A Review: Effect of Heartwood Proportion in Wood Properties

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Abstract

This study aims to examine the effect of heartwood proportion on wood properties for construction materials by reviewing 98 journal articles and non-articles. The data were collected through an online search using seven keywords: heartwood proportion, heartwood effect, physical properties, mechanical properties, wood dimensional stability, wood gluing, and wood preservation. By eliminating the irrelevant papers, 45 journal articles and non-articles were selected. The review shows that the proportion of heartwood has a positive correlation with wood density and dimensional stability. High wood density will have a positive correlation with the mechanical properties of wood. However, the dimensional stability is not only affected by the proportion of the heartwood but also the microfibril angle and the arrangement of the wood cells. Further, sapwood has a higher moisture content than heartwood. The high moisture content causes the wood drying process to take longer and require more energy. However, it should be noted that the heartwood in some Acacia species has a higher moisture content than that in the sapwood, which is commonly called wet heartwood. Therefore, a suitable treatment is needed to minimize the moisture content in the heartwood. In addition, heartwood is difficult to preserve because of the high extractive content in the lumen. The color of the wood is another important indicator to determine the quality of wood, especially the heartwood color, because it is related to the aesthetic value and durability of the wood. Meanwhile, a better understanding of the acid and alkaline properties of extractive substances is necessary to perfectly conduct the wood gluing process.

Keywords: Heartwood proportion, heartwood effect, wood density, mechanical properties, dimensional stability

Introduction

Heartwood is located in the inner layers of the wood and is physiologically inactive in the growing tree; these inner layers are not involved in the physiological process or no longer contain living cells (IAWA committee 1964). The reserve material, such as starch, is removed or converted into heartwood (IAWA committee 1964). Heartwood could optimize the sapwood volume and provide structural support (Taylor *et al*. 2002). Heartwood is one of the most important parameters, including in wood economic values, because it could affect the final use of wood. Heartwood is necessary to the final wood product, especially for wood construction, because it provides natural durability and an excellent color that is associated with heartwood extractives. In contrast, sapwood parts are more susceptible to wood-destroying organisms and have a pale color. The sapwood most often has a light color and low biological resistance while the heartwood has a higher resistance to decay and is darker than sapwood (Moya and Berrocal 2010; Thulasidas *et al*. 2006). Some species form colored heartwood because the xylem parenchyma cells synthesize heartwood substances, such as polyphenol groups, which contribute to wood's color and natural durability before its death (Bamber and Fukazawa, 1985; Hillis 1987; Magel 2000; Taylor *et al*. 2002).

Heartwood proportion has a negative impact on the quality of pulp and paper; such a condition is caused by the high extractives of the heartwood and by pitch problems (Jansson and Nilvebrant 2009; Lehr *et al*. 2021). However, if the wood is used for construction materials, the large heartwood is highly necessary because it will positively affect the basic properties of the wood, such as physical properties (basic density, moisture content, and wood color), mechanical properties (modulus of elasticity, modulus of rapture, and compression strength from the parallel to the grain), dimensional stability (shrinkage and swelling), wood finishing, and natural durability (Armstrong *et al*. 1984; Rust 1999; Singleton *et al*. 2003; Grabner *et al*. 2005; Ekeberg *et al*. 2006; Pratt *et al*. 2007; Ayobi et al., 2011; Uetimane Jr and Ali 2011). Several previous studies have reviewed the effect of extractives on pulp, paper, and natural durability (Taylor *et al*. 2002; Jansson and Nilvebrant 2009; Lehr *et al*. 2021). However, to date, only a few studies have reviewed the effect of heartwood on its basic properties of the wood. Therefore, this study will review the effects of heartwood on the wood's basic properties.

This study aims to conduct a literature review of the heartwood's effects on the basic properties of wood. This study identified articles and non-articles were through online searches from different search engines. The keywords for searching journals and non-journal articles are "heartwood proportion," "basic density," "wood color," "mechanical properties," "dimensional stability," "wood drying," and "wood finishing." This study collected 98 journal articles and non-journal articles. However, after eliminating some duplicating and irrelevant manuscripts, 45 were combined for this study (Figure 1).

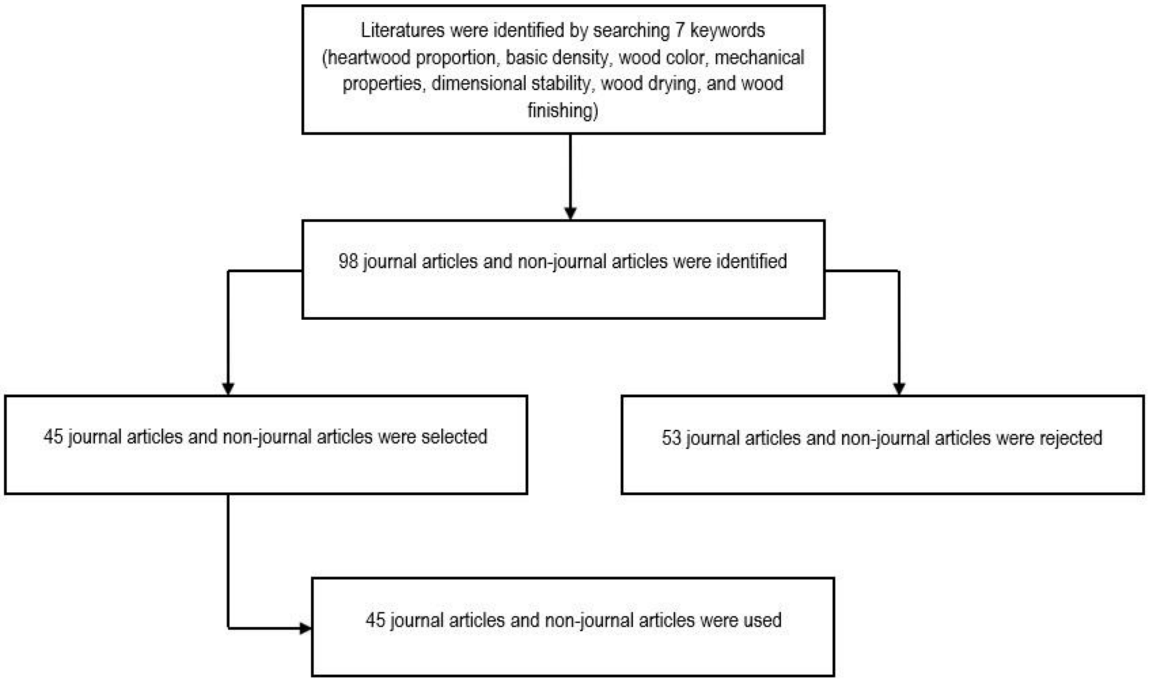

Figure 1. Review processes for this study.

Heartwood and Natural Durability

Heartwood is known to contain a lot of extractives, including phenolic extractives, which provide an attractive appearance to the color of the wood and show natural durability that acts as a potential bio-protectant against various pathogens (Kampe and Magel 2013). Natural durability is intended to wood-decay fungus attack due to extractive antifungal. Martinez-Sotres et al. (2012) report that hexane extract of *Dalbergia congestiflora* wood with medicarpine as the predominant antifungal compound causes inhibition of fungal growth up to 100%. However, wood biodeterioration is caused not only by fungi but also by insects, such as termites, beetles, and marine borers (Kampe and Magel 2013). Tsuruta *et al*. (2011) report that *Pinus thunbergii* heartwood is rich in alpha-terpineol and longifoline, which are components that inhibit the growth of red tide plankton. Therefore, it is proposed as a useful construction material.

Recent publications emphasize extractives of heartwood or heartwood that exhibit fungitoxic and termiticide activities (Kampe and Magel 2013). This is important because termites cause large economic losses to wood, especially in the tropics region. Dungani *et al*. (2012) report that quinones appear to be the dominant toxic component for termites in the extracts of the *Tectona grandis* heartwood. Acetone water from the oldest part of the heartwood shows a mortality rate of up to 100% in the termite of *Coptotermes curvignathus*. Rodrigues *et al*. (2011) report that rubrynolide from *Sextonia Rubra* wood is identified as the most effective protective agent against termites. Because of its potential to inhibit the growth of tropical and invasive termites, rubrynolide is a potential substitute for synthetic termiticides.

Heartwood, Moisture Content, and Basic Density

One of the most important traits required for the utilization of wood is the moisture content of the logs. Growing trees contain an adequate amount of moisture for about 50% of their fresh weight (Larcher 1995). Most of the moisture must be removed to obtain satisfactory performance for the most frequently used wood. Wood with a higher moisture content dries slower than one with lower moisture content and is generally more susceptible to drying defects (Simpson 1991).

Heartwood is also known to have a lower moisture content than sapwood (Rust 1999). In most tree species, the moisture content of heartwood is different from that of sapwood. Taylor *et al*. (2002) state that hardwoods depend on species because it has lower moisture content than sapwood in conifers. In general, high wood density has lower moisture content due to the proportion of heartwood with low moisture content. It could be related to the density of the wood.

Heartwood proportion has the highest extractive concentration, which could contribute to basic density. Singleton *et al*. (2003) explain that extractives could affect basic density values in 19 young-growth western hemlock samples. Moreover, they deploy that the concentration of extractives is slightly higher and near the pith (1-5 rings) and has the highest basic density along the radial profile.

Furthermore, Imamura (1989) explains that wood extractives are mainly located in the lumen cell, which fills empty spaces in wood, reduces porosity, and increases density. Therefore, the presence of a high extractive content in wood is an advantage for materials of construction or furniture. Several authors have also mentioned that the basic density in heartwood is higher than that in sapwood in some species (Ayobi *et al*. 2011; Uetimane Jr and Ali 2011). Aguilera and Zamora (2009) express that the basic density value in the heartwood (0.71 g. cm^{-3}) is higher than that in sapwood (0.60 g. cm^{-3}). The difference between sapwood's densities and heartwood's densities is partly related to the amount of extractive embedded in the vessels of heartwood and parenchyma cells (Uetimane Jr *et al*. 2009). Thus, the resulted difference between the strength properties of sapwood and heartwood is most likely explained by density due to its widely known effect on several mechanical properties (Armstrong *et al*. 1984; Grabner *et al*. 2005). The same pattern is also found in the mechanical properties (MOR and compressive parallel to the grain) due to the effect of extractive in the heartwood (Ayobi *et al*. 2011). The significant amount of extractives is stored in heartwood twice or three times as much as that in sapwood (Panshin and de Zeeuw 1980).

Heartwood does not always have a lower moisture content than sapwood. Yamamoto *et al*. (2003) argue that the moisture content of *Acacia mangium* (*A. mangium*) and hybrid acacia wood in heartwood is 253% compared to 149% and 154% in sapwood, respectively. It is also mentioned that the moisture content of *A. mangium* from Malaysian heartwood is around 100–110%, and that in sapwood is 80–90% (Anon 1977). Heartwood with high moisture content is usually called wet wood to indicate an abnormal type of heartwood (Ward 1984). However, Yamamoto *et al*. (2003) claim that the heartwood of Acacia species is normal because heart rot and high concentrations of inorganic elements in the heartwood are not recognized.

The heartwood of *A. mangium* and Acacia hybrid particularly near the pith will be referred to as "wet heartwood" because it has higher moisture content than sapwood. Wet wood or "wet heartwood" causes problems during wood drying. Due to a large amount of water in the logs, especially in the heartwood of Acacia species, the drying times become longer (Ward 1984) and could cause problems for sawn timber production in the wood industry. Moisture content could be related to tree growth ecology. Fast-growing species, such as the Acacia species, may absorb excessive water from the soil; thus, they could have a negative effect on soil properties and cause high moisture content in the heartwood. Further studies should be carried out to identify suitable conditions to produce acacia wood with lower stem moisture content.

Heartwood and Dimensional Stability

The presence of extractives affects the drying process of wood. Several studies have investigated the effect of chemical extractives on drying shrinkage of several species (Stamm and Loughborough 1942; Adamopoulos 2002; Hernandez 2006; Hernandez and Almeida 2007) and discovered that removal of wood extractives impacts shrinkage behavior. The dimensional changes of wood could be increased by removing the extractives (Choong and Achmadi 1991; Militz and Homan 1993; Mantanis *et al*. 1994; Adamopoulos 2002). In 1986, a study of 12 *Eucalyptus* species after chemical extraction (Chafe 1986) has revealed positive and negative correlations between extractive content and shrinkage, depending on the selected solvents. This condition indicates that all metabolites do not have the same effects. In addition, Ayobi *et al*. (2011) have revealed that the shrinkage and swelling of the heartwood in *Quercus castaneaefolia* are greater than that in the sapwood. The shrinkage variation is influenced not only by the sapwood-heartwood ratio but also by the microfibril angle, the presence of a gelatinous layer, moisture content of fluctuations from zero to fiber saturation point, wood rays, and different arrangement of the fibers in the cell walls.

Heartwood and Wood Color

Heartwood extractives contribute to the color that is related to the aesthetic values of the wood. The darker color is produced by the secondary metabolites, namely extractives of the heartwood, which give the heartwood natural durability and aesthetic characteristics. Thus, the quality and commercial values of wood are largely based on the extractive quality and quantity of the heartwood (Hillis 1987; Taylor *et al*. 2002; Ekeberg *et al*. 2006). Meanwhile, there is a large color difference between sapwood and heartwood; the selection of wood components based on color also plays an important role in some wood applications (Dzifa *et al*. 2004). Color is an important factor in determining certain uses, such as furniture and decorative coating that refer to pivotal marketing attributes (Mazet and Janin 1990). Wood color in the heartwood is also related to the natural durability of the wood which has been intensively studied (Gierlinger *et al*. 2004; Bhat *et al*. 2005; Kokutse *et al*. 2006; Lukmandaru and Takahashi 2008; Moya and Berrocal 2010). The relationship between color and decay resistance is not direct but is based on extractive effects in both parameters (Gierlinger *et al*. 2004). However, durability and natural coloration do not always correlate with the extractive concentration of the heartwood (Hillis 1987; Taylor *et al*. 2002).

Conclusions

Heartwood extractives play an important role in improving the quality of wood for construction because of their effect on the basic properties of wood. It is positively correlated with the basic density, where a high density will improve the mechanical properties of the wood. Meanwhile, low wood density is commonly found in sapwood with a higher moisture content than in heartwood. The high moisture content causes the drying process to take a long time. Therefore, the energy required to dry the wood is greater. However, it should be noted that wet-heartwood in some species occurs such as in Acacia species. Fast-growing species like Acacia can absorb excess water from the soil. Thus, the heartwood can contain more water, which is called wet-heartwood, compared to the moisture content in the normal heartwood. Therefore, the selection of the good or suitable location is should be explored in further research. Extractive content in heartwood also has a negative correlation with the wood preservation process, because preservatives will be difficult to enter into the lumen cells that filled with extractives. Meanwhile, the process of gluing wood requires a good understanding of the acidity and wetness of the extractive substances on the adhesive used. In addition, the presence of heartwood extractives also contributes to stabilize the dimensions of the wood, considering that the shrinkage and swelling of the wood were smaller in heartwood than in sapwood. However, the wood dimensions are not only affected by extractive substances, but also was influenced by the microfibril angles and the arrangement of fibers in the cell wall. Therefore, evaluation of the wood quality for construction materials, is not only the ratio of heartwood and sapwood, but also the investigation of anatomical properties is should be conducted.

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