Wood Permeability Assessment of Young Teak (*Tectona grandis* L.f.)

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Abstract

Wood properties of young teak (*Tectona grandis* L.f.) is inferior, and then preservative treatment is one possible solution to enhance its service life. The uptake and movement of preservatives through wood cell structure is directly connected to the wood permeability. There are two simple methods to identify wood permeability: water soaking and bubble test methods. This paper assesses the young teak permeability by water soaking and bubble test methods. The assessment was conducted on five cm thick young-teak discs by soaking in the red-dye water and blowing air into the discs which had been coated with soap. Results show that the heartwood is less permeable than sapwood. Red-dye penetrates almost 100% of the sapwood area, and the red-dye did not penetrate in the heartwood. The red-dye only penetrates in the cracked heartwood through the void volume in the cracking heartwood. There is a transition zone between sapwood and heartwood, and it is refractory. Bubble test with air pressure from compressor could open the air-pathway in the heartwood and sapwood of young-teak discs taken from Bogor (wet site). The bubble test result of young-teak discs from Madiun (dry site) showed air-pathway only in the sapwood, but not in the heartwood. The air pressure is not capable of moving the vapour through the wood cell. It indicates that the heartwood of young-teak from Madiun is less permeable and less possibility for pressure treatment.

Keywords: Young-teak, permeability, water soaking, bubble test, heartwood, sapwood, transition zones.

Introduction

Teak wood (*Tectona grandis* Linn. f) is one of the most valuable woods for the construction of boats, furniture, flooring, decorative objects, and decorative veneer. However, the use is limited due to scarcity and high cost. Mature teak heartwood has excellent dimensional stability and a very high degree of natural durability. In general, teak is worked with moderate ease with hand and machine tools (Falk 2010). Mature teak is mostly harvested from the plantation at the age of 50-80 years old in India and Indonesia (Soerianegara and Lemmens 1994). This long rotation has caused the price of teak wood to increase significantly due to a limited supply. Iskak (2005) stated that the shortage of teak as a raw material had been estimated at approximately 2 million m^3 per year. Consequently, timber industries that rely on teak as raw material face difficulties in its continuity of supply (Krisdianto and Sumarni 2006).

This situation motivates the silviculturists to investigate various methods which would allow establishing a shorter rotation and a faster growth of teak. One of the methods already developed is through vegetative cultivation, such as tissue culture, bud grafting and shoot cutting. As a result, the rotation age can decrease from 50-80 years to 20-40 years (Yunianti 2012). Fast-growing tree with high productivity forest plantations is becoming an essential supply of wood in the tropics, especially in the countries where agricultural and forest sectors support the economy. Increasing wood production is important since the commercial dimensions are reached in a relatively short period (Kanninen 2003). However, this intensive timber production may induce alteration in the anatomical and technical properties, and as a result, the suitability of the wood for high-quality products is reducing (Saranpaa 2003). In Indonesia, many varieties of fast-growing teak have been widely cultivated. Timber communities call this timber "super teak". One of them is *Jati Utama Nasional* (JUN). The combination of breeding technology and intensive silviculture treatment has enabled teak timber producers to harvest the tree at a very young age of 5 years old.

The inferior characteristic of young teak could be overcome by preserving timber in the means of penetrating preservatives into the timber, to improve its service life (Lebow 2010). Preservative treated wood can be protected from the attack of decay fungi, harmful insects, or marine borers. The uptake and movement of preservatives through the wood cell structure is directly connected to the wood permeability. In 2007, Kamke and Lee mentioned that permeability is physical properties of wood related to the ease with which fluids are transported through a porous under differential pressure, indicating the magnitude liquid flow in the material and varying factors such as chemical and anatomical properties, flow direction and type of fluid. Ahmad and Chun (2009) and Pokki *et al*. (2009) stated that wood permeability is of great variability due to structure and vessels orientation, which facilitates longitudinal flow and play a major role in the movement of liquids.

There is a variation of wood permeability radially. Liquid penetration into the wood cell varies according to the wood cell component, shapes, and cell wall content, which allows liquid penetration through diffusion. Heartwood being less permeable, showed a reduction in the volume of vapour that moved through the wood as well as much lower moisture content compared to the sapwood. Between heartwood and sapwood, there is a transition zone which is claimed as refractory. Barnacle and Ampong initially studied the wood transition zone in 1974. Hillis (1987) mentioned that the transition zone is: *"a narrow, pale-coloured zone surrounding some heartwoods and injured regions, often containing living cells, usually devoid of starch, often impermeable to liquids, with a moisture content lower than the sapwood and sometimes also the heartwood."* The state of permeability variation is obvious. This paper studies the permeability of young teak wood transversely by observing young-teak disc by a simple method of water soaking and bubble soap.

Materials and Methods

Sample Preparation

Twenty 5-year old fast grown teak discs were collected from Bogor area (A) and Madiun area (B). The disc collected from Bogor area represented the teak which has been planted in the wet area, while disc from Madiun area known as teak from the dry area. Five cm thick discs (14-29 cm in diameter) were cut from the breast-high teak tree and grouped into water soaking and bubble soap methods. Both disc surfaces were sanded by 150-grit sandpaper followed by 400-grit sandpaper for uniformity. The discs were then air-sprayed to clean up the sawdust and dirt on the surfaces.

Water Soaking Method

Twenty-five ml red-food-dye was diluted into a litre of aquadest in the plastic container. Teak wood discs were then soaked in upper-side one by one for four days. Red-dye water movements of the wick action from the bottom part into the upper part were identified carefully.

Bubble Test Method

On the upper part of the disc, liquid soap was coated in the 4 cm width line across the diameter through the pith to the bark. Parallel with the line through the pipe on the bottom part of the disc, and the air was blown through the air compressor, which set into 10 bar. The bubble on the upper surfaces shows the blown soap indicates the flowing pattern longitudinally.

Results and Discussion

Water soaking method showed red-dye penetrated to all of the sapwood portion of the discs and not the heartwood. Figure 1 shows red-dye penetrated in the sapwood and little crack of the heartwood.

The wick action of heartwood and sapwood part of the discs were investigated with distinct moisture distribution, and behaviours found. Heartwood, being less permeable, showed no red-dye penetration compared to the sapwood. The outer portion of the tree known as sapwood is living cell, the inner sapwood zone matures and dies as the wood ages.

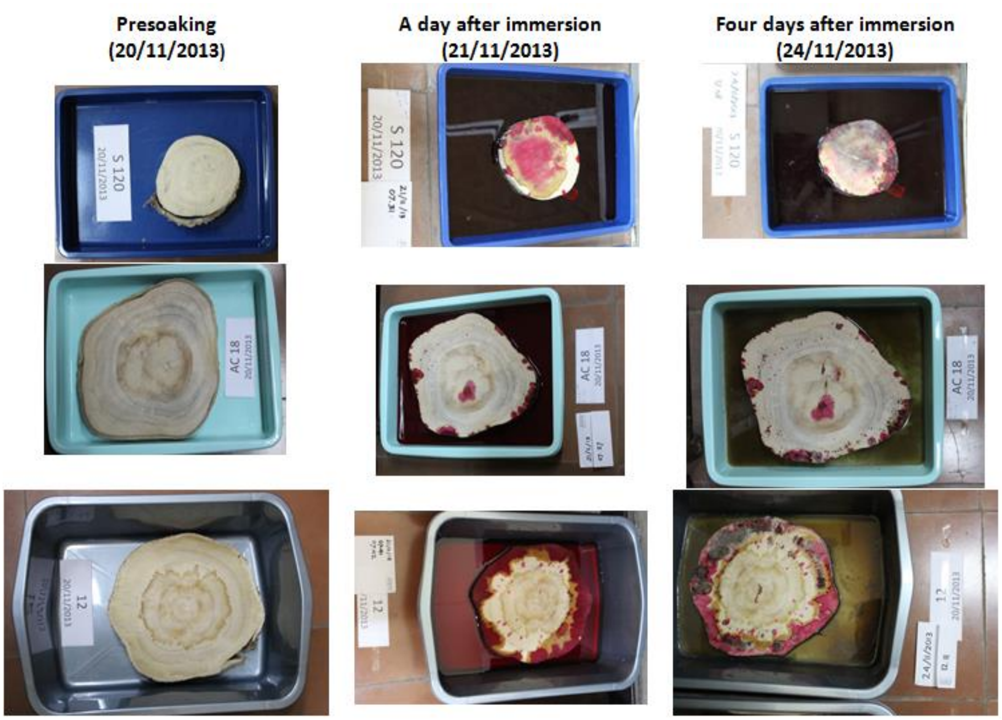


Figure 1. Red-dye penetration of the young-teak discs.

During the maturation process, extractives and other extraneous chemicals begin to precipitate in the pits and other fine pores of the lumen (Stamm 1964; Butterfield and Meylan 1980). The build-up of this material in the older sapwood alters various properties of the wood, including colour, permeability, density and durability (Kollman and Cote 1968). The dark non-conducting inner wood is known as heartwood, which could be 100 times less permeable than sapwood from the same tree. The permeability change is usually gradual, with the inner wood being the least permeable. Diffusion is not limited by permeability, with the diffusion coefficient of heartwood being only slightly less than the corresponding diffusion coefficient of sapwood (Stamm 1964).

In teak wood, there is transition zone lays between sapwood and heartwood and it is known as the refractory zone, which may raise problems in preservative treatments in teak wood (Barnacle and Ampong 1974) and similarly found in poplar (Murphy *et al.* 1991). Barnacle and Ampong (1974) observed preservative problems associated with the occurrence of a relatively wide zone of intermediate wood nearly impermeable to treatment in fence posts cut from 15 cm in diameter of 15-year old un-pruned plantation-grown *Tectona grandis* trees, and alternating penetrated. Non-penetrated bands of heartwood in some preservative-treated small fence posts. The characteristics of this zone were pale in colour, in contrast to sapwood, about 1.5 cm in width, free from starch, impermeable, and containing tyloses. This phenomenon was also observed surrounding the heartwood of *Manilkara multinervis.* Furthermore, observations made at the Forest Products Research Institute (FPRI), Kumasi, indicated that intermediate wood is a common feature in fence post of teak from at least one district in Ghana and that it is generally impermeable to treatment even at a pressure of 200 lb in^{-2} (Barnacle and Ampong 1974).

The same phenomenon was also observed in another hardwood genus, poplar. In the course of study on the CCA treatment and durability of poplar timber, a zone of refractory wood at the sapwood/heartwood boundary was observed. The most striking feature of CCA in *Poplar tacamahaca x trichocarpa 32* was the observation of an impermeable zone, generally consisting of two growth rings, at the boundary of the sapwood and heartwood (Murphy *et al.* 1991). Furthermore, in 2012, Norton conducted a vacuum pressure impregnation using copper-based preservative system (CCA and Copper Naphthenate) on six and a half year old of teak containing sapwood and heartwood obtained from tropical north Queensland Australia. The result showed that from the six specimens, the outer zones of the sapwood were fully penetrated and the heartwood remained un-penetrated. The transition zone is apparent in samples 9, 10 and 12 and is not penetrated (Figure 2).

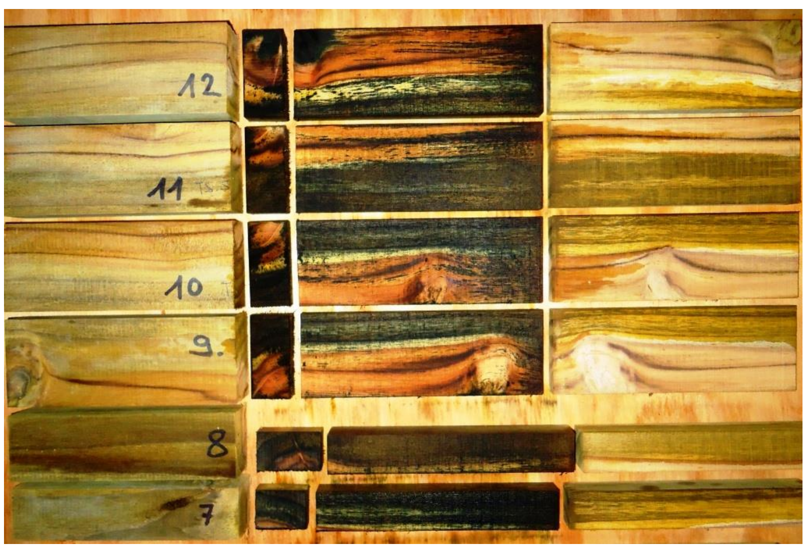


Figure 2. CCA treated test specimen from Australia. (Source: Norton 2012).

The part at least of the relatively white or colourless appearance of the transition zone is due to a moisture content that is lower than that of the adjacent sapwood and sometimes the heartwood. In *Taxus baccata* felled in late autumn, the moisture content (MC) of the transition zone (50%) was less than that of the heartwood (100%) and the sapwood (130%) (Craib 1923 in Hillis 1987). Yazawa and Ishida (1965b in Hillis 1987) found a similar but less marked contrast with *Sorbus*, *Acer*, *Cornus*, *Magnolia*, *Acanthopanax*, *Octrya*, *Tilia*, and *Quercus* species. In *Pinus radiata,* the MC of the transition zone is similar to that of the heartwood (about 40% on a dry weight basis) compared with 160% for the surrounding sapwood (Shain and Mackay 1973a in Hillis 1987).

The width of the transition zone usually about 1-3 growth rings, can vary seasonally, that depends on site and climatic conditions (Shain and Mackay 1973a in Hillis 1987). Samples were taken at increasing heights in the tree reach a level where heartwood is no longer present, and only the transition zone and sapwood exist (Hillis 1987). In irrigated and non-irrigated specimens of various provenances of the latter species, the transition zone had the same width of almost one growth ring (Polge 1982 in Hillis 1987). Different to Shain and Mackay (1973a in Hillis 1987), J.M. Harris (personal communication in Hillis (1987) observed a transient region of transition zone up to about 60 mm thickness within the dry wood zone of *Pinus radiata* which was present at all times. The transition zone of *P. radiata* grown in New Zealand first become evident in late winter at a point some distance up the tree extends upward and downward in the tree during early spring. It disappears in late spring and early summer, presumably with the formation of heartwood (Harris 1954 in Hillis 1987). With the same species are grown in Australia, a dry transition zone was observed in all trees examined throughout the year (Shain and Mackay 1973 in Hillis 1987).

Transition zones occur around mechanical injuries, as in *Sorbus alnifolia* (Yazawa and Ishida, 1965b in Hillis 1987), or the wounds formed by S*irex noctilio* in *Pinus radiata* and around the necrotic, phenol-enriched sapwood of *Picea abies* affected by *Formes annosus*. Usually, the transition zone is up to 3 mm wide in *Pinus radiata* and with a width of less than one growth ring, up to 7 mm wide in *Eucalyptus* species and a width of less than two growth ring and *Cryptomeria japonica* can have a width of 10-18 mm containing 4-10 growth rings (Nobuchi and Harada 1983 in Hillis 1987).

In some species, the dark discolouration can be found in the heartwood boundary that is the third type of stain formed during the transition of sapwood into the heartwood. Two other types of dark discolouration are found in fully functional sapwood as a result of injury, and the second is found in normally coloured fully mature heartwood. Sachs et al. (1966 in Hillis 1987) observed these three types of dark discolouration in the wood of living *Quercus*. The specific gravity of the sapwood-heartwood boundary stain is greater than either the adjacent sapwood or heartwood and its ash content is lower than the adjacent sapwood. Still, there are more copious amounts of dark-coloured substances than in normal heartwood. The distribution of these substances varies from surrounding the annual rings to other confined to one quadrant of the stem.

Longitudinally, their length varies from one or two meters to the entire length of the stem connecting a large crown branch with a major root (Hillis 1987; Murphy *et al*. 1991). Almost all the tree examined (Bulgrin and Ward 1968 in Hillis 1987) which contained sapwood-heartwood boundary stain were found growing on moist soils which might even have been water-saturated for extended periods. Some stains at the heartwood boundary or transition zone were formed with neither bacteria nor fungi being detected in the discoloured wood. It was considered that the general site characteristics, together with soil pH and soil texture, may be involved. Similar strains have been observed in *Acer* and *Juglans* species (Good et al. 1955 in Hillis 1987; Hart and McNabb 1963 in Hillis 1987; Scheffer and Cowling 1966 in Hillis 1987).

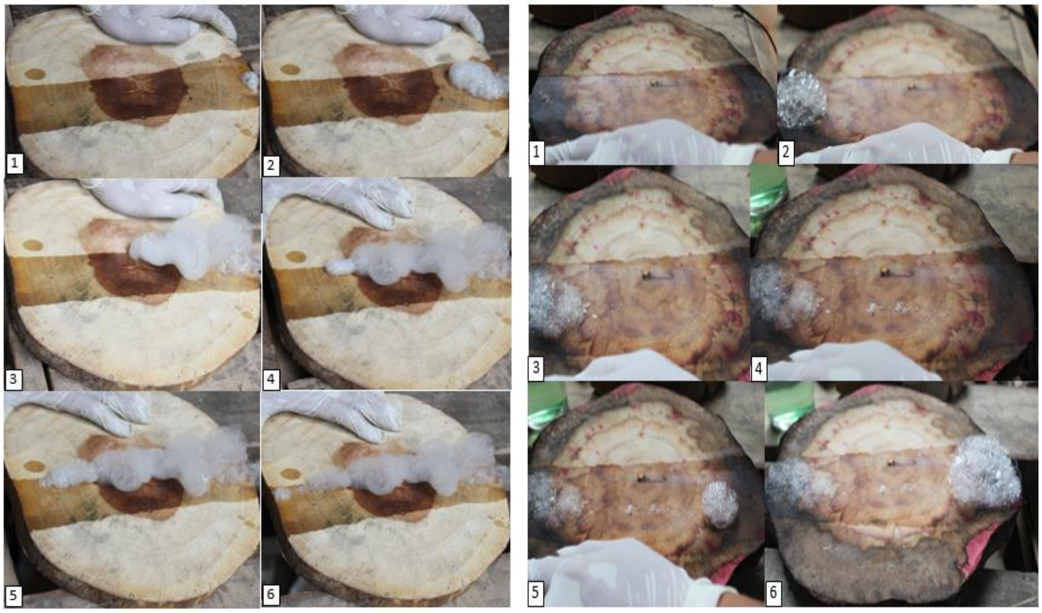
Panshin *et al.* (1964) stated that the highest resistance of wood is in transition between sapwood and hardwood. The inner heartwood of teak was less resistant to pathogen attack than the intermediate or outer heartwood (Kokutse *et al.* 2003). These similar results have been found in teak (Simatupang and Yamamoto 1999), as well as tropical species, e.g. *Piptadeniastrum africanum* (Deon *et al.* 1980), and temperate species, e.g. *Castanea sativa* (Dumonceaud 2001).

The function of this structure in heartwood formation is uncertain. The sharp boundaries have been associated with a sudden, and sometimes abrupt, aspiration of pits at the outer edge of the transition zone in conifers (and tyloses in some hardwoods) (Hillis 1987). It appeared that the presence of substantial lipid deposits in ray tissues of sapwood/heartwood zone could be a significant factor influencing the lateral impermeability of this region. This lipid could be redistributed during the flow of the preservative liquid into the wood leading to blockage of pits, or the lipid may exert a protective effect on pit membranes and prevent cracking during drying (Murphy *et al.* 1991).

Furthermore, Hillis (1987) stated that the consequent market decrease in permeability of these tissues results in their separation from the water stored in the inner sapwood. These changes at the outer periphery of the transition zones have been attributed to water tension in the inner sapwood at times of physiological drought in the rest of the tree so that gas accumulates in the inner layers, the pits aspirate, and tyloses form. Initiation of the formation of the transition zone in those species with regular heartwood formation is more likely to be caused by activation of the parenchyma in the inner sapwood than by water stress. As the parenchyma (and the resin canal epithelium when present) remain alive, the loss of water would take place from the surrounding tissues of the transition zone (Hillis 1987).

Although starch has been detected in the transition zone in some species, the translocation of a considerable amount of primary metabolites from the sapwood to the transition zones is required to form the high level of extractive found in some heartwoods. This could take place through the living ray parenchyma over a period of time, and the moisture required by those heartwoods wetter than the transition zone could pass through the same route (Hillis 1987).

In the majority of cases, the impermeable zone extended for most of the length of the sample (about 700 mm) (Hillis 1987; Murphy *et al*. 1991). This impermeability was not only seen on lateral faces but also affected the axial permeability/movement of preservative. As such, it may be a considerable barrier to the extent of penetration achievable in poplar round wood even in the case where sapwood and heartwood are both permeable. More work should be carried out before firm conclusions are drawn on the significance and causes of this effect (Murphy *et al.* 1991). Furthermore, Barnacle and Ampong (1974) stated that the characteristics referred to the refractory intermediate zone (if common in all size of teak), could make difficult the quality control of commercial treatment plant operations, viz, the determination of true retention figures.



A. Bogor (wet) disc samples B. Madiun (dry) disc samples

Figure 3. Bubble test results in the young-teak discs.

Figure 3A shows the bubbles appears in the upper surfaces (heartwood dan sapwood) of discs collected from Bogor (wet area). In contrast, bubbles do not appear in the heartwood part of discs originated from Madiun (dry area). The airflow from the bottom part of the discs creates bubble on the upper surfaces indicates the airflow is capable of moving the vapour through the wood. In the young-teak discs from Bogor area, the void volume is decreased caused by air pressure from the bottom part of the discs. It indicates the possible pressure treatment to enhance wood permeability. In young-teak discs collected from Madiun, the bubble only appears in the sapwood part. It indicates that the heartwood of young-teak discs originated from Madiun is less permeable and less possibility for possible pressure treatment. Possibly, it was because teak wood from dry site is thought to have more extractive materials than wood from wet locations (Damayanti *et al.* 2020).

Conclusions

Red-dye water absorption and soap bubble methods are visible for wood permeability indicators. The heartwood of young-teak wood is less permeable than sapwood, and the transition zones are refractory. The transition zones may induce problem in preservative treatment, then additional pre-treatment should be conducted prior to preservative treatment. Bubble methods shows permeability indicators with pressurized air flows through the discs. The heartwood and sapwood of young-teak discs collected from Bogor is permeable, while the heartwood of young-teak discs collected from Madiun is impermeable. The heartwood of young-teak originated from dry area is not readily treated with pressure preservative treatment.

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