Abstract

The durability of wood, or the natural resistance of wood against termites, is an extremely variable property. The durability of 22 Malaysian commercial timber species has been reviewed based on the European Standard 350-1 (1994) (laboratory trials) of the Heartwood of mature timbers harvested from the natural forest. Based on this, the European standard EN118 (2005) was used for termites test. Coptotermes curvignathus was introduced to different wood species in controlled conditions for 8 weeks. The efficacy in wood degradation was calculated based on average of weight loss and visual rating of each timber species. The results showed that 2 timber species fall under durable and 3 species under moderately durable while the other 17 species under susceptible class.

Keywords: Deterioration; Durability; Malaysian timbers; EN118; Subterranean termites

Highlights

a. Twenty two Malaysian commercial timber species were determining their natural durability against termites based on European Standard EN350:1994.

b. Only 5 Malaysian timber species are better than Pinus spp. i.e. 2 species fall under durable class and 3 species under moderately durable.

c. Certain treatments are needed especially to susceptible timber species in order to ensure a longer service life of the wood.

Introduction

As defined in BS EN 350-1 [1], natural durability is the inherent resistance of wood to attack by wood destroying organisms. Eaton and Hale [2] defined natural durability or decay resistance as the ability of the Heartwood of any wood species to resist decay. Normally, natural durability is measured by exposing the wood to biological agents such as termites, beetles, fungi and marine borers e.g., [3,4]. While the natural durability of Heartwood is important for situations either to be used partially or fully exposed to the weather, sapwood is always regarded as having low natural durability (perishable or non-durable) except if treated. Certain types of timber are noted for their marked resistance to deterioration and are commonly used as untreated material. In contrast, non-durable timbers generally require preservative treatment if they are to be used in exposed conditions, adding significantly to their cost.

A number of factors influence the durability of a timber, including wood density, tree age, and growing location. The wood resistance, especially against fungal attack also could be increased by the presence of lignin, which, surrounding the crystalline cellulose and even though only 0.03-0.1% of nitrogen content in the wood, to some extent contributed to the natural resistance of the wood [5]. However, the most important factor is the extractives within the wood itself, which are formed after the sapwood is transformed into Heartwood [6]. It’s having long been recognized as key features that impart natural durability in the Heartwood of certain wood species [7,8].

Preliminary studies have found that Malaysian timbers are categorized as not durable based on graveyard test, but durable when they are determined by EN 350-1 [1]. Malaysia suffered a loss in terms of price premiums as most Malaysian timbers are placed in Grade 4 and 5 based on earlier studies which indicated that 80% of the wood has been categorized as moderately durable and not durable by the graveyard test. Low natural durability of the wood could shorten the service life of a structure or even lead to structural strength failure, when the surrounding conditions e.g. climate, are stimulating growth of fungi in the wooden members. In that case it is important to know the durability of timber in order to minimize the cost of building constructions. Keeping the durability grades meaningful, it might be necessary to define a laboratory test with regard to insect/termite which could be used to compare the natural durability of wood species relative to each other.
As mentioned by Silva et al. [9], one of the most limiting factors for the commercial utilization of wood is because of its low resistance to termites and fungi. This study aims to determine the natural durability of Malaysian timbers upon exposure to damaging agents such as termites as stipulated in EN 350-1 [1]. A total of twenty-two Malaysian timber species has been identified to undergo a stress test (durability) of wood in laboratory condition trials with Pinus sp. included as reference timbers. Subterranean termite, Coptotermes curvignathus which is among the aggressive species in Malaysia will be used.

Materials and methods

Raw materials

The wood species used in this study are the most commercial Malaysian wood species which were extracted from the Terengganu forest reserve. Southern yellow pine; Pinus spp. was used as a control block as indicated in European Standard EN118 [10]. All wood species from basal portion of three trees were cut into wood blocks of the size of $(50 \times 50 \times 10\text{mm})$ (radius x tangential x longitudinal). Relevant wood characteristics of these Malaysian timbers are described in Table 1.

Bioassay test against termites

Ten (10) replicates of wood blocks used for each wood species. Testing method adopted was European Standard EN118 [10] using Asian subterranean termites (Coptotermes curvignathus Holmgren (Isoptera: Rhinotermitidae) collected from active field colonies at the Forest Research Institute Malaysia (FRIM) campus using a method described before [11].

| Species          | Local Name     | Basic Density (kgm-3) | Strength Group | Sapwood & Heartwood Defined? | Natural Durability | Treatability with CCA |
|------------------|----------------|------------------------|----------------|------------------------------|--------------------|-----------------------|
| A. mangium      | Akasia (LHW)   | 290-580                | C              | Yes                          | ND                 | Easy                  |
| O. sumatrana     | Binuang (LHW)  | 270-465 kg             | D              | Yes                          | ND                 | Easy                  |
| C. arborescens   | Geronggang (LHW) | 350-610               | D              | Yes                          | ND                 | Easy                  |
| Parashorea spp.  | Gerutu (LHW)   | 640-880                | C              | Yes                          | ND                 | Difficult             |
| D. costulata     | Jelutong (LHW) | 420-500                | D              | No                           | ND                 | Very easy             |
| D. aromatica     | Kapur (MHW)    | 575-815                | B              | Yes                          | D                  | Difficult             |
| Canarium spp.    | Kedondong (LHW) | 495-980               | C              | Poor                         | ND                 | Difficult             |
| C. malaccensis   | Kekatong (HHW) | 880-1,155              | A              | Poor                         | MD                 | Difficult             |
| Syzigium sp.     | Kelat (MHW)    | 495-1,010              | B              | Poor                         | MD                 | Difficult             |
| Artocarpus sp.   | Keledang (MHW) | 500-945                | B              | Yes                          | MD                 | Easy                  |
| N. cadamba       | Kelemayan (LHW) | 290-465               | D              | No                           | ND                 | Easy                  |
| Dipterocarpus spp.| Keruing (MHW)  | 690-945                | A&B            | Yes                          | MD                 | Very easy             |
| S. borneensis    | Kulim (MHW)    | 640-975                | B              | Yes                          | MD                 | Easy                  |
| M. indica        | Machang (LHW)  | 545-610                | C              | Poor                         | MD                 | Very easy             |
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| Species                | Common Name          | Range (mm) | Density | CCA Treatability | Durability |
|------------------------|----------------------|------------|---------|------------------|------------|
| *Cinnamomum spp.*     | Medang (LHW)         | 350-880    | C       | Yes              | ND         |
| *Heritiera spp.*      | Mengkuang (MHW)      | 625-895    | B       | Yes              | ND         |
| *S. platyclados*      | Meranti bukit (LHW)  | 505-870    | C       | Poor             | MD         |
| *S. parvifolia*       | Meranti sarang punai (LHW) | 385-755 | C       | Yes              | ND         |
| *Anisoptera sp.*      | Mersawa (LHW)        | 515-735    | C       | No               | D          |
| *P. velatinus*        | Pelung (LHW)         | 480-835    | D       | No               | ND         |
| *E. malaccense*       | Sesendok (LHW)       | 305-655    | D       | No               | ND         |
| *F. fragrans*         | Tembusu (HHW)        | 640-1,075  | B       | No               | D          |
| *Pinus spp.*          | Southern Yellow Pine | 375-585    | D       | No               | ND         |

Density class is based on strength and durability [36]. HHW-heavy hardwood, MHW-medium hardwood, LHW-light hardwood. Durability rating [14]: ND-nondurable (<2 years), MD-moderately durable (2-5 years), D-durable (>5 years). CCA treatability [39]: Very easy (>320 lit/m³), East (240-320 lit/m³), Difficult (80-160 lit/m³). Heartwood-sapwood boundary: well-defined (yes), poorly defined (poor), heartwood absent (no).

The ground glass end of one tube (110mm length x 25mm width) was attached with non-toxic termite adhesive in the center of each wood block (Figure 1). Some wet sand (1:4 v/v water-sand ratio) was added to each tube, occupying at least two-thirds of the volume of the tube, and 250 termite workers, 5 soldiers and 5 nymphs were distributed. Test assemblies were kept in a culturing chamber with air circulation controlled at 22±2°C and 65±5% relative humidity for 8 weeks. Ten *Pinus* spp. samples were used to check the termite virulence. The tubs were unsealed at the end of the test period and the number of live termite workers, soldiers and nymphs were counted in order to determine the survival rate. Each wood block was also examined and visually rated using a standard rating system [10] (Table 2).

**Statistical analysis**

A suitable analysis of variance (ANOVA) was performed with wood consumption, degree of attack and the termite mortality rates resulted from the termite test as variables, in resistance to bio-deterioration.

**Table 2:** Visual assessment rating of termite attack according to EN118 (2005).

| Rating | Description |
|--------|-------------|
| 0      | No attack   |
| 1      | Attempted attack:  
|        | i. Superficial erosion of insufficient depth to be measured on an unlimited area of the test specimen; or  
|        | ii. Attack to a depth of 0.5mm provided that this is restricted to an area or areas not more than 30mm² in total; or  
|        | iii. combination of i) and ii) |

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Results and discussions

Wood density

The result of density tests for the twenty two selected wood species shown in Table 3 revealed classification into three density classes: C. malaccensis, S. borneensis, Dipterocarpus spp., D. aromatica, Artocarpus sp., Canarium spp., F. fragrans, S. platyclados, P. velutinus, Syzigium sp. and M. indica were in high density class with values of 988, 925, 880, 799, 735, 722, 717, 676, 641 and 639kg/m-3, respectively; Parashorea spp., A. mangium, Anisoptera sp. and C. arborescens were in the medium density group had 575, 532, 523 and 497kg/m-3, respectively, while Pinus spp., Heritiera spp., S. parvifolia, Cinnamomum spp., D. costulata, N. cadamba and O. sumatrana in the low density group (474, 470, 466, 457, 378, 359 and 267kg/m-3, respectively).

Table 3: Visual rating and durability classes of 22 Malaysian timbers and Pinus spp. according to EN118 (2005).

| Scientific Name            | Visual Rating | Durability Class |
|---------------------------|---------------|-----------------|
| A. mangium                | 4             | Susceptible     |
| O. sumatrana              | 4             | Susceptible     |
| C. arborescens            | 4             | Susceptible     |
| D. aromatica              | 2             | Moderately durable |
| Parashorea spp.           | 3             | Susceptible     |
| D. costulata              | 4             | Susceptible     |
| Canarium spp.             | 2             | Moderately durable |
| M. indica                 | 4             | Susceptible     |
| Cinnamomum spp.           | 1             | Durable         |
| Heritiera spp.            | 4             | Susceptible     |
| S. platyclados            | 4             | Susceptible     |
| S. parvifolia             | 4             | Susceptible     |
| Anisoptera sp.            | 3             | Susceptible     |
| P. velutinus              | 4             | Susceptible     |
Visual rating

Figure 2 gives the general appearances of twenty two Malaysian timber species specimens after the termite standard test. It is apparent that *A. mangium*, *O. sumatrana*, *C. arborescens*, *D. costulata*, *M. indica*, *Heritiera* spp., *S. platyclados*, *S. parvifolia*, *P. velutinus*, *E. malaccense* and *F. fragrans* were the species that intensely attacked (visual rating of 4) which classified as susceptible timbers. Another four timber species (*Parashorea* spp., *Syzigium* sp., *Artocarpus* sp. and *Anisoptera* sp.) also classified as susceptible timbers, but with a visual rating of 3 which means that there is a potential for wood is classified under a durable medium if the age of the tree is older [12]. *D. aromatica*, *Canarium* spp. and *S. borneensis* were moderately attacked, while *C. malaccensis* and *Cinnamomum* spp. be almost untouched. *Pinus* spp. proved to be completely susceptible to subterranean termites (all 10 replicates had 4 visual rating after eight weeks exposure, Table 4). The same findings were also observed by Tho [13] on plantation-grown exotic softwood (*P. caribaea* from Malaysia and Indonesia against *C. curvignathus*, *P. insularis* by Mohd Dahlan & Tam [14] and *P. sylvestris* against *C. formosanus* in the laboratory by Grace et al. [15].
Weight loss or wood consumption

Generally, *C. curvignathus* were unable to survive for the full 8 weeks of exposure on all timber tested. However, the woods were damaged before the termites died and the damaged varied considerably among these timber species (Table 4). Analysis of variance also revealed the mean difference was significantly different from one another (F; 7.859; d.f. 3:8;11; P<0.001). The termite choice test showed that among the twenty two wood species tested, *A. mangium* (11.71%) and *D. costulata* (11.17%) had higher average wood consumption (>10%) followed by another eleven timber species; *Heritiera* spp. = 9.44%, *N. cadamba* = 9.25%, *Dipterocarpus* spp. = 8.90%, *Parashorea* spp. = 8.79%, *O. sumatrana* = 8.22%, *E. malaccense* = 8.11%, *S. parvifolia* = 7.59%, *S. platyclados* = 7.44%, *Artocarpus* sp. = 6.96%, *M. indica* = 6.54% and *P. velutinus* = 6.33%. Nine wood species had less than 5% of weight loss; *F. fragrans* (4.25%), *Syzgium* sp. (3.51%), *C. arborescens* (3.16%), *Anisoptera* sp. (3.13%), *D. aromatica* (2.42%), *Canarium* spp. (1.66%), *Cinnamomum* spp. (0.98%), *C. malaccensis* (0.47%) and *S. borneensis* (0.27%). *Pinus* spp. control samples were strongly attacked by the termite species with an attack of 4 (visual rating) and 11.38% of weight loss. Thus, it can be deduced that *A. mangium* and *D. costulata* constituted the termite’s first and second choices, respectively, while *C. malaccensis* and *S. borneensis* were not preferred (distasteful) by the termites since it was left alone by the termites after an exploratory nibbling etched the wood surface damaged during the 8 weeks exposure. On the other hand, Tamashiro et al. [16]
stated that weight loss or wood consumption less than 3% would be considered as cosmetic damage which unlikely to create a structural hazard, but additional field evaluations are needed to determine the treatment requirements for timbers. Meanwhile, the first third teen timber species were easily degraded despite the toxicity of some of the resinous extractives against termites [15], the content of which may be insufficient to override the presence of feeding stimulant chemicals in the wood [17]. Along with wood extractive, chemical components such as cellulose, lignin and total phenolic content of wood showed influence on the rate of degradation [18]. The higher cellulose content, the less resistance to termite attacked [19] and the higher lignin and total phenolic content, the more resistance of the wood against termite attack [20]. On the other hand, *C. malaccensis* and *Cinnamomum* spp. have proved in this test to be highly resistant against *C. curvignathus* although these two species were found to be susceptible using other standard methods [21,22]. Meanwhile, these termites are fond to *A. mangium*, *D. costulata* and *Pinus* spp. based on the high percentage of wood consumption (more than 10%) (11.71%, 11.17% and 11.38%, respectively) with all visual rating are 4. Resistance situation can be meaning that the death of termites was caused by starvation or a volatile substance in the wood while susceptible means no repellent or insufficient repellent to prevent substantial feeding for [23] but then, different feeding on different timber species may be due to some differences in chemical composition. For example, a higher quantity of carbohydrates (especially starch content) can make the timbers relatively more relatively more susceptible to insect attack [24-26].

### Table 4: Density and wood consumption of 22 Malaysian timbers and *Pinus* sp. against *C. curvignathus*.

| Scientific Name       | Density Range (kg/m-3) | Wood Consumption (%) | Termite Mortality (%) |
|-----------------------|------------------------|----------------------|-----------------------|
| *A. mangium*          | 513-561                | 11.71 (0.17)         | 100                   |
| *O. sumatrana*        | 244-970                | 8.22 (1.35)          | 100                   |
| *C. arborescens*      | 461-518                | 3.16 (0.19)          | 100                   |
| *Parashorea* spp.     | 549-611                | 8.79 (0.79)          | 100                   |
| *D. costulata*        | 342-439                | 11.17 (1.17)         | 100                   |
| *D. aromatica*        | 777-830                | 2.42 (0.83)          | 100                   |
| *Canarium* spp.       | 693-746                | 1.66 (0.34)          | 100                   |
| *C. malaccensis*      | 978-1008               | 0.47 (0.15)          | 100                   |
| *Syzgium* sp.         | 597-667                | 3.51 (1.26)          | 100                   |
| *Artocarpus* sp.      | 727-751                | 6.96 (0.09)          | 100                   |
| *N. cadamba*          | 350-364                | 9.25 (2.18)          | 100                   |
| *Dipterocarpus* spp.  | 763-916                | 8.90 (0.83)          | 100                   |
| *S. borneensis*       | 915-934                | 0.27 (0.10)          | 100                   |
| *M. indica*           | 632-646                | 6.54 (0.88)          | 100                   |
| *Cinnamomum* spp.     | 432-469                | 0.98 (0.41)          | 100                   |
| *Heritiera* spp.      | 463-484                | 9.44 (0.21)          | 100                   |
| *S. platyclados*      | 681-758                | 7.47 (0.17)          | 100                   |
| *S. parvifolia*       | 457-479                | 7.59 (0.67)          | 100                   |
| *Anisoptera* sp.      | 467-557                | 3.13 (0.73)          | 100                   |
| *P. velutinus*        | 609-736                | 6.33 (0.31)          | 100                   |
| *E. malaccense*       | 347-368                | 8.11 (1.60)          | 100                   |
| *F. fragrans*         | 700-743                | 4.25 (0.63)          | 100                   |
| *Pinus* spp.          | 465-504                | 11.38 (0.55)         | 100                   |

Notes: Mean (+ SD) of 10 replicates for each species. Percentage values followed by the same letter are not significantly different in the same group at the 0.05 level of probability.
In the case of *C. arborescens*, *D. aromatic*, *Canarium* spp., *Syzygium* sp., *Anisoptera* sp. and *F. fragrans* that fell under moderately durable and susceptible, but with a lower percentage of wood consumption (1.66% to 4.25%) could be due to the unequally distributed of resistant components present in the part of the plant and there is a need to further investigate the nature of the compounds having anti-termitic properties within these woods. As mentioned by Aihetasham & Iqbal [27], the occurrence of organic chemicals such as phenol, quinines, terpenoids and high concentration of lignin may also affect the areas where feeding takes place.

**Termite mortality**

Interestingly, the standard test revealed that the termite survival rate is not necessarily related to the durability of the wood species due to the same (100%) average percentage of termite death was observed in all test containers. From this, it might be inferred that although *C. malaccensis* and *Cinnamomum* spp. be classified as durable against termites, it can be attacked. In fact, both the termite standard and choice tests showed signs of slight attacks. This confirmed the assertion that no wood is completely immune from the attack of termites, only the degree of resistance is varies [28,29].

**Correlation between wood density and wood consumption**

Even though past studies [30] that densities influence the termite’s ability to fragment the wood mechanically with its mandibles, Figure 3, show that there was a poor or weak correlation ($R^2=0.322$) between density and wood consumption which revealing that with the increasing of wood density values, it is not sure that the wood consumption will decrease. Same studies done by Roszaini and Hale (2012) on 12 Malaysian commercial wood species also found the similar trend even though they used other standard methods, ASTM D3345-74 (1988). Peralta et al. [31] on their study under field conditions also did not find a strong correlation between wood density and termite resistance of different forest species. So the use of density factor alone is not sufficient to determine the durability of Malaysia timber which means that density alone cannot confer durability of timber. Other factors such as the presence of toxic extractives should be taken into consideration [32] because in no-choice laboratories tests, where termites have to feed on the single wood species presented to them, an accumulation of wood toxins in the confined environment could lead to high mortality [33].

**Correlation between wood density and visual rating**

A linear regression analysis (Figure 4) was performed to establish a correlation between wood density and visual rating for all timber species. As the wood density increased, the visual rating decreased (more resistance). However, results show that there was a weak correlation ($R^2=0.27$) between both variables. On the other hand, study by Owoyemi et al. [30] shows a strong and positive correlation ($R^2=0.83$) existed between visual rating and wood density of ten selected Nigerian wood species against *Macrotermes syphylus* (subterranean termites). They concluded that higher wood density species tend to more resistance than medium and low density species.

**Correlation between wood consumption and visual rating**

The regression equation of correlation analysis between wood consumption and visual rating (samples damage) is plotted in Figure 5. The relationships between both variables for twenty two Malaysian commercial wood species were strong ($R^2=0.6789$). The results show that when the percentage of wood consumption increased, the visual rating increased (less termite resistance). Wong et al. [33] reported that there was a tendency towards higher mass loss or reduced termite mortality to correspond with the lower visual ratings (low termite resistance) of 5 lesser-known species of Malaysian hardwoods: kekatong (*Gynometra* sp.), kelat (*Eugenia* spp.), mempening (*Lithocarpus* spp.), perah (*Elateriospermum tapo*) and pauh kijang (*Irvingia malayana*)
against Coptotermes curvignathus. In another situation, Lee et al. [34] found a strong correlation between these two variables for treated samples [zinc borate (R²=0.94) and calcium borate (R²=0.82)].

![Figure 5: Correlation between wood consumption and visual rating for 22 Malaysian commercial timber species after an 8 weeks laboratory termite test. Visual rating – Damage rating based on 1-4 scale with 4 denoting the most damage.](Image)

**Conclusion**

The natural durability of 22 Malaysian timber species was evaluated based on laboratory test. A. mangium, O. sumatrana, C. arborescens, D. costulata, N. cadamba, M. indica, Heritiera spp., S. platyclados, S. parvifolia, P. velutinus, E. malaccense, F. fragrans and Pinus spp. be all susceptible to termites. Parasoreha spp., Syzgium spp., Artocarpus sp. and Anisoptera sp. be also rating as susceptible but with durability class of 3. D. aromatica, Canarium spp. and S. borneensis be moderately attacked while C. malaccensis and Cinnamomum spp. be durable against termites. Certain treatments are needed to susceptible timber species in order to ensure a longer service life of the wood.

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**Conflict of interest**

The author declares that he has no conflict of interests.

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