ANATOMICAL CHANGES OF LIGHT COCONUT WOOD (*Cocos nucifera* L.) DUE TO STEAM-PRESS DENSIFICATION

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ABSTRACT

Coconut palm (*Cocos nucifera* L.) is known as 'multi-purposes tree' as almost all part of the tree can be utilised. Coconut timber utilization is limited on hard or denser part, while lighter coconut timber remains unused. Theoretically, mechanical densification could improve physical properties of light coconut timber, which may be useful for diversifying its uses. This study examined some anatomical changes in coconut wood that occurred during mechanical densification. Coconut wood samples measuring 40 mm thick, 40 mm wide and 50 cm long were steamed at 126^0C for 30 minutes prior to being compressed by 23.75 kg/cm^2 pressure. Anatomical measures were undertaken using light microscope and scanning electron microscope on both non-compressed and compressed samples. Results showed that the treatment significantly reduced void volume and increased vascular bundles frequency, decreased vessel and parenchyma cell diameter. The wood density also increased by more than 50%.

Keywords: Coconut, lightweight, density, compression, anatomy

I. INTRODUCTION

Coconut palm (*Cocos nucifera* L.) has been utilized for a very long time and known as multi-purposes tree (Heyne, 1950). These plants belong to family of Palmae, sub family of Cocoideae and is part of the so-called Cocoid palms (Tomlinson, 1961). Its distribution covers all coastal regions in the tropics reaching inland for approximately 200 km at altitudes of up to 300 m above sea level.

Coconut palm is known as 'multi purposes tree'. This is because almost any parts of the coconut trees, with some of the undergoing biological/physical/chemical treatments can be used for beneficial items, such as oils/fats, coconut milk steam-treated from shredded coconut fruit meat, vegetables, alcohols, woody fibers, charcoal carbonized from coconut shells and coconut timber as briefly described in the following. Oils and fats can be extracted from its dried endosperm of the nut; coconut milk is used as beverage and for cooking; vegetable is obtained from the youngest sprouts at vegetational tip; and alcoholic beverages is fermented from sap pressed from inflorescences. Still others are fibers for ropes, sacks and mats produced from the fruit mesocarp, charcoal for energy and medicinal use from the nutshell.

Coconut timber procured from round-shaped coconut tree stems has been processed at the industrial scale for furniture and households. Traditionally, coconut wood has been sawed for house construction, which is known as '*glugu*'. Coconut and other palm wood are

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extremely difficult to work with simple tools. Therefore, coconut wood at present is mainly employed as round wood for foundations, vertical support and bridge construction. In some areas, sawn coconut timber is also used for construction, furniture, souvenir and household. Coconut timber for such uses is taken from denser part, while the lighter part still so far remains unused.

As monocotyledon species, coconut tree has different growing system. It has no cambium so that it grows apically. In round wood, the tree is hard in outer and soft in central zone. Sulc (1976) in Frühwald *et al.* (1992) graded 60 year coconut timber into three density ranges: high, medium and low. Almost similar to the case of round wood, the lowest density portion originates from the center core of the coconut tree stem and upper part of the stem. Barly *et al.* (2004) reported 19 year old coconut timber density ranged between 100 - 900 kg/m^3 with major portion of 100 - 300 kg/m^3. The density variation in common coconut timber is shown in Figure 1.

Wood density is the most commonly quoted wood property, which is correlated to general wood characteristics as well as physical and mechanical properties (Dadswell, 1972). Density is the weight of wood substances per unit of volume. More specifically, coconut timber density is also the weight of its cell components that build its structure per unit of volume. It has a positive relation to the thickness of the woody cell wall and is influenced by variation in the relative proportions of different cell types and their dimensions in wooden material (Jane, 1970). In a piece of wood, for example, higher density wood has thicker cell walls.

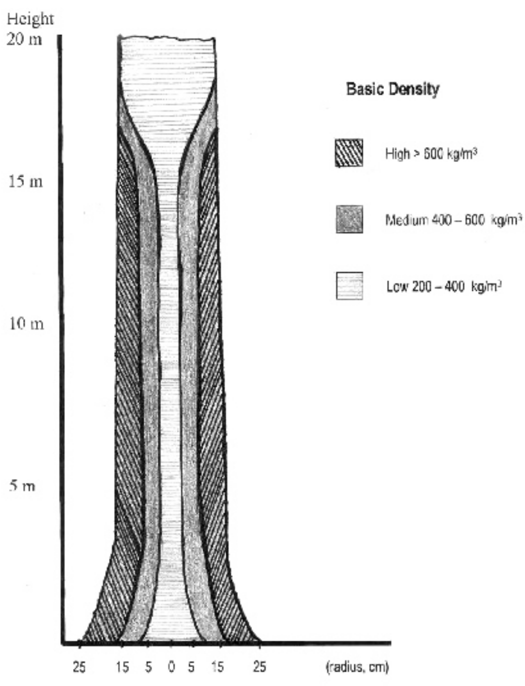

Figure 1. Profile of density variation within coconut tree stem
Source: Killman (1983)

Theoretically, wooden material can be densified by various combinations of either chemical and thermal or compressive and thermal treatments (Kollman *et al.,* 1975). Likewise, the unused light portion of coconut tree stem or so-called coconut wood is potentially developed by densification process. Light coconut wood can be steamed to plasticize the cell structure and then compressed to obtain density improvement. Such treatment would bring about anatomical changes in the wooden structure. This paper describes the results of experiment investigating anatomical changes of light coconut wood due to steam press densification.

II. MATERIALS AND METHOD

Coconut woods were taken from Parungkuda, West Java. Light coconut timbers which were taken from core of its corresponding round-shaped stems coconut logs were sawn into square shaped specimens or samples measuring 40 mm x 40 mm with length of 50 cm. Before densification, the samples were steamed for 30 minutes in temperature of 120^0C. After steaming, the samples were compressed at 23.75 kg/cm^2 for about 30 minutes. In addition, uncompressed samples were prepared as control and arranged in pair with the compressed samples.

Afterwards, anatomical changes were analysed using conventional microscope and Scanning Electron Microscope (SEM). Parameters observed using conventional microscope were: metaxylem vessel shape and size and metaxylem vessel frequency per 40 mm^2, while parenchymatous cell diameters were observed using SEM.

Density of compressed and non-compressed coconut wood was determined in oven dry condition. Volume and weight of non-compressed and compressed samples were measured after drying in an oven at temperature of $103 \pm 2\,^0$C and reach constant weight.

III. RESULTS AND DISCUSSION

Comparison of cross sectional appearances between the compressed coconut wood and control can be seen in Figure 2. It is clear that the shape of vessels become oval to ellipse after compression. Such changes resulted from the fact that the heat applied during steaming soften the coconut wood components, enabling the pressure to push round vessel becoming oval or elliptic. The void volume in coconut wood vessel as well as parenchyma cell are reduced, meaning the air in the void volume that does not support wood physically, is replaced by the compressed wood components that may give the structural improvement.

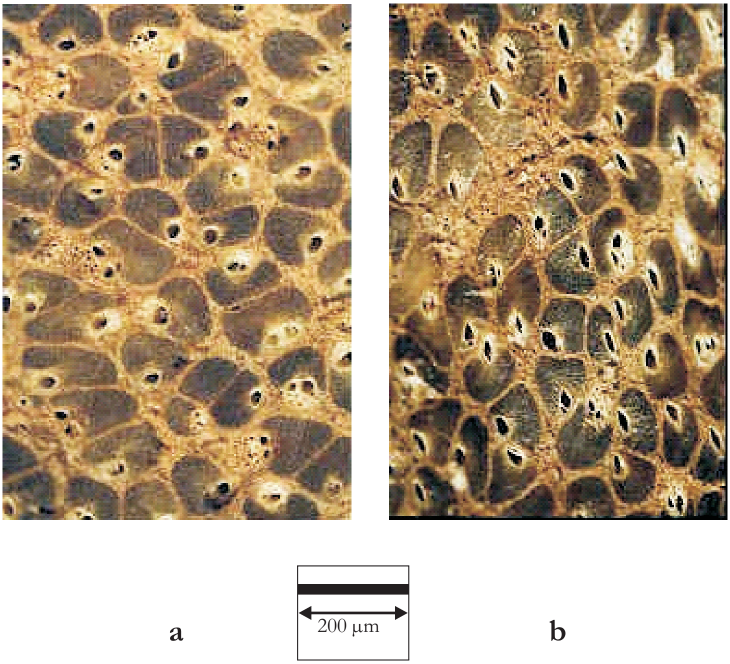

Figure 2. Round-shaped vessels in non-compressed coconut wood (a) and oval to ellipse in compressed coconut wood (b)

Not only did the treatment change the vessel shape, but also caused some changes in vessel's diameter and its frequency. The comparison between vascular bundles frequency per 40 mm^2 and metaxylem vessel diameter of non-compressed and compressed is shown in Table 1.

Table 1. Comparison of vascular bundles frequency, metaxylem vessel diameter and parenchyma cell diameter in compressed and non-compressed light coconut wood

Sample Code	Vascular bundles frequency per 40 mm^2			Metaxylem vessel diameter (μm)			Parenchyma cell diameter (μm)		
	Control	Compressed	Change (%)	Control	Compressed	Change (%)	Control	Compressed	Change (%)
K_1B_1	8	15	87.50	201.05	67.37	66.49	52.33	22.23	57.52
K_1B_2	11	14	27.27	167.37	68.71	58.95	52.91	20.36	61.52
K_1B_3	10	16	60.00	188.72	74.28	60.64	50.83	18.28	64.04
K_1B_4	7	11	57.14	193.27	58.36	69.80	56.19	19.39	65.49
K_1B_5	8	15	87.50	178.34	66.45	62.74	48.29	20.04	58.50
K_1B_6	9	14	55.56	197.12	67.38	65.82	47.22	21.16	55.19
K_1B_7	12	16	33.33	178.88	70.46	60.61	49.74	22.94	53.88
K_1B_8	14	18	28.57	189.37	72.42	61.76	51.82	19.73	61.93
K_1B_9	12	18	50.00	182.57	58.49	67.96	50.33	18.39	63.46
K_1B_{10}	10	16	60.00	198.45	62.39	68.56	49.39	17.11	65.36
K_2B_1	12	17	41.67	211.28	64.99	69.24	48.29	16.23	66.39
K_2B_2	9	17	88.89	158.42	66.28	58.16	50.21	15.67	68.79
K_2B_3	8	15	87.50	166.91	68.93	58.70	49.22	15.39	68.73
K_2B_4	12	18	50.00	207.31	72.19	65.18	48.39	16.92	65.03
K_2B_5	10	14	40.00	193.22	70.93	63.29	47.22	17.28	63.41
K_2B_6	7	13	85.71	189.39	72.32	61.81	49.19	16.92	65.60
K_2B_7	8	13	62.50	199.84	71.81	64.07	50.03	15.89	68.24
K_2B_8	8	12	50.00	167.37	70.92	57.63	51.21	14.78	71.14
K_2B_9	12	18	50.00	178.39	68.84	61.41	50.06	15.55	68.94
K_2B_{10}	14	16	14.29	202.3	69.37	65.71	49.98	16.29	67.41
K_3C_1	11	16	45.45	172.85	70.02	59.49	48.9	17.34	64.54
K_3C_2	12	14	16.67	183.22	71.11	61.19	47.23	18.7	60.41
K_3C_3	10	15	50.00	184.28	78.29	57.52	44.67	19.45	56.46
K_3C_4	11	16	45.45	189.29	68.32	63. 91	48.39	23.28	51.89
K_3C_5	13	21	61.54	208.51	67.92	67.43	46.19	24.21	47.59
K_3C_6	12	20	66.67	189.11	65.39	65.42	47.85	25.37	46.98
K_3C_7	10	16	60.00	168.19	59.02	64.91	48.39	20.19	58.28
K_3C_8	12	18	50.00	172.91	60.92	64.77	48.9	19.56	60.00
K_3C_9	14	22	57.14	188.73	61.82	67.24	47.65	18.89	60.36
K_3C_{10}	13	16	23.08	200.47	68.38	65.89	50.61	17.82	64.79
Average	**10.6**	**16**	**53.11**	**186.90**	**67.80**	**63.54**	**49.39**	**18.85**	**61.73**

Vascular bundles frequency of compressed samples was denser than that of the non-compressed samples. The average frequency of the non-compressed samples was about 10.6 bundles per 40 mm^2, while the compressed samples were about 16 bundles. Such frequency difference was 53.11% greater in compressed samples. It was particularly caused by the great reduction in metaxylem vessel diameter as mentioned earlier.

Metaxylem vessel diameter of compressed coconut wood was significantly smaller than that of the control (Table 1.). The vessel diameter of compressed wood was about 63.5% less than that of non-compressed samples. The compressed wood had average diameter of 67.8 μm, while the vessel diameter of non-compressed samples was 186.9 μm. Figures 2 and 3 clearly shows the differences between the non-compressed and compressed samples. Such notable changes were particularly due to the pressure direction imposed during treatment.

SEM pictures on Figure 4 is clearly shown the differences between non-compressed parenchyma cell and that of compressed samples. Round parenchyma cell in non-compressed samples show significant difference in compressed samples. The average diameter of parenchyma cell of non-compressed samples is about 49.39 μm, while the compressed sample is about 18.85 μm, which is lesser about 61.73%.

Paired T-tests in Table 2. indicated that from all parameters measured: vascular bundles frequency per 40 mm^2, metaxylem vessel diameter and parenchyma cell diameter were significantly different at the level of 95% confidence.

Table 2. Results of T-test on paired samples

	Pair	df	T	t table
Pair – 1 (vascular bundles frequency)	Non-compressed vs Pressed	29	17.379 **	2.04
Pair – 2 (vessel diameter)	Non-compressed vs Pressed	29	45.705 **	2.04
Pair – 3 (parenchyma diameter)	Non-compressed vs Pressed	29	44.111 **	2.04

Remarks: ** Significantly different at the level of 95% confidence

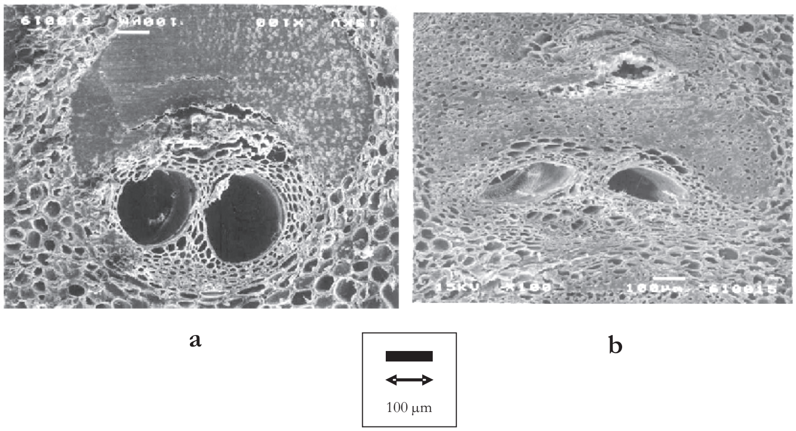

Figure 3. Vascular bundle of non-compressed (a) and compressed light coconut wood (b)

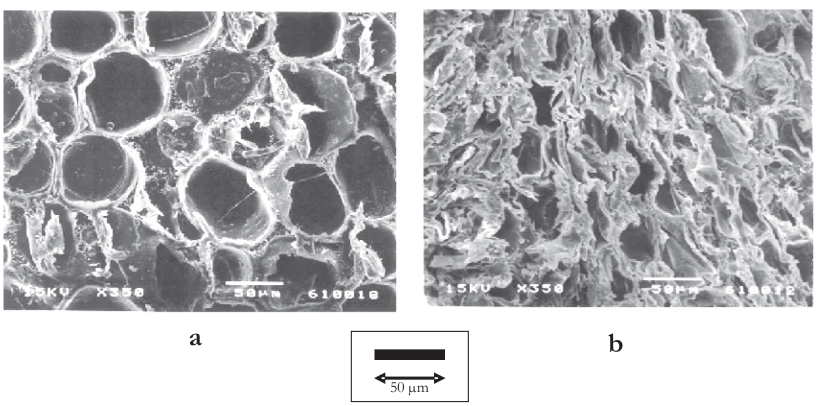

Figure 4. Ground parenchyma tissue of non-compressed (a) and compressed light coconut wood (b) analysed by Scanning Electron Microscopy (SEM)

The anatomical changes mentioned above caused physical alteration such as density improvements of compressed samples (Table 3.). The average density of non-compressed coconut wood was about 0.26 g/cm^3, while the compressed wood is about 0.40 g/cm^3. Density improvement of compressed coconut wood is approximately 55.94%.

Table 3. Density improvement in compressed light coconut wood

Sample code	Density (g/cm³)		Density Improvement (%)
	Non-compressed	Compressed	
K_1B_1	0.12	0.18	46.47
K_1B_2	0.31	0.46	47.86
K_1B_3	0.35	0.59	69.13
K_1B_4	0.34	0.53	55.67
K_1B_5	0.34	0.51	51.29
K_1B_6	0.36	0.51	42.72
K_1B_7	0.34	0.44	31.82
K_1B_3	0.32	0.48	48.65
K_1B_9	0.34	0.52	52.47
K_1B_{10}	0.28	0.49	75.62
K_2B_1	0.11	0.16	45.37
K_2B_2	0.30	0.54	78.68
K_2B_3	0.34	0.58	69.81
K_2B_4	0.34	0.44	29.59
K_2B_5	0.34	0.42	23.60
K_2B_6	0.22	0.31	45.18
K_2B_7	0.34	0.44	31.01
K_2B_3	0.12	0.19	48.84
K_2B_9	0.34	0.51	51.64
K_2B_{10}	0.29	0.50	74.52
K_3C_1	0.14	0.24	68.68
K_3C_2	0.31	0.54	74.18
K_3C_3	0.10	0.13	26.20
K_3C_4	0.26	0.45	73.69
K_3C_5	0.35	0.53	52.87
K_3C_6	0.11	0.20	88.58
K_3C_7	0.12	0.20	68.41
K_3C_3	0.12	0.19	58.05
K_3C_9	0.17	0.31	82.85
K_3C_{10}	0.31	0.50	64.65
Average	**0.26**	**0.40**	**55.94**

Pearson correlation tests indicated that strong relationship between density improvement and other single parameter was observed in this study. Correlation between vascular bundles frequency and density improvement was 0.801, while those between vessel diameter and parenchyma cell diameter were 0.752 and 0.889 respectively. The denser the fiber bundle the greater density improvement, while the smaller vessel and parenchyma diameter, the greater density improvement.

During compression, vascular bundles were moving together closer to each other becoming densely packed and then resulting improvement in density of coconut wood. As mentioned before, the void volume in coconut vessel and parenchyma cells that does not support coconut wood physically, was replaced by woody components such as xylem, woody fibers that give structural improvement.

Densification on light coconut wood is similar to that of studying carried out on less dense conventional wood. Krisdianto and Balfas (2005) reported that anatomical changes of Kekabu (*Bombax ceiba* L.) wood, which was caused by steam-pressure densification, reduced void volume and improved density of light Kekabu wood. The anatomical changes of Kekabu wood depend on grain orientation of the wood samples. Sloping forces during compression was causing fracture to occur.

As monocotyledon species, coconut timber has no ray parenchyma. As a result, there are only two main directions of fiber orientation: longitudinally and laterally. In this condition, forces during compression were mostly perpendicular to lateral surfaces. As a result, similar grain orientation was not causing fracture on coconut timber.

IV. CONCLUSION

1. Steam-press densification causes anatomical changes of coconut wood both structurally and dimensionally.
2. The densification results in deformations of metaxylem vessels and ground parenchyma tissue.
3. There is a strong relationship between density improvement and fiber bundle frequency, vessel diameter as well as parenchyma cell diameter. The denser the fiber bundles, the greater the density improvement, while the smaller vessel and parenchyma diameter, the greater density improvement.

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