FRIM TIMBER TECHNOLOGY BULLETIN
NO. 111, 2021
ISSN: 139-258

SAPWOOD/HEARTWOOD PROPORTION OF PLANTATION LOGS

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INTRODUCTION

In the past, the proportion of the sapwood/heartwood of a sawlog was hardly a concern in the production of sawn timbers. During that time, the dimensions of logs were satisfactorily sizable in obtaining a substantial volume of sapwood-free planks. Sap-free timber is certainly preferred in the solid-form uses, especially for structural or exposed applications since it is relatively more durable against deterioration agents. Besides, in terms of timber-moisture relation, the heartwood is dimensionally more stable which is significant in producing boards with lesser drying defects. Furthermore, sapwood is relatively lower in resistance to insects and fungal attacks. Additional process such as chemical impregnation or heat treatment is required to increase durability; hence, it increases the manufacturing cost.

In plantation forestry, quantitative study of the sapwood/heartwood proportion is absolutely necessary to evaluate the quality and economics of the commodity. Unlike the trees of natural forest, plantation logs are much smaller in size. For instance, the logs of mature *Hopea odorata* were recorded of having an average of 100 cm in diameter at breast height, whereas plantation logs of 13-year-old trees ranged merely 20 to 30 cm (Figure 1). Moreover, due to the juvenility, the percentage of sapwood in plantation logs is considerably higher compared to logs of mature trees. For the production of sawn timbers from plantations, high percentage of heartwood is more preferable as both durability and grade are the decisive points in the market. Contrariwise, in pulp and paper making, the accumulation of extractives in heartwood causes higher consumption of pulping chemicals, lower pulp yield and brightness; thus, a higher percentage of sapwood is more economical.

This article is about the recommended methods and formulae with regard to the analysis of the sapwood/heartwood proportion of plantation logs. The analysis is useful to evaluate the expected output of the sawing procedure as an initial indication of the appropriate drying and machining processes, plus to provide insight on the probable usage of the timber.

Figure 1 The sapwood and heartwood of a *Hopea odorata* log from plantation

DISTINGUISHING BETWEEN THE SAPWOOD AND THE HEARTWOOD

Sapwood is the newly formed, outermost region timber of woody plant. It contains a variety of cell types, most of which are living and physiologically active. Sapwood has three main functions in the living tree i.e. support, conduction and storage. As the older sapwood cells age and die, they become heartwood. In contrast to the sapwood, heartwood has no living cells and neither conducts water or stores reserve materials. These changes occur gradually through a layer of cells of variable width known as the transition zone. In this zone, increased amounts of tannins (polyphenolics) and coloured materials are deposited in the rays and axial parenchyma and these materials diffuse into the surrounding tissue. The development of heartwood colour is due to this deposition. Most of the colours undergo a change with age, becoming darker and more brown. Frequently the heartwood substances are unevenly distributed giving rise to bands of wood of different colour. Nevertheless, a great number of timber species do not produce coloured heartwood (Bamber 1987).

The analysis of the sapwood/heartwood proportion is performed on the cross-sectional surface of either the sample disc or the log itself. Although the literal definition of the sapwood and heartwood is straightforward, the actual exercise to differentiate the two regions is rather complicated. In reality, distinguishing the sapwood from the heartwood is not always easy. The sapwood/heartwood of some timber species are visually similar. Even if they are different in colour, the exact boundary between the sap and heartwood is sometimes confusing. The cross-sectional image of the sapwood/heartwood of some plantation species are presented in Appendix 1. Below are the common methods to distinguish between the sapwood and the heartwood of a log.

Based on the colour of the timber

For the sapwood/heartwood of different colours, the boundary can be distinguished through visual observation of pigment dissimilarity. However, the colour differences can either be demarcated or gradually changing. For demarcated boundary such as in *Tectona grandis*, the sapwood/heartwood proportion is clearly defined and should be easily measured (Figure 2). On the other hand, the gradual pigmentation change through the sapwood/heartwood boundary in some timber species such as *Khaya ivorensis* is difficult to evaluate (Figure 3). In such case, the usual practice is to consider the central part of consistent colouration (usually darker) as the heartwood whereas the gradually changing pigmentation towards the bark as the sapwood.

Figure 2 A demarcated boundary of sapwood/ heartwood in *Tectona grandis*

Figure 3 A gradually changing pigmentation through the transition zone in *Khaya ivorensis*

Exposure to sunlight

For some species, the colour of the timber surface can be slightly "adjusted" by exposing to sunlight. The exposure of timber to ultraviolet and radiant heat from sunlight for certain period of time can enhance the pigmentation; hence, it enables a more reliable analysis. For example, the natural colour of *Dialium* spp. sapwood is white to yellowish white and the heartwood is golden brown or red-brown. The heartwood darkens to dark brown on exposure (Figure 4). This pigmentation change is generally superficial.

Figure 4 The colour of *Dialium* spp. darkens on exposure (left) and a newly cut cross-sectional surface of *Dialium* spp. after exposure (right)

Fungi growth method

An alternative method to distinguish the proportion of sapwood/heartwood is by observing the staining of the timber surface caused by fungal attack. Sample disc is placed under the exposure to weathering to allow for the growth of fungi. Since heartwood is more resistance to decaying agents, the development of fungi on the surfaces of the sapwood and heartwood is distinct. Thus, sapstain fungi are normally observed on stockpiled round logs (Figure 5). The regions of the sapwood and heartwood can be visually distinguished and easily measured.

Figure 5 Sapstain in *Khaya ivorensis*

Density profile method

The transition point between sapwood and heartwood zones can be determined by plotting the density values of the timber in the radial direction, i.e., from the pith towards the bark (Figure 6). This method is particularly useful for species with non-distinct colouration between the sapwood and the heartwood. Small cubic specimens are cut in-line from the pith towards the bark in both opposing radius. The sapwood/heartwood boundary is normally taken at the transition point in the density curve. However, the results are expected to be less accurate.

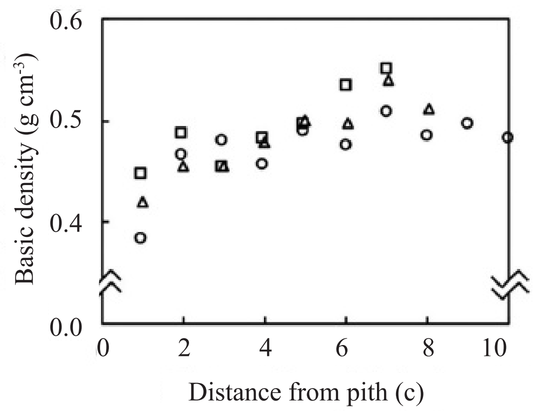

Figure 6 An example of a density profile in radial direction (Ishiguri et al. 2021)

Chemical method

The differences of cellular contents and distribution in the heartwood, sapwood, and bark are distinct, thus enable investigators to differentiate them through chemical analyses (Xiao et al. 2019). The heartwood generally contains more lignin than the sapwood, and chemical compound such phloroglucinol and acid solution can be used to detect the presence of lignin in timber (Blaschek et al. 2020). Besides, it was reported that the transition zone between the heartwood and sapwood has a specific chemical composition which make it easy to be determined (Bertaud & Holmbom 2004).

THE BARK

The bark is another obvious region of a log when observed on the cross-sectional surface. Bark thickness varies with species, age and tree height. It is important to note that in the production of sawn timber, the cross-sectional surface of a log is usually assessed excluding the bark. The bark of many species has fissures and voids which can lead to incorrect estimation of the merchantable timber. The thickness might differ even between trees of the same species and age. Nevertheless, since the bark is an important source of biomass and has other potential uses, data regarding the bark of plantation sawlogs is undoubtedly valuable. For instance, knowing the volume of a round log inclusive of the bark in the studies of forest-based energy is worthy of note.

MEASUREMENTS AND ANALYSES

Measurement of bark

The bark refers to the outermost anatomical layers of the log which consist of outer bark, inner bark and cambium. The thickness of the bark is measured on the cross-sectional surface using a ruler or a tape. Since the thickness of bark is not consistent even in a tree, it is recommended to conduct the measurements at several samples based on different height. Bark with fissures forms a fluted-like outer surface. The thickness of the bark in a sample could be varied; thus, a single value is averaged from the minimum and maximum measurements (Figure 7):

$$B = \frac{b_{max} + b_{min}}{2}$$

where B is the thickness (mm) of the bark of a sample disc/log, b_{max} is the maximum thickness measurement (mm), and b_{min} is the minimum thickness measurement (mm).

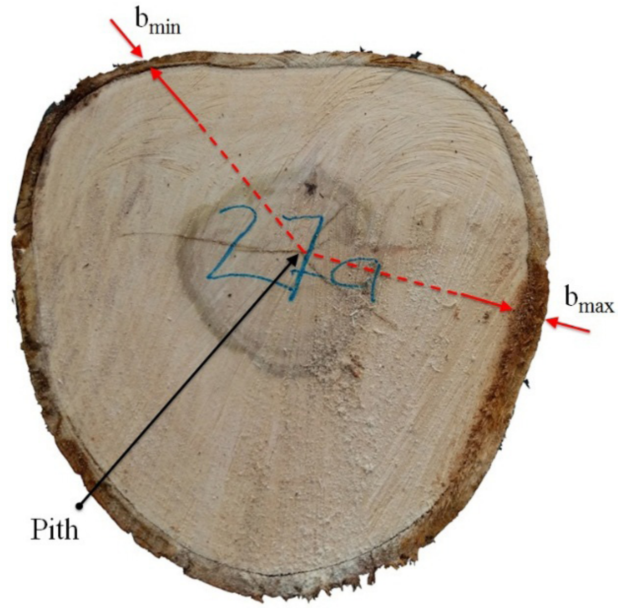

Figure 7 Measurements of bark

Diameter of log

Common profiles of the cross-sectional surface of logs are round and elliptical. The diameter of a disc/ log, D (cm) is measured based on the formula:

$$D = \frac{d_1 + d_2}{2}$$

where d_1 is the largest diameter (cm) across the pith and d_2 is the diameter (cm) measured perpendicular to d_1 (Figure 8). The diameter is customarily measured on the cross-sectional surface using a ruler or a tape. It is recommended to take the measurements across the pith for consistent and repeatable readings (If the measurement is made through the geometric centre, it shall be the same for the entire appraisal and the centroid point of each surface shall be marked). For logs of irregular cross-sectional profiles such as fluted, triangular, square, unsymmetrical, or crescent, detailed measurements of diameter can be referred to Mohd-Jamil & Nor Marzuina (2020). The diameter of a log can as well be measured using a diameter tape, but the results could be slightly different, especially for fluted logs.

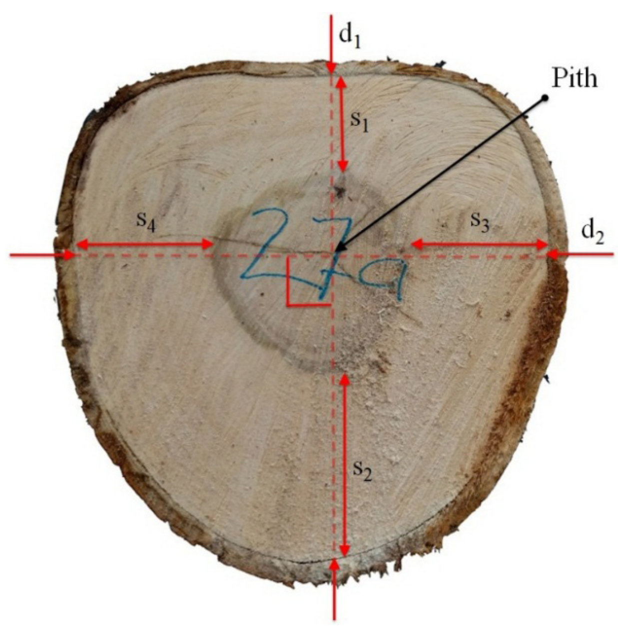

Figure 8 Measurements of diameter and sapwood

Percentage of sapwood

The radius of a disc/log, R (cm) is diameter, D divided by 2.

$$R = D/2$$

The width of the sapwood, S (cm) of a sample disc is measured based on the formula:

$$S = \frac{s_1 + s_2 + s_3 + s_4}{4}$$

where s_1, s_2, s_3 and s_4 are the measurements of width (cm) of the sapwood in-line with d_1 and d_2 (Figure 8).

Hence, the radius of the heartwood, r (cm) is S subtracted from R.

$$r = R - S$$

The percentage of sapwood, SW (%) of a disc/log is calculated using the formula (Reilly & Robertson 2006):

$$SW = \left(\frac{R^2 - r^2}{R^2}\right) \times 100\%$$

The percentages of sapwood of some plantation species are summarised in Table 1.

Table 1 The percentage of sapwood of some plantation species

No.	Species	Percentage of sapwood	Reference
1.	*Acacia mangium* (16-year-old)	Range: 5-18% Bottom: 12% Middle: 9% Top: 11%	Lim et al. (2011)
2.	*Azadirachta excelsa* (10-year-old)	Average: 57% Bottom: 48% Middle: 58% Top: 63%	Nordahlia et al. (2014)
3.	(*Eucalyptus* hybrid) *Eucalyptus grandis* × *E. urophylla* (5.8-year-old)	Bottom: 55-66% Middle: 69-87% Top: 76-95%	Zairul et al. (2020)
4.	*Shorea roxburghii* (12-year-old)	Average: 72%	Suffian et al. (2021)
5.	*Tectona grandis* (15-year-old)	Range: 35-55% Bottom: 48% Middle: 43% Top: 44%	James & Zamrie (2011)

SUMMARY

Quantitative study of the sapwood/heartwood proportion is absolutely necessary to evaluate the quality and economics of plantation logs. The actual evaluation of the sapwood/heartwood proportion is not straightforward. Several methods can be applied to distinguish between the sapwood and the heartwood regions based on the colouration, fungi growth method, chemical analyses or density profiling. Important formulae, shown herein, include the measurement of the bark, log diameter, and percentage of the sapwood can be used to assess the proportion of sapwood and heartwood of logs from plantation.

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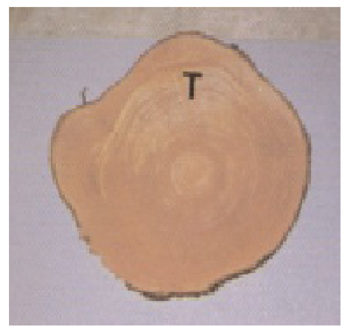
APPENDIX 1 CROSS-SECTIONAL SURFACES OF SOME PLANTATION SPECIES

Acacia mangium
16-year-old
Lim et al. (2011)

Azadirachta excelsa
10-year-old
Nordahlia (2013)

Eucalyptus grandis* × *E. urophylla
5.8-year-old
Zairul et al. (2020)



Hevea brasiliensis
Lim (1998)

Hopea odorata
13-year-old

Khaya ivorensis
15-year-old

Tectona grandis
15-year-old
James & Zamrie (2011)

Shorea macrophylla
22-year-old
Lim et al. (2011)

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The logs of plantation forest are much smaller in size and having a considerably higher percentage of sapwood when compared to the logs of natural forest. The research and development of plantation timbers emphasizes on the analyses of the logs in order to assess the expected output of sawmills, to give initial indication of the drying and machining processes, plus to provide insight regarding the potential usage. This article explains on the analysis and formulae concerning the proportion of the sapwood/heartwood of plantation logs.

Series Editor : Mohamad Omar MK & Ong CB
Managing Editor : Vimala S
Typesetter : Rohayu Y

Set in Times New Roman 12

Printed by Publications Branch, Forest Research Institute Malaysia
52109 Kepong, Selangor