0.301-0.355 | 0.63 |
| Absorbed energy in impact bending (kg·m/cm²) | 0.155-0.482-0.914 | 0.062-0.112-0.156 | 0.23 |

sion were compared among three mutually perpendicular axes. In the compression perpendicular to grain test, as it was impossible to get the maximum strength, stress values at proportional limit were compared. But in tension test, tensile strength among three mutually perpendicular axes were compared.

The figures are expressed in terms of percentage, by taking the values at longitudinal direction as 100%. It can be said that Canarium, Sengawan, Alstonia, Jong Kong and Agathis showed strong anisotropy and that Teak and Intsia showed weak anisotropy for Young's moduli in compression and tension.

For the stress at proportional limit in compression, Alstonia, Sengawan and Agathis were regarded as a strong anisotropy group, while Teak, Intsia and Balau were regarded as a weak anisotropy group.

Sengawan and Agathis showed remarkable anisotropy in tensile strength, whereas Teak, Calophyllum and Terminalia showed lesser anisotropy.

Average values of all hardwoods tested are also shown in Table 4. In the case of Young's moduli, the ratio of 100 : 8.5 : 4.5 was concluded for L : R : T. Tensile strength ratio for three axes was regarded as 100 : 7.6 : 4.5.

## Some mechanical properties of *Acacia mangium*

Some mechanical properties of *Acacia mangium* in small clear specimen are presented. The materials were obtained from Sabah, Malaysia. The logs were straight, five meter long and their butt end diameter ranged from 10.5 cm to 20.0 cm. All logs were said three years old.

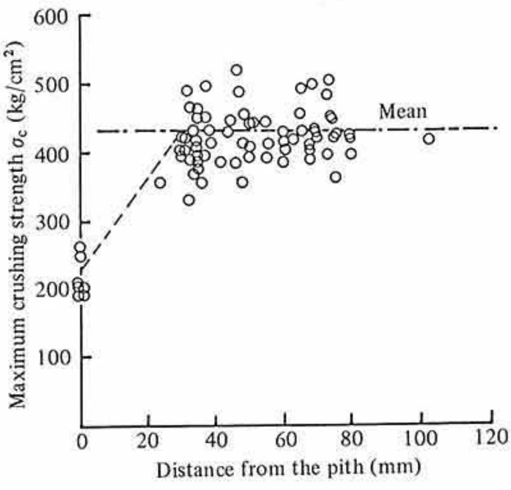


Fig. 3. Relationship between maximum crushing strength and distance from the pith

The test method and the size of specimen were the same as described above. The moisture content at the test was 13.5%.

Test results are tabulated in Table 5. An example of the relationship between mechanical properties and distance from the pith is shown in Fig. 3. In this limited range of the test, it was shown that the mechanical properties of the wood within 2 cm of distance from the pith were nearly half those of the remaining outward portion. This point should be taken into consideration in deciding the cutting pattern of logs and the use of lumbers as a structural member.

## References


1) Hatayama, Y.: Mechanical properties of ten species from Kalimantan and New Guinea, *Bull. Govern. For. Exp. Sta.*, **262**, 82–90 (1974) [In Japanese].
2) Kondo, K. & Yamai, R.: Mechanical properties of a few red meranti woods grown in Sarawak, *Bull. Govern. For. Exp. Sta.*, **191**, 127–133 (1966) [In Japanese with English summary].
3) Kondo, K. & Yamai, R.: Mechanical properties of kapur woods grown in North Borneo, *Bull. Govern. For. Exp. Sta.*, **197**, 74–88 (1967) [In Japanese with English summary].
4) Kondo, K. & Yamai, R.: Mechanical properties of apitong woods grown in the Philippines, *Bull. Govern. For. Exp. Sta.*, **208**, 116–131 (1968) [In Japanese with English summary].
5) Kondo, K. & Yamai, R.: Mechanical properties of thirteen species of Kalimantan woods, *Bull. Govern. For. Exp. Sta.*, 218, 144–175 (1968) [In Japanese with English summary].
6) Nakai, T. & Yamai, R.: Mechanical properties of seven species from New Guinea and Solomon Islands, *Bull. Govern. For Exp. Sta.*, 244, 129–136 (1972) [In Japanese].
7) Nakai, T. & Yamai, R.: Mechanical properties of eight species from Sarawak and New Guinea, *Bull. Govern. For Exp. Sta.*, 254, 78–87 (1973) [In Japanese with English summary].
8) Nakai, T. & Hatayama, Y.: Mechanical properties of nine species from New Guinea and other areas, *Bull. Govern. For Exp. Sta.*, **269**, 23–30 (1974) [In Japanese with English summary].
9) Nakai, T. & Yamai, R.: Properties of the important Japanese woods. The mechanical properties of 35 important Japanese woods, *Bull. Forestry and Forest Products Res. Inst.*, **319**, 13–46 (1982) [In Japanese with English summary].
10) Nakai, T.: Some Mechanical properties of the three year old *Acacia mangium* planted in Sabah, Proceedings of Wood Engineering Group Meeting, IUFRO, Madison (1983).
11) Sawada, M.: Studies on the mechanics of wood beams I. Strength and its affecting factor of wood beams of rectangular cross section, *Bull. Govern. For Exp. Sta.*, **71**, 39–79 (1954) [In Japanese with English summary].
12) Yamai, R. & Kondo, K.: Mechanical properties of Cambodian woods, *Bull. Govern. For. Exp. Sta.*, **194**, 7–39 (1966) [In Japanese with English summary].
13) Yamai, R. & Kondo, K.: Mechanical properties of kuruing woods grown in Kalimantan. *Bull. Govern. For. Exp. Sta.*, **206**, 30–41 (1967) [In Japanese with English summary].
14) Yamai, R. & Kondo, K.: Mechanical properties of bangkirai and white meranti woods grown in Kalimantan, *Bull. Govern. For. Exp. Sta.*, 218, 45–58 (1968) [In Japanese with English summary].
15) Yamai, R. & Kondo, K.: Mechanical properties of kuruing woods grown in Malaya, *Bull. Govern. For. Exp. Sta.*, 221, 90–108 (1969) [In Japanese with English summary].
16) Yamai, R. & Kondo, K.: Mechanical properties of red lauan wood from the Philippines, *Bull. Govern. For. Exp. Sta.*, **234**, 42–66 (1971) [In Japanese with English summary].


(Received for publication, April 25, 1984)