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Characterization of major, unused, and unvalued Indonesian wood species I. Dependencies of mechanical properties in transverse direction on the changes of moisture content and/or temperature

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Abstract Mechanical property changes due to the moisture content (MC) and/or temperature changes were examined for 15 Indonesian wood species. A static bending test was carried out at 20°C, 65% relative humidity (air-dry), and water-saturated at 20°C (wet-20) and 80°C (wet-80). For individual test conditions, modulus of elasticity (MOE) and modulus of rupture (MOR) increased linearly with specific gravity regardless of wood species; however, maximum deflection did not correlate with specific gravity for any MC or temperature conditions. The relative values of MOE and MOR measured in wet-20 to air-dry conditions were variously affected from slightly to strongly depending on the wood species. However, the relative values always decreased markedly when saturated in water at 80°C, regardless of wood species. The relative MOE, MOR, and maximum deflection values due to the change in MC or MC and temperature combined were independent of specific gravity but may be dependent on wood type: softwood or hardwood.

Key words Indonesian wood species · Static bending test · Modulus of elasticity · Modulus of rupture

Introduction

In the drying and manufacturing of wood and wood-based materials, variation of mechanical properties accompanying the changes of moisture content (MC) and temperature is extremely important in relation to the quality and yield of the products. However, little information on mechanical properties has been obtained for not only major tropical wood species but also for abundant lesser-used and fast-growing tropical wood species. When intending to use such tropical woods in Japan as well as in tropical countries, it may be essential to clarify the dependency of mechanical properties in the transverse direction on MC and temperature.

The ultimate objectives of this study are to determine optimum and novel uses for major wood species and to develop effective guidelines for use of lesser-valued wood species. As part of the overall goals, this present study aimed to evaluate and characterize the mechanical properties of 15 Indonesian wood species against MC and temperature changes. Furthermore, data on the conventional use of such wood is being collected. Through a comparative study, we will be able to find effective and high-performance uses for tropical wood resources.

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Experimental

Materials

Fifteen Indonesian wood species [14 hardwoods and 1 softwood (agathis)], were investigated. Their air-dry densities are shown in Table 1. The densities ranged from 0.27 for randu alas to 0.81 for lamtoro.

The size of each test specimen was 10 (T) × 110 (R) × 4 mm (L). Fifteen specimens, consecutive in the longitudinal direction, were cut from a block of each wood species. In order to free the internal stress, all specimens were immersed in water under reduced pressure, kept at 80°C for 3 h, and then conditioned.

Methods

Specimens equilibrated at 20°C, 65% relative humidity (RH) (air-dry), saturated in water at 20°C (wet-20), and saturated in water at 80°C (wet-80) were subjected to a static bending test. To achieve water saturation, the specimens were kept under water for more than 1 week after aspiration.

Table 1. The 15 Indonesian wood species tested[1–3]

No.	Local name	Specific gravity in air-dry condition	Botanical name
1	Agathis	0.53	*Agathis damara* (Lambert) Rich
2	Acacia	0.52	*Acacia mangium* Willd
3	Albizia	0.31	*Paraserianthes falcataria* (L.) Nielson
4	Angsana	0.45	*Pterocarpus indicus* Jacq.
5	Bacang	0.58	*Mangifera foetida* Lour
6	Durian	0.45	*Durio zibethinus* Murray
7	Karet	0.71	*Hevea brasiliensis* (Willd.ex.A.L.Juss) Muell. Arg
8	Kecapi	0.48	*Sandoricum koetiape* (Burm.f.) Merr
9	Lamtoro	0.81	*Leucaena glauca* (Willd) Benth
10	Mahoni	0.65	*Swietenia mahaghony* (L) Jacq
11	Manii	0.50	*Maesopsis eminii* Engl.
12	Mindi	0.46	*Melia azedarach* (L)
13	Nangka	0.64	*Arthocarpus heterophyalla* Lamk
14	Puspa	0.70	*Schima wallichii* (DC) Korth
15	Randu alas	0.27	*Bombax ceiba.* L

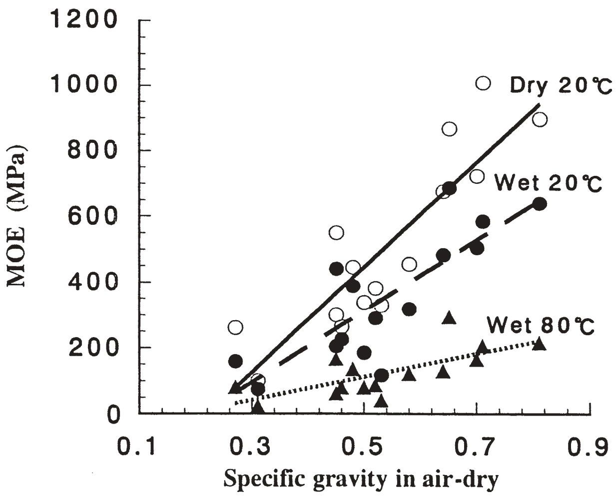

Fig. 1. Relationship between modulus of elasticity (*MOE*) and specific gravity in air-dry conditions

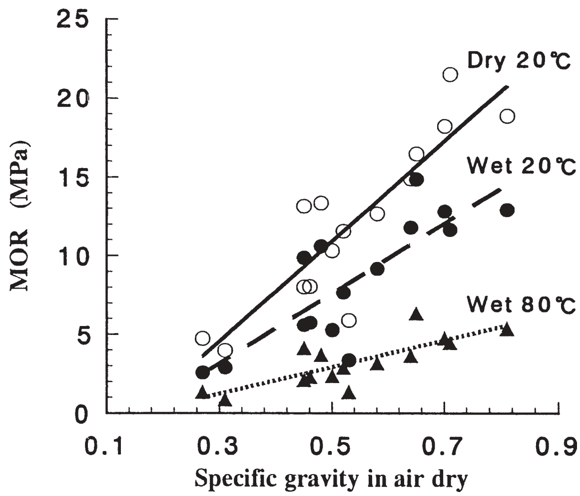

Fig. 2. Relationship between modulus of rupture (*MOR*) and specific gravity in air-dry conditions

The test was conducted at 20°C and 65% RH using a conventional testing instrument with a constant cross-head speed (5mm/min), with loading at the center, while being supported at two points 80mm apart. In the water-saturated state, the load was applied to the specimen standing in a water bath controlled at 20°C or 80°C. Specimens consecutively cut from a longitudinal block were assigned to the three conditions, and tests were replicated 4 times for each test condition.

Results and discussion

In Figs. 1, 2, and 3, modulus of elasticity (MOE), modulus of rupture (MOR), and maximum deflection were plotted against specific gravity in air-dry specimens, respectively. The MOE and MOR increased linearly with specific gravity, regardless of wood species. The slopes of the regression lines for MOE were 1.57, 1.02, and 0.33GPa for air-dry, wet-20, and wet-80, whereas those of MOR were 31.3, 21.1, and 8.4MPa, respectively. The wet-20/air-dry ratios for the slopes in regression lines were 0.65 and 0.67, while wet-80/air-dry ratios were 0.21 and 0.27 for MOE and MOR, respectively. For Japanese wood species, Iida[4] has reported that the wet-20/air-dry ratios for MOE and MOR were 0.52 and 0.62, and wet-80/air-dry ratios were 0.18 and 0.29, respectively. The influences of MC change on MOE and MOR were somewhat smaller for the 15 Indonesian wood species than for the Japanese wood species. On the other hand, the influences of combined MC and temperature changes to MOE and MOR did not differ between Indonesian and Japanese wood species.

Maximum deflection values did not show a definite correlation with specific gravity in any testing condition (Fig. 3). This was probably due to the different response of each wood species to the MC and temperature changes.

Figures 4, 5, and 6 show the relative values of MOE, MOR, and maximum deflection, respectively, for wet-20 and wet-80 to those in air-dry. Relative MOE significantly decreased with increases of MC or MC and temperature. The values of relative MOE in wet-20 were classified into the slightly affected group (more than around 0.7) for kecapi, mindi, angsana, mahoni, acacia, albizia, nangka,

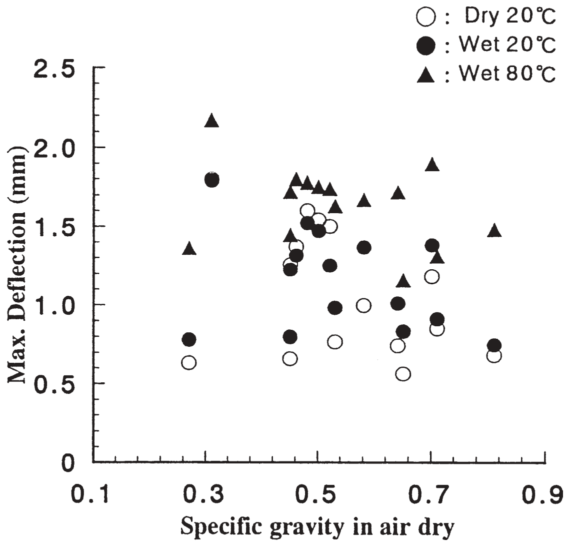

Fig. 3. Relationship between maximum deflection and specific gravity in air-dry conditions

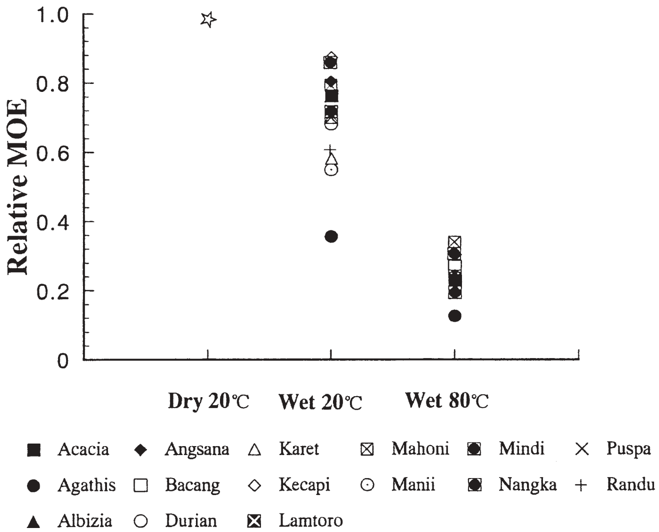

Fig. 4. Decrease of MOE due to moisture content (MOE in wet 20°C/MOE in dry 20°C) and both moisture content and temperature change (MOE in wet 80°C/MOE in dry 20°C)

lamtoro, puspa, bacang, and durian, and moderately affected group (around 0.6) for randu, karet, and manii. The MOE was affected still more by increases of both MC and temperature, and the wet-80/air-dry ratios of MOE decreased to less than 0.4.

Agathis was markedly affected by increased MC as well as MC and temperature: the relative MOE decreased to 0.35 in wet-20, and 0.12 in wet-80. The decrease of relative MOE due to increase of MC or MC and temperature was independent of specific gravity. For example, the relative MOE of acacia, whose specific gravity is the same as agathis, decreased only 0.76 in wet-20, and 0.23 in wet-80. Agathis, which was the only softwood tested in this experiment, may have a lower softening temperature than the common hardwoods.

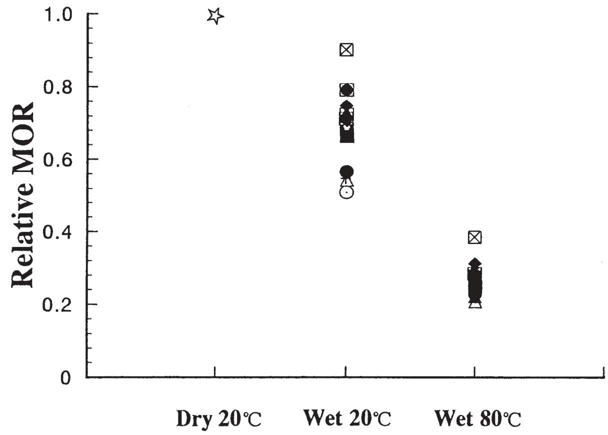

Fig. 5. Decrease of MOR due to moisture content (MOR in wet 20°C/MOR in dry 20°C) and both moisture content and temperature change (MOR in wet 80°C/MOR in dry 20°C)

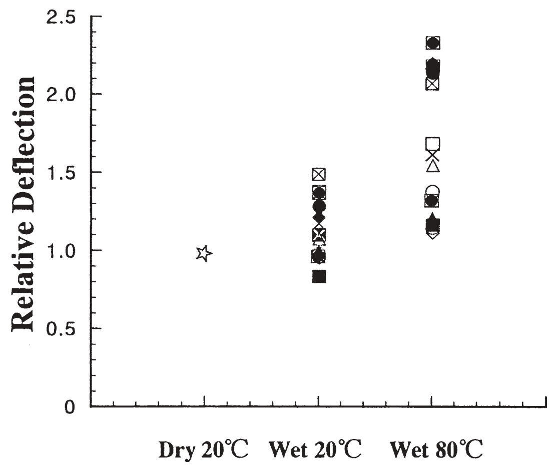

Fig. 6. Increasing of maximum deflection due to moisture content (deflection in wet 20°C/deflection in air dry 20°C) and both moisture content and temperature change (deflection in wet 80°C/deflection in air dry 20°C)

Concerning the relative MOR, we recognized that mahoni is most stable against the increase of MC and temperature combined as well as MC alone: the relative MOR decreased to only 0.9 in wet-20 and 0.4 in wet-80. The relative MOR in wet-20 can also be classified into moderately affected species (0.8–0.65) kecapi, mindi, angsana, acacia, albizia, nangka, lamtoro, puspa, bacang, and durian, and markedly affected species (0.6–0.5) agathis, randu, karet, and manii. The relative MOR for most wood species decreased to 0.2–0.3 in wet-80.

Figure 6 shows that the relative values of maximum deflection in wet-20 increased up to 1.5 times for most species. Meanwhile, maximum deflections of albizia, durian, mindi, manii, and kecapi were unchanged, and that of acacia was rather smaller than that in air-dry.

The relative value of maximum deflection significantly increased in wet-80. The values could be classified into largely affected species (increased more than 2 times) nangka, angsana, randu, agathis, and mahoni; moderately affected species (more than 1.5 times) bacang, puspa, and

Table 2. Classification of the species based on relative MOE, MOR, or maximum deflection affected by increase of moisture content (wet 20°C) and both moisture content and temperature (wet 80°C)

Wet at 20°C		Wet at 80°C	
MOE			
Weakly decreased (>0.7)	Kecapi, mindi, angsana, mahoni, acacia, albizia, nangka, lamtoro, puspa, bacang, durian	Moderately decreased (0.4–0.12)	Kecapi, mindi, angsana, mahoni, acacia, albizia, nangka, lamtoro, puspa, bacang, durian, randu, karet, manii
Moderately decreased (~0.6)	Randu, karet, manii	Markedly decreased (<0.12)	Agathis
Markedly decreased (<0.4)	Agathis		
MOR			
Slightly decreased (0.9)	Mahoni	Moderately decreased (0.4)	Mahoni
Moderately decreased (0.80–0.65)	Kecapi, mindi, angsana, acacia, albizia, nangka, lamtoro, puspa, bacang, durian	Markedly decreased (0.3–0.2)	Agathis, kecapi, mindi, angsana, acacia, albizia, nangka, lamtoro, puspa, bacang, durian, randu, karet, manii
Markedly decreased (0.6–0.5)	Agathis, randu, karet, manii		
Maximum deflection			
Hardly increased (~1)	Acacia	Slightly increased (<1.5)	Acacia, kecapi, mindi, albizia, durian, manii
Moderately increased (<1.2)	Kecapi, mindi, albizia, durian, manii		
Markedly increased (>1.2)	Agathis, angsana, mahoni, nangka, lamtoro, puspa, bacang, randu, karet	Moderately increased (~1.5)	Puspa, bacang, karet
		Markedly increased (>2)	Agathis, angsana, nangka, randu, mahoni

Values in parentheses are the MOE, MOR, and maximum deflection relative to values for air-dry conditions at 20°C

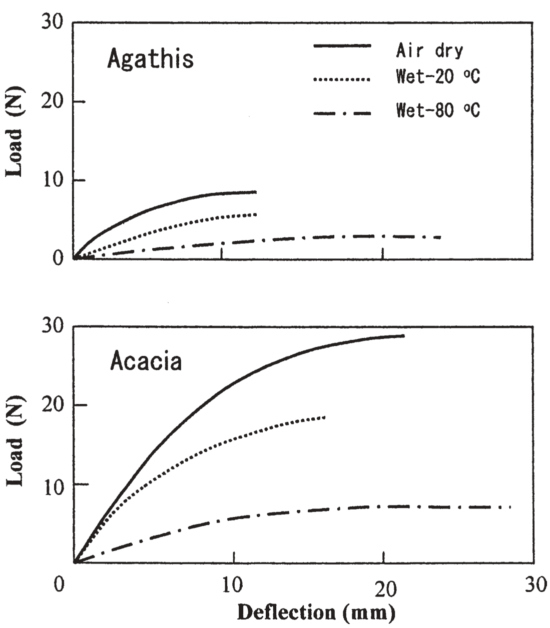

Fig. 7. Load-deflection curves for agathis and acacia

karet; and hardly affected species (less than 1.5 times) durian, mindi, albizia, acacia, manii, and kecapi.

The changes of maximum load due to the changes in MC and MC plus temperature were also independent of specific gravity. Figure 7 shows load-deflection curves for agathis and acacia, whose specific gravities were at the same level. We found that agathis was more seriously affected by the change of MC or MC and temperature combined than acacia.

In Table 2, the responses against the changes in MC and MC and temperature are comprehensively summarized. Iida[4] determined the elastic and strength properties for 24 Japanese wood species by a static bending test in a radial direction perpendicular to the grain in air-dried conditions at 20°C and water-saturated states at 20°C and 100°C. He found a difference between the mean ratios of MOE, MOR, and maximum deflection of softwoods and those of hardwoods, when MC and temperature were increased. He concluded that the hygro-thermal properties of lignin significantly affect the changes of elastic and strength properties of wood that occur due to hygro-thermal effects.

In this experiment, the mechanical properties of agathis, a softwood, were most markedly affected by change of MC or MC and temperature combined. Nevertheless, there were some Indonesian hardwoods whose MOR was also easily affected by change of MC, e.g., randu, karet, and manii, and MOR values of almost all species were extremely affected by increases of both MC and temperature.

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