東南アジア研究 10巻4号 1973年3月

Decay Resistance of Sixty-Five Southeast Asian Timber Specimens in Accelerated Laboratory Tests

by

Munezoh TAKAHASHI* and Tsuneo KISHIMA*

Abstract

Decay resistance of sixty-five specimens of Southeast Asian timbers, which covered 23 families, including 37 genera, was tested in laboratory sand block tests against a soft rot fungus, *Chaetomium globosum* Kunze, and a white rot fungus, *Coriolus versicolor* Quél. It was shown that there was a tendency, especially in the case of *Co. versicolor*, for dense and/or extractive-rich species to be more resistant to decay, and that the greater part of extractive-rich species became more susceptible to decay after treatment with hot methanol. *Ochanostachys amentacea, Scorodocarpus borneensis, Eusideroxylon zwageri, Cantleya corniculata, Shorea exelliptica, Shorea hypoleuca* and *Shorea laevis* retained high resistance even after the treatment. In addition, different reactions to methanol extractives between the two test fungi were observed in several species.

Introduction

Utilization of timbers has been increasing enormously year after year in our country. The production of native timbers, however, is unable to supply the demand, hence annual increases in the import of foreign timbers are regarded as a matter of course.

Southeast Asian timbers, so called "Nanyo-zai" have always occupied the greater part of imported timbers, but the sources of timber are obviously changing according to the current of the times. In the past two decades, Philippine timbers occupied 90% of imported timbers and almost all of them were named "Lauan". Recently, however, imported timbers from other regions—Sabah, Sarawak, Kalimantan, Sumatra, Cambodia, Malaya, Thailand, New Guinea, etc.—have increased gradually, and Philippine timbers have decreased to 60% of imported timbers (Sudo, 1970). Following such a transition, an increase in species and a diversity in the quality of imported timbers have become prominent.

* 高橋旨象・貴島恒夫, Wood Research Institute, Kyoto University, Japan.

In the present utilization of Southeast Asian timbers, practical experience tends to be ahead of any systematic study on wood quality, and as a result troubles often occur in practical use. Such troubles are generally attributed to an insufficient knowledge of the names of timber species distributed in tropical zones and to the lack of information on the quality of each species (Kishima, 1968). Of course to solve this problem, it is essential to carry out a systematic investigation and survey, but these works are now only beginning in our country.

In studying wood quality, several properties—biological, physical, chemical, mechanical and technological—should be investigated. The natural durability of wood, including decay resistance, is associated with these several properties and it is an important factor in considering the suitable use of wood.

In the decay of wood by fungi, three major types of decay, namely brown rot, white rot and soft rot, heve been established. An apparent host-wood preference has been found to exist for many of the wood decaying fungi (Côté, 1968). White rot fungi are associated most frequently with the decay of hardwoods and brown rot fungi with the decay of softwoods, although there seems to be no complete specificity involved. In the decay by soft rot fungi, preference to hardwoods is strong.

It is well known that softwoods contain more lignin and less hemicellulose than hardwoods and that there are characteristic differences in the nature of these components. In relation to hemicellulose, hardwoods and softwoods are characterized by a high content of xylans and mannans, respectively. The chemical composition of tropical softwoods is similar to temperate softwoods, whereas tropical hardwoods contain more extractives and ashes, and less hemicellulose, especially xylans, than temperate hardwoods (Migita, 1968).

Different susceptibility to soft rot fungi in softwoods and hardwoods is usually attributed to the higher degree of lignification and the higher density of the cell walls in softwoods (Bailey, Liese and Rösch, 1968), or to the higher content of xylans in hardwoods (Savory and Pinion, 1958). Furthermore, the lower mannanase activity compared to the xylanase activity in culture filtrates from a soft rot fungus has been reported (Keilich, Bailey and Liese, 1970). Consequently, it would be rather interesting to clarify the susceptibility of tropical hardwoods to soft rot fungi, but relatively little is known about that.

The authors obtained many specimens of tropical timbers through the kindness of the Indonesia, Malaysia and Singapore governments while visiting these countries in order to survey the biological deterioration and durability of Southeast Asian timbers in 1971 (Kishima, Hayashi and Takahashi, 1971).

In the present investigation, the comparative decay resistance of 65 specimens of Southeast Asian timbers, which covered 23 families, including 37 genera, was estimated with reference to specific gravity and heartwood extractives.

Materials and Methods

Timber species and preparation of test blocks

The timber species used in the experiment are listed in Table 1. Excepting No. 1 (*Agathis alba*), all species are classified as hardwoods. Most of them are important species in the countries they grow in. The durability of many species has been roughly established and used as a guide for tropical regions, although such reputed durability is not always directly applicable in the temperate regions of our country.

Many reports have found that decay resistance in heartwood increases with increasing distance from the pith (e. g. Findlay, 1956 ; Rudman, 1964; Scheffer and Duncan, 1947). The outermost heartwood therefore tends to represent the maximum value of durability, whereas the innermost heartwood, close to the pith, signifies the minimum value. The rest of the heartwood which is most likely to be used commercially represents moderate or intermediate durability. Consequently, in order to represent the species adequately, with its tendency to show radial variation in durability, the test blocks should be made as long as possible in the radial direction (Da Costa and Osborne, 1967). In the present investigation, however, timbers with whole portions of heartwood were not obtainable, hence the samplings were made only from the portions regarded as commercially useful.

Considering the surface action of soft rot fungi to wood block, the size of test blocks was decided at 2.0 (tangential) × 2.0 (radial) × 0.5 (longitudinal) (cm).

Test fungi

Chaetomium globosum Kunze (Strain No. 8059), a soft rot fungus, and *Coriolus versicolor* Quél. (No. 1030), a white rot fungus, were selected for their preference to hardwoods. A brown rot fungus, *Tyromyces palustris* Murr. (No. 0507) was also added to the test fungi.

Measurement of specific gravity and extraction with hot methanol

It is frequently pointed out that dense wood species are more resistant to decay and that the durability of a specific heartwood is due to toxic materials in the wood. However, little experimental evidence in relation to density has been published and data on toxic extractives have been restricted to comparatively narrow ranges in botanical taxonomy. Antifungal action of extractives is not only due to the inhibiting action of the enzyme secreted by fungi but also to the protective action of the susceptible components such as cellulose and hemicellulose in woody cell walls. (Kayama, 1968). The amount of extractives is therefore also an important factor as is the nature of extractives for the durability of wood.

By definition, extractives are those substances which are removed from wood by extraction with neutral solvents. Although no single sequence of extractions is equally applicable to all woods owing to the variable composition of the extractives, methanol is preferentially used as the first solvent for successive extractions.

In order to clarify the effect of the removal of extractives on decay resistance, one half of the test blocks were extracted with hot methanol for 8 hours and exposed to test fungi. The content of methanol soluble extractives was calculated by reweighing the extracted test block.

Specific gravity was determined on an oven dry basis according to Japanese Industrial Standard Z 2102.

Decay tests

The decay tests were carried out by the sand block method. Cylindrical glass bottles (9 cm in diameter and 16 cm in height), containing 350 g of quartz sand (20 to 40 mesh) and 120 ml of nutrient solution, were screwed tight with metal caps. The bottles were autoclaved and inoculated with the test fungi which were allowed to cover the surface of the medium before the test blocks were inserted.

The composition of the nutrient solutions was as follows;

for the decay test using *Ch. globosum*

NH_4NO_3 3.0 g, KH_2PO_4 2.5 g, K_2HPO_4 2.0 g, $MgSO_4 \cdot 7H_2O$ 2.0 g, glucose 20.0 g and distilled water 1000 ml.

for the decay test using *Co. versicolor* and *T. palustris*

KH_2PO_4 3.0 g, $MgSO_4 \cdot 7H_2O$ 2.0 g, peptone 5.0 g, malt extract 10.0 g, glucose 25.0 g and distilled water 1000 ml.

The weighed test blocks were sterilized by fumigation with propylene oxide, and three blocks were placed in each bottle. Test blocks for the decay test using *Ch. globosum* were soaked in sterilized distilled water after the fumigation, since soft rot fungi have a preference for wet conditions. The temperature was maintained at 28 ± 2°C during a 56-day incubation period (determined by preliminary tests with beech wood as a non-durable species).

The decayed blocks, cleaned of mycelium, were dried to constant weight in a preconditioned room and oven. The percentage weight loss, calculated from initial and final weights, was used as a measure of the amount of decay.

Total number of test blocks was;

65 wood specimens
× 2 treatments (non-extracted and extracted)
130
× 3 test fungi
390
× 6 blocks of each specimen into two bottles
2340 blocks

Table 1 Timber species used in the experiment

No.	Family	Botanical Name	Vernacular Name*	Source**
1	Araucariaceae	*Agathis alba*	Damar minyak, Sanum, Tsanum (Mly), Damar putih, Tjana(In), Tolong(Br), Bindang(Swk), Kauri (NG).	Sin
2	Fagaceae	*Castanopsis argentea*	Saninten, Belangan saninten(In).	In
3	〃	*Querqus* sp.	Pasang(In).	In
4	〃	*Querqus* sp.		Sab
5	Olacaceae	*Ochanostachys amentacea*	Petaling(In, Mly, Br), Petikal (Swk, Br), Tanggal(Sab), Amin, Lembasung, Pilung, Satan bagiuk, Tilokot, Tumbung asu(In).	In
6	〃	*Scorodocarpus borneensis*	Kulim(Mly, In), Ungsumah(Swk), Bawan, Kasino, Madudu, Sinduk (In), Bawang hutan(Swk, Mly, Sab, Br), Bawing hutan(Br).	In
7	Lauraceae	*Eusideroxylon zwageri*	Belian(In, Sab, Swk), Uling, Ulin, Oelin, Onglen, Bulian, Bandjudjang, Talihan, Tihin, Tabulin(In), Tambulian(Ph).	Sab
8	〃	*Eusideroxylon zwageri*	*Ibid.*	In
9	Hamamelidaceae	*Altingia excelsa*	Rasamala(In), Jutili(Ind).	In
10	Rosaceae	*Parinari oblongifolium*	Merbatu(In), Ampili, Karup daun pandjang, Katutukan, Ubah ubah lebar daun(In), Membatu, Mentelor, Kemalau (Sab).	Sab
11	Leguminosae	*Dalbergia latifolia*	Sono keling, Angsana keling, Java palissandre(In), Rosewood(Ind, Bma), East Indian rosewood(Ind), Bombay blackwood, Blackwood (Bma).	In
12	〃	*Intsia* sp.	Merbau(In, Mly, Sab), Kwila(NG), Lum–pho, Lumpaw, Makamong (Th).	In
13	〃	*Koompassia malaccensis*	Kempas(In, Mly, Swk), Empas (Sab), Impas(Sab,In), Pah, Mengeris, Upil(In).	Sin
14	〃	*Samanea saman*	Trembesi(In), Rain tree, Acacia, Monkey pod.	In

15	Burseraceae	*Canarium* sp.		Sab
16	〃	*Santiria laevigata*	Kedondong(Mly, Br, Sab), Kerantai lichin(Mly), Lalan, Longori, Peongga, Tapi tapi, Merambang(In).	Sab
17	Euphorbiaceae	*Neoscortechinia forbesii*		Sab
18	Anacardiaceae	*Mangifera pajang*	Bambangan(Sab).	Sab
19	Aquifoliaceae	*Ilex cissoides*		Sab
20	Icacinaceae	*Cantleya corniculata*	Bedaru(In, Swk), Seranai(In), Dedaru(Mly).	In
21	Sapindaceae	*Pometia pinnata*	Kasai(Sab, Swk), Kasai daun besar(Mly), Malugai(Ph), Truong (Viet), Matoa, Taun(NG), Kasai besar daun, Kaseh, Kasie, Lando-eng, Djampanga, Galunggung, Kempil kujat, Pangah, Singkuang (In).	Sab
22	Tiliaceae	*Pentace chartacea*		Sab
23	Theaceae	*Schima wallichii*	Puspa(In), Medang gatal(Sab, Mly), Ketinchi pudi(Br), Talo, Mangtan(Th), Gegata(Mly).	In
24	Dipterocarpaceae	*Anisoptera costata*	Pengiran kesat, Mersawa daun lebar, Mersawa kesat, Kakan, Perapat hutan, Mersawa(Sab, Swk, Br, In).	Sab
25	〃	*Anisoptera* sp.	Mersawa(Sab, Swk, Br, In).	Sin
26	〃	*Balanocarpus heimii*	Chengal, Penak(Mly), Takien chan(Th).	Sin
27	〃	*Cotylelobium* sp.	Giam(In), Resak(Mly).	In
28	〃	*Dipterocarpus confertus*	Keruing kobis(Sab, Swk, Br), Keruing tempurung(In).	Sab
29	〃	*Dipterocarpus grandiflorus*	Keruing belimbing(Sab, Mly), Keruing hidjau(In), Apitong (Ph).	Sab
30	〃	*Dipterocarpus* sp.	Keruing–(In).	In
31	〃	*Dipterocarpus* sp.	Keruing–(Mly).	Sin
32	〃	*Dryobalanopus aromatica*	Kapur(Mly), Kapur biasa(Sab), Kapur peringgi(Swk, Br), Kapur singkel(In).	Sin
33	〃	*Dryobalanopus keithii*	Kapur gumbiat(Sab), Kalampait, Malampait, Santjulit, Tuali(In).	Sab

34	Dipterocarpaceae	*Hopea ferruginea*	Selangan mata kuching(Sab), Luis merah(Swk, Br), Merawan dasal(In).	Sab
35	〃	*Hopea sangal*	Gagil(Sab), Merawan siput(Mly), Tjengal(In).	Sab
36	〃	*Parashorea* sp.	Urat mata-(Sab).	Sab
37	〃	*Shorea fallax*	Seraya daun kasar(Sab).	Sab
38	〃	*Shorea gysbertsiana*	Kawang jantong(Sab), Engkabang jantong(Swk, Br), Tengkawang telur(In).	Sab
39	〃	*Shorea leprosula*	Seraya tembaya(Sab), Meranti tembaya(Sab, In), Meranti tembaga(Mly, Swk, Br), Saya(Th).	Sab
40	〃	*Shorea macroptera*	Seraya melantai(Sab), Meranti melantai(Mly, Swk, Br), Saya(Th).	Sab
41	〃	*Shorea ovalis*	Seraya kepong(Sab), Meranti kepong(Mly, Swk, Br), Meranti kelungkung(In).	Sab
42	〃	*Shorea parvifolia*	Seraya punai(Sab), Meranti serang punai(Mly, In), Meranti samak(Swk, Br).	Sab
43	〃	*Shorea platycarpa*	Seraya paya(Sab), Meranti paya (Mly, Swk, Br, In).	Sab
44	〃	*Shorea* sp.	Meranti-(Mly)(light red meranti).	Sin
45	〃	*Shorea* sp.	Meranti-(Mly)(dark red meranti).	Sin
46	〃	*Shorea* agami	Melapi agama(Sab), Meranti puteh timbul, Badau pipit(Swk, Br).	Sab
47	〃	*Shorea symingtonii*	Melapi bunga(Sab).	Sab
48	〃	*Shorea* sp.	Meranti-(Mly)(white meranti)	Sin
49	〃	*Shorea gibbosa*	Seraya kuning gajah(Sad), Lun gajah(Swk, Br), Damar hitam gajah(Mly), Damar buah(In).	Sab
50	〃	*Shorea hopeifolia*	Seraya kuning jantan(Sab), Lun jantan(Swk, Br), Damar kunjit, Maru kuning(In).	Sab
51	〃	*Shorea exelliptica*	Selangan batu tembaga(Swk, Br), Balau tembaga(Mly), Balau laut batu(In).	Sab
52	〃	*Shorea hypoleuca*	Selangan batu kelabu(Sab).	Sab
53	〃	*Shorea laevis*	Selangan batu kumus(Sab, Swk, Br), Balau kumus(Mly), Balau tanduk(In).	Sab

54	Dipterocarpaceae	*Shorea leptoderma*	Selangan batu biabis(Sab).	Sab
55	〃	*Shorea* sp.	Balau-(In, Mly).	In
56	〃	*Shorea* sp.	Balau-(In, Mly).	Sin
57	〃	*Vatica micrantha*	Resak bulu(Sab).	Sab
58	Gonystylaceae	*Gonystylus* sp.	Ramin(Sab).	Sab
59	Lythraceae	*Lagerstroemia speciosa*	Bungur, Langoti, Oindoloe(In), Bungor, Bungor ayer(Mly), Pinma (Bma), Banlang(Viet), Intanin (Th), Banaba(Ph), Jarul (Ind, Pak).	In
60	Myrtaceae	*Metrosideros* sp.	Lara(In).	In
61	Ebenaceae	*Diospyros macrophylla*	Kaju malam, Kaju hitam, Balam ayer, Bali, Tekam garam, Merpinang(Sab, Swk, Br), Kaju arang, Meribut, Siangus(Mly), Kaju arang siamang, Loting, Oela, Tonga, Banjan hitam, Itam, Kiling, Kising, Mitem, Salam bibit, Tulang tadung(In).	Sab
62	〃	*Diospyros* sp.		In
63	Loganiaceae	*Fagraea fragrans*	Tembesu, Anrali, Kolahi, Nosoe (In), Tembesu padang(Mly, Br, Swk), Temasuk(Sab), Urung(Ph), Anan, Ananma, Burma yellow heart(Bma), Kankrao, Tatrau, Trai(Cam).	In
64	Apocynaceae	*Alstonia* sp.	Pulai — (In, Mly)	Sab
65	Rubiaceae	*Neonauclea bernardoi*	Bangka(Sab), Ludek(Ph).	Sab

* Mainly according to "Nanyo-zai" (Sudo, 1970).
Bma: Burma, Br: Brunei, Cam: Cambodia, In: Indonesia, Ind: India, Mly: Malaya, NG: New Guinea, Pak: Pakistan, Ph: Philippine, Sab: Sabah, Swk: Sarawak, Th: Thailand, Viet: Vietnam.

** Name of the organization which kindly offered the specimen.
In: Forest Products Research Institute, Bogor, Indonesia.
Sab: Conservator of Forests, Forestry Department, Sandakan, Sabah.
Sin: Trade Division, Ministry of Finance, Singapore.

Results and Discussion

Virtually no attack on the test blocks by *Tyromyces palustris* occurred, except for two species (Nos. 25 and 57). The percentage weight loss in these blocks were 1.04 and 17.78 in No. 25, and 3.34 and 16.56 in No. 57, for non-extracted and extracted blocks, respectively. The reason for such a poor reaction to the test blocks is not clear. However, 2.0 × 2.0 × 2.0 (cm) blocks from temperate wood species were considerably affected by this fungus, and inactivity in the test blocks observed in this experiment may be attributed to the thinness of blocks or to an unknown inadequacy in tropical timbers as a host organism. Since *T. palustris* has been designated as a test fungus for decay tests in the Japanese Industrial Standard, the suitability of this fungus in decay tests for tropical timbers should be immediately examined. Descriptions in this paper therefore have been made exclusively with the other two test fungi, *Chaetomium globosum* and *Coriolus versicolor*.

Table 2 and Table 3 show the summarized results with the decay resistance of

Table 2 Summarized data for decay resistance, specific gravity and content of methanol extractives of 65 timber specimens

Fungus	*Ch. globosum*				*Co. versicolor*			
Class in decay resistance*	I	II	III	IV	I	II	III	IV
Average specific gravity	0.74	0.64	0.56	0.53	0.80	0.63	0.60	0.48
Average content of methanol extractives(%)	5.03	2.76	2.32	2.07	5.54	3.11	2.78	2.11
Number of specimen	25	18	19	3	20	16	18	11

* Weight loss due to decay, I : 0—5(%), II : 5—15(%), III : 15—25(%), IV : over 25%.

Table 3 Statistical significance among four classes of decay resistance (see Table 2) of 65 timber specimens in relation to their specific gravity and content of methanol extractives

Fungus		*Ch. globosum*				*Co. versicolor*			
	Class	I	II	III	IV	I	II	III	IV
Specific gravity	I	—	2.381*	4.153**	2.150*	—	5.177**	5.674**	7.336**
	II	2.381*	—	2.077*	1.420	5.177**	—	0.878	3.592**
	III	4.153**	2.077*	—	0.347	5.674**	0.878	—	2.637*
	IV	2.150*	1.420	0.347	—	7.336**	3.592**	2.637*	—
Content of methanol extractives	I	—	2.484*	3.317**	1.468	—	2.338*	3.153**	3.103**
	II	2.484*	—	1.158	0.977	2.338*	—	0.542	0.702
	III	3.317**	1.158	—	0.369	3.153**	0.542	—	1.684
	IV	1.468	0.977	0.369	—	3.103**	0.702	1.684	—

* 5%, ** 1% level of significance by t-distribution, respectively.

65 timber specimens correlated with specific gravity and content of methanol extractives. Percentage weight loss due to decay ranged from 0 to 57.9 (%) in this experiment. Thus, decay resistance was divided into four classes as follows based on this range ;

I: percentage weight loss 0 to 5 (%), very durable class.

II: percentage weight loss 5 to 15 (%), durable class.

III: percentage weight loss 15 to 25 (%), moderately durable class.

IV: percentage weight loss over 25 (%), non-durable class.

These classes might be narrower compared with the usual divisions in decay resistance. However, percentage weight loss in beech wood as a representative non-durable species was 30 to 40 (%) in the preliminary test, therefore the above divisions are not unreasonable.

It can be seen from Table 2 that the average specific gravity and the amount of methanol extractives of the timber species in the more durable class are higher than those of the less durable class in both cases of test fungi. As shown in Table 3, this tendency was significantly confirmed statistically, and the relationship between specific gravity and decay resistance was most pronounced for *Co. vorsicolor*.

When using *Ch. globosum*, there are a greater number of timber specimens in class I and a smaller number in class IV than when using *Co. versicolor*. This indicates that *Ch. globosum*, has a somewhat lower wood-decaying capacity than *Co. versicolor*. It has been reported that decay by soft rot fungi, even under what are believed to be favorable conditions, occurs more gradually than decay by Basidiomycetes under conditions favorable to them (Baechler, Blew and Duncan, 1962).

From the data obtained here, it may be possible to generalize that dense or extractive-rich species are more resistant to decay, though the more resistant species have not always been dense and rich in extractives. The specific gravity and the amount of extractives are frequently associated reciprocally. High densities in No. 26 (*Balanocarpus heimii*), No. 53 (*Shorea laevis*) and No. 57 (*Vatica micrantha*) may indeed possibly be associated with their high content of methanol extractives (see Table 4), but dense and durable species called "Selangan batu" or "Balau" do not contain so great a quantity of extractives (see Nos. 51, 52, 54, 55 and 56 in Table 4), with the exception of No. 53.

Shorea spp. have been usually divided into four groups, namely red meranti, white meranti, yellow meranti and Selangan batu, according to their specific gravity, hardness and color. Nos. 37-45 belong to red meranti, Nos. 46-48 to white meranti, Nos. 49 and 50 to yellow meranti, and Nos. 51-56 to the Selangan batu group. Fig. 1 shows the relationship between the percentage weight loss of 20 *Shorea* spp. due to decay by *Co. versicolor* and their specific gravity. It suggests that the correlation between decay resistance and specific gravity is highly significant in this case.

In Tables 4-7, specific gravity, content of methanol extractives, weight loss of non-extracted and extracted blocks due to decay, and the effect of methanol extraction on decay have been included for the individual timber species classified according to their natural resistance to decay as shown in Table 2.

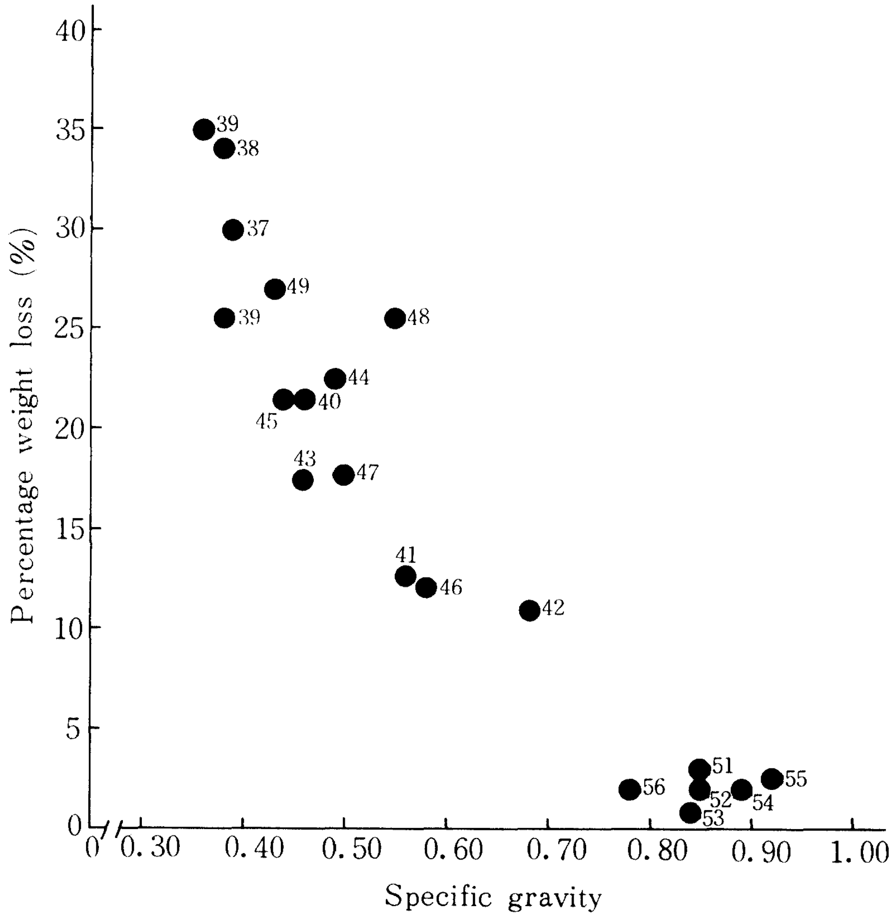

Fig. 1 Relationship between weight loss of *Shorea* spp. due to decay by *Coriolus versicolor* and their specitic gravity (number on each plot corresponds with the number of timber specimens shown in Table 1)

As seen in Table 4, the majority of the very durable species were common to both cases of the two test fungi and all species (with only one exception of No. 60) assigned to class I by their decay resistance to *Co. versicolor* were classified in the same class in the case of *Ch. globosum*, too. Such a trend, however, did not hold for the other classes of decay resistance, possibly reflecting the generally higher decaying ability of *Co. versicolor* and the different preferences for host timbers in the test fungi. Examination for significance in percentage weight loss of non-extracted blocks between the two test fungi indicated that only 6 species were more susceptible to *Ch. globosum* than to *Co. versicolor*, and 28 species were more susceptible to *Co. versicolor*, and the remaining 31 species were equally susceptible to both fungi.

Table 4 Weight loss, specific gravity and content of methanol extractives of each timber specimen in class I**

No.*	Specific gravity	Content of methanol extractives(%)	*Ch. globosum*			*Co. versicolor*		
			Weight loss(%)		Effect of extraction on decay***	Weight loss(%)		Effect of extraction on decay***
			Not treated	Extracted by methanol		Not treated	Extracted by methanol	
1	0.44	1.55	1.09	0.15			in class II	
5	0.66	4.19	1.38	1.43		2.29	2.59	
6	0.68	1.32	0.30	0.14		1.48	2.43	+
7	0.98	3.82	1.22	0.41		1.04	0.60	
8	0.84	7.85	1.30	1.04		0.94	0.46	
11	0.71	9.19	1.20	11.78	+	1.51	10.44	+
12	0.67	11.47	2.02	2.21		2.47	12.33	+
20	0.98	2.64	2.03	4.52	+	2.77	2.60	
23	0.52	1.44	0.61	1.75			in class III	
26	0.80	11.93	0.64	3.12	+	0.78	6.75	+
27	0.77	10.26	0.18	3.03	+	0.41	8.39	+
35	0.65	6.29	0.85	16.38	+	0.15	18.87	+
40	0.46	1.96	3.06	1.00	−		in class III	
41	0.56	2.33	2.89	3.17			in class II	
46	0.58	5.18	0.67	13.56	+		in class II	
51	0.85	3.41	2.30	4.09		3.04	1.49	−
52	0.85	3.05	1.30	1.79		1.90	1.80	
53	0.82	10.24	0.40	2.19	+	0.81	4.17	
54	0.89	2.54	1.67	7.36	+	1.97	3,20	
55	0.92	2.81	1.52	7.40	+	2.60	1.80	−
56	0.78	3.53	2.18	4.03		1.88	2.80	+
57	0.84	8.17	1.87	23.76	+	4.14	8.69	+
59	0.64	1.27	0.86	1.36		1.47	0.37	
60	0.85	1.72		in class II		4.23	3.33	
62	0.90	5.08	1.83	10.70	+	4.16	4.39	
63	0.68	2.78	4.36	8.06	+		in class II	

* See Table 1. ** See Teble 2. *** Examined at 1% level of significance by t-distribution.

Particularly, *Querqus* spp. (Nos. 3 and 4) and *Gonystylus* sp. (No. 58) were more susceptible to *Ch. globosum*, and likewise Nos. 23, 32, 33, 37, 38, 40, 41, 44, 45, 48, 61 and 64 were more susceptible to *Co. versicolor*.

From the data indicating the effect of methanol extraction on decay in Tables 4-7, it is clear that a positive effect (higher percentage weight loss of extracted blocks than that of non-extracted blocks) occurred more frequently in extractive-rich species and a negative effect (lower percentage weight loss of extracted blocks) occurred

Table 5 Weight loss, specific gravity and content of methanol extractives of each timber specimen in class II**

No.*	Specific gravity	Content of methanol extractives(%)	*Ch. globosum*			*Co. versicolor*		
			Weight loss(%)		Effect of extraction on decay***	Weight loss(%)		Effect of extraction on decay***
			Not treated	Extracted by methanol		Not treated	Extracted by methanol	
1	0.44	1.55		in class I		8.48	22.91	+
2	0.62	6.46	7.31	20.67	+	11.17	22.43	+
3	0.70	2.35		in class III		12.43	10.86	
4	0.79	1.05		in claas IV		14.27	11.84	
10	0.62	1.63	14.54	11.46		8.44	9.66	
13	0.69	1.57	13.87	10.55			in class III	
14	0.59	4.80	8.49	21.78	+	9.54	10.53	
17	0.69	2.41	5.57	4.87	−	8.06	7.38	
18	0.74	2.10	14.29	11.70			in class III	
22	0.57	1.09		in class III		12.85	24.58	+
24	0.52	2.79		in class III		14.97	15.94	
28	0.76	3.90	14.22	8.23	−		in class III	
29	0.68	9.70	6.24	9.01		11.49	12.21	
32	0.66	3.68	5.21	4.90			in class III	
33	0.70	1.91	8.89	4.32	−		in class III	
34	0.61	4.18	8.38	27.58	+		in class III	
41	0.56	2.33		in class I		12.71	8.17	−
42	0.68	2.21	10.18	13.62	+	11.09	8.02	
43	0.46	1.47	11.61	17.01	+		in class III	
44	0.49	2.90	8.51	5.83			in class III	
45	0.44	3.06	6.73	6.71			in class III	
46	0.58	5.18		in class I		11.92	27.01	+
48	0.55	3.80	8.35	11.97			in class IV	
58	0.64	1.81		in class III		8.62	9.58	
60	0.85	1.72	7.41	6.43			in class I	
63	0.68	2.78		in class I		6.87	12.99	
65	0.71	1.68	6.71	8.36		14.97	11.74	

* See Table 1. ** See Table 2. *** Examined at 1% level of significance by t-distribution.

more frequently in extractive-poor species, possibly suggesting a correlation between decay resistance and amount of extractives. Furthermore, a positive effect was observed in 23 species when tested with *Ch. globosum* and 16 species when tested with *Co. versicolor*, but a positive effect common to both fungi occurred in only 10 species (Nos. 2, 11, 25, 26, 27, 30, 35, 46, 49 and 57). This suggests that the two test fungi have different sensitivities to wood extractives. Nos. 14, 24, 34, 50, 54, 55 and

62, in particular, had a pronounced positive effect when tested with *Ch. globosum*, and Nos. 1, 12, 22 and 47, likewise, had a pronounced positive effect when tested with *Co. versicolor*. Among these species, it may be interesting to study *Agathis alba*, *Dalbergia latifolia*, *Intsia* sp., *Samanea saman*, *Hopea ferruginea*, *Hopea sangal*,

Table 6 Weight loss, specific gravity and content of methanol extractives of each timber specimen in class III**

No.*	Specific gravity	Content of methanol extractives(%)	*Ch. globosum*			*Co. versicolor*		
			Weight loss(%)		Effect of extraction on decay***	Weight loss(%)		Effect of extraction on decay***
			Not treated	Extracted by methanol		Not treated	Extracted by methanol	
3	0.70	2.35	19.84	20.97			in class II	
9	0.63	2.73	23.81	35.45		24.52	35.79	
13	0.69	1.57		in class II		17.78	10.98	
15	0.70	1.28	15.93	22.88			in class IV	
16	0.68	2.08	16.93	14.89		22.98	10.33	
18	0.74	2.10		in class II		16.47	11.43	
21	0.54	3.01	16.91	17.24		16.04	12.22	
22	0.57	1.09	16.28	14.84			in class II	
23	0.52	1.44		in class I		18.67	18.34	
24	0.52	2.79	19.51	26.12	+		in class II	
25	0.50	3.24	21.62	28.95	+	18.42	45.12	+
28	0.76	3.90		in class II		17.76	13.16	
30	0.60	3.16	21.16	28.42	+	20.14	29.12	+
31	0.76	5.47	16.15	24.89	+	21.08	23.76	
32	0.66	3.68		in class II		20.39	16.54	
33	0.70	1.91		in class II		22.97	16.30	−
34	0.61	4.18		in class II		15.81	10.91	
36	0.59	0.50	24.93	29.42			in class IV	
37	0.39	1.34	16.26	15.93			in class IV	
38	0.38	1.72	21.15	13.79	−		in class IV	
39	0.38	2.79	16.05	11.37	−		in class IV	
40	0.46	1.96		in class I		21.51	8.31	−
43	0.46	1.47		in class II		17.53	23.04	
44	0.49	2.90		in class II		22.35	30.43	
45	0.44	3.06		in class II		21.60	22.83	
47	0.50	2.18	16.99	17.51		17.68	29.34	+
50	0.36	3.30	22.56	34.04	+		in class IV	
58	0.64	1.81	16.51	6.63	−		in class II	
61	0.44	1.85	16.42	15.11			in class IV	
64	0.71	1.48	19.83	22.61			in class IV	

* See Table 1. ** See Table 2. *** Examined at 1% level of significance by t-distribution.

Table 7 Weight loss, specific gravity and content of methanol extractives of each timber specimen in class IV**

No.*	Specific gravity	Content of methanol extractives(%)	*Ch. globosum*			*Co. versicolor*		
			Weight loss(%)		Effect of extraction on decay***	Weight loss(%)		Effect of extraction on decay***
			Not treated	Extracted by methanol		Not treated	Extracted by methanol	
4	0.79	1.05	30.98	30.31		in class II		
15	0.70	1.28	in class III			29.07	7.64	−
19	0.38	2.47	50.05	39.06	−	57.94	27.19	−
36	0.59	0.50	in class III			26.20	22.92	
37	0.39	1.34	in class III			29.96	30.63	
38	0.38	1.72	in class III			34.08	30.08	
39	0.38	2.79	in class III			25.54	12.38	
48	0.55	3.80	in class II			25.49	33.64	
49	0.43	2.70	25.89	38.11	+	27.03	36.99	+
50	0.36	3.30	in class III			34.94	25.31	
61	0.44	1.85	in class III			30.48	18.41	
64	0.71	1.48	in class III			41.04	27.46	

* See Table 1. ** See Table 2. *** Examined at 1% level of significance by t-distribution.

Shorea agami and *Vatica micrantha* for antifungal activity in heartwood extractives.

Nos. 15, 19, 40 and 58 had a pronounced negative effect. Such an effect has often been observed in the extractive-poor and less durable species such as beech wood. Consequently, it is possible to attribute such an effect to the removal of substances from wood blocks by methanol extraction, which facilitate the attack by wood decaying fungi.

As stated in *Materials and Methods*, the content of methanol extractives was determined by weighing the wood blocks. It was therefore expected that the extractives would not be completely removed from the wood blocks due to the lower diffusibility of the solvent and extractives compared with the wood meal. Hence, the content of extractives as shown in this paper does not necessarily represent the total amount of methanol extractives in each species. In this respect, the data on extractives might be regarded as a degree of removability of extractives in each species. However, the data may still be used as an important factor in considering the durability of timber for exterior use.

The greater number of timber species in class I have been reputed to be very durable species in tropical environments since long ago. Decay resistance in the species *Ochanostachys amentacea* (No. 5), *Scorodocarpus borneensis* (No. 6), *Eusidero-*

xylon zwageri (Nos. 7 and 8), *Cantleya corniculata* (No. 20), *Balanocarpus heimii* (No. 26), *Cotylelobium* sp. (No. 27), *Shorea* spp. called "Selangan batn" (Nos. 51–56), and *Metrosideros* sp. (No. 60) was not influenced much by methanol extraction, whereas decay resistance in *Agathis alba* (No. 1), *Dalbergia latifolia* (No. 11), *Intsia* sp. (No. 12), *Hopea sangal* (No. 35), *Vatica micrantha* (No. 57), *Diospyros* sp. (No. 62), and *Fagraea fragrans* (No. 63) was influenced considerably by methanol extraction. In spite of their high decay resistance in non-extracted blocks, these results cast a problem on the use of these species in severe conditions such as in cooling towers. It is generally accepted that, in most cases of premature decay in cooling towers, chemicals in the water have played an important role in accelerating the loss of the protective extractives from the naturally durable wood, thus rendering it vulnerable to decay (Baechler, Blew and Duncan, 1962).

Roles of specific gravity and extractives in natural durability of wood have been discussed in this paper. From the results obtained, it may be concluded that dense and extractive-rich species are more resistant to decay. However, specific gravity and content of extractives are frequently associated, hence in the long term use of dense and durable species, of which high density is mainly attributed to its high content of extractives liable to removal, lowering of durability due to loss of the antifungal extractives must be anticipated.

Although field stake tests for durability of timbers were not carried out in this investigation, a high correlation between laboratory results and field tests has been reported (Clark, 1969; Da Costa and Osborne, 1967). Nevertheless, the effects of termite damage or cooperative attacks by many fungal and bacterial species should be considered in field tests, together with the effects of weather deterioration. The field test is therefore still necessary in determining the most suitable exterior uses for tropical timbers.

Acknowledgement

The authors wish to acknowledge their debt to staffs of the Forest Products Research Institute, Bogor, Indonesia, the Conservator of Forests, Forestry Department, Sandakan, Sabah, East Malaysia, and the Trade Division, Ministry of Finance, Singapore, all of whom kindly gave us timber specimens for this investigation. We also wish to express our gratitude to Toyo Menka Kaisha, Ltd., Jakarta, Sandakan and Osaka, for their help in transportation of timber specimens, and to Mr. A. Adachi and Mr. S. Hashimoto for their technical assistance in carrying out this experiment.

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