

THE USE OF COCONUT HUSK IN HIGH PRESSURE LAMINATE PRODUCTION

R Glowacki¹, MC Barbu^{2, 3, *}, J van Wijck⁴ & P Chaowana⁵

¹Deutsches Biomasse Forschungs Zentrum GmbH, Torgauerstr. 116, 04347 Leipzig, Germany

²Department of Wood Sciences, University of Hamburg, Leuschner Str 91, 21031 Hamburg, Germany

³Faculty for Wood Engineering, Transilvania University Brasov, Str Colina Universitatii, 1 500084 Brasov, Romania

⁴Trespa International BV, Technology Centre, Wetering 20, 6000 AC Weert, Netherlands

⁵School of Engineering and Resources, Walailak University, 81160 Nakorn Sri Thammarat, Thailand

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GLOWACKI R, BARBU MC, VAN WIJCK J & CHAOWANA P. 2012. The use of coconut husk in high pressure laminate production. This research investigated the possibilities of applying coconut husk in fibreboard production. The objective was to reduce the amount of phenol formaldehyde (PF)-resin in highly water resistant fibreboards such as high pressure laminates (HPL). The milling process of coconut husk was analysed, tested and verified. Recommendations were worked out for the storage, transportation and preparation of coconut husks. The main steps such as preparation of raw material including resination, forming and pressing of boards, and their effects on the performance of boards were analysed. HPL boards were manufactured in the laboratory and tested following the European Norms (EN 438). Different particle sizes of coconut husk and blending ratios to wood fibre were chosen. The 100% based coconut husk HPL boards (without PF resin) showed impressive water resistance performance after the 2 hour boiling test. A ratio of PF resinated spruce fibre of 50% and the rest coconut husk showed high mechanical and physical properties.

Keywords: Water resistant fibreboard, PF resin ratio

GLOWACKI R, BARBU MC, VAN WIJCK J & CHAOWANA P. 2012. Penggunaan sabut kelapa dalam penghasilan papan lapis bertekanan tinggi. Kajian ini menyelidiki kemungkinan penggunaan sabut kelapa dalam penghasilan papan gentian. Tujuannya adalah untuk mengurangkan penggunaan resin fenol formaldehid (PF) dalam papan gentian yang mempunyai kerintangan air yang tinggi seperti papan lapis bertekanan tinggi (HPL). Proses pengisaran sabut kelapa dianalisis, diuji dan ditentusahkan. Penyimpanan, pengangkutan dan penyediaan sabut kelapa disyorkan. Langkah utama seperti penyediaan bahan mentah termasuk penambahan resin, pembentukan dan penekanan papan serta kesan parameter-parameter ini terhadap prestasi papan dianalisis. Papan HPL dihasilkan di makmal dan diuji menggunakan Piawaian Eropah (EN 438). Saiz partikel sabut kelapa serta nisbah sabut kelapa:gentian kayu yang berbeza-beza digunakan. Papan HPL yang mengandungi 100% sabut kelapa (tanpa resin PF) menunjukkan kerintangan air yang sangat baik selepas ujian pendidihan selama dua jam. Campuran 50% gentian pokok fir dengan PF dan yang lain sabut kelapa menunjukkan ciri-ciri mekanik dan fizikal yang baik.

INTRODUCTION

Fossil resources are running low but energy requirements have increased dramatically. This also affects the wood-based panel industry as synthetic resins are made from crude oil and gas. Price increase or fluctuation indicates shortage of raw materials for board production. Alternatives based on renewable sources have to be looked for. One alternative is to use the natural bonding properties of lignin, a polymer found in almost any tissue of plant. An exceptionally high amount of lignin can be found in the coconut husk.

In order to utilise this natural raw material in fibreboard production, this investigation was carried out.

In India coconut husk boards are being produced on an industrial level for exterior use. The use of 100% coconut husk for board production was analysed at A & R Wageningen, Netherlands in order to produce building and packaging materials made from pure coir fibre without using synthetic binders. The studies succeeded in manufacturing high density

*Author for correspondence. E-mail: m.barbu@holz.uni-hamburg.de

panels (1400 kg m⁻³) with better properties than reference tests from medium density fibreboards (MDF) (Snijder et al. 2005).

On-going studies at the Department of Wood Sciences at the University of Hamburg in cooperation with industrial partners (Trespa, A & R Wageningen and Maier) investigated the possibilities of applying coconut husk in high pressure laminate (HPL) production. The aim of the trials was to reduce the amount of phenol formaldehyde (PF) resin used in the highly water resistant HPL boards.

MATERIALS AND METHODS

Milling trials

Chipped coconut husks were milled in the laboratory by employing different mill types, conditions and moisture contents as presented in Table 1.

Table 1 Overview of milling trials

Mill type	Condition	Moisture content (%)
Pallmann PS 3-5	3 × 38 mm	30
Retsch laboratory mill	2.5 mm	30
Retsch laboratory mill	2.5 mm	5
Retsch laboratory mill	1 mm	5
Mayer MPF9/430	2200 rpm	4.2
Mayer MPF9/430	2500 rpm	4.2

Sieve analyses showed the generated particle size distribution. To test various fractions of milled coconut husk in board production, sieving was carried out to separate the highly lignified pith from the coir fibres. Two screen arrangements were used:

- (1) 2, 1, 0.5 and finally 0.2 mm mesh sizes
- (2) 1, 0.2 and finally 0.1 mm mesh sizes

Production of sample boards

The spruce fibres were blended with PF-resin in a blender with paddles and rotating mill head on orthogonal axes. The resin in methanol was applied onto the fibres using a spray gun. The coconut husk material was fed and blended in the blender. The fibre furnish was dried at low temperature to evaporate the methanol. The total volatile content (water and other volatiles) was estimated using an infrared drying device.

The furnish was manually spread onto a 30 × 30 cm mould directly on the lower pressing plate. It was compressed first manually and then at 24 bar for 2.5 min in the cold state. Subsequently, the mat was hot pressed under various parameters such as pressure, pressing temperature and pressing time. The temperature was measured in the middle of the board during pressing using a thermocouple device. A pressing temperature of 165 °C was applied. This value was also used by Snijder et al. (2005) who recommended an optimum pressing temperature between 160 and 170 °C for pure coconut boards.

After pressing, the boards were cut into test specimens and placed in a conditioning room maintained at 65% RH and 20 °C until constant weight was attained. The physical and mechanical properties were determined in accordance with EN 438 (European Standard 2005a).

Effect of pressing time

Boards made from 100% coconut husk material milled in a Mayer MPF9/430 at 2500 rpm were manufactured to analyse the effect of pressing time on board properties. The pressing parameters were 120 bar and 165 °C. The furnish moisture content was 10%. Various pressing times of 4 to 12 min were applied.

Effect of particle size

Boards made from 50% PF-resinated spruce fibre and 50% coconut husk of various particle sizes were produced to study the effect of particle size. The boards were pressed under constant parameters, at 120 bar and 160 °C for 4 min. The furnish moisture content was 9%. Four fractions of coconut husk were used: milled as described above with a mesh size of 3 × 38 mm, at 2.5 mm, at 1 mm and a screened fraction between 0.2 and 0.1 mm.

Effect of coconut husk ratio in boards

For this trial, the fines fraction (screened between 0.2 and 0.1 mm) was used. A board made from 100% resinated fibres containing 75% wood fibres and 25% PF-resin was pressed. The coconut husk was added stepwise. Boards with a ratio of 15, 25, 35, 50, 65, 75 and 100% coconut husk were manufactured and tested.

Effect of pressing pressure

Maintaining the same parameters (160 °C, 4 min, coconut husk/ resinated spruce fibre ratio = 1:1, moisture content = 9%), boards were pressed at 90 and 120 bar. The effects of pressure on water resistance and mechanical properties were determined.

Optimisation of pressing parameters

This trial series combined the results of previous experiments concerning pressing time, pressure, temperature, moisture content as well as the mixing ratio of coconut husk and resinated wood fibre. Boards pressed at optimum pressing parameters were expected to yield the best properties.

Benchmarks

Two major benchmarks were picked: mechanical properties (especially bending strength) and swelling and water uptake after 2-hour boiling test.

Established testing methods for mechanical and physical properties are described in EN 438. ‘High-pressure-laminates’ Part 4 ‘Classification and specifications for interior applied panels’ and Part 6 ‘Classification and specifications for boards in exterior use’ provide good testing standards and benchmarks (Table 2).

The thickness swelling according to EN 438 (European Standard 2005a) should be measured 5 mm away from the edges to the centre of a 50 × 50 mm specimen. In this study, thickness increase was determined directly at the sample edge which was the most sensible spot for swelling reactions. The measuring couples were overlapping the edges about 50%.

According to Trespa’s experience, the swelling determined at the edges was around four times higher than measured 5 mm from the edges to

the centre of the board as recommended in the EN 438 (European Standard 2005a). So, in this study thickness increase meant edge swelling.

Testing

The properties of the two major types of panels were investigated: the mechanical properties (bending modulus or E-modulus) and physical properties (after 2 hours boiling in water).

2-hour water boiling test

This test was performed according to the EN 438 (European Standard 2005a). For every panel, the dimensions, weight and volume of three samples prior to the 2-hour boiling test were determined.

The edge swelling of the samples was measured after 1 hour cooling in water at 20 °C. Then, the weight and volume were determined. The water uptake, edge swelling and density were calculated.

Bending test

The E-modulus in bending and flexural strength were tested in a standard 3-point bending test using a Zwick Roell testing device. The sample size for HPL (EN 438) was different from wood-based panels (width and length). The appearance of fracture was analysed to obtain an impression of the quality of resin curing and the behaviour of the coconut material.

RESULTS AND DISCUSSION

Milling of coconut husk

Quality of coconut husk material

When harvesting, the coconuts were thrown onto the ground. During the drying process, sand, metal, plastic and concrete were found.

Table 2 Requirements of EN 438 for high pressure laminates

Property type	Property (unit)	Interior (Part 4)	Exterior (Part 6)
Bending	Flexural modulus (E-modulus) (N mm ⁻²)	9000	9000
	Flexural strength (N mm ⁻²)	80	80
	Density (g cm ⁻³)	1.35	1.35
Boiling in water (2 hours)	Mass increase (%)	2.0	5.0
	Thickness increase (%)	2.0	–

The impurities led to problems during husk size reduction, pressing of boards and sample processing. The wear of saw blades was observed to be higher when sawing panels made from coconut husk material.

When improving the production process an additional cleaning step must be implemented to guarantee impurity-free raw material. When purchasing coconut husk, special care must be taken to keep the material as clean as possible.

Observations on the milling process

Three kinds of equipment were used for the size reduction of coconut husk.

Pallmann PS 3–5 is a medium-sized laboratory mill (A & R Wageningen). The high moisture content of 30% caused jamming while milling. A 3 × 38 mm screen was used (Figure 1 left).

Retsch laboratory mill is a small laboratory mill and can be equipped with various screen mesh sizes (A & R Wageningen). Milling of coconut husk at moisture content 30% led to jamming of the screen. Dryer material could be milled more easily. At a mesh size of 1 mm, the processing capacity was very low.

Mayer MPF9/430 is an attrition mill designed for crushing raw material on an industrial scale.

The trials investigated the milling process of coconut husk on an industrial scale (Mayer). The particle size distribution showed a small per cent of very fine milled pith material below 0.032 mm (Figure 1, right). This fraction could not be separated by common cyclones. This effect should be considered when industrial up-scaling design takes place.

Particle size distribution

After milling, sieve analysis was carried out, grading the milled coconut husk into fractions (Table 3).

The fractions above 0.5 mm mesh size showed mainly coir fibres. The yielded fractions below 0.25 mm showed mainly pith material. The bulk density was estimated at 195 kg m⁻³. During the milling process, the coir fibres were totally separated from the pith material (Figure 2). Only small cut fibre fragments could be observed.

It should be mentioned that coir fibres were about 10 times thicker than spruce fibres (340 to 360 µm). To achieve homogenous fibre–coconut husk boards, the raw materials (resinated spruce fibres and coconut husk) should have similar particle size. A sieve analysis of PF-resinated

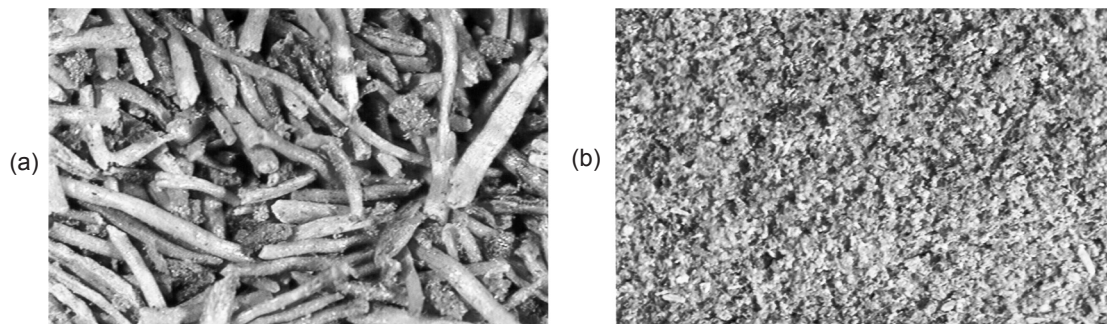


Figure 1 Coconut husk milled and graded in (a) coir fibres and (b) pith material

Table 3 Description of fractions of sieve analysis

Mesh size (mm)	Description of fraction
> 2	Boulder of coir fibre, partly with pith material
> 1	Coir fibres, some pith boulders
> 0.5	Many small boulders of pith, pure coir fibres and coir fibres with adhering pith
> 0.25	Many pure coir fibres (without adhering pith), fine pith material
> 0.125	Very fine pith, many small and short coir fibres (pure)
> 0.063	Mostly pith powder, a few thin and pure coir fibres
> 0.032	Pith dust
< 0.032	Very fine pith dust

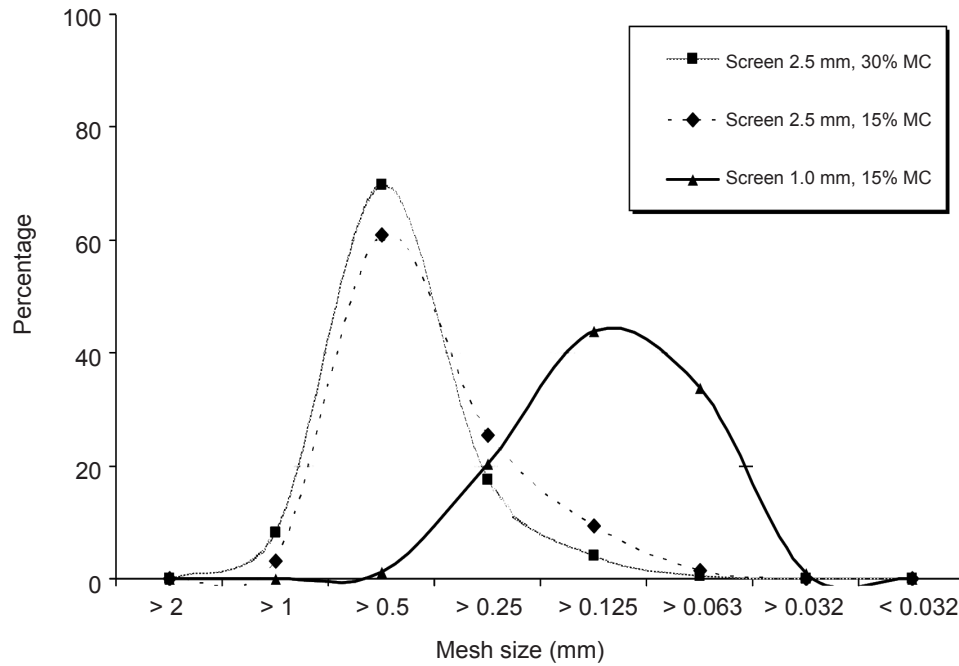


Figure 2 Particle size distribution of milled coconut husk generated in a Retsch laboratory mill. MC = moisture content

spruce fibre showed a peak for the fraction below 0.25 mm mesh size (Figure 2).

Figure 2 shows the particle size distribution of milled coconut husk in a Retsch laboratory mill at 2.5 mm screen and moisture content 30 and 15% as well as at 1 mm screen at moisture content 15%. Lower moisture content of coconut husk chips led to finer particles. This effect was also described by Kruse and Frühwald (2001).

A particle size distribution similar to that of spruce fibres (peak < 0.25 mm) could be achieved when milling with a 1 mm screen size. This type of milling is limited to the lab scale preparation of raw material.

Figure 3 shows the particle size distribution when milling in a Pallmann PS 3–5 and a Mayer MPF 9/430 at two moisture content levels of coconut husk. The Pallmann PS 3–5 generated coarse particles, mainly above 0.25 mm fraction. The particle size distribution using the Mayer MPF mill could be steered by adjusting the rotation speed. A higher rotation speed (2500 rpm) led to finer particles: 2200 rpm led to a peak at 0.125 mm while 2500 rpm led to a peak at 0.063 mm mesh size.

For maximum fine particles, the Mayer MPF at 2500 rpm showed the best results. Almost 90% of the milled coconut husk material had a particle size below 0.2 mm which fitted the particle size distribution of PF-resinated spruce fibre.

Grading of milled coconut husk

The major part of the board production trial requires fine coconut husk particles. Thus, separation by screening was carried out. Mechanical sieving at 1, 0.2 and 0.1 mm screen mesh sizes led to jamming of the screens. Manual sieving at 2, 1, 0.5 and finally 0.2 mm screen mesh sizes yielded the best results.

The material screened above 0.2 mm mesh size was almost pure coir fibre. The hard and thick coir fibres formed balls during sieving. If the mesh sizes were carefully selected, jamming of the meshes could be avoided.

The particle fractions between 0.2 and 0.1 mm were chosen for some board production trials. The fine pith material (< 0.125 mm) contained high amounts of lignin.

Mechanical screening was not feasible on an industrial scale. Separation by air-based methods should be further investigated.

Recommendations for the processing of coconut husk

After harvesting the coconuts, the husk must be separated from the nut. Mechanical procedures should be applied to keep the temperature in the process below 120 °C (not the retting method) to avoid pre-curing reaction of lignin as described by

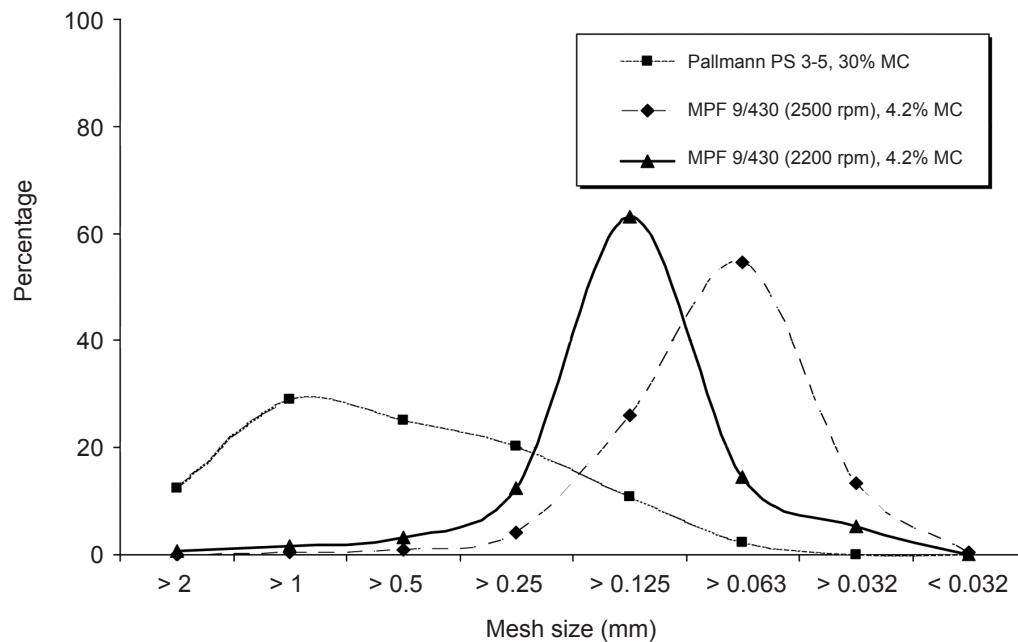


Figure 3 Particle size distribution of coconut husk particle milled in Pallmann PS 3-5 and MPF 9/430 at two moisture content levels

Van Dam (2004). Then the coconut husk has to be chipped and impurities have to be separated. Before milling the chipped husk must be dried (below 20% moisture content).

The milling device could be a simple rotor mill, for example the MPF 9/430. Upgrading from laboratory to industrial level led to very good results. All these production steps should be conducted close to the coconut producing site (plantation). Solar energy could be used to reduce the drying cost. The volume of raw coconut husk material could be substantially reduced by milling on site, which lowered the transport costs (bulk density of 195 kg m^{-3} close to wood chips).

Refining was not recommended due to the huge diameter of coir fibres (10 times thicker than spruce fibres). Their helix morphology would cause problems when refining using discs.

Board production and performance

Effect of pressing time

The water resistance after 2 hours of boiling of pressed boards was greatly increased when applying longer pressing time (Figure 4). Edge swelling and water absorption after the boiling test were more than 50% lower when the pressing time was increased by three times (12 min).

The mechanical properties did, however, decrease slightly. This indicated a better reaction and curing of the coconut husk lignin at higher energy input. The lignin polymers started softening and began to flow. Under heat and pressure, they were compressed and their polymers were interwoven and filled out the small hollow spaces in the board. The carbohydrates (xylose and glucose) were formed under heat furfural and formaldehyde which reacted with lignin. Double bonds between the lignin's propane units were connecting the lignin polymers (chromophores). After cooling down under pressure, the lignin polymers became stiff again and remained in the new bonded and interwoven structure binding the board.

In addition, the cellulose molecules are bonding via hydrogen bonds and condensation reactions. With higher, longer energy input, the condensation reactions lead to shorter cellulose chains, decreasing the mechanical properties. This leads to slightly weaker mechanical properties.

Compared with the boards produced in the study of Snijder et al. (2005), the same E-modulus of about 5200 N mm^{-2} was obtained. With regard to swelling properties, another method (2-hour boiling vs. 24-hour water immersion) was used in the other study, so no comparison was possible. Compared with classical HPL, these properties were relatively low.

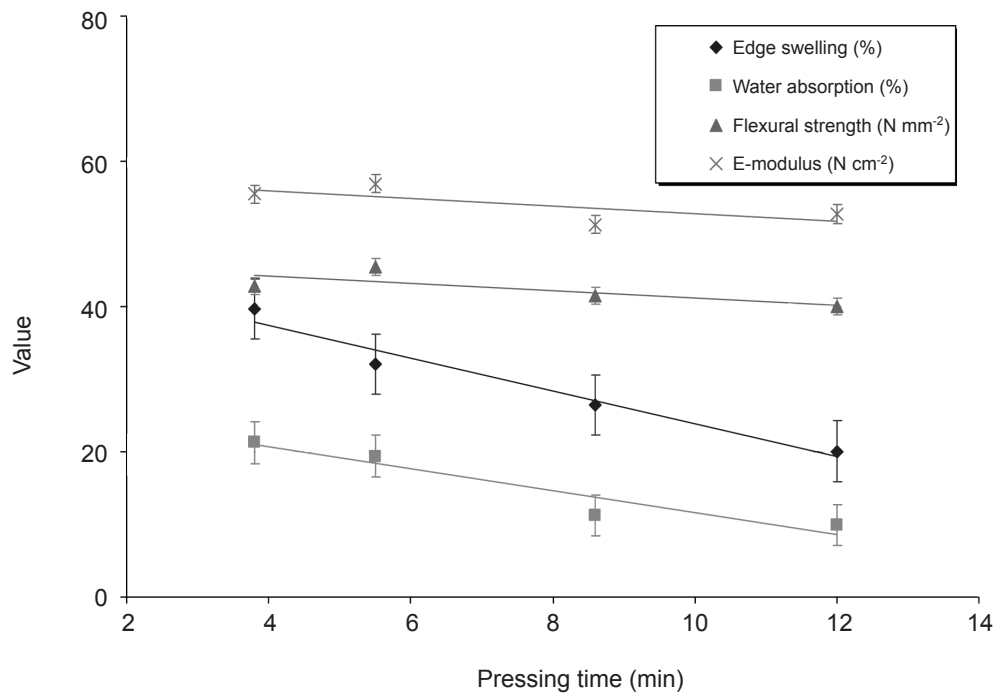


Figure 4 Influence of pressing time on the HPL (thickness 6.1 mm, density 1400 kg m⁻³) made from 100% coconut husk (without PF resin). Number of replicates per treatment is four

Effect of particle size

The smaller the particle size, the lower the edge swelling and water absorption after the 2-hour boiling test (Figure 5). Constant parameters for this trial were blending ratio coconut husk/wood fibres 1:1, pressure 120 bar, pressing temperature 160 °C, pressing time 4 min and 9% MC.

Finer milled coconut husk material resulted in better water resistance properties. The impact on the mechanical properties was low. The reference showed values according to EN438 (European Standard 2005a).

Using finer milled coconut husk resulted in more homogenous board structure. The coarse milled material and thick coir fibre led to interspaces which soak up water. The panel made from coarse particles was more accessible to water during the boiling test. This caused swelling and higher water absorption.

Smaller particles fit better into the mixture of resinated spruce fibres and coconut husk material. Distances between particles are smaller; as a result better curing reactions can take place. Compared with the effect of wood dust in the boards, the finer milled coconut husks improve the mechanical properties of the boards.

Effect of coconut husk ratio

Figure 6 presents the flexural strength and water resistance after the boiling test (Figure 6). All boards containing spruce fibre had been pressed at 120 bar, 160 °C pressing temperature, for 4 min and a moisture content of 9% except for board made from 100% coconut husk which was pressed at 165 °C for 11.5 min (density 1400 kg m⁻³, thickness 6.3 mm).

With regard to swelling and water uptake after the 2-hour boiling test, surprisingly good board performances were achieved. Up to a mixing ratio of 1:1, the water resistance was close to that of reference board of 100% resinated wood fibres.

The E-modulus in bending and flexural strength decreased with wood fibre content. However, the water uptake and swelling after the 2-hour boiling test increased.

The mechanical properties of the board were strongly dependent on the wood fibre content. The wood fibres strengthened the panels. At least 65% of wood fibres must be used to reach an E-modulus of 9000 N mm⁻² as required by EN 438 (European Standard 2005a, b).

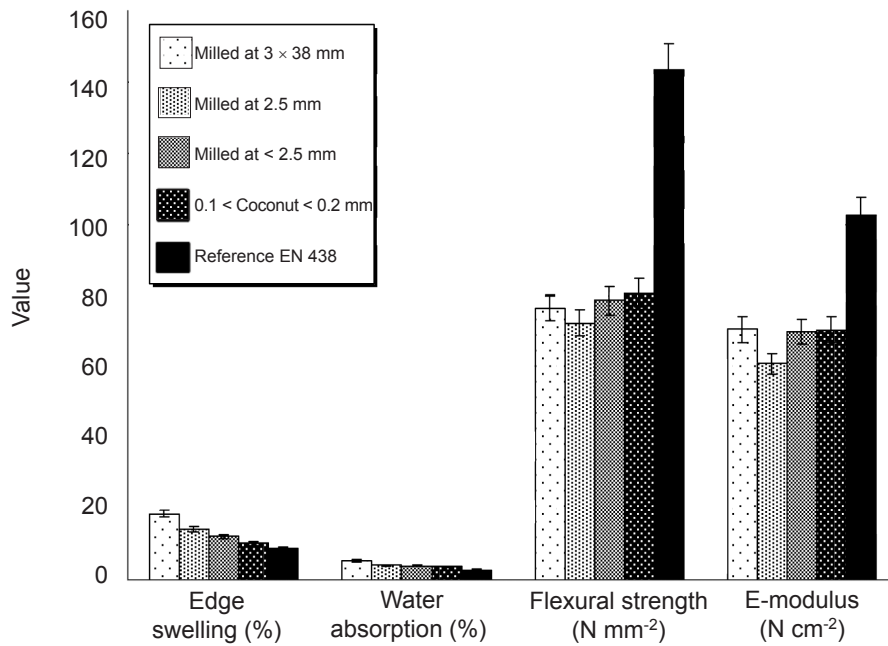


Figure 5 The impact of coconut husk particle size on the HPL (thickness 6.1 mm, density 1400 kg m⁻³)

Effect of pressure

Test runs to determine the ideal pressure showed slightly better performance of the boards when applying at a pressure of 90 bars. The effect was low but lower pressure meant lower energy consumption in production. Most of the laboratory trials were carried out under pressing pressure of 120 bar.

Boards pressed using optimised parameters

A combination of parameters determines the optimum parameters to produce boards from PF-resinated wood fibre and coconut husk particles:

- Material, milled in a MPF 9/430 at 2500 rpm at 4.2% moisture content, peak in particle size distribution below 0.125 mm mesh size
- Mixing ratio of resinated spruce fibre and coconut husk of 1:1 (50% spruce fibre)
- 90 bar pressure
- 165 °C pressing temperature
- Pressing time of 11.5 min
- Moisture content of blended furnish 8%

Figure 7 shows the properties of boards made from 50% coconut husk material and 50% PF-resinated spruce fibres at optimum pressing parameters. Board density was the same, close to 1400 kg m⁻³.

Low edge swelling and water absorption after the 2-hour boiling test indicated high water resistance. The edge swelling of 8.23% almost met the requirement of EN 438 (8.0%) and was much better than boards made from 100% coconut husk (20.1%). Similarly, for water absorption after the 2-hour boiling test, 3.4% was closer to the recommended 2% and much better than the 100% coconut husk boards (9.9%). The values of 100% coconut husk boards with regard to water resistance after the 2-hour boiling test were impressive—these boards bonded without additional resin.

The mechanical properties behaved differently. While the flexural strength of coconut husk/wood fibre boards (77.4 N mm⁻²) almost met the target value of 80.0 N mm⁻², the modulus of elasticity in bending was significantly lower (7000 vs. 9000 N mm⁻²). Both properties were higher than those of pure coconut husk (5200 N mm⁻²).

The high water resistance is based on good curing of the hot-pressed materials. Two polymers are built during the pressing process in the panel: (1) fast curing resol-PF polymer and (2) slow curing lignin polymer. Lignin is cross-linking at long pressing time. It starts flowing and reacting above pressing time of 5 min, when the PF-resin is almost completely cured. No reaction between PF and lignin takes place. With longer pressing time (expressed in higher curing numbers), the lignin

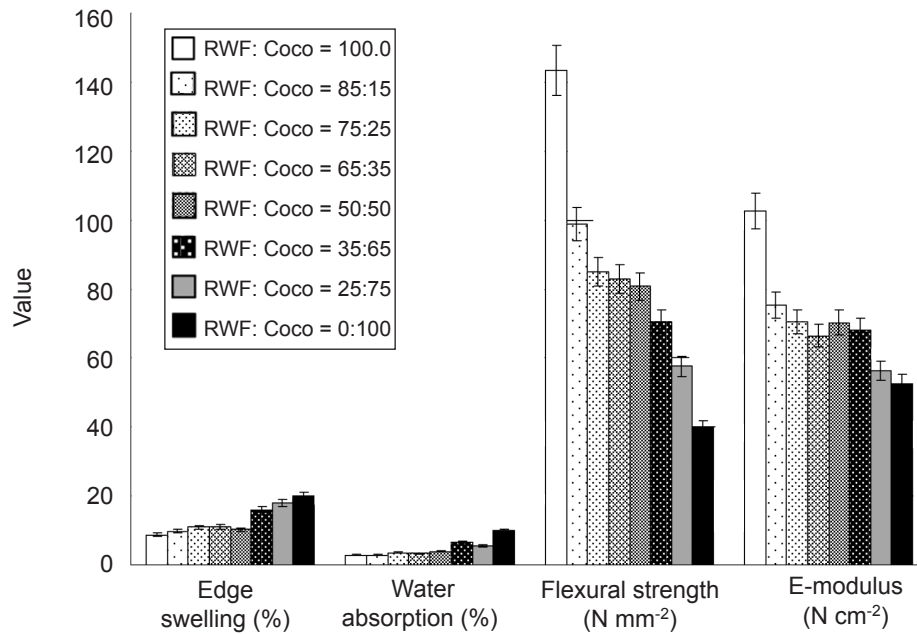


Figure 6 Influence of the mixing ratio (PF resinated wood fibre/coconut husk material) on the HPL (thickness 6.1 mm, density 1400 kg m⁻³). RWF = resinated wood fibre, coco = coconut

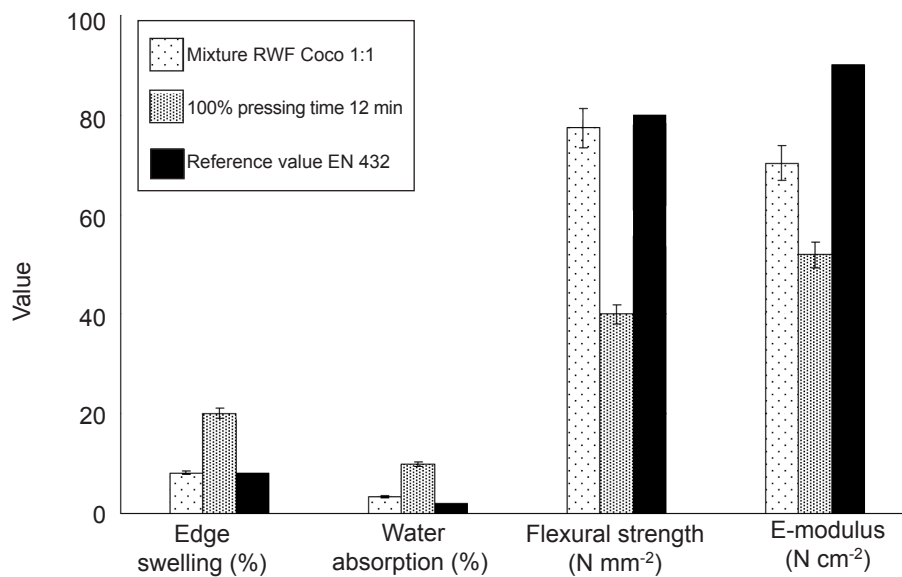


Figure 7 Comparison of HPL properties with reference values of EN 438. RWF = resinated wood fibre, coco = coconut

is cross-linked. A second three dimensional polymer is built up in the board. Due to their different molecular sizes, the polymers fill the interspaces and no water can enter the board. The reactive OH-groups of the carbohydrates are partly degenerated and water molecules cannot swell the cellulose chains, which are additionally covered with resin or lignin. This two-polymeric panel shows high water resistance.

CONCLUSIONS

The use of coconut husk for manufacturing of water resistant boards for exterior application is an attractive alternative especially for regions having the raw material in the surrounding areas.

Important aspects to be taken into consideration are: proper storage of husks without contaminating with mineral matters,

specialised equipment and parameters for milling, optimised pressing parameters and appropriate ratio between the resinated wood fibre and coconut husk.

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