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The effects of drying temperatures on preservative retention and penetration of some Malaysian fast-growing species timbers

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ABSTRACT

This study was conducted to investigate drying properties of some Malaysia fast-growing species timbers exposed to drying under different temperatures, and evaluated the effects of these drying temperatures on preservative retention and penetration of the dried timbers. Four Malaysian fast-growing species, namely acacia (*Acacia mangium*), rubberwood (*Hevea brasiliensis*), sentang (*Azadirachta excelsa*), and kelempayan (*Neolamarckia cadamba*) obtained from a local plantation in Kelantan, Malaysia were used in this study. Drying specimens with dimension of 30 × 150 × 500 mm were dried under air-drying condition, a constant temperature of 60, 80, 100, and 120 °C until the moisture content of the specimens reaches an equilibrium moisture content at each drying condition. The drying properties of the specimens were then examined. After drying, stick specimens with a dimension of 20 mm (radial) × 20 mm (tangential) × 110 mm (longitudinal) obtained from the heartwood of the drying specimen were immersed in cupper azole (CuAz) wood preservative solution for 10 minutes under normal atmospheric pressure for rubberwood and kelempayan, and 30 minutes for acacia and sentang. Retention and penetration of the specimens were evaluated. The results confirmed that drying temperature had a significant effect on drying time. Drying under air-drying condition demanding considerable time, particularly drying acacia and sentang under air-drying condition required longer drying time than the other timber species. Drying temperature also had significant effects on preservative retention of all timber species, except kelempayan. The results demonstrated that preservative retention of all timber species tends to increase as drying temperature increased. In addition, high-temperature drying gives a positive effect on preservative penetration. Drying acacia under temperature of 100 °C could maintain a higher percentage of preservative coverage area until a sufficient depth from the penetration surface. This finding suggests that high-temperature drying is more desirable for better preservative retention and penetration of the specimens used in this study.

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KEYWORDS
Fast-growing species; drying; preservative retention and penetration; anatomical feature

Introduction

Malaysia is establishing large-scale plantations for reforestation and production of wood for pulp and paper as well as for light building construction purposes. It was reported that the Malaysian government set a target to establish 375,000 ha of forest plantations by 2020. The reforestation program is mainly focused on two major timber species, namely rubberwood (*Hevea brasiliesis*) and acacia (*Acacia mangium*), and the other timber species, including sentang (*Azadirachta excelsa*) and kelempayan (*Neolamarckia cadamba*).[1,2]

It is well known that fast-growing species planted in forest plantation grows faster than the other species from natural forest. Thus, fast-growing species have short growth rotation resulting sustainability of timber supply. Unfortunately, timber obtained from forest plantation usually has inferior properties, especially its natural durability, and utilization of the timber has been limited to pulp, paper, and fuel woods. Therefore, we suggest that the timber obtained from forest plantation should be treated to improve its durability and thus can increase its economic value in a wider range of end-uses.

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Generally, preservative treatment is used to improve the durability of the timber. One of the desirable characteristics of good preservative treatment is the ability of the preservative to penetrate the timber to a reasonable depth. Timber characteristics such as anatomical features are one of the factors affecting preservative treatability. Other factors include moisture content (MC) of the timber and drying method used to dry the timber were reported to have significant effects on preservative retention and penetration. It was reported that timber with high MC is not suitable to preservative impregnation, and thus it has been recommended that MC of the timber has to be reduced before preservative treatment.[3]

In some reports, timber exposed to high-temperature drying has higher permeability than that exposed to air-drying or conventional kiln-drying. This is because high-temperature drying triggered resin movement and modified resin properties. Moreover, high-temperature drying also caused partially damaged in some wood cell elements such as apertures in some bordered pits and minor-crack occurrence in the cell walls.[4–7]

In contrast, some authors reported that the permeability of the timber tends to decrease as drying temperature increased. Comstock and Côté[8] investigated the effect of drying methods on gas permeability in some coniferous sapwoods and reported that high-temperature drying corresponds with lower gas permeability due to aspirated pit. Similar results were found in Japanese cypress sapwood. Sakagami et al.[9] investigated the effects of drying temperature on preservative permeability of the timber, and reported that reduction in permeability was associated with the appearance of aspirated bordered pits due to high-temperature drying.

Another perspective was described by Rhatigan et al.[10] They investigated the effects of drying temperatures on gas permeability and the preservative treatability of western hemlock. The results identified that drying temperatures had no significant effect on the gas permeability of western hemlock. Interestingly, drying temperatures were found to have a considerable effect on preservative penetration. A higher preservative penetration of the timbers dried under high-temperature drying was obtained when ammoniacal copper zinc arsenate preservative was used, whereas the opposite result was found in chromated copper arsenate. These results offer vital evidence that preservative types also affect the treatability of timber.

These contradictory results are influenced by many factors. As stated above, drying methods and timber characteristics related to various anatomical features in different timber species, as well as preservative types, are some factors affecting the preservative treatability. Therefore, it is important to clarify the effects of drying temperature on the preservative treatability of every specific timber species. However, basic information regarding the effects of anatomical features, drying temperature, and preservative types on the preservative treatability of Malaysian fast-growing species are still insufficient and not clear yet. Therefore, this study was conducted to investigate the effects of drying temperature on the preservative treatability of some Malaysia fast-growing species timber. The focus of the study was on the effects of different drying temperatures on drying properties, and retention and longitudinal penetration of cupper azole (CuAz) wood preservative on acacia, rubberwood, kelempayan and sentang timber.

Materials and methods

Materials

Four Malaysian fast-growing species trees, namely acacia (*Acacia mangium*), rubberwood (*Hevea brasiliensis*), sentang (*Azadirachta excelsa*), and kelempayan (*Neolamarckia cadamba*) obtained from a local plantation in Kelantan, Malaysia were used in this study. The trees with a height up to 20 m and the diameter at breast height up to 30 cm were selected and harvested for specimen preparation. The trees were then cross-sectionally cut to five logs of 500 mm length. The logs were then cut parallel to the grain, producing four sawn timbers with a thickness of 40 mm. In addition, four 50-mm-disc to determine the average initial MC of the timber were obtained from each tree. The average initial MC of the timber was 97.8, 52.7, 42.0, and 75.8% for acacia, rubberwood, sentang, and kelempayan, respectively. The sawn timbers were then processed to drying specimen with a final dimension of 30 × 150 × 500 mm. Cutting diagrams of the specimen are shown in Figure 1.

Copper azole (CuAz) wood preservative was used in this study. CuAz wood preservative is a relatively new kind of wood preservative product with high efficiency and low environmental impacts. CuAz solution 1:30 (g/g) was used to treat the timbers.

Methods

Drying

A total of three drying specimens obtained from the same log was dried under the same drying condition

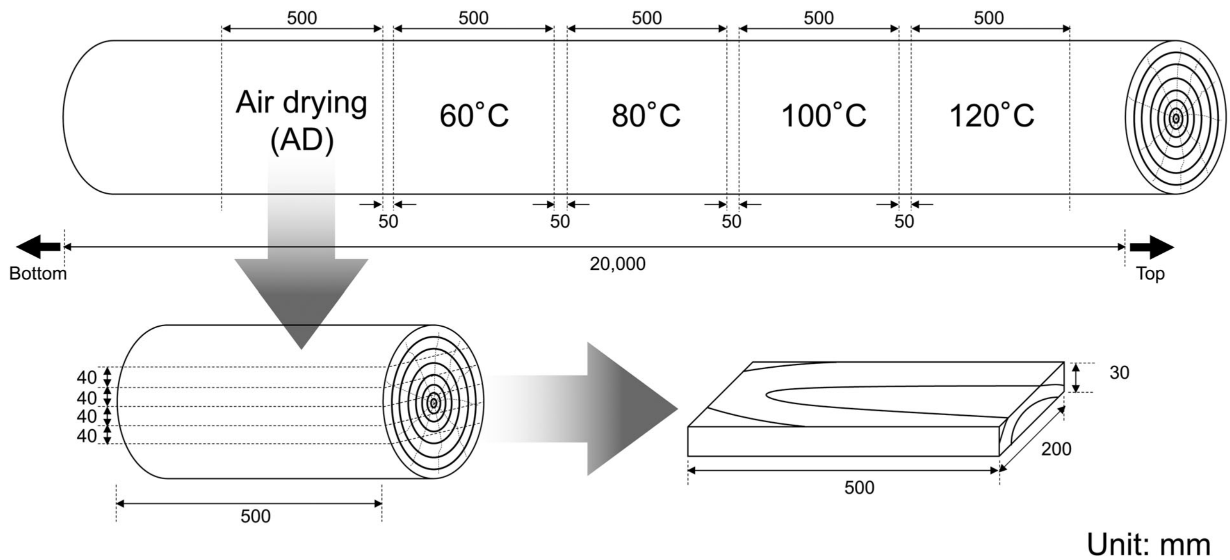

Figure 1. Cutting diagram of the specimens.

Table 1. Drying conditions.

Temperature (°C)	Relative humidity (%)	Equilibrium Moisture Content (%)
Air-drying	–	15.4*
60	78	12.5
80	80	11.6
100	87	11.8
120	–	3.0**

*Obtained from annual average temperature and relative humidity in Jeli, Kelantan, Malaysia.
**Obtained from measurement of wet-bulb depression.

by using laboratory controlled temperature and humidity chamber until moisture content (MC) of the specimens reach equilibrium moisture content (EMC) under each drying condition. Air-drying was conducted in an open-air under the shaded area. Laboratory oven was used to dry the specimens under the temperature of 120 °C without relative humidity (RH) control. The drying conditions are presented in Table 1. Before drying, both ends of the specimens were sealed with silicone sealant to prevent excessive drying from the end-grain.

During drying, the weight of the specimens was periodically measured, and MC of the specimen was calculated and plotted against drying time, showing a drying curve of the specimens under each drying condition. In addition, the non-dimensional moisture ratio (MR) of the specimens under each drying condition was calculated and plotted against drying time. The MR curve was then fitted to the Newton model to identify drying parameter (k) of the specimens under each drying condition by using the following equation:

$$\mathrm{MR} = \frac{M_t - M_e}{M_i - M_e} = \exp(-kt) \quad (1)$$

where MR is non-dimensional moisture ratio, M_t, M_e and M_i are MC at t time, equilibrium MC and initial MC, respectively, k is drying parameter, t is drying time.

Lastly, the drying rate of the specimens exposed to drying under each drying condition was calculated by using the following equations:

$$\mathrm{DR} = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

where DR is drying rate, M_t and M_{t+dt} are MC at t, and t + dt time, respectively, t is drying time.

After drying, the specimens were stored under room temperature.

Preservative treatment

A total of four clear stick specimens with a dimension of 20 mm (radial) × 20 mm (tangential) × 110 mm (longitudinal) obtained from the heartwood of the drying specimens was used for preservative treatability evaluation. Before preservative treatment, the specimens were conditioned at a temperature of 20 °C and 66% RH by using laboratory controlled temperature and humidity chamber. The average MC and density of the specimen after conditioning were 11.5 and 0.59, 11.6 and 0.58, 13.6 and 0.60, and 14.0% and 0.42 g/cm^3 for acacia, rubberwood, sentang and kelempayan, respectively. As this study focused on longitudinal penetration, five surfaces of each specimen were sealed with epoxy resin, remaining one cross-section surface for preservative penetration purposes. The specimens were placed in a vacuum desiccator, and pressure inside the desiccator was adjusted to 21.3 kPa for 10 minutes to remove the air inside the specimens.

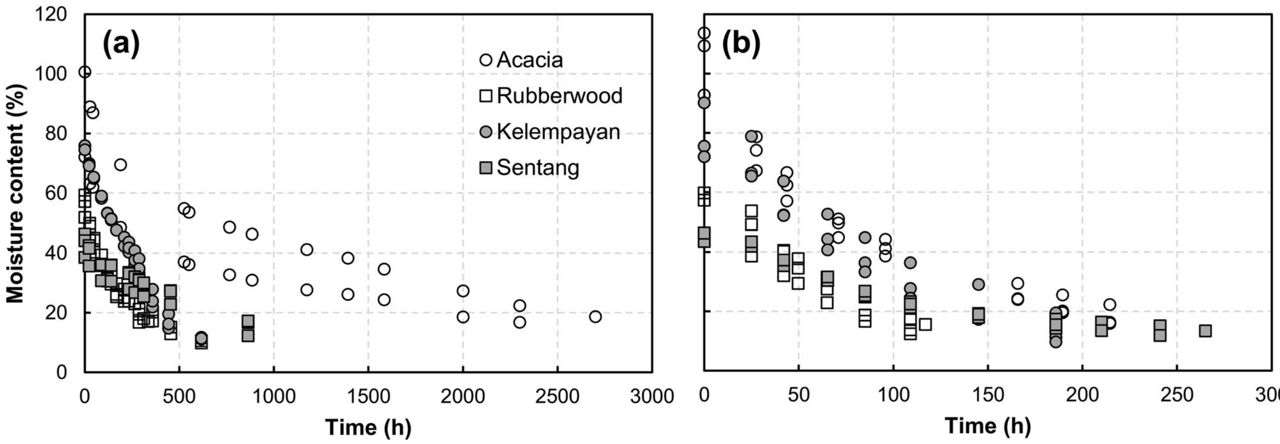

Figure 2. Drying curve of the specimen dried under air-drying condition (a) and temperature of 80 °C (b).

The preservative was then inserted into the desiccator, and the specimens were immersed for 10 minutes under normal atmospheric pressure for rubberwood and kelempayan, and 30 minutes for acacia and sentang.

The amount of preservative retention was calculated from the weight of each specimen before and after preservative immersion. For preservative penetration evaluation, each specimen was cross-sectionally cut at a 10-mm-length interval starting from the preservative penetration surface to around 50 mm depth resulting in six consecutive 10-mm-length specimens. Each cross-section of 10-mm-length specimens was then spread with a 0.5% solution of Chrome Azurol S in 1% sodium acetate to reveal the preservative coverage area and then scanned with a flatbed scanner. The preservative coverage area was identified by a binary method using ImageJ software. The percentage of the preservative coverage area of each cross-section of the 10-mm-length specimen was then calculated.

Microscope image

Images of wood cell elements such as vessel and fiber of the specimens dried under each drying condition were taken by a digital microscope (SEL-80, Selmic co., ltd, Kusatsu, Japan). Images were acquired with a CCD camera of 1.3 million pixels. Radial surface smoothed with a razor under a microscope was observed.

Results and discussion

Drying characteristics

Figure 2 presents a typical drying curve of the specimens dried under air-drying condition (a) and temperature of 80 °C (b). As predicted, the specimens dried under air-drying condition have longer drying time in comparison to those drying under the other drying conditions. As can be seen from the figure, drying acacia under air-drying condition has the longest drying time, which required more than 2,500 h to reach MC of 15.4%. The results are consistent with other recent findings showing that drying time required to dry a 30-mm-thick acacia from an initial MC of 96.5 to 21.4% under air-drying condition was 102 days.[11] These results confirmed that drying acacia under air-drying condition demanding considerable time. This is because acacia is well known for its high initial MC, presence of wet pocket, as well as for high variation in MC distribution,[12,13] and thus leads to a longer and irregular drying process. In addition, although sentang has a relatively lower initial MC, drying sentang under air-drying condition required longer drying time in comparison to kelempayan and rubberwood. This is probably due to the presence of depositions of looked like extractives in the vessel of sentang heartwood.[14] It is well known that dried extractive deposition gives a negative effect on the permeability of timber due to partial or total occlusion and becomes a barrier to liquid or gas flow.[15,16] Figure 2 also shows that drying acacia, kelempayan, and sentang under temperature of 80 °C required relatively the same drying time, and as can be seen in Figure 3b, the MR curve of those specimens was almost similar.

Table 2 summarizes the drying parameter (k) of the specimens dried under each drying condition. It was reported that k value corresponds with drying kinetic, and thus k value has a tendency to increase as drying temperature increased. From the table, it can be observed that drying acacia under air-drying condition has the lowest k value, and thus has the longest drying time. In addition, drying sentang under air-drying condition has a lower k value than kelempayan and rubberwood. This finding was in line with the result stated above that drying sentang under air-

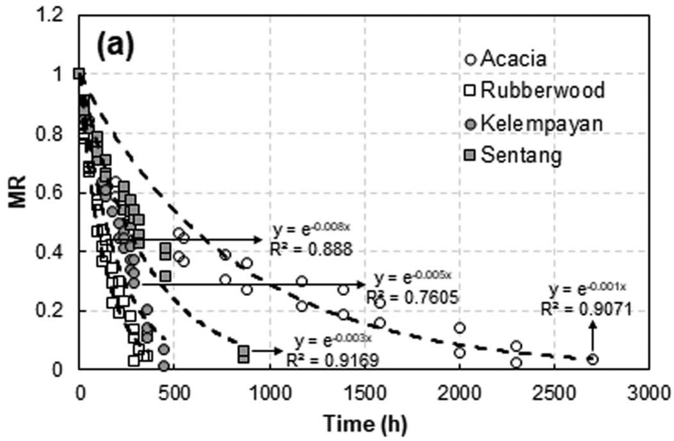

Figure 3. Non-dimensional moisture ratio (MR) curve of the specimen dried under air-drying condition (a) and temperature of 80 °C (b).

Table 2. Drying parameter (k) of the specimen dried under each drying condition.

	k			
Temperature (°C)	Acacia	Rubberwood	Kelempayan	Sentang
Air-drying	0.001	0.008	0.005	0.003
60	0.003	–	0.019	0.015
80	0.012	0.021	0.013	0.012
100	0.016	–	0.021	0.023
120	0.048	–	0.090	0.059

Note: Measurement was not conducted.

drying condition required longer drying time in comparison to kelempayan and rubberwood,

Figure 4 illustrates a typical drying rate of the specimens dried under air-drying condition (a) and temperature of 80 °C (b). The figure shows that at the same MC, drying rubberwood both under air-drying condition and temperature of 80 °C has a relatively higher drying rate in comparison to the other timber specimens. This finding proved that rubberwood has relatively higher permeability than the other timber specimens. This is probably because rubberwood is highly susceptible to fungi and other biodeteriorating organisms attack. As reported by several authors, fungi attack would increase the permeability of the timber due to the degradation of ray parenchyma cell walls and pit membranes.[17–19] Figure 4 also indicates that at the same MC, the drying rate of acacia, kelempayan, and sentang dried under temperature of 80 °C was almost similar. This finding confirmed the result stated above that drying acacia, kelempayan, and sentang under temperature of 80 °C required relatively the same drying time.

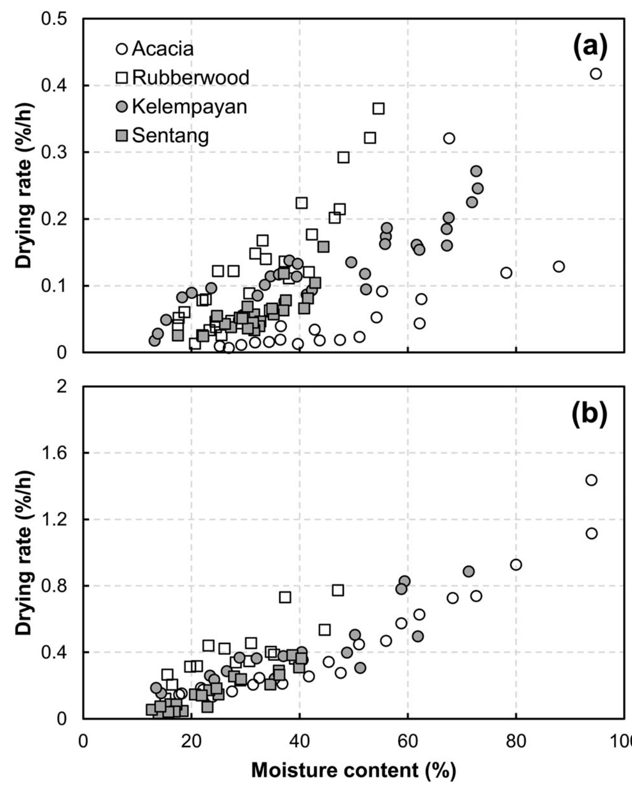

Figure 4. Drying rate of the specimen dried under air-drying condition (a) and temperature of 80 °C (b).

Preservative retention and penetration

Figure 5 shows the preservative retention of the specimens dried under each drying condition. As can be seen from the figure, preservative retention of the specimens tends to increase as drying temperature increased. The figure also describes that drying temperature has a significant effect on preservative retention of the specimens, except kelempayan. This tendency was observed clearly in sentang. Preservative retention of the specimens exposed to drying under temperature below 120 °C was relatively low, and drastically increase when dried under temperature of 120 °C.

In case of acacia, although preservative retention was lower than rubberwood and kelempayan, the

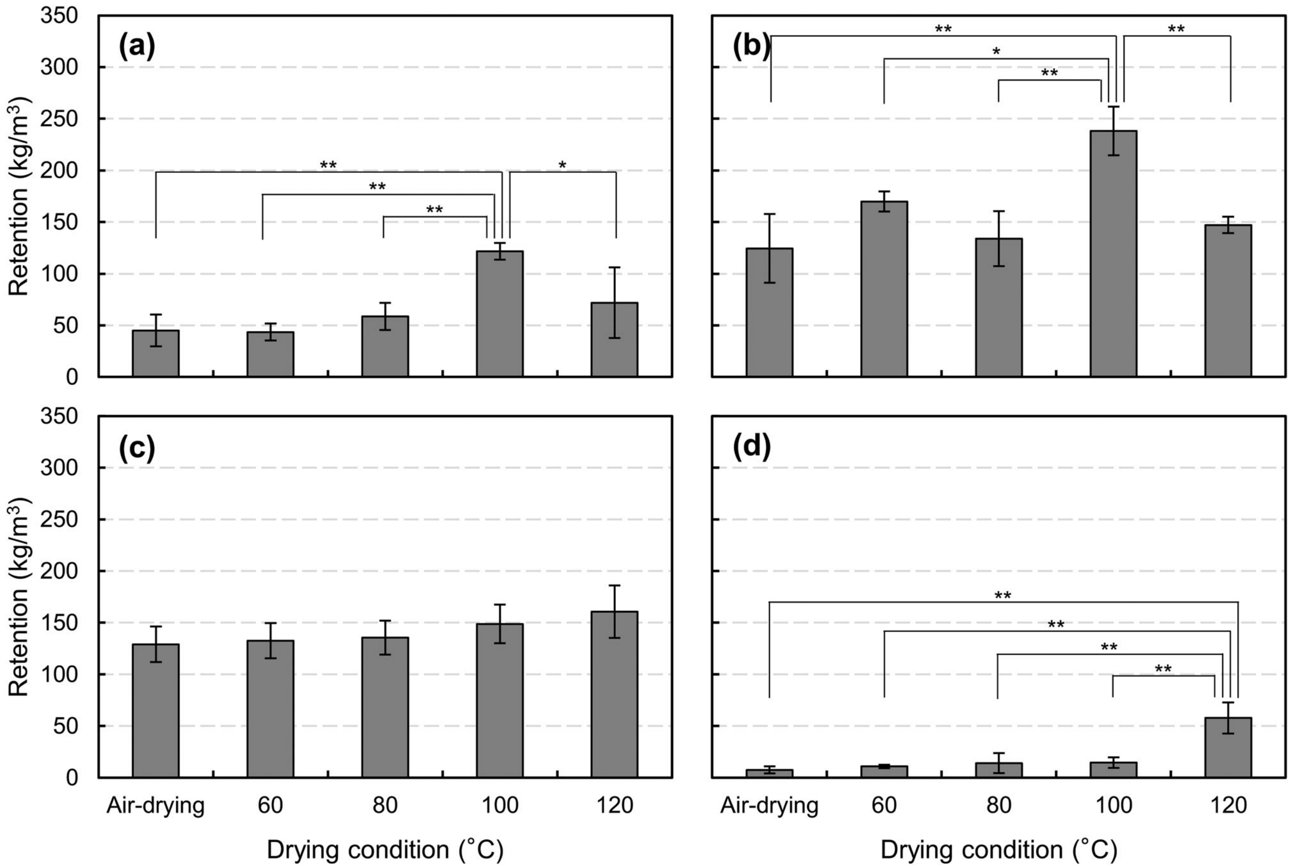

Figure 5. Preservative retention of acacia (a), rubberwood (b), kelempayan (c), and sentang (d) exposed to drying under each drying condition. *Note*: *: $p < 0.05$. **: $p < 0.01$.

Table 3. Selected anatomical properties of the species.

Properties	Species			
	Acacia	Kelempayan	Rubberwood	Sentang
Vessel diameter (μm)	150–280[28]	140–200[28]	150–240[28]	200–250[28]
Porosity	Diffuse-porous[14,28]	Diffuse-porous[28,29]	Diffuse-porous[28]	Ring-porous[14,28]
Vessel content	Filled with dark brown deposits[14]	Tyloses and deposits absent[29]	Rarely filled with tyloses[28]	Heartwood filled with dark-colored deposits[14]
Ray height (μm)	230–450[28]	2100–4700[28]	150–1850[28]	350–650[28]
Fiber length (mm)	0.7–1.4[28]	0.3–1.4[30]	1.1–1.4[31]	0.8–1.5[28]
Fiber diameter (μm)	15–30[28]	30.1–40.2[30]	26.7–33.5[31]	15–27[28]
Fiber wall thickness (μm)	1.5–2.5[28]	4.1–5.6[30]	5.1–5.8[31]	2.5–3.6[32]

highest preservative retention was obtained from the specimens dried under temperature of 100 °C followed by the specimens dried under temperature of 120 °C. It is believed that higher preservative retention was closely related to internal check occurrence in the specimen exposed to high-temperature drying because many internal checks were appeared in the specimens dried at temperature of 100 °C. It is well known that internal check occurrence increases as drying temperature increased due to the high level of drying stress reversal before MC of the specimens reach below the fiber saturation point.[20–22] Moya et al.[23] reported that drying defects such as internal check, split, and warp in acacia are much higher than other fast-growing species in tropical regions. This internal check opening improved the pathways of preservative penetration into the specimens, and many authors have reported that internal check gives a positive effect to liquid permeability[24–26] and as consequences increased the preservative retention of the specimens. However, severe internal checks could affect the mechanical properties of the timber, and thus considerable attention must be paid when used for structural purposes.

Although Nasrou and Shahrani[27] stated that longitudinal permeability of wood was affected mostly by vessel diameter, and fiber dimensions, however, as summarized in Table 3, these anatomical characteristics

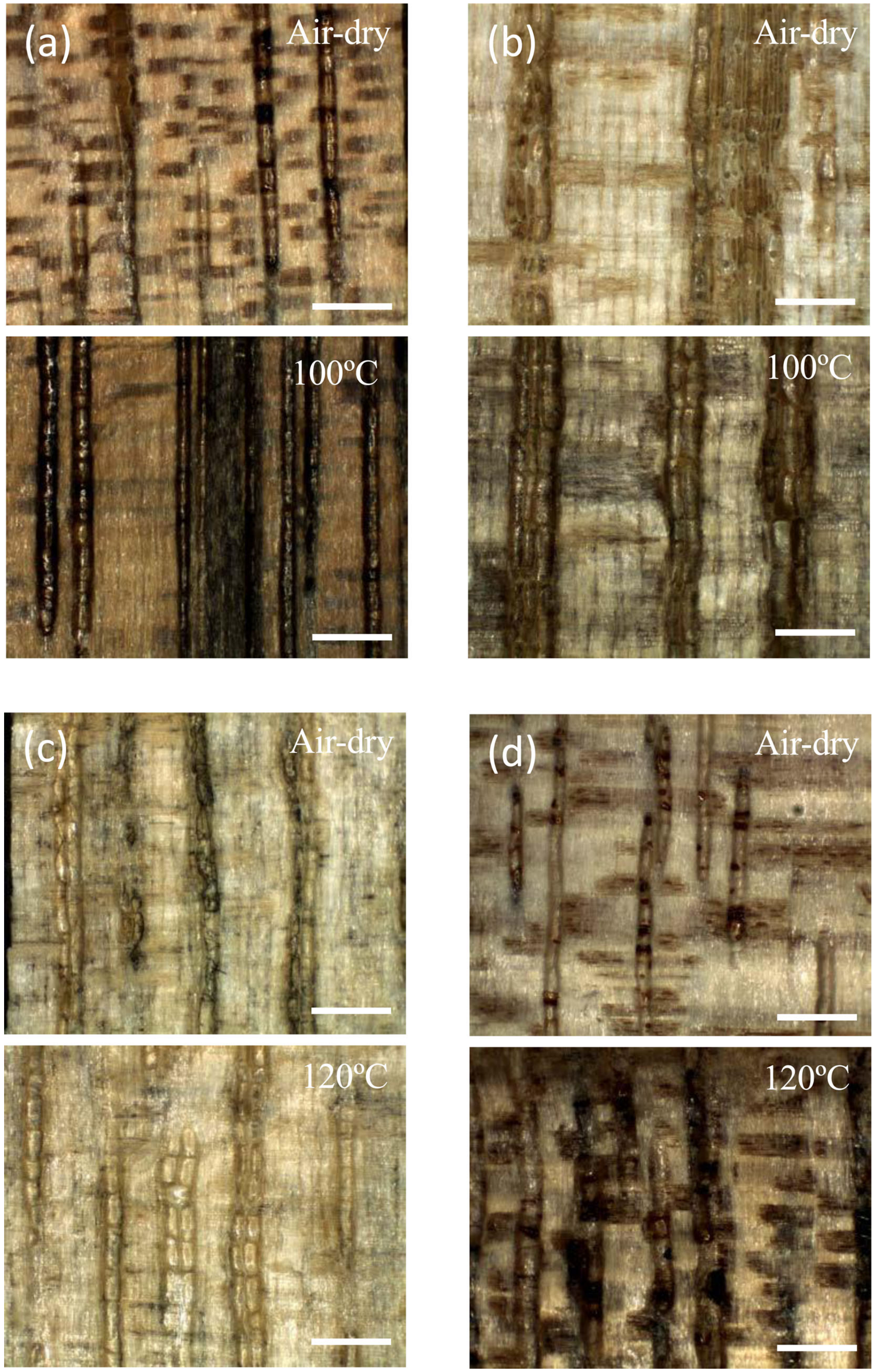

Figure 6. Microscopic images of acacia (a), rubberwood (b), kelempayan (c), and sentang (d). Air-drying condition and higher temperatures of 100 or 120 °C are shown upper and bottom sides, respectively. White bars show 500 μm.

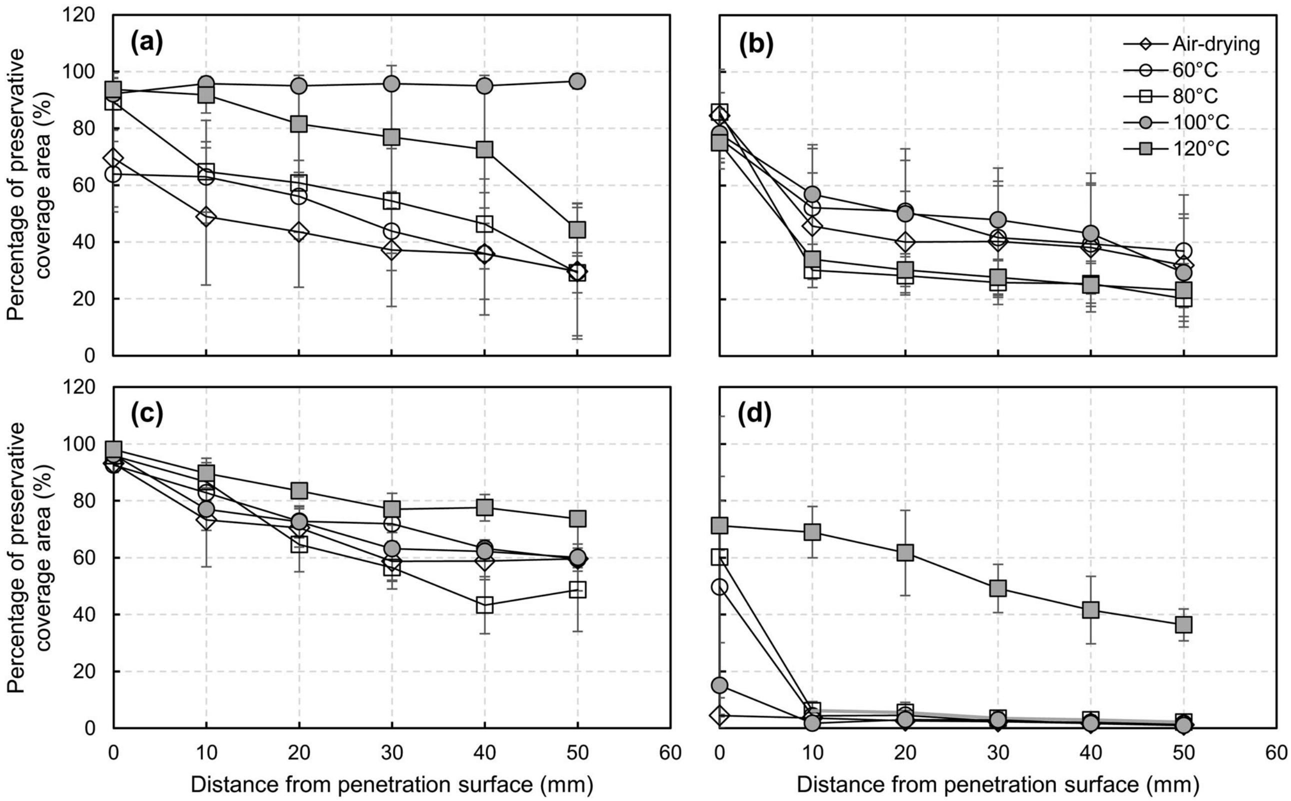

Figure 7. Percentage of preservative coverage area from the preservative penetration surface to a 50-mm-depth of acacia (a), rubberwood (b), kelempayan (c), and sentang (d) exposed to drying under each drying condition.

seem not to be related to the preservative treatability of the specimen. On the other hand, vessel content appears to have a considerable impact on the permeability of the specimen. Images taken by a digital camera on the radial surface of the specimens dried under air-drying condition and higher temperatures of 100 °C or 120 °C were illustrated in Figure 6. The reason showing lower preservative retention in acacia and sentang was clearly proved with these images. Many depositions of looked like extractive were observed in the vessels of the specimens dried both under air-drying condition and temperature of 100 or 120 °C. It was assumed that the penetration of preservative through the vessels was obstructed by the presence of these depositions, which appear in all specimens dried under each drying condition. In contrast, less or no deposition was observed in the vessels of rubberwood, and kelempayan could be associated with increased fluid permeability and thus resulting in higher preservative retention. An increase of preservative retention, especially in sentang dried under high-temperature drying might be triggered by an improvement of liquid flow in the vessels of the specimens due to removal or relocation of thermally softened or melted depositions in response to MC gradients during drying, which was assumed by the images of the specimens including darker colored-fibers and deformation of the depositions. However, more detailed research is expected to reveal the reason for the enhancement of preservative retention of the specimens dried under higher temperatures.

Figure 7 compares the average percentage of the preservative coverage area of the specimen dried under each drying condition. It can be seen from the figure that the specimens dried under high-temperature drying could maintain the percentage of preservative coverage area in comparison to those dried under lower temperatures. Particularly in acacia, the specimens dried under a temperature of 100 °C could maintain the percentage of preservative coverage area above 90% until a 50-mm-depth from penetration surface. As stated above, this is because internal check occurrence increase with increasing the drying temperature, and these checks improved the pathways of preservative penetration into the specimens. A similar tendency was observed in sentang. However, the percentage of preservative coverage area in sentang was relatively low in comparison to the other specimens. The results revealed that the specimens dried under air-drying condition have the lowest percentage of preservative coverage area. This finding suggests that high-temperature drying is more desirable for better preservative penetration into the specimens used in this study.

Conclusions

In this study, we investigated drying properties of some Malaysia fast-growing species timber exposed to drying under different temperatures and evaluated the effects of these drying temperatures on preservative retention and longitudinal penetration of the dried timbers. The results confirmed that drying temperature had a significant effect on drying time and drying under air-drying condition demanding considerable time in comparison to the other drying conditions used in this study. Particularly drying acacia and sentang under air-drying condition required longer drying time than the other timber species. Drying temperature also had significant effects on preservative retention of all timber species, except kelempayan. The results demonstrated that preservative retention of all timber species tends to increase as drying temperature increased. In addition, high-temperature drying gives a positive effect on preservative penetration. Drying acacia under temperature of 100 °C could maintain the percentage of preservative coverage area until a sufficient depth from the penetration surface. This finding suggests that high-temperature drying is more desirable for better preservative retention and penetration of the specimens used in this study.

However, further work on preservative penetration in the radial and tangential direction is needed to elucidate the effects of drying temperatures on preservative treatability, including the development of preservative treatment methods based on the drying characteristics of each species for industrial purposes.

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