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EXPERIMENTAL APPROACH OF COCONUT PEELING PROCESS

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ABSTRACT

A substantial area of senile coconut palms exists within the Asia-Pacific region. Once coconut palms become over-mature and senile, their production of traditional products, such as coconuts, significantly decreases, resulting in profitability challenges for farmers. Presently, few profitable markets exist for over-mature, senile coconut palms. Using the coconut palm stem in composite or engineered wood products could, however, provide an attractive alternative. Coconut palm wood differs substantially from hardwood, softwood, and even the wood of other palms. Due to some of its unique characteristics, a processing system able to recover wood from the high-density zone near the stem periphery is desirable. A series of rotary veneer laboratory trials were undertaken to establish fundamental benchmark lathe settings and veneering characteristics for coconut palm stems. Different pressure bar configurations, billet pre-treatment temperatures, and veneer thicknesses were tested and the resulting cutting forces and veneer quality were assessed.

Keywords: Coconut wood; Veneer; Rotary peeling, Lathe.

INTRODUCTION

A large portion of the Asia-Pacific region's coconut palms are over-mature. Often, it does not produce enough coconuts or by-products to be profitable. In addition, the low financial returns from these over-mature palms is a barrier preventing effective harvest and replanting. The Asia-Pacific's senile coconut plantations present a substantial opportunity for sustainable wood production. There is an expanding regional and international market for wood veneers and composite wood products. Because access to the traditional resources for these products, particularly tropical rainforests, is constrained, the substantial volume of wood held in the estimated 120,000 hectares of senile coconut plantations on Pacific islands represents an attractive alternative resource (1).

Coconut wood significantly differs from hardwood, softwood, and even the wood of other palm stems in terms of structure and density distribution. The complex tissue organization of palms such as coconut wood cannot be classified in a strict botanical sense as "wood" because it differs notably from that of dicotyledonous plants (e.g., scattered vascular bundles). Coconut palm "wood" is therefore referred to as "cocowood" throughout this paper. Cocowood is a complex plant tissue with a structure somewhat like parallel cables embedded in foam. The simple botanical description of cocowood is a blend of two different tissues: fibrovascular bundles and the surrounding parenchyma (ground tissue).

The fibrovascular bundle architecture follows an interlocked helix formation as it ascends the trunk. The specific architecture of cocowood has been described as a triple helix structure (2, 3, 4).Unlike the dicotyledonous trees traditionally used by the forest products industry, coconut palm (Cocos nucifera L.) is a monocotyledon. Due to the huge variation in cocowood's density, production of high-quality veneers from the external part of coconut palm logs appears to be the most attractive way to use this resource (Figure 1). However, the unique structure of cocowood requires tight control of peeling parameters.

Figure 1: Coconut disc showing that the most valuable area for high density veneer production lies between the blue circles

Low-cost spindle-less lathe equipment and the associated processing technologies provide great opportunities to add value to underutilized resources such senile coconut palms.

A literature review on the peeling parameters of palms has revealed little baseline data on the veneer processing of cocowood. The main objective of this study was to analyse the effect of key rotary peeling parameters for the production of dense, homogeneous veneer. Since the number of samples was limited and there was no technical information available on the peeling process characteristics for cocowood when the investigation began, a sequential trial approach was chosen to investigate the key parameters. Although such an approach is not exhaustive, it minimized the number of experiments required and provided valuable, practical, and novel information.

MATERIALS AND METHODS

Cocowood Sampling

A total of 43 senile coconut palms (70 or more years old) were sampled from several Fiji plantations. Four discs, 25 mm thick, were taken from each palm trunk. These were cut from the trees at breast height (approximately 1.3 m from the ground) and then 25, 50, and 75% of the stem height and were labeled D1, D2, D3, and D4, respectively. Green sample discs were stored in air-tight film in a refrigerated chamber prior to further processing and trials.

Disc allocation to trials ensured that they were grouped based on their diameter and density patterns. Both properties are known to vary from the bottom to the top of the palm, as described by 4 and 2. The bottom part of the palm is denser with a steep density increase from the centre to the periphery. The top part is less variable from the centre to the periphery and has smaller bundle sizes in higher concentrations. It should be noted that at the same height, the average density of cocowood, and the centre-to-periphery density variation, can differ significantly between trees and is influenced mainly by age (2, 5). According to authors, density reach from around 100 kg/m3 in the centre of the trunk to more than 1000 kg/m3 on the periphery.

Veneer Processing

Veneer processing was done using an instrumented micro-lathe system developed by the LaBoMaP (Arts et Métiers ParisTech AMPT) in Cluny, France (6). The micro-lathe system peels discs (Figure. 2) equipped with displacement and force sensors. It allows processing parameters, such as cutting forces, to be recorded precisely and quickly for a large number of specimens Taken from the same tree. In front of a lack of knowledge concerning the effect of processing parameters on cocowood veneer quality, a series of pertinent parameters were selected within the normal range for traditional wood veneer production. These parameters also influence the cutting forces required and therefore the machining behaviour (i.e., machinery loading, power usage, and wear and tear) as described by 7.

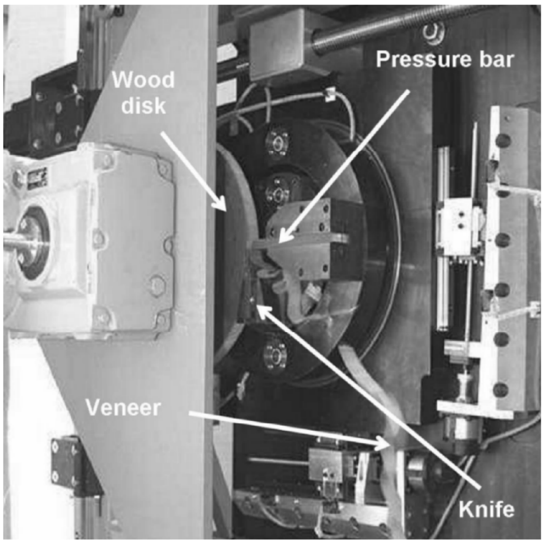

Figure 2: Micro-lathe (Butaud et al 1995)

The first parameter of interest was the type of pressure bar used. An angular pressure bar, commonly used for homogeneous wood species, and a roller pressure bar, more suitable for heterogeneous wood species, were tested. To understand the effect of bar pressure on veneer quality (e.g., checks and thickness variation), a standard compression rate range (from 0 to 20%) was investigated. This was set by adjusting the horizontal gap following the procedures described by 8 and 9. The compression rate, τ, was expressed as a percentage of the veneer thickness (e) relative to the knife gap (Eq. 1) (p, in Figures. 3 a and b).

$$\tau = \left(\frac{e-p}{e}\right) \times 100 \qquad (1)$$

A total of 35 trials were done to determine the effects of three compression rates (5, 10, and 20%) and five vertical gap (Cv) settings (0.1, 0.4, 0.7, 1, and 1.26 mm) on veneer quality.

The heating temperature was also studied. 10 reported that most high-density species benefit from hydrothermal treatment. This treatment improves deformability (11) and reduces the cutting forces required, limiting damage to the veneers (12, 7, 13). In the traditional wood veneering industry, billet heating temperatures usually range from 50 to 80 °C. Given that the overall chemical composition of cocowood is close to that of wood (14), sample discs were heated for 1 h in a water bath to 50, 60, 70, or 80 °C. Ambient temperature discs were also included. A preliminary trial demonstrated that 1 h of heating was sufficient to achieve the target temperature.

Veneer thickness was also studied (1, 1.5, 2, 2.5, 3, 3.5, and 4 mm). This range includes most of the common veneer thicknesses produced within the traditional wood rotary veneer industry.

Finally, the knife clearance angle (or pitch angle) was studied since it was reported by 15 to have the most influence on the machining quality of thin veneers, particularly of dense woods. The high density of the outer part of the cocowood trunks influenced the decision to limit the knife clearance angle range investigated to 0, 1, and 2°.

For each lathe setup, the forces were measured (Figures. 3 a and b). The measurements were recorded according to the methodology described by 6 and 7 in which Xc and Yc were measured on the knife, and Xb and Yb were measured on the pressure bar.

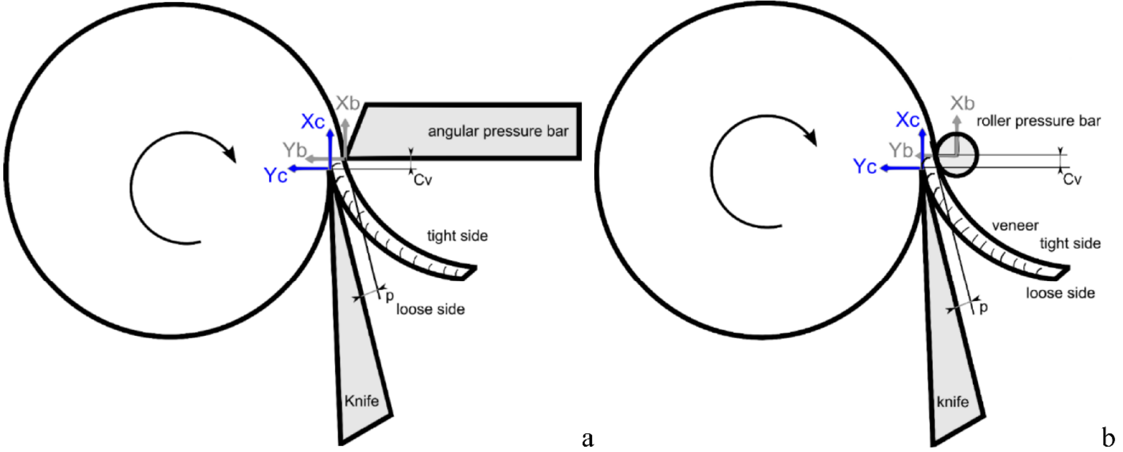

Figure 3: Cutting force reference system for angular (a) and roller (b) pressure bar. P is the knife gap and Cv is the vertical gap

A 21° knife angle was used in this study because the density of cocowood was similar to that of common, high-density hardwood species (16). Given the high density and minerals content of the outer part of coconut logs (2), the cutting speed was deliberately limited to 45 m/min. Although this is slower than the speed used for most common wood species (9), this conservative speed was chosen to limit tool breakage (17).

Cutting forces

The 25 mm thick discs were first debarked and rounded to remove the natural trunk edge. A specific drive system with large-diameter (110 mm) clamping plates was performed to prevent problems gripping the low-density cocowood disc centre. The forces exerted in the cutting plane, both on the pressure bar and the knife, were measured using piezoelectric load cells with the signal smoothed by a low-pass filter (50 Hz) prior to being sampled at 1000 Hz sampling frequency. The revolution angle was simultaneously recorded to obtain data as a function of the peeling revolution. An example of the measurement and data extraction of the cutting forces is displayed in Figure. 4.

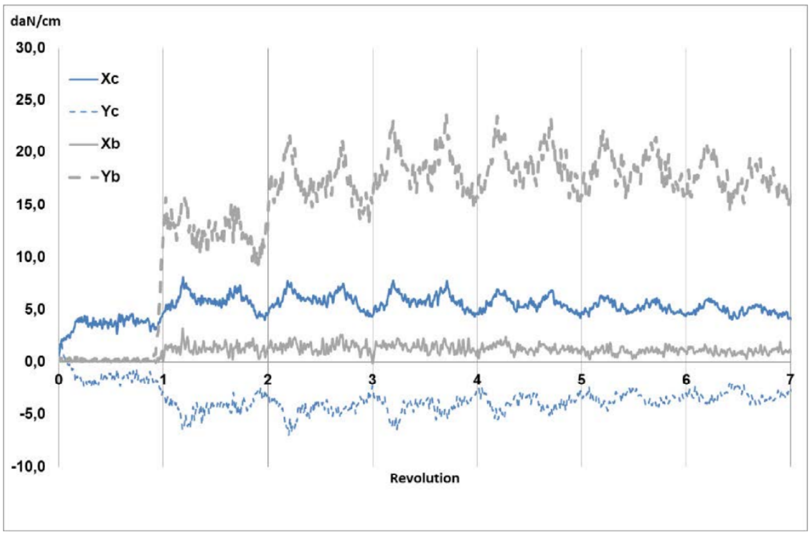

Figure 4: Example cutting force data profile

Veneer Quality Assessment

In a first approach, quality assessments were conducted using a visual method. The quality was categorized into four categories ranging from a very fragmented, rough, and fuzzy veneer (1) to a continuous, smooth, and polished veneer (4). A specifically designed apparatus (SMOF, 18) was used to characterize veneer lathe checks. Veneer checks produced during peeling are opened by bending the veneer on a diameter roller. The software algorithm identifies each check, calculates its depth, and determines the distance between consecutive checks. Only veneers with a visual score of 2 or above were assessed with the SMOF.

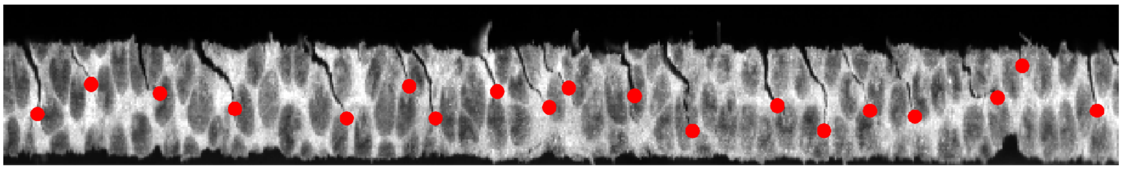

Figure 5: Coconut wood veneer (2.5-mm-thick) lathe checks recorded by the SMOF

RESULTS AND DISCUSSION

The cutting forces often display periodicities which could be due to tangential density variation or over-thickness patterns. The latter type of periodicity is common when peeling very dense wood, according to (15). The region of interest in this study was restricted to 5 cm in depth from the periphery, since this region contains the highest-density wood (>600 kg/m3) and offers potentially superior-quality veneers (see Figure. 1). The analyses were based on the forces extracted from rotations 4, 5, and 6 counted from the first contact of the nose bar.

Pressure Bar

An initial trial was conducted using an angular pressure bar. Only veneers machined from discs taken from the top of the palm (50 and 75% of the stem height) produced acceptable, semi-continuous veneer ribbons with adequate roughness and checks (visual scores of 3 or 4) (see Fig.

6b). The discs from the bottom of the palm produced short, fragmented veneer ribbons of poor quality (visual scores of 1 or 2).

It was hypothesised that the production of relatively poor-quality veneers was because the angular pressure bar acted as a rasp against the alternating bundles of hard and soft ground tissue on the cocowood surface. This phenomenon is supported by Fig. 6a in which the tight face (bottom side) of the veneer displayed evidence of large-diameter bundles being torn from the veneer surface. The upper, external part of the palm trunk is made of smaller-diameter bundles in higher concentration than in the bottom part of the trunk. This explains the lower impact of the angular pressure bar on the veneer quality of the discs sourced from higher parts of the palm trunk.

The mechanism of peeling checks was carefully described by 19. In summary, checks develop due to the action of the knife resulting in tensile stress normal to the plane of the crack and perpendicular to the bundle axis. After initiation, the cracking propagates ahead of the knife edge and then curves towards the tight face under the flexion movement imposed by the knife to the veneer (Figure. 3). This mechanism was observed during the cocowood peeling process with the development of peeling checks on the loose face (Figure 6). The size and, to a lesser extent, the frequency of the bundles significantly influence check propagation.

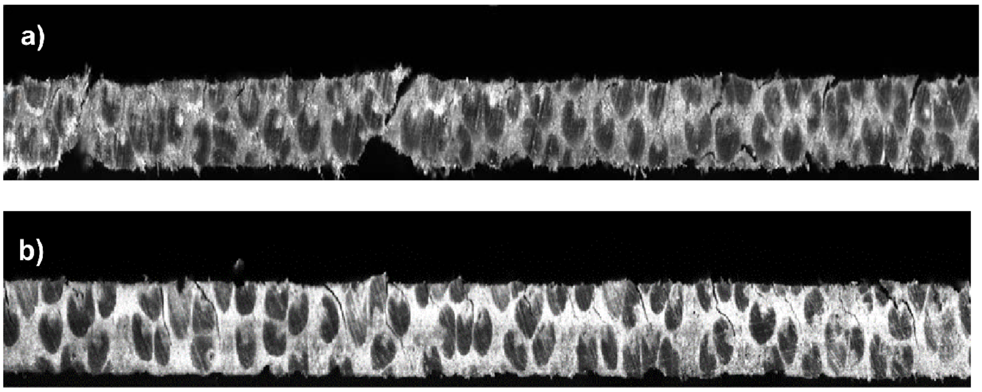

Figure. 6: Cocowood veneers peeled with an (a) angular pressure bar or (b) roller pressure bar

A pressure bar imposes an extensive tangential movement of the surface of the disc, resulting in shear stresses. At the tissue scale, the bundles can be considered non-deformable cylinders, and the induced shear stresses cause incipient fractures or avulsions visible on the tight face of the veneer (Figure. 6a). Along with peeling checks, this dual splitting mechanism (on both sides) explains the extreme fragility of the veneer manufactured with the angular pressure bar. A roller pressure bar reduce friction, limit the locale rise of shearing stress and then favours the continuity of the ribbon (Figure 6b). Following trials were performed only with a roller pressure bar.

Temperature

During the preliminary tests on discs processed at room temperature, it was not possible to produce a continuous veneer ribbon. In addition, excessive damage (i.e., dents, chips, and blunting) to the knife cutting edge was apparent after only a few meters of peeled veneer were produced (17).

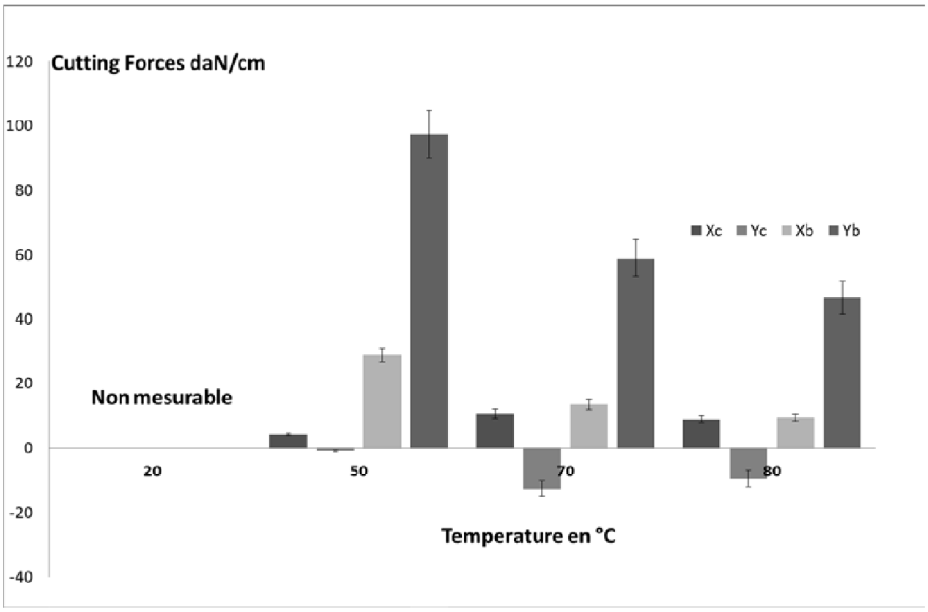

Figure 7: Effect of temperature on cutting forces. The cutting conditions were a roller pressure bar, 10% pressure, 2.5-mm veneer thickness, and 45 m/min speed.

The forces measured on the pressure bar were substantially reduced (about 50%) when the disc temperature increased (Figure. 7). Moreover, the forces perpendicular to the knife cutting plane (Yc) changed from nearly zero at 50 °C to negative values at temperatures above 70 °C, reflecting slight knife dive, reported by 15 as a favourable cutting behaviour. The forces acting on the tools were particularly high compared to those when peeling traditional wood species under similar conditions. (20) reported trials processing Douglas fir (thickness, 3 mm; $\tau = 5\%$; $Vc = 1$ m/s; $T = 80$ °C) in which the observed maximum of any of the four forces per revolution was 4.5 daN/cm. (13) demonstrated the beneficial effect of temperature on check occurrence and magnitude. Subsequent trials were performed with a nominal disc temperature of 80 °C.

Cutting Forces versus Veneer Quality

The cutting force was proven to be a relevant predictor of veneer quality, as shown in Figure 8. As the visual quality of the veneer improved, the average cutting forces and their variability decreased. This observation is in accordance with the findings of (7). The radial force on the pressure bar decreased significantly with increasing veneer quality, indicating that cutting with a lower compression rate improved veneer quality. Notice that even when cutting conditions were favourable and the quality of the veneer was good (visual rank 4), the cutting forces for cocowood remained significantly high compared to those of traditional woods (20).

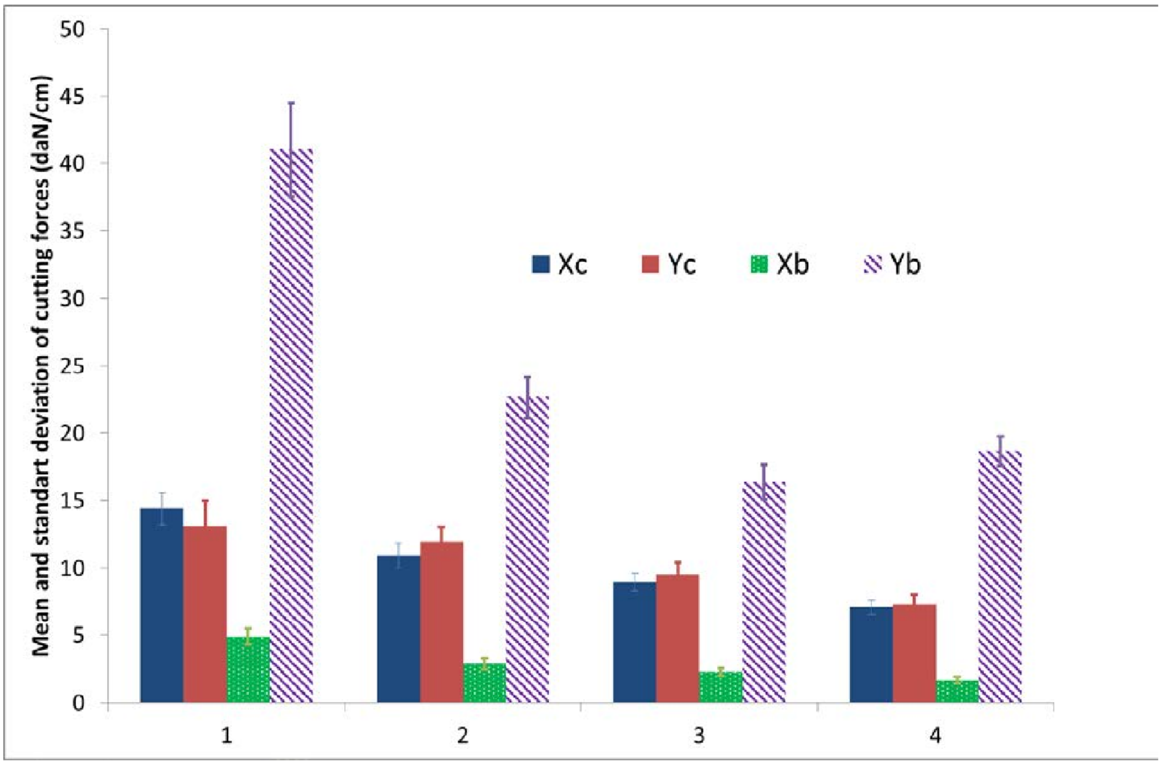

Figure 8: Mean cutting forces versus visual veneer quality. The standard deviations of the forces are represented by the error bars.

Table 1 : Mean Cutting Forces and Mean Veneer Quality Scores for Different Compression Rates

Compression rate (%)	Mean Xc (daN/m)	Mean Yc (daN/m)	Mean Xb (daN/m)	Mean Yb (daN/m)	Mean veneer quality score
5	9.05	8.60	2.26	-16.65	2.64
N=14	(1.48)	(2.66)	(0.61)	(3.93)	(1.39)
10	10.17	10.30	2.65	-23.68	2.42
N=12	(1.71)	(2.00)	(0.70)	(3.05)	(1.16)
20	15.10	14.61	5.77	-53.65	1.67
N=9	(2.20)	(3.19)	(1.32)	(6.90)	(1.32)

The cutting conditions were a roller pressure bar, 2.5-mm veneer thickness, 45 m/min speed, and 80 °C. N is the number of discs peeled. The standard deviations are shown in parenthesis.

Moreover, as shown in Table 1, for low compression rates (5 and 10%), the cutting forces are lower and more stable than when applying 20% compression rate. Lower compression rates resulted in superior veneer quality. In addition, the variability of the results, as indicated by the standard deviation in Table 2, was lower when lower compression ratios were in use. This result demonstrates that compression rates should be limited for cocowood veneer cutting. This is not common for homogenous species which support high pressure rate (>10% most of the time)

Table 2 : Veneer Quality Assessments Using the SMOF System for Different Compression Rates

Compression rate (%)	Mean Check Depth (mm)	Median Distance Between Checks (mm)
5 (N=8)	1.30 (0.26)	2.94 (1.27)
10 (N=5)	1.21 (0.19)	4.08 (3.31)
20 (N=2)	1.21 (0.22)	2.03 (0.29)

The cutting conditions were a roller pressure bar, 2.5-mm veneer thickness, 45 m/min speed, and 80 °C. N is the number of discs peeled. The standard deviations are shown in parenthesis.

Table 2 illustrates the veneer ribbon qualities as assessed using the SMOF system. The average check depth was not significantly affected by the compression rate. However, unlike in homogeneous woods, the median distance between checks was clearly maximized at a compression ratio of 10% (see Table 2). These findings suggest a moderate compression rate can limit crack formation in cocowood veneers. The optimum compression rate would be influenced by the diameter of the roller pressure bar used.

Veneer Thickness

The veneer quality was found to be poor when targeting veneer thicknesses below 2 mm. Indeed, the bundles constitutes a local strong heterogeneity. Their important diameter important (0.5 to 2 mm) makes veneer excessively fragile under a minimal thickness. At the same time, the high cutting force reached for large and dense disc impose to limit cutting path. At the end, a veneer thickness of 2.5 mm was selected for the large part of the experimental plan.

Clearance Angle

Only clearance angles of 1 and 2° produced acceptable-quality veneers. There was no noticeable difference between these two settings. This finding is consistent with observations in literature regarding peeling trials on other, very dense wood species and large-diameter peeler billets (16; 19).

CONCLUSIONS

The outer part of the trunk was targeted because it contained high-density wood thought to have the greatest potential to produce high-quality veneer. The study proposes a first analysis of cutting settings parameters for coconut wood peeling process. Because of this context, the use of a spindleless lathe appears logical.

1. Steaming logs above 70 °C is recommended to limit cutting forces required, improve surface quality, and limit premature knife damage. Anyway, the cutting forces involved still are considerable as regard to wood cutting forces.
2. The use of a roller nose bar and a relatively low compression rate (around 10%) provided a favourable effect on most of the critical processing parameter (cutting forces, checks, and surface quality).
3. The minimum peelable veneer thickness (around 2 mm) is limited by the size of the fibrovascular bundles.

4. The high density of cocowood requires a positive clearance angle to limit the forces on the clearance face of the blade.
5. These observations should be confirmed using an industrial spindleless lathe with a large-diameter roller pressure bar to enhance the positive effect of the bar on the checking mechanism.
6. The friction phenomenon observed when using an angular nose bar highlights the unusual cutting characteristics of coconut wood. In future studies, it would be relevant to analyse the choice of knife alloys to optimize the cutting properties (21).

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