# Mechanical Properties and Biological Performance of Particle Board Made of Sendan (*Melia azedarach*)

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Sendan (*Melia azedarach*), a domestic fast-growing species in Japan, was used as a material of particle board (PB). Sendan lumber was crushed into chips using a hammer mill, and PB was made of these chips with p-MDI adhesive. For a reference, recycled chips including softwood were also used for a fabrication of PB. The mechanical properties of PB and the biological performance of solid wood and PB were investigated. Bending strength, internal bonding strength, and thickness swelling were evaluated for mechanical properties of PB, meeting the Japanese industrial standard (JAS). For the biological performance tests, solid woods of sendan and sugi were used. Termite resistance and decay resistance of both the solid woods and the PBs were evaluated. The mechanical properties of sendan and recycled PBs met the criteria of JAS. A white-rot jungus, *Trametes versicolor* decayed sendan heartwood and sendan PB more easily than sugi heartwood and recycled (softwood) PB, respectively. The termite resistance of sendan heartwood and sendan PB was superior to that of sugi heartwood and recycled PB, respectively. The higher density and the solvent removal of extractives in sendan heartwood were likely to be responsible for their high termite resistance.

*Keywords: Melia azedarach; Particle board; Termite resistance*

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## INTRODUCTION

In recent Japanese forestry, some coniferous species such as sugi (*Cryptomeria japonica*) and hinoki (*Chamaecyparis obtuse*) are planted for long-term harvesting (40 to 60 years). However, such a long harvest term makes it difficult to assess future demand, and thus, to adjust the supply of wood with regards to species and quality. Some fast-growing broad-leaved trees such as eucalyptus, acacia, and poplar have been planted in tropical–temperate regions for limited industrial purposes, such as pulp and fuel wood. However, furniture and interior applications employing high-quality hardwood are still dependent on natural forest resources. Superior hardwoods from natural forest are declining because of the protection of natural forests and the ever-increasing demand in markets. To resolve this situation, researchers have focused on the domestic forestry of fast-growing broad-leaved trees in Japan (Matsumura *et al*. 2006). In Kumamoto Prefecture, sendan (*Melia azedarach*) was selected as a fast-growing tree to realize short-term forestry because: (1) it is indigenous to Japan, (2) it shows fast growth, and (3) it is already established in the Japanese market. Sendan plantation was started in Kansai district in 2014 (Murata 2014), and the plantation site was expanded to abandoned farmlands in Hyogo Prefecture in 2016 (Honda 2016).

Sendan is indigenous to Japan and has long been in use as a material for furniture because of the excellent grain on its surface. In addition, it has also been in use as a construction material due to its good termite resistance in Okinawa Prefecture (Yaga 1978). In Indonesia, *M. azedarach* is known as Mindi and planted as an important species for community forestry (Irmayanti *et al*. 2015). Researchers in the Middle East, South America, and South-east Asia have reported its usage as a constituent of PBs (Hegazy and Aref 2010, Trianoski *et al*. 2011, Suhasman *et al*. 2012).

PB is a type of wood-based panel that has some advantages compared with solid woods. It is a homogeneous material because the composites are of a well-mixed blend of reconstituted material, which gives flexibility in size. However, it has presents some disadvantages, such as swelling due to water absorption. Recently, PB has begun to be used as load-bearing wall components in Japan, in addition to furniture materials. Resistance for biodeterioration may become an important property of PB. However, fabrication of PB based on Japanese sendan and evaluation of its biological performance under Japan's environment has not been investigated so far.

In this study, Japanese sendan was utilized to fabricate PB, and its performance was determined again after exposure to subterranean termite and wood decay fungi. Previous studies on PBs made of *M. azedarach* explained only the contribution of density toward its termite resistance (Suhasman *et al*. 2012), while Yaga (1978) reported notable termite resistance for the extractives of Sendan powder. The present work concerns the performance of solid wood and PB to biological agents for construction applications, and examines the effect of extractives on termite resistance.

## EXPERIMENTAL

### Fabrication of Particle Board

A sendan log native to Fukui prefecture was cut into small strips (approximately 50 year old). These strips, which were almost all greenwood, were crushed into wood chips using a hammer mill (Fig. 1). Recycled wood chips, which were used for commercial PBs, were prepared as a reference and mainly consisted of softwood chips. Both types of wood chips were graded by an automatic sieve with two types of clearances (5.9 mm and 0.9 mm). A middle-sized chip (0.9 mm to 5.9 mm) was selected that passed through the large clearance but blocked the small clearance. The chips differed in shape: the sendan chips were fibrous like cotton, whereas the recycled chips appeared needle-like (Fig. 1). The chips were dried to less than 15% moisture content by oven-drying. The apparent density (bulk density) values of the sendan chips and the recycled chips were 0.07 and 0.012 g/cm$^3$, respectively.

The fabricated PB had dimensions of 300 mm × 300 mm × 9 mm and a density of 750 kg/m$^3$. The adhesive content was 8% based on the weight of the oven-dried particles. Acetone was added to as-received p-MDI resin (Mitsui Chemicals & SKC Polyurethanes, COSMONATE M200) by 10% due to decrease its viscosity. The diluted adhesive was sprayed into a revolving blender containing the wood chips. The manually formed mat was compressed at 180 ºC for 3 min. After curing, the mat was aged in a climate chamber (20±3 °C, 65±10 % RH) for a week.

The PB was cut into small specimens for each test. Solid wood specimens of sendan and sugi were also prepared to determine their biological performance. The average densities and moisture content of the two specimens are shown in Table 1.

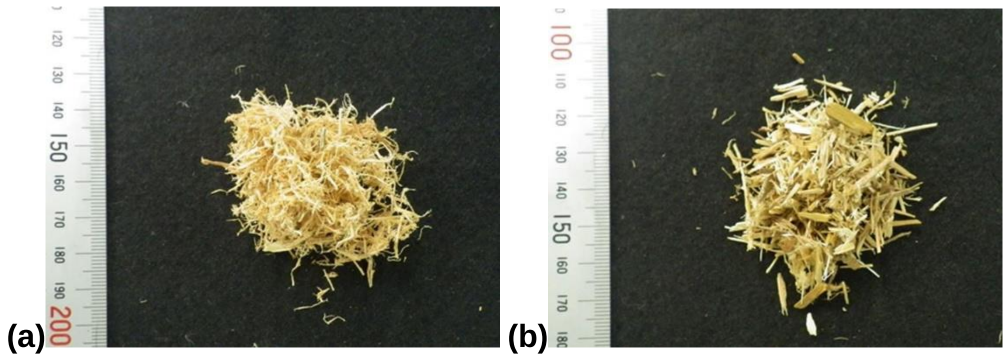


**Fig. 1.** Wood chips for particle board. (a) sendan chips, and (b) recycled chips

**Table. 1.** Density and Moisture Content of Wood Specimens

| Specimen | | Density (kg/m$^3$) | Moisture content** (%) |
|---|---|---|---|
| Sendan PB | | 745 | 7.4 |
| Recycled PB | | 735 | 6.8 |
| Sendan Solid wood | Transition region* | 520 | 21.3 |
| | Heartwood | 520 | 17.4 |
| | Including pith | 510 | 15.5 |
| Sugi solid wood | Sapwood | 370 | 9.8 |
| | Heartwood | 410 | 10.8 |

*Transition region refers to a specimen that include both the sapwood and heartwood.
** Moisture content were measured by oven-dry method.

## Mechanical tests

*Bending strength test*

Five specimens with dimensions of 300 mm × 30 mm × 9 mm were cut from each type of PB. The three-point bending test was performed using a universal material testing machine (Shimadzu, AG-I 100kN) according to JIS A 5908-6.5 (2015). The specimens were loaded under a displacement control with a crosshead speed of 10 mm/min and a span of 150 mm. Young's modulus and bending strength were obtained using the following formula,

$$\sigma_b = \frac{3PL}{2bt^2} \tag{1}$$

where $P$ is the maximum load, $L$ is the bending span, and $b$ and $t$ are the width and thickness of the specimen, respectively. Five specimen were prepared for both types.

*Internal bond (IB) test*

Five specimens with dimensions of 50 mm × 50 mm × 9 mm were cut from each type of PB, and the IB test was conducted according to JIS A 5908-6.8 (2015). Specimens were glued to attachments with epoxy resign and cured for less than 48 h. The tensile test was performed under a displacement control at a crosshead speed of 2 mm/min. The IB strength was obtained using the following formula,

$$\sigma_b = \frac{P}{bL} \tag{2}$$

where $b$ and $L$ are the width and length of the specimen, respectively. Five specimen were prepared for both types.

*Thickness swelling test*

The test was performed according to JIS A 5908-6.5 (2015). Six specimens with dimensions of 50 mm × 50 mm × 9 mm were cut from each type of PB for the thickness swelling test. First, the size and weight of air-dried specimens were measured. Next, the specimens were immersed in distilled water at room temperature for 24 h. During this process, the specimens were fixed at a depth of 3 cm under water. Thereafter, the size and weight of the specimens were measured again. The TS was calculated using the following formula,

$$\alpha_{TS} = \frac{t_2 - t_1}{t_1} \times 100(\%) \tag{3}$$

where $t_1$ and $t_2$ are thickness of the specimen before and after soaking, respectively. In addition to p-MDI, three types of adhesive were used to manufacture PB for thickness swelling test, urea resign (U), melamine-urea resign (M), and phenol resign (P). Each adhesive content was according to commercial products, of which adhesive contents in face/core were 5%/3.5% (p-MDI), 12%/7.5% (U), 12%/7.5% (M), and 12%/3.5% (P). P-type panel consisted of phenol resign face and p-MDI core.

*Decay resistance test*

The test was performed by the following method. Ten specimens with 10 mm x 10 mm 5 mm in size were cut from the 7 samples: sendan heartwood, sendan heartwood with pith, sendan intermediate part of heartwood and sapwood, sugi heartwood, sugi sapwood, sendan PB, and recycled PB. Sugi is the most popular species in Japan and JIS has determined that sugi sapwood is a control specimen in decay-resistance test. The specimens were oven-dried for 48 h at 60 °C to obtain the weights before the decay resistance test, followed by sterilization. Five specimens from the each sample were exposed to the pre-cultured *Fomitopsis palustris* (brown rot) with the plastic spacer or *Trametes versicolor* (white rot) without the plastic spacer on the PDA medium. Exposure lasted for 6 weeks in the fungi culturing room of the Deterioration Organisms Laboratory (DOL), Research Institute for Sustainable Humanosphere, Kyoto University at 26±2 °C in the dark. After exposure, all the samples were recovered, washed, and oven-dried to obtain the weights after the test. The mass losses of the samples were calculated by the weights before and after the test.

*Termite resistance test*

The test was performed according to JIS K 1571 (2010). Three specimens with 20 mm x 20 mm 9-10 mm in size were sawn from the seven samples as shown above. The specimens were oven-dried for 48 h at 60 °C to obtain the weights before the termite resistance test. Each specimen was set on the plastic mesh in the center of the plaster bottom of the acrylic cylindrical container with 80 mm diameter and 60 mm in height. One hundred and fifty workers and 15 soldiers obtained from a laboratory colony of *Coptotermes formosanus* maintained in the termite breeding room of the Deterioration Organisms

Laboratory (DOL), Research Institute for Sustainable Humanosphere, Kyoto University were put into the container, and kept in the dark for 3 weeks at 28±2 °C and over 65% RH. After the test period, all the samples were recovered, washed and oven-dried to obtain the weights after the test. The mass losses of the samples were calculated by the weights before and after the test.

*Removal of extractives*

Three specimens with 20 mm x 20 mm 9-10 mm in size were sawn from sendan heartwood and sendan PB, and were extracted by a Soxhlet apparatus with 100 mL 99% EtOH (both samples) or mixture of acetone and EtOH (1:2) (only sendan heartwood) for 24 h. The mass losses by the extraction were calculated by the change of oven-dried weights (Table 2). After the extraction, the specimens were subjected to the termite resistance test by the same method described above. Un-extracted sendan heartwood, sendan PB, sugi sapwood, and recycled PB were used as controls.

**Table 2.** Weight Decreasing Ratio in Extraction Process

| Specimen | Solvent | Weight decreasing ratio (%) |
|---|---|---|
| Sendan PB | Ethanol | 1.9 |
| Sendan heartwood | Ethanol | 1.7 |
| Sendan heartwood | Acetone and Ethanol | 1.2 |

## RESULTS AND DISCUSSION

### Mechanical Properties of PB

The results of bending and internal bond tests are shown in Table 3. The modulus of rupture (MOR) and internal bond strength (IB) of Sendan PB were higher than those of recycled PB and the JIS criteria values (JIS A5908: 2015). The modulus of elasticity (MOE) of Sendan PB was slightly less than that of recycled PB and the JIS criteria value; however, since the JIS regards MOE as only an advisory, the MOE value is not very critical. Generally, the density of the surface layer affects the mechanical properties. However, little difference was observed between the densities of the PBs when the density profiles were measured using a profiler (EWS DENSE-LAB, Germany) (Fig. 2). There is also a possibility of the mechanical properties being affected by the shape of the chips. The MOE values obtained in previous studies (Hegazy and Aref 2010; Trianoski *et al*. 2011; Suhasman *et al*. 2012) are similar to those in this study, whereas the MOR values are smaller. In the earlier study, PB of *M. azedarach* was prepared using urea-formaldehyde resin adhesive. This difference in the adhesive used may have affected the MOR of the Sendan PB.

**Table 3.** Mechanical Properties of Sendan PB and Recycle PB

| | MOE (GPa) | MOR (MPa) | IB (MPa) |
|---|---|---|---|
| Sendan PB | 2.72 | 26.4 | 1.90 |
| Recycle PB | 3.01 | 20.9 | 1.20 |
| JIS* - 18 type | 3.00 over | 18.0 over | 0.3 over |

*JIS A5908: 2015

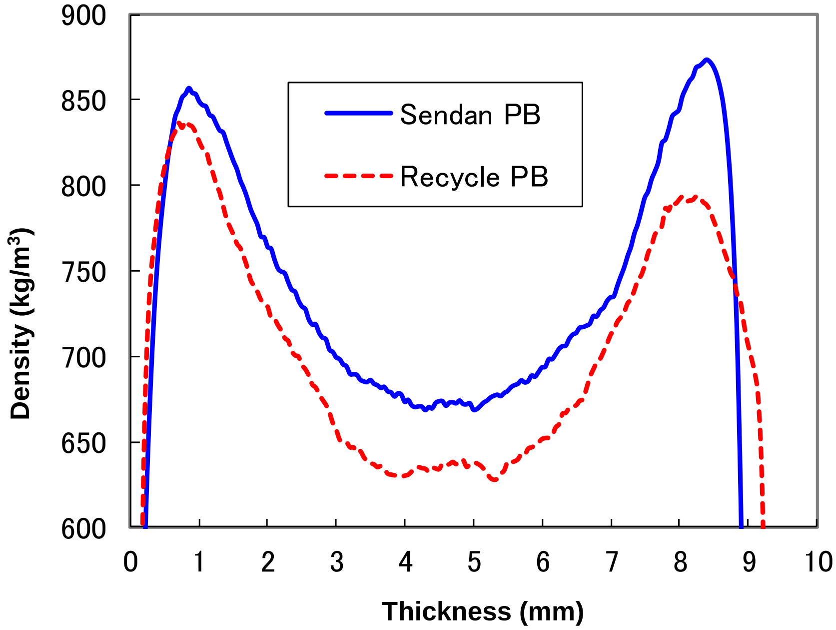


**Fig. 2.** Density profiles of particle boards

## Thickness Swelling (TS)

The results of thickness swelling tests are shown in Fig. 3. Water-resistance adhesives, M, P, and p-MDI, are used for construction purposes because water absorption is a weak point of PB. For both the PBs immersed in water at room temperature, the TS values of sendan PB were less than that of recycle PB, except for urea resign (U), which is not used for construction purposes. This result is similar to previous studies (Hegazy and Aref 2010; Trianoski *et al.* 2011). Sendan PB has exhibited good performance for construction purposes regarding TS.

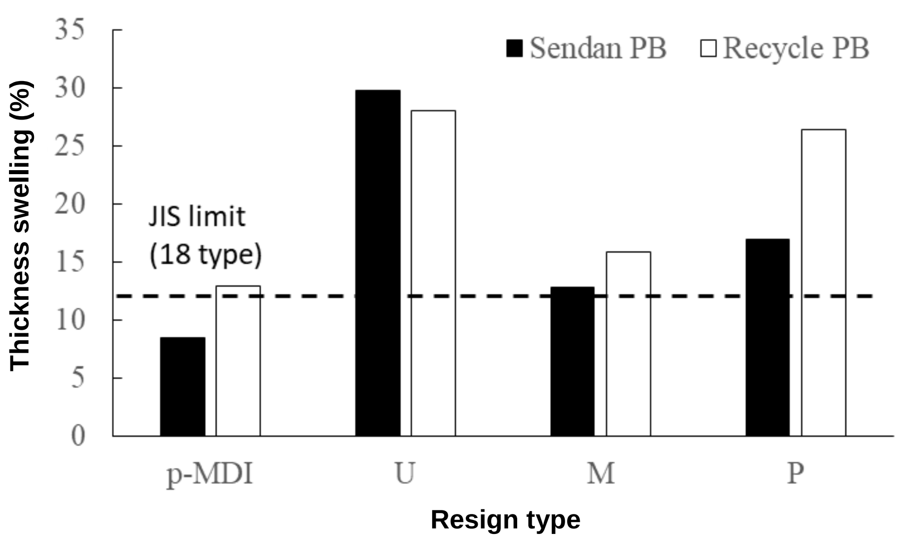


**Fig. 3.** Thickness swelling of the PBs after absorbing water

## Decay Resistance

The results of the decay resistance tests are shown in Table 4. When the specimens were exposed to a white rot fungus, *T. versicolor*, the higher average mass losses were obtained in sendan solid wood (25 to 37%) and sendan PB (24%) as compared with those of sugi heartwood (3%) and recycled PB (8%). These results are acceptable because white rot fungi generally prefer hardwood over softwood. For a brown rot fungus, *F. versicolor*, mass loss of sendan heartwood was comparable to those of sugi heartwood: 1 to 5%.

These results clearly suggest that sendan heartwood and sendan PB have the lower decay resistance in comparison with sugi heartwood.

**Table 4.** Mass Losses of 7 Samples after 6 Weeks Exposure to *T. versicolor* and *F. palustris*[1]

| | | Mass loss (%) | |
|---|---|---|---|
| | | *T. versicolor* | *F. palustris* |
| Sendan solid wood | Intermediate region | 25.2±3.3% | 18.4±10.9% |
| | Heartwood | 34.2*±3.4% | 5.2*±9.8% |
| | Heartwood with pith | 36.7*±8.5% | 23.2±3.9% |
| Sugi | Sapwood | 29.4±4.0% | 41.1±8.7% |
| | Heartwood | 2.9*±2.0% | 1.0*±0.6% |
| Sendan PB | | 23.5**±2.1% | 23.4**±5.4% |
| Recycle PB | | 8.3±1.2% | 3.6±0.3% |

[1] Average of 5 specimens ± SD
* significant difference (T-test, P<0.01) to Sugi Sapwood
** significant difference (T-test, P<0.01) to Recycle PB

## Termite Resistance

Table 5 shows the results of the termite resistance tests. Workers of *C. formosanus* consumed 30 mg (1.5%) sendan heartwood and 32 mg (1.8%) sendan heartwood with pith after 3 weeks with 65% and 54% survival rates, respectively, while 73 mg (5.1%) mass loss of sugi heartwood was observed with 67% survival rate of workers. Sendan intermediate region showed more than 100 mg mass loss, and almost all the attack was located in the sapwood region. Sugi sapwood and recycled PB samples were severely attacked by workers of *C. formosanus* with 182 mg and 140 mg mass losses after 3 weeks, respectively. Interestingly, most of soldiers were dead within 3 weeks when exposed to sendan heart wood samples, including intermediate region. These results clearly suggest that sendan heartwood has higher termite resistance than sugi heartwood, which has a high termite resistance in Japan (Ohmura *et al.* 2011). In addition, sendan PB also showed higher termite resistance in comparison with recycled PB.

Suhasnman *et al.* (2012) compared the termite resistance of PBs made of three fast-growing species, *M. azedarach* (Sendan), *Paraserianthes falcataria* and *Gmeria arborea*, and found that *M. azedarach* PB was superior to the other two species. They concluded that the density was the most important factor affecting the termite resistance. In the present tests, density was similar between heartwood and sapwood regions in the specimens. This might indicate the existence of the other factor in terms of the termite resistance of sendan heartwood. Yaga (1978) stated the effects of extractives in sendan on the termite resistance. Thus, the termite resistance of the solvent-extracted samples was examined.

**Table 5.** Mass Losses of the Samples and Survival Rates of Workers after the 3 Weeks Exposure to *C. formosanus*[1]

| | | Mass loss | | Survival rate (%) | |
|---|---|---|---|---|---|
| | | mg | (%) | Worker | Soldier |
| Sendan | Intermediate region | 102.0*±2.5 | (5.1±0.1) | 63.3±18.6 | 0** |
| | Heartwood | 30.2*±5.0 | (1.5±0.3) | 65.3±7.6 | 2.2**±3.8 |
| | Heartwood with pith | 32.3*±5.6 | (1.8±0.3) | 54.2**±9.1 | 6.7**±6.7 |
| Sugi | Heartwood | 73.3*±13.1 | (5.1±0.9) | 66.7±11.0 | 20.0±0.0 |
| | Sapwood | 185.0±13.9 | (14.3±1.1) | 77.1±1.5 | 46.7±20.2 |
| Sendan PB | | 87.6***±12.3 | (3.3±0.5) | 66.2±8.3 | 24.4±15.4 |
| Recycled PB | | 139.7±28.8 | (5.2±1.1) | 49.8±11.6 | 24.4±13.9 |

[1]Average of 3 specimens ±SD
* significant difference (T-test, P<0.01) to sugi sapwood
** significant difference (T-test,  P<0.05) to sugi sapwood
*** significant difference (T-test, P<0.05) to recycle PB

## Effect of Extraction on Termite Resistance

Table 6 shows the results of termite resistance tests with solvent-extracted sendan heartwood and sendan PB samples. Solvent-extraction of sendan heartwood resulted in the double consumption by workers of *C. formosanus* with slightly higher survival rates regardless of solvents. In line with Yaga's report (1978), these results clearly show the effects of heartwood extractives on the termite resistance of sendan. Both density and heartwood extractives might contribute to the termite resistance of sendan heartwood. Meliaceae plants are rich in limonoids. Huang *et al.* (1995) reported on the insect anti-feeding property of limonoids in sendan. Hence, limonoids may have an ameliorative effect on the termite resistance of sendan heartwood.

**Table 6.** Mass Losses of the Solvent-extracted Samples and Survival Rates of Workers after 3 weeks Exposure to *C. formosanus*[1]

| | Mass loss | | Survival rate (%) | |
|---|---|---|---|---|
| | mg | % | Worker | Soldier |
| EtOH Sendan heartwood | 41.6*±4.2 | 2.1±0.2 | 91.3*±2.0 | 82.2**±3.8 |
| Ace-EtOH Sendan heartwood | 46.8*±6.8 | 2.4±0.4 | 92.9*±1.0 | 91.1**±10.2 |
| EtOH Sendan PB | 77.9***±7.4 | 2.8±0.2 | 91.3±1.3 | 82.2***±3.8 |
| Sendan heartwood | 22.6±2.6 | 1.2±0.1 | 74.0±0.7 | 68.9±3.8 |
| Sugi sapwood | 153.0±15.1 | 10.5±1.1 | 71.8±1.0 | 57.8±7.7 |
| Sendan PB | 111.9±12.7 | 4.2±0.6 | 92.4±3.4 | 68.9±10.2 |
| Recycled PB | 139.9±10.9 | 5.3±0.4 | 82.9±1.5 | 71.1±15.4 |

* significant difference (T-test, P<0.01) to sendan heartwood
** significant difference (T-test, P<0.05) to sendan heartwood
*** significant difference (T-test, P<0.05) to sendan PB
[1]Average of 3 specimens ± SD; EtOH and Ace-EtOH mean extracting with EtOH and acetone-EtOH, respectively.

As shown in Table 6, EtOH extracted Sendan PB showed lower mass loss than that of un-extracted sendan PB with the similar survival rates. This does not fit with the results in solid wood samples. Iswanto *et al*. (2010) reported that hot-water immersion improved the termite resistance of OSB made of *Melia excelsa*. Similarly, Febrianto *et al*. (2012) showed the improvement of the termite resistance of OSB made of betung bamboo. These results may support our present results. However, future studies are needed to elucidate the mechanism underlying the improvement of the termite resistance of sendan PB by solvent extraction.

## CONCLUSIONS

Sendan, which is indigenous to Japan, was used for the fabrication of PB, and its mechanical properties and biological performance were studied for furniture and construction purpose. In addition to PB, solid wood of sendan and sugi was used in decay resistance and termite resistance tests. The results are as follows:

1) The mechanical properties of sendan PB were comparable to those of recycled PB, which is used for commercial purposes. The MOR values obtained in our study were larger than those reported in a previous work, while the MOE values were similar. In the previous study, the PB of *M. azedarach* was made using urea-formaldehyde resin adhesive. The p-MDI adhesive used in our study may have affected the MOR and thickness swelling of sendan PB.
2) In the decay resistance test, sendan heartwood exhibited the lower resistance against a white-rot fungus, *Trametes versicolor* than sugi heartwood. Moreover, sendan PB showed the lower resistance against *T. versicolor* and a brown-rot fungus, *Fomitopsis palustris* in comparison with recycled PB.
3) In the termite resistance test, the sendan heartwood specimen showed the strongest resistance against a subterranean termite, *Coptotermes formosanus* among all the samples. For specimens containing sapwood, the resistance was slightly lower. Sedan PB exhibited the higher termite resistance than recycled PB.
4) Extraction of sendan heartwood by organic solvents resulted in causing significant reduction of the termite resistance. This clearly suggests that extractives which can be removed the organic solvent are responsible for its termite resistance. On the contrary, extractives-removed sendan PB showed higher termite resistance than non-extracted sendan PB.

Sendan wood has a good resistance for biodeterioration because of extractives. Sendan PB has a good performance for construction use, as stated above.

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