Coir Based Building and Packaging Materials

Final Report of Project CFC/FIGHF/11

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TECHNICAL REPORT

Project title:

Coir Based Building and Packaging Materials (CFC/FIGHF/11)

Main participating institutions:

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- **PCA**: Don Mariano Marcos Ave., Cor Elliptical Rd., Diliman Quezon City, The Philippines
- **FIDA**: BAI Compound Visayas Ave., Diliman, Quezon City, The Philippines
- **FPRDI**: 4031 College, Laguna, The Philippines

Abbreviations

A&F	Agrotechnology & Food Innovations B.V.	
AGAT	Agta Tall	(coconut variety)
BAYT	Baybay Tall	(coconut variety)
CATD	Catigan Green Dwarf	(coconut variety)
CFC	Common Fund for Commodities	
DM	dry matter	
FAO	Food and Agriculture Organisation of the United Nations	
FIDA	Fiber Industry Development Authority	
FIGHF	Intergovernmental Group on Hard Fibres	
FOB	Free On Board	
FPRDI	Forest Products Research and Development Institute	
GPa	giga-pascal	
kN	kilo-newton	
kWh	kilowatt-hour	
LAGT	Laguna Tall	(coconut variety)
MDF	Medium Density Fiberboard	
MPa	mega-pascal	
N	Newton	
PCA	Philippine Coconut Authority	
RH	Relative Humidity	
RIT	Rennel Island Tall	(coconut variety)
TAGT	Tagnanan Tall	(coconut variety)
TGA	Thermo Gravic Analysis	
wt.%	weight percentage	

Content

Foreword

Finding new applications for relatively low value materials can greatly contribute to providing additional benefits for low-income commodity producers. The use of coir as the base material for higher value-added board material is one of the projects that the Common Fund has considered worthwhile supporting. As will be known, coconut fibre, or coir, is a low-value by-product of coconut production and it is regarded in most coconut producing countries as waste material. Only in a few countries coir is processed into commercially traded products.

The present Technical Paper is the result of the work undertaken in a project, which specifically focused on technology development for the use of coir as the base material far the production of environment-friendly, binderless, high performance board materials. A pilot production unit has been set up to provide detailed insights in the technical and financial components of a fully operational production unit. The project, entitled Coir-based Building and Packaging Materials, was implemented by the Agrotechnological Research Institute[1], Wageningen, the Netherlands. In line with its mandate, providing support to developing countries making them less dependent on often unprocessed exports of commodities, the Fund has financed this project, at the request of the FAO Intergovernmental Group on Hard Fibres (FIGHF), the designated International Commodity Body for hard fibres.

Research work and subsequent pilot production activities have taken place both in the Netherlands as well as in the Philippines, where the Philippine Coconut Authority, the Fibre Industry Development Authority as well as the Forest Products Research and Development Institute proved good partners in the project. The project was implemented under the technical supervision of the FAO Intergovernmental Group on Hard Fibres.

This Technical Paper has been commissioned by the Common Fund in line with its policy to make results and experiences obtained in its projects available to a wider audience. It is hoped that the technical information provided in the report as well as its detailed assessment of the commercial potential for its larger-scale uptake will be sufficient for relevant decision makers in the private and public sector to further pursue the 'possibilities of using coir as a base material for board products.

It is the wish of the Common Fund that this publication in the series of CFC Technical Papers will thereby contribute to a further development of the coir sector, and may result in an increased demand for coir, leading to higher incomes for its producers.

Amb. Ali Mchumo
Managing Director
Common Fund for Commodities

[1] *Recently renamed into: Agrotechnology & Food Innovations BV.*

1 General introduction to the project

1.1 Objective and scope

This report describes the final technical results of the CFC/FAO research project on Coir Based Building and Packaging Materials (CFC/FIGHF/11).

The central objective of the project was
to establish the technical and financial/economic parameters for a cost-effective, non-polluting production of high quality coir fibre board as the basis of the presently not (or under) utilized coir fibre, without the use of additional chemical binders.

The project has aimed to prove the feasibility of a new, technically efficient and financially competitive method for the use of fresh coir fibre for the production of environmentally safe, high performance construction materials. It has demonstrated the potential of the application of a specific technology for the production of high quality coir fibre boards, by making use of the specific chemical composition of the coir fibre, in particular its high content of lignin. The project has focussed on the demonstration of the feasibility of the production of coir fibre boards through laboratory-level process development and pilot-scale testing/production of coir boards, including performance testing. Technical and financial/economic viability of the technology developed have been demonstrated and documented in such a manner that the technology can be applied at an industrial scale in a commercial environment in Developing Countries. This commercial uptake falls beyond the scope of the present project. Successful development of the technology to be used is expected to result in new applications for coir fibre, thus increasing the scope for adding value to the coconut, a commodity which is being produced by an estimated 50 million, mostly small-scale producers in some 50 countries.

1.2 Project Rationale

The project has aimed to demonstrate the potentials of (fresh) coconut husks as raw material for the production of environmental safe and high performance construction materials. The project has been designed to identify the perspective of expansion and diversification of the production and trade of high value-added products for coir producing countries. End-users will be local as well as export markets for building materials, but also packaging industries and potential export markets for price competitive and environmentally safe consumer goods. Potentials of the products in other areas than building markets or packaging could be found in a wide variety of consumer goods and furniture.

The overall costs of the coir board production were expected to be substantially lower than for the cheapest building boards on the market. Based on initial experiments, it was expected that the quality of the obtained boards would be comparable to the performance of MDF ("Medium Density Fibre" board), which is substantially more expensive than particle boards. Cost-effective fibre processing techniques will lead to increased use of coir in a wide range of products. Value-added exports of coir can be developed if production of high performance materials can be realized which will enhance the earnings of coir producing industries and improve the income and living standards of many local workers.

2 General introduction to the technology

A simple and efficient technology has been developed to produce high strength - high density board materials from whole coconut husks, without the addition of chemical binders. The board material has been shown to exhibit excellent properties, which are comparable with or even superior to commercial wood based panels.

2.1 Introduction

The project 'Coir based building and packaging materials', as funded by the Common Fund for Commodities (CFC) and supervised by FAO, was aimed to develop

> *a cost-effective process for the processing of coconut husk into binderless building and packaging board material.*

This process should be suitable for production of board materials in the vicinity of the coconut producing areas. The board products and materials should be attractive for local use and have the high performance quality required for exporting markets.

Four research institutes – Agrotechnology and Food Innovations (A&F, previously ATO), in Wageningen The Netherlands, Philippine Coconut Authority (PCA, Manila, Philippines), Fiber Industry Development Authority (FIDA, Manila, Philippines) and Forest Products Research & Development Institute (FPRDI, Los Baños, Philippines) – have investigated the technical, economic and logistic potential of the production process of coconut based panels or boards, specifically for the Philippine market situation. The results, however, can easily be transferred to the local situation of any coconut producing country.

2.2 Principle of the process

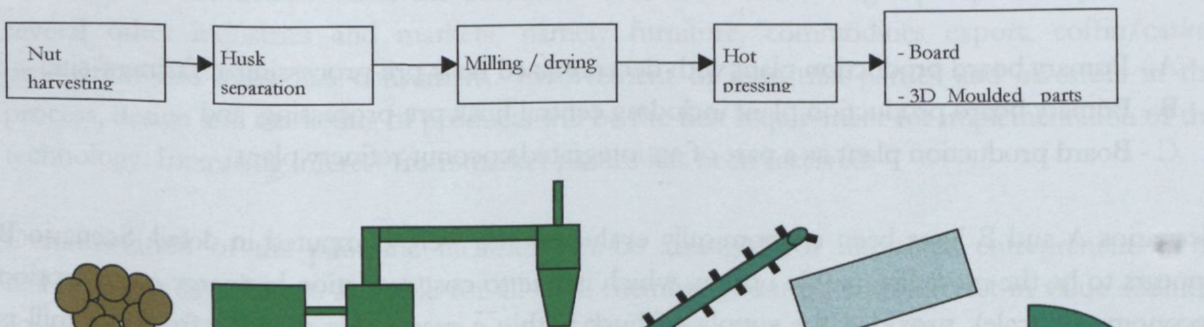
The coconut husk is composed of coir fibre and pith, which have to be separated for traditional fibre applications in woven carpets, ropes, brushes and matting. This can be achieved by retting procedures or mechanical decortication. The residual pith, however, contains a large amount of lignin, which has been demonstrated to act as a thermosetting binder resin for the coir fibres.

The basic principles of the resulting process from the performed detailed investigations on coconut husk processing are as follows:

After separation from the coconut, the husk is refined to small particles and short fibres using a simple opening technique by dry hammer milling, yielding suitable material for conversion into boards by hot pressing (scheme 1). After drying to moisture contents below 12% the milled husk material is evenly spread in the mould/press plate and compressed at high pressure and temperature.

The obtained boards show very good mechanical properties (strength of 50 MPa and stiffness of 5 GPa) comparable to those of commercial MDF and by far surpassing those of particle board (strength of 15 MPa and stiffness of 3 GPa). The thickness swelling and water absorption of the coconut husk board is lower than for MDF. After immersion in water, the coconut husk binderless boards show mechanical properties that surpass those of MDF by a factor of two. The density of the coconut husk boards (1.3 – 1.4 g/cm^3), however, is higher than for commercial MDF and particleboard (0.8 and 0.7 g/cm^3 respectively).

The very good performance of the binderless boards produced in this way opens many possibilities for the development of cheap and strong building materials. In principle 3D moulded products can be produced as well, which may lead to marketable products such as beams, laminates, cups, trays and pallets or plant pots. Products of varying shapes or moulded parts with lower densities can be produced with proportional lower mechanical properties. Fine tuning of the processing conditions would therefore be required for each end use.



Scheme 1 Overview of the processing chain from coconut to binderless board.

2.3 Availability and potential

Coconuts are abundantly growing in coastal areas of tropical countries. The husk surrounding the nutritious nut is abundantly available as cheap residue from coconut production for food purposes. The husk is known to yield the coarse coir fibre and in the extraction process large amounts of pith is obtained. This pith or coir dust currently finds more and more use as peat moss substitute in horticultural substrates. Those husks comprises circa 30 wt.% coir fibres and 70 wt.% pith based upon dry weight. At this moment only a small part of the available husk material is used for fibre extraction or find added value. The proposed eco-friendly production of fibre boards from whole coconut husk as wood substitute for building applications could create novel economic activities in rural areas.

The market potential for timber replacement is impressive. The annual world consumption of timber is in the order of 300 million tons. Annual world production of approximately 40 million tons of coconuts (corresponding to ± 25,000 million coconuts) yields more than 2 million tons of fibres of which only a small part is exploited. The world production of coir fibres is estimated at ±400,000 tons annually. There is no need to enhance the volume of the annual production as only 15-20% of the available coir fibres is currently utilised.

2.4 Economic evaluation of the production process and price comparison with competing products

The economic feasibility of the production process for binderless coconut husk boards has been evaluated based upon a conservative cost-profit analysis. For production of coconut husk binderless boards at industrial scale different possible scenarios were considered:

A - Primary board production plant with decentralized husk pre-processing at farmers' site;
B - Primary board production plant including central husk pre-processing, and
C - Board production plant as a part of an integrated coconut refinery plant

Scenarios A and B have been economically evaluated and were computed in detail. Scenario B appears to be the most favourable option, which is due to cost reduction in energy consumption (economy of scale), provided the supply of husk within a reasonable distance from the mill is guaranteed. Longer transportation distances to the production plant of husk raw material will increase the cost substantially. In addition, practical constraints related to local husk processing - especially in mountainous areas - make scenario A the less favoured choice. Calculations for scenario C have not been made because the whole infrastructure of such production plant with respect to energy requirement or storage capacity is too strongly dependent on the situation.

The optimal annual production rate – i.e. total volume per annum giving the investor the highest Return of Investment - is estimated to be between 10,000 and 20,000 tonnes of finished product. The production of 20,000 tonnes board material (4*8 feet., ¼ inch thick, equal to 122 x 244 cm and 6.4 mm thickness) requires an investment of ~60 million Pesos (1 million US$), which consumes approximately the husks obtained from ~80 million nuts. This amount of husks can be produced in an average Philippine coconut production area of circa 255 km^2, which was considered the maximum area for land transportation. A choice can be made to produce *export* quality at *F.O.B. price of PhP 157/board* (equal to 2.86 US$/board). The computed profit is 25%.

Section 6 of this report explains in more detail the investment- and production costs, and the coconuts' availability versus strategic locations for a coirboard production plant. In addition scenario B is subjected to a sensitivity analysis.

In Scenario C it can be assumed that both raw material- and energy cost can be reduced in an integrated coconut refinery plant, which consumes more than 70% of the production costs under scenario B, the market price of both export and local quality coirboard is expected to become significantly more competitive.

2.5 Status of development

The exact conditions for high performance board production have been determined on lab-scale both in The Netherlands and The Philippines. Subsequent semi-industrial scale trials were performed in The Philippines. The techno-economic calculations on production scale, investments and feasibility of the production have been critically evaluated based upon these data. Demonstration of the production on pilot scale has been realised in 2005 at FPRDI, Los Baños, Philippines.

The price performance ratio of products based on coir husk has been compared with competing market products. Comparison with commercial scale wood based MDF and particle board materials shows promising perspective particularly for coir-based binderless building board production (the project title suggests markets for packaging applications as well; the marketing study in the Philippines could not make this specific. On the other hand the study makes clear - see section 7 for details - that the binderless coir board has a bright prospect of penetrating several other industries and markets, namely furniture, commodities export, coffin/casket production and individual consumers.. Involvement of industrial parties and investors in the process, design and marketing of products will be the first requirement for implementation of the technology. Increasing interest from market parties has been received.

Demonstration of the pilot-line facilities can be arranged for interested entrepreneurs. The technology is in principle available for all CFC member countries with interest in value addition for the coconut fibre and husk. In process fine tuning and product design and development possibilities for market protection for commercial parties should be identified.

2.6 Structure of this report - a guideline for readers

This report is the reflection of the R&D work as performed within the project. Although it aims at being as complete as possible, it can raise questions - technically, technologically, economically. This is inevitable as every reader will read it with its own background. Nevertheless we are positive of the results and hope that you feel inspired to the technology and/or further diversify the products which can arise from it.

In general, the report consists out of three different sections: a technical section, a technological section and an economic section. Chapter 3 contains the technical section; it covers detailed aspects like the influence of coconut variety and age on board manufacturing and board properties, the influence of moisture and the chemical composition of fibre, pith and husk. Chapters 4 and 5 describe many technological aspects of producing coir-based boards from coconut husk - going from small- to pilot scale; each step in the processing line is described in detail including the variations in procession and how this impacts the final board quality. The economic and marketing aspects, finally, are described in chapters 6 and 7. Chapter 6 in detail specifies each individual investment and production cost aspect of the process, resulting in suggested (F.O.B.) board prices. Chapter 7 uses these data for a detailed marketing overview and identifies potential market sectors based on currently used materials and the results of the techno-economic evaluation of the coir-based board materials.

Each section can be read separately - it is not necessary to start from the beginning in order to understand the final sections, or vice-versa. Naturally, each section uses results which are described in more detail in one of the other sections - depending on its character (for instance, the technological section describes the influence of moisture/drying on final board quality whereas more details and background information is given in the technical section).

Furthermore each section uses abbreviations which in most cases are fully written down when used for the first time. For the readers' convenience a list of abbreviations is provided in the beginning of this report.

3 Raw materials and processing versus product properties

This section describes in detail the influence of coconut variety and the influence of age of the nut at harvest on the board manufacturing process and mechanical board properties. The influence of storage and pressing conditions and especially of high air humidity on board properties has been described.
The chemical analysis of fibre, pith and husk has been studied and compared for different varieties and different age of the nut at harvest. Also the composition of pressed boards has been examined, which indicates that before or after hot pressing the amount of extractives is declining and the lignin fraction increases. Young nuts show an earlier onset of thermal degradation processes (< 200 °C), which property is retained in the boards produced from it. The mechanical properties of boards produced from young nuts (6 or 7 months at harvest) are poorer than those made from older husk material.

3.1 Hot pressing - Introduction

Hot pressing is the standard procedure for manufacturing fibre boards for building applications. Commonly, a synthetic resin is applied to glue the fibres. The elevated temperatures and pressure are applied to cure the resin and to compress the fibre mat to the desired density. In this project the intrinsic binding properties of lignin present in the husks has been explored to produce self-gluing or binderless fibre boards.

For the production of binderless boards the coconut husk needs first a mechanical pretreatment – the fibre opening or 'milling process'. In the next step the material is pre-dried to achieve the desired dry matter content after which it can be compressed and cured in a hot pressing step. During the pressing process high temperatures are applied to melt the lignous adhesive present in the husk and to initiate and facilitate the endothermic cross-linking reaction of the binder that behave similar as thermosetting resins in board production. Pressure is applied to obtain a desired density and smooth surfaces of the board materials.

3.1.1 The fibre milling process

Various fibre opening processes have been evaluated as pre-treatment of coconut husk material in board production processing. For the production of homogeneous board materials it is essential that the fibre material can be distributed evenly in the pressing mould or in the fibre mat on the screen. Therefore refining to smaller particles is required. Of the methods dry milling of the husk was selected as the cheapest and most simple and effective method. Other methods such as steam-explosion or extrusion-refining require more energy and higher investment in equipment. Moreover, the quality of the produced boards was lower, than as obtain by dry milling.

After dehusking of the coconuts the husks were milled in a cutting mill with mesh size of 2.5 and 8 mm, respectively. The throughput and energy consumption were determined. The normalised energy consumption per ton of husk was calculated. The particle size distribution of the milled husks was determined.

3.1.2 The hot pressing process

Conventional hot pressing of fibre boards is a batch-wise process and commonly very robust. The technique comprises the compression of a (resinated) fibre sample between two heated mould halves, either flat platens or 3D moulds. For commercial board production, typical values for the applied temperature and pressure lie around 150°C and 40 bar. Conditions found in literature for similar binderless board production processes of other lignocellulosic materials report temperatures in the range of 125–230°C and pressures of 42–400 bar.

Alternatively, hot pressing of flat board materials can be performed continuously as well, using a so called double belt press. Investment for these more advanced processing lines, however, is considerably higher and the achievable maximum pressure is lower and therefore not considered suitable for this product-market combination.

3.1.3 Technical characteristics for production of binderless coconut husk boards

Test specimens of coconut husk boards produced on lab-scale at A&F were made in a circular flat mould (figure 1). The pre-opened husk was homogeneously distributed in the mould. Hot pressing was performed in the temperature range 100–250°C and the pressure range 80–200 bar during 10–60 minutes. The reproducible conditions with best mechanical properties for these boards were obtained for dry-milled husk applying 15 minutes 150 bar pressure at 180°C.

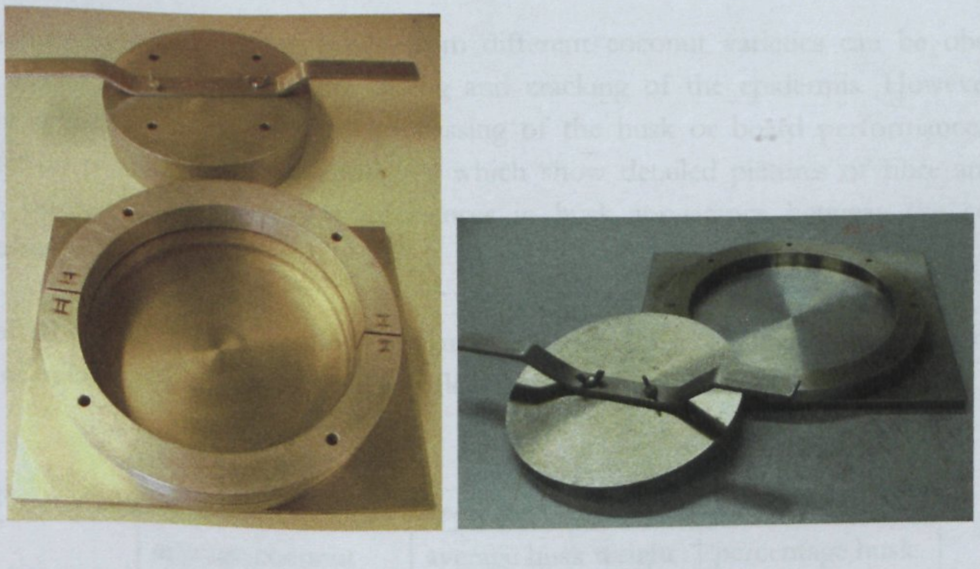


Figure 1 Photograph of mould in which husk is hot pressed.

At dry matter contents of the husk below 65%, water is pressed out of the husk and out of the mould at 150 bar pressure. The board quality is superior when the moisture content during pressing remains below 12%.

The results presented in chapter 3 and 4 refer to board materials that are produced following the above mentioned processing conditions.

3.1.4 Conclusions

- Binderless board materials with high technical quality can be produced from coconut husk with use of simple standard equipment
- dry-milling of the husks is the most suitable method for husk pre-processing
- moisture content of the husk material is critical during hot pressing
- Both flat and 3D products can be formed using the hot pressing technique.
- Hot pressing of 3D products is a batch process; flat products can be manufactured both batch-wise and continuously.
- Basic safety measures will enable not-trained workers to operate hot pressing equipment.

3.2 Influence of coconut variety on board manufacturing and board properties

To investigate the effects of the coconut raw material properties on board manufacturing and board properties, coconuts of different ages and of different varieties have been used for preparation of test panels. These varieties used are Tagnanan Tall (TAGT), Baybay Tall (BAYT), Laguna Tall (LAGT), Catigan Green Dwarf (CATD), Rennel Island Tall (RIT) and Agta Tall (AGAT). The husks were subjected to detailed analysis for comparison of morphological and chemical features. All varieties are available in the Philippines and only RIT originates from a different country, the Solomon Islands.

The husks were milled in a Retsch mill, conditioned to 90% dry matter content, milled again to a greater fineness and finally hot pressed into boards. The mechanical performance and the water absorption characteristics of these boards were determined.

3.2.1 Specifications of coconut varieties

The coconut varieties investigated differ in size and yield percentage of husk. The average weight of the complete nuts and of the husk and the percentage of husk per variety is presented in table 1. A graphical overview of these data is presented in figure 2. Obviously, small nuts do not necessarily have the lowest amount of husk. AGAT and CATD have the largest percentage of husk, whereas BAYT and RIT have the lowest.

No significant differences between husks from different coconut varieties can be observed, except that AGAT shows a premature drying and cracking of the epidermis. However, this different skin is not expected to affect processing of the husk or board performance. Also, scanning electron micrographs (Appendix A), which show detailed pictures of fibre and pith morphology, do not show significant differences in husk appearance between the coconut varieties investigated.

The husks of all coconut varieties show similar ease of handling for board manufacturing, i.e. distribution of milled husk into the mould and flow of pith during hot pressing.

Table 1 Weight of whole coconut and husk and the percentage of husk for 6 varieties.

	average coconut weight [grams]	average husk weight [grams]	percentage husk [%]
TAGT	1932	571	30
BAYT	1867	481	26
LAGT	1674	502	30
CATD	1488	534	36
RIT	1933	517	27
AGAT	1803	718	40

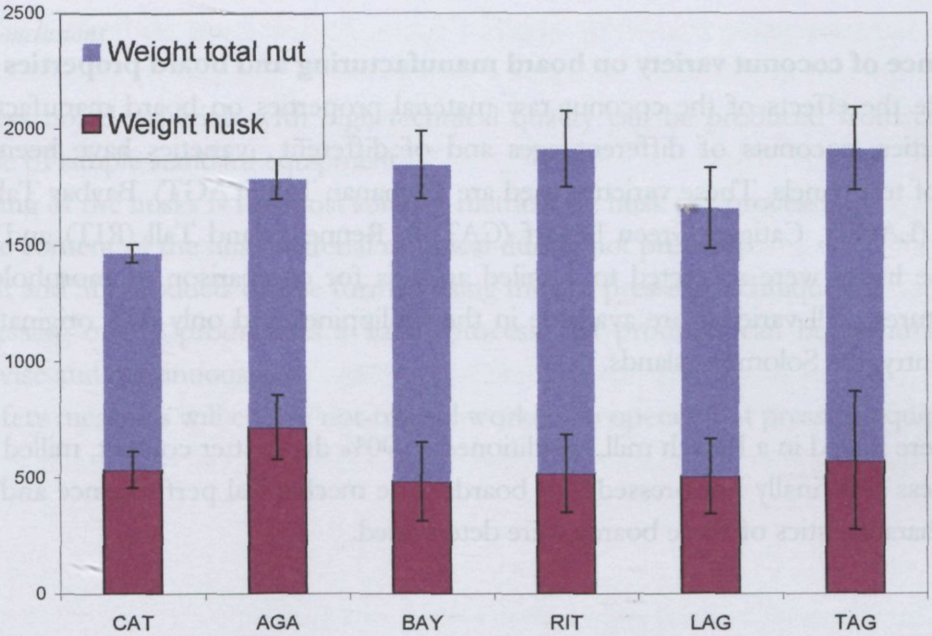


Figure 2 *Overview of total coconut weight and husk weight of six different coconut varieties.*

3.3 Mechanical properties of boards

The modulus and flexural strength of the boards produced based on the six coconut varieties are very close and reproducible at values around 5 GPa for stiffness and 50 MPa for strength. The varieties TAGT, BAYT and LAGT are performing slightly better (figure 3). All boards are performing equally or better than MDF, although it has to be noted that these boards have a higher density, i.e. 1.4 vs. 0.8 g/cm^3 for MDF. All coconut husk boards perform far better than particle board.

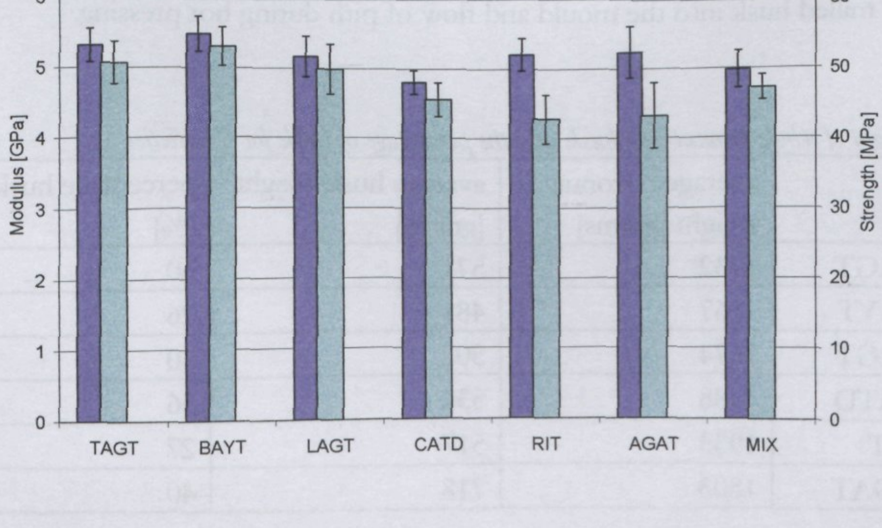


Figure 3 *Flexural modulus and strength of boards based on husk of six coconut varieties and from a mixture of five of these varieties, hot pressed at 180°C and 550 kN during 15 minutes*

3.3.1 *Flexural properties after water absorption*

An important criterion for performance of board materials in building applications is the water sensitivity and effects of moisture on the mechanical properties. The modulus and strength of the coconut husk boards after soaking in water for 24 hours are presented in figure 4. The modulus reduces with circa 60% as compared to untreated board, while the strength reduces with 30 - 40%. All boards perform much better than MDF after 24 hours soaking in water. This is a promising result for application of the boards in countries with a wet tropical climate.

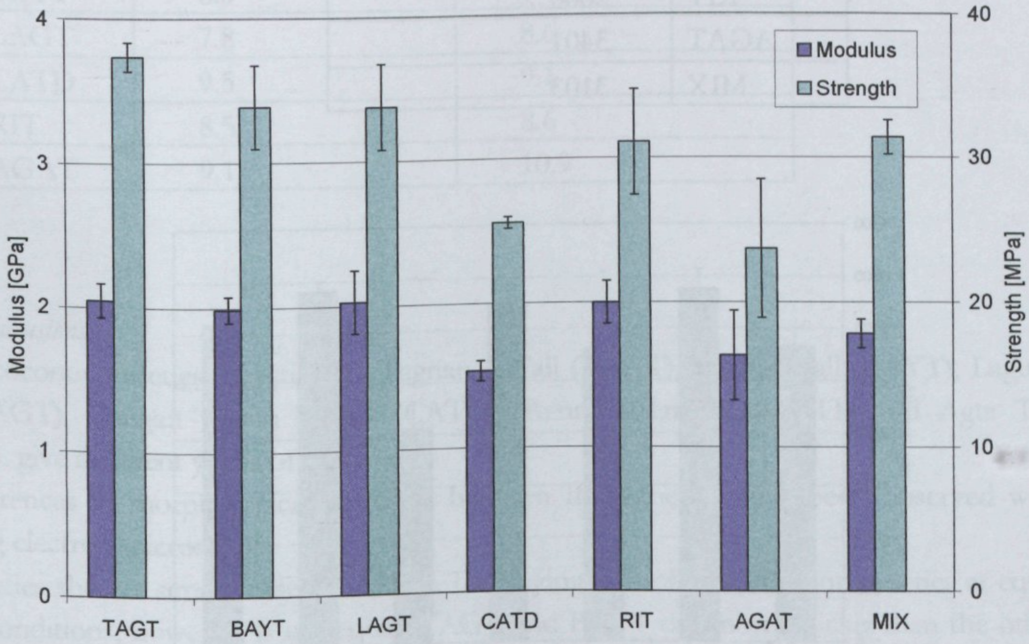


Figure 4 *Flexural modulus and strength of water soaked board (24 hours) which is based on husk of six different coconut varieties and from a mixture of five of these varieties, hot pressed at 180°C and 550 kN during 15 minutes.*

3.3.2 *Board handling*

The various high density boards produced from coconut husk by the method described yield boards that can be easily handled with common tools for wood working. The boards can be sawn, drilled, glued and sanded, without difficulty. Also common coatings for wood can be applied. The boards are less suited for use of nails, however, which can be expected with this high density and high stiffness. Screwing requires pre-drilling for good fastener performance.

3.3.3 *Screw withdrawal test*

The results of the screw withdrawal tests are given in table 2 and in figure 5. Since the boards were of similar thickness, the screw withdrawal forces can be compared. The screw withdrawal forces of all husk based boards are substantially higher than the 1555 N which is required for 17 mm thick high density boards as specified by the American National Standard for Basic Basic Hardboard[2]

[2] *Value with reference given in 'Paper and Composites from Agro-based Resources', edited by R.M. Rowell, R.A. Young and J.K. Rowell, CRC Lewis Publishers, 1997, p. 323.*

Table 2   Screw withdrawal force of boards based on husk of six coconut varieties and based upon a mixture of five of the varieties; between brackets the standard deviation is given.

	Screw withdrawal force [N]
TAGT	2824
BAYT	3377
LAGT	2791
CATD	3247
RIT	2060
AGAT	3401
MIX	3103

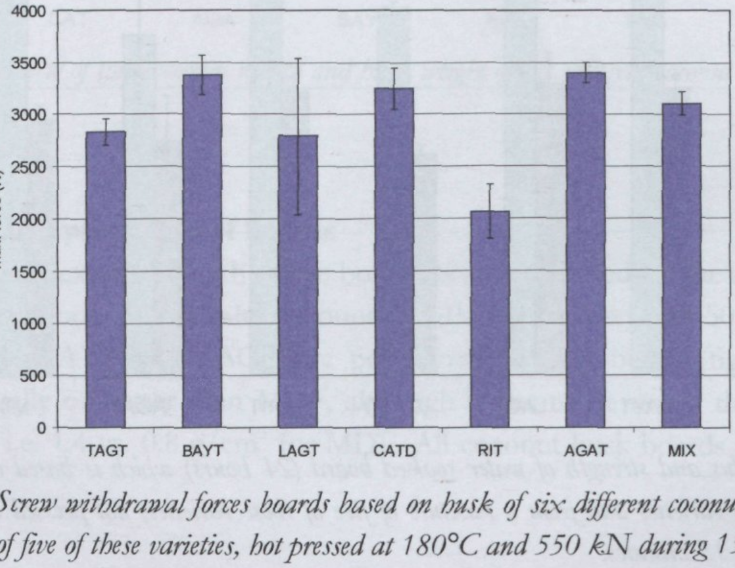


Figure 5   Screw withdrawal forces boards based on husk of six different coconut varieties and from a mixture of five of these varieties, hot pressed at 180°C and 550 kN during 15 minutes.

3.4 Water absorption and thickness swelling

3.4.1 Experimental

The dimensions and weight of five conditioned specimens of different board types were determined using a vernier calliper and an analytical balance. After 24 hours immersion in demineralized water at room temperature the dimensions and weight were again determined, giving the exact values for water absorption (wt.%) and thickness swelling (%).

3.4.2 Results

The water absorption and thickness swelling data of all boards are presented in table 3. The water absorption and thickness swelling are comparable for the boards of different coconut varieties. Boards with the lowest mechanical performance after 24 hours soaking in water, CATD and AGAT, also show the highest water absorption and thickness swelling. These values, however, are still much lower than for MDF and particle board as determined earlier, respectively 24 and 17% for MDF and 65 and 21% for particle boards.

Table 3 Water absorption and thickness swelling of boards based on six coconut varieties and on a mixture of five of these varieties after 24 hours soaking in water; between brackets the standard deviation is given.

	Water Absorption [wt.%]	Thickness Swelling [%]
TAGT	7.5	7.6
BAYT	8.0	8.9
LAGT	7.8	8.6
CATD	9.5	9.1
RIT	8.5	8.6
AGAT	9.1	10.9

3.4.3 Conclusions

- The six coconut varieties investigated, Tagnanan Tall (TAGT), Baybay Tall (BAYT), Laguna Tall (LAGT), Catigan Green Dwarf (CATD), Rennel Island Tall (RIT) and Agta Tall (AGAT), give different yields of husk.
- No differences in morphological structure between the varieties have been observed with scanning electron microscopy.
- The varieties show a similar ease of milling. The drying rate of the different varieties at equal drying conditions, however, is not equal. TAGT and BAYT dry more quickly than the other four varieties.
- Milled husk can be easily handled during board manufacturing.
- The values of stiffness of the boards based on the different coconut varieties are comparable, ranging between 4.8 GPa (CATD) and 5.3 GPa (TAGT). The flexural strength values from 43 MPa (RIT) to 53 MPa (BAYT).
- Boards based on a mixture of milled husk of five varieties give the average mechanical performance of all boards from individual varieties.
- Common tools for wood working can be used for the coconut boards. The boards can be sawn, drilled, glued and sanded, without difficulty.
- The screw withdrawal force of the husk boards is around 3000 N at a board thickness of 15 mm, except for RIT which yields a screw withdrawal force of around 2000 N. These values are all substantially higher than the 1555 N, which is required for 17 mm thick high density boards as specified by the American National Standard for Basic Hardboard.
- Nailing is not suitable for the high density boards without pre-drilling.
- After 24 hours soaking in water, the strength and modulus values reduce respectively by 30 - 40% and circa 60%.
- The water absorption of all boards after 24 hours soaking is in the range 8 - 10%, which is substantially lower than for MDF (24%).
- The thickness swelling of all boards is in the range 8 - 11%, which is lower than for MDF (17%).

3.5 Influence of coconut age on board manufacturing and board properties

3.5.1 Specifications of coconut ages

Five coconuts (LAGT variety) of different maturity were selected for evaluation. The largest amount of husk material available in Philippines are of mature nuts of 11 months and older. Nuts of 6 and 7 months old are also consumed in large quantities and the discarded husk is abundantly available in all coconut producing countries.

Separation of shell and husk of the 6 and 7 months old nuts is not practically applicable. Therefore boards have been produced from a combination of husk and (at this stage still very soft) shell.

The nuts of five different ages: 6, 7, 9, 11 and 13 months showed different composition and developmental stages: The copra layer was thickest in the 13 months nut, the shell developed from very soft and white at 6 months to black and hard. The density of the whole nut declined from above 1 to only 0.75 for the 13 months old nuts.

In figure 6 the measured weight of the whole nut, the wet and dry weight of the husk is given.

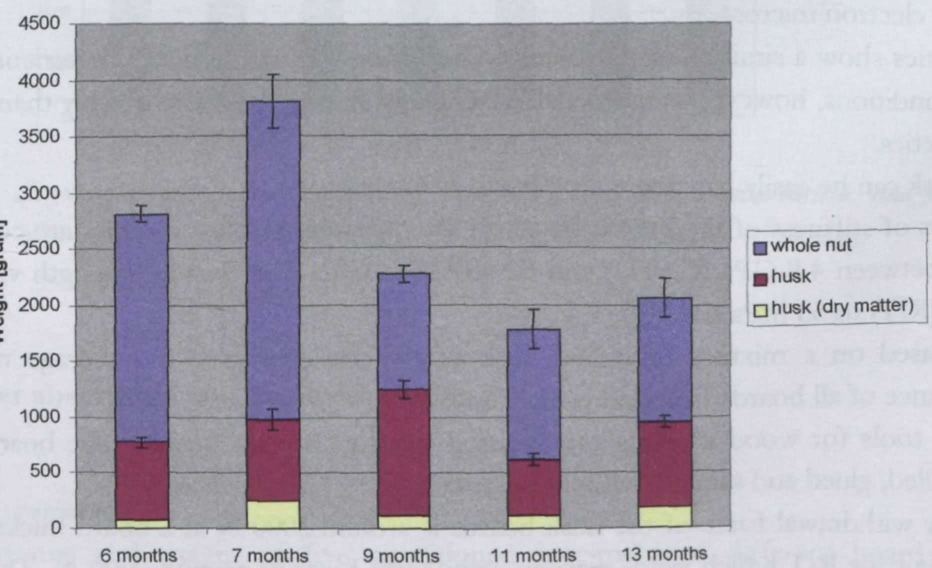


Figure 6 The weight of the different part of the nuts send to the Netherlands.

In figure 7 the percentage of dry husk of the whole wet weight of the nut is given. This number represents the amount of board material [kg] that can be produced from a given amount of nuts [kg] of different ages.

From figure 7 it can be concluded that the yield of dry husk fraction increases with increasing coconut age. As a result coconuts which are harvested after 6 months produce the smallest amount of husk (as raw material for the production of boards), whereas coconuts which are harvested after 13 months produce the highest amount of husk.

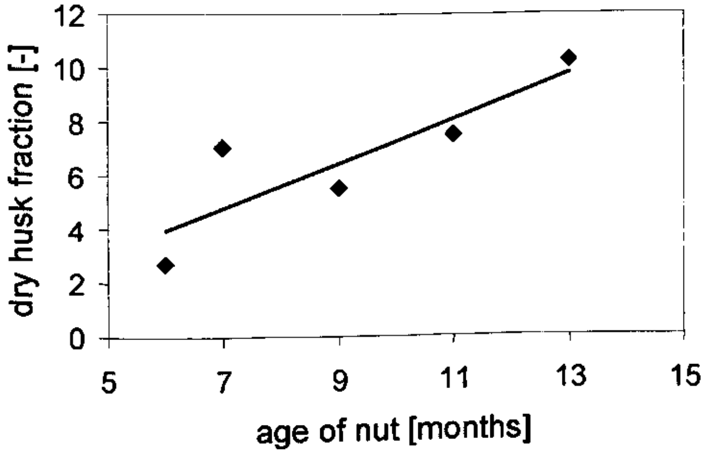


Figure 7 *The dry husk fraction [wt/wt] of the nut as a function of age.*

3.5.2 Board manufacturing

The density of the husk of the 6 and 7 months old nuts after drying is much higher than of the previously dried 11 months old nuts. The boards of 6 and 7 months nuts -produced under the same conditions- look very similar. Except that they have a darker colour and a stronger odour than the boards of 11 months old nuts. The density of the 6 and 7 months boards at 1.4 g/cm^3 is also close to that of boards of 11 months nuts. The warping of the 6 months boards, when uncontrolled relaxation is allowed, is much stronger than warping of boards produced of older nuts. Boards including the soft shell produced of 6 and 7 months old nuts are of very similar appearance, except that they show blistering of the surface.

3.5.3 Mechanical properties of boards

The stiffness and flexural strength of the 6 and 7 months boards is far lower than of the 11 months boards (figure 8). The presence of soft shell particles, which caused formation of blisters, has no further negative effect on stiffness and strength. The performance of a board manufactured from a mixture of 7 and 11 months old husk material showed average mechanical properties.

3.5.4 Flexural properties after water absorption

The stiffness and strength of the 7 months boards after soaking in water for 24 hours are presented in figure 9. The reduction in strength and stiffness is larger than for the 11 months boards, around 80% vs. around 50% for the 11 months boards. This reduction brings the mechanical performance of the 7 months board to the level of particleboard and below that of

MDF. Unless coated, boards from young coconuts can not compete to commercial boards with respect to mechanical performance.

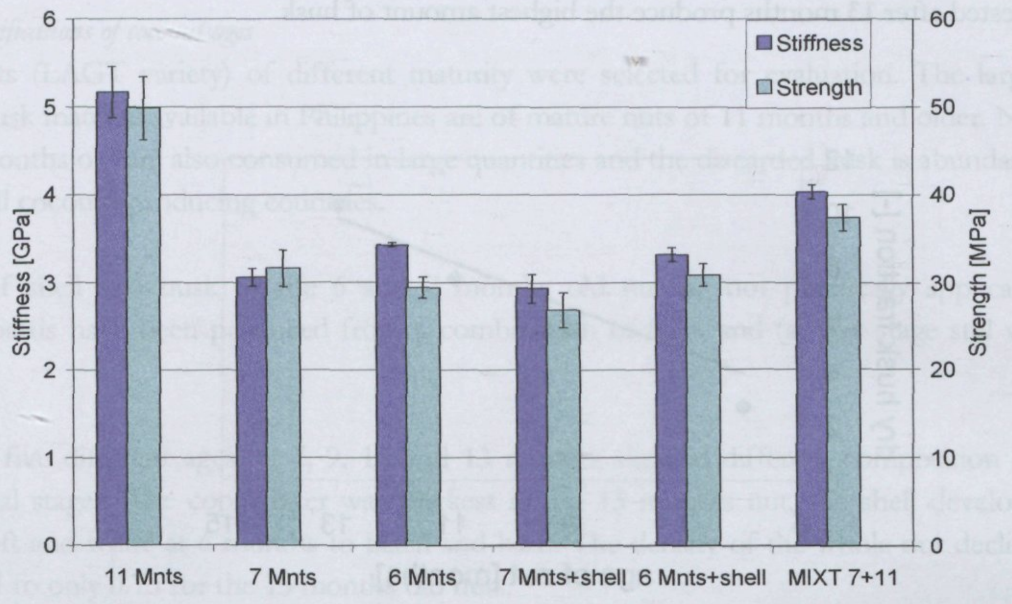


Figure 8 *Flexural stiffness and strength of boards based on husk of Laguna coconuts with different ages, hot pressed at 180°C and 550 kN during 15 minutes.*

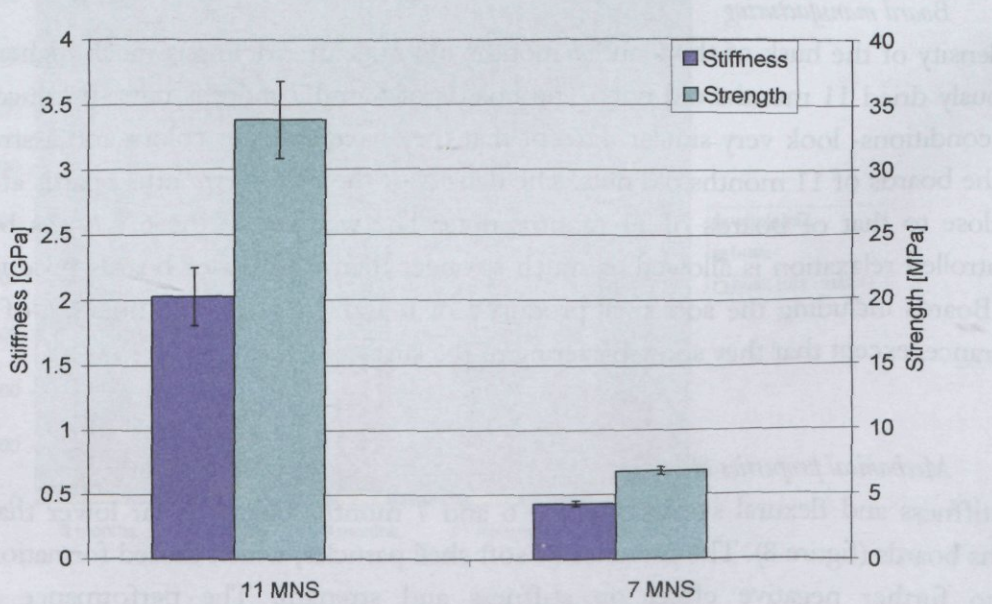


Figure 9 *Flexural stiffness and strength of water soaked board (24 hours) based on Laguna coconuts with different ages, hot pressed at 180°C and 550 kN during 15 minutes.*

3.5.5 Water absorption and thickness swelling

The water absorption and thickness swelling data of the boards prepared from 7 and 11 months old husks are presented in table 4. The water absorption of the 7 months boards is substantially higher than of the board material of 11 months at similar densities. The water absorption is 50%

higher for the 7 months board, the thickness swelling is about 100% higher. These values are lower than swelling of MDF and particle board, however they confirm that 7 months old coconuts may be less suitable for board production than 11 months old nuts.

Table 4 Water absorption and thickness swelling of boards based on Laguna coconuts with different ages after 24 hours soaking in water

Nut age [months]	Water Absorption [wt.%]	Thickness Swelling [%]
7	13	17
11	8	9

3.5.6 *Conclusions*

- The compaction due to drying of young coconut husk has no effect on the ease of milling and the milled material can be handled very well during board manufacturing.
- The manufactured 7 months boards give minimal warping, around 3 mm, the 6 months boards show pronounced warping, 2-17 mm.
- The density of the 6 and 7 months boards is 1.41 g/cm^3, the same as for the 11 months boards.
- The flexural stiffness and strength of both the 6 and 7 months boards is similar, around 3.1 GPa and 31 MPa respectively. These values are significantly below those of 11 months boards and MDF (5.0 GPa and 50 MPa), but comparable or better than those of particle board (3.1 GPa and 13 MPa).
- After 24 hours soaking in water, the stiffness of the 7 months boards reduces by circa 85% and the strength reduces by circa 80%. This brings the mechanical properties of soaked boards made of young nuts to the level of particle board.
- The water absorption and thickness swelling of the 7 months board after 24 hours soaking is 13 and 17% respectively, which is far better than observed for particle board (67% and 21%) and comparable or better than for MDF (24% and 17%).
- The presence of shell particles in the husk of young nuts has no effect on the mechanical properties of the boards, however, the boards show blisters and the surface is not flat.
- A board based on a mixture of 7 and 11 months nuts gives an average mechanical performance of the individual nuts.

3.6 Influence of raw material moisture content and pressing conditions on board properties

The moisture content of the raw material that is used in the lab-scale board pressing stage influences the properties of the final product. A high moisture content result in blisters and warping, very low moisture content reduce the flowability of the lignin during the process. However the mechanical properties of the product are also influenced, this influence is shown here.

Furthermore, this paragraph deals with the optimum conditions for board manufacturing. The effects on board properties manufactured at varying pressure, temperature and pressing time are discussed. Since investment costs for pressing equipment depend largely on maximum pressure required attention to reduced pressure for board manufacturing was addressed

The lab scale board manufacturing process is performed in a discontinuous way. This implies that during hot pressing the mould requires heating and cooling for each board. Industrial production will be continuous for higher processing efficiency. To obtain high production rates, the hot pressing and the cooling part needs to be separated. In this paragraph the effect of a pre-heated mould and cycle time on board performance is discussed.

3.6.1 Experimental

The coconuts were dehusked, dried to the desired moisture content and milled in a Retsch type SM1 over a 2.5 mm sieve. 240 Grams of this husk was uniformly distributed into a circular mould with a diameter of 215 mm and a height of 60 mm. Before filling, the mould was sprayed with a teflon® release agent. The milled husk was pressed at standard conditions at 180°C and 550 kN during 15 minutes. Boards were manufactured in triplo.

After hot pressing, the boards were conditioned at 23°C and 50% relative humidity for at least 7 days. Subsequently, the boards were cut to test specimens of 25*150 mm^2. Four such samples have been subjected to flexural loading at a span length of 24 times the sample thickness, i.e. 120 mm (according to ASTM D1037). The cross head speed was 2.5 mm/min for all specimens.

The dimensions and weight of four 25*50 mm^2 test specimens of all three boards have been determined using a vernier calliper and an analytical balance. Subsequently the samples were put in demineralized water for 24 hours and the dimensions and weight were determined again. From the dimension and weight data the water absorption (wt.%) and the thickness swelling (%) have been determined.

3.6.2 Results

It was demonstrated that the flexural strength and modulus of the boards produced under standard conditions using different raw material moisture contents show optimum around 10% moisture content.

3.6.3 *Influence of temperature and pressure*

The flexural modulus and strength of the boards pressed at varying conditions (pressure and temperature are given in figure 11.

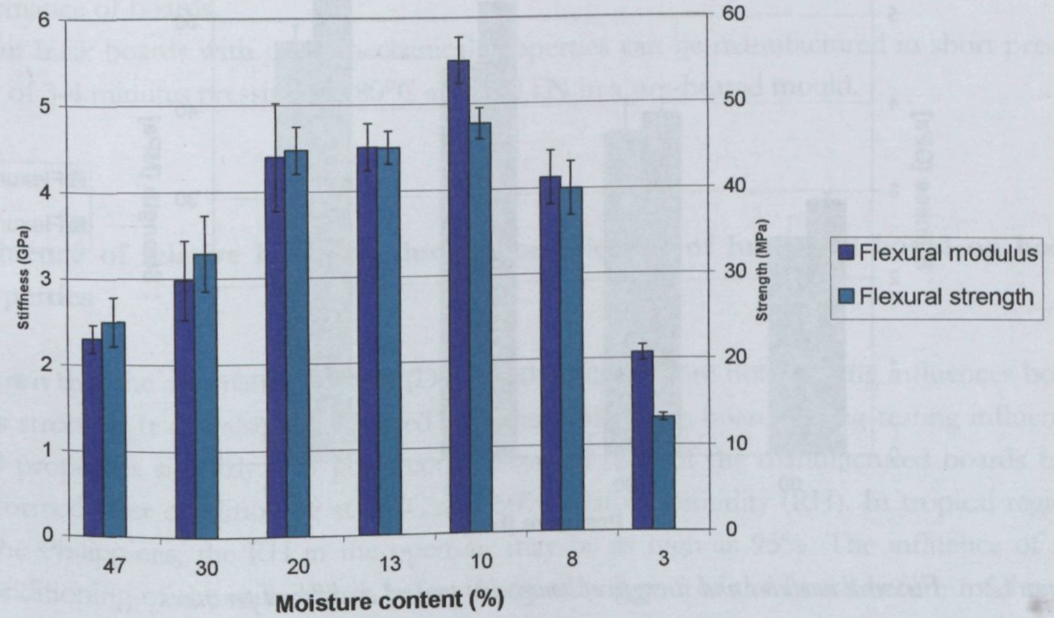


Figure 10 Influence of moisture content on the board's mechanical properties

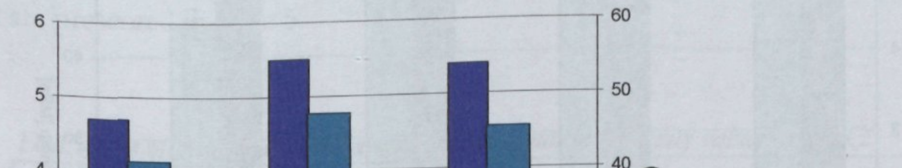


Figure 11 Flexural modulus and strength of boards hot pressed at different temperatures.

3.6.4 *Influence of pre heated mould*

To determine the minimum cycle time for binderless board production with high performance the pressing time was investigated hot pressed. In a pre-heated mould shorter pressing cycles are possible. The flexural strength and modulus of board materials are comparable to the properties of board hot pressed in a cold mould for 15 minutes (figure 13).

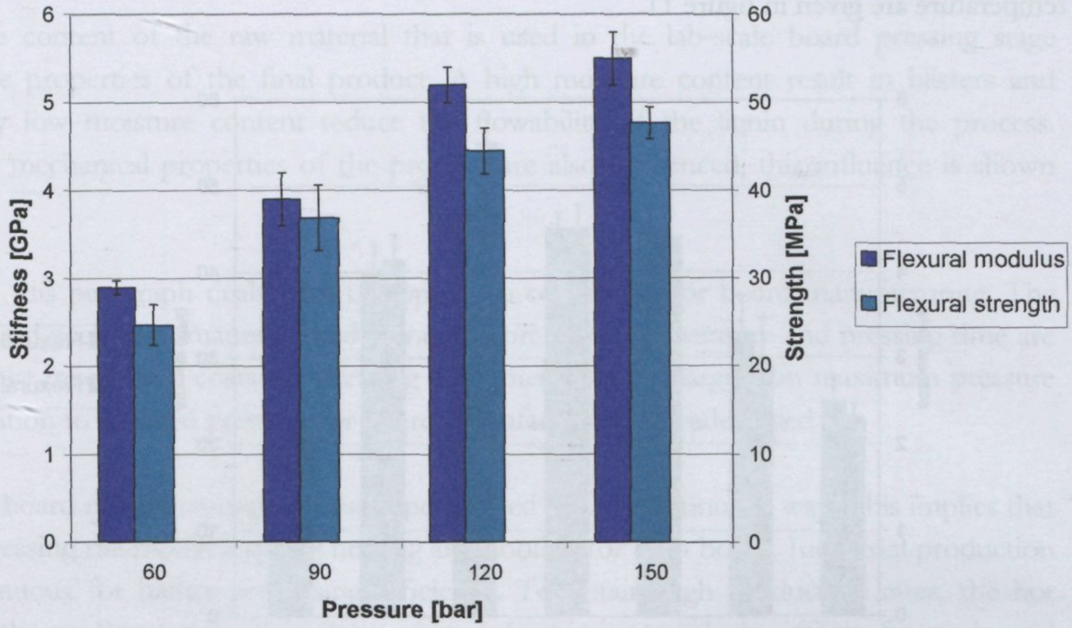


Figure 12 *Flexural modulus and strength of boards hot pressed at different pressures.*

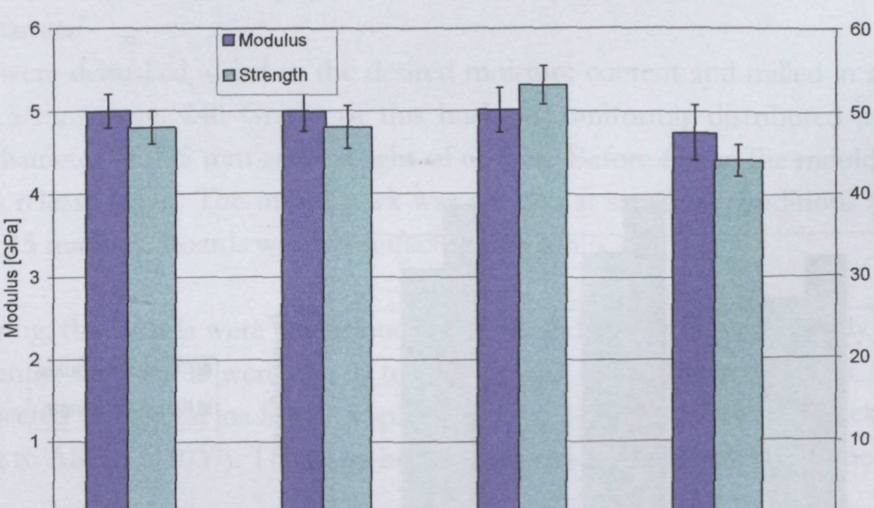


Figure 13 *Flexural modulus and strength of boards based on an equal mixture of husk of five coconut varieties, hot pressed in a pre-heated mould at 180°C and 550 kN during 5, 4 and 3 minutes; as a reference the properties of a board hot pressed in a cold mould during 15 minutes, the standard procedure in this research, is inserted.*

3.6.5 Conclusions

- Storage of 11 months old coconuts during at least 5 months at 2°C does not influence the flexural properties of boards produced from their husk.

- Storage of a mixture of dried husk during 5 months does not influence the flexural properties of boards produced.
- Reduction of consolidation pressure reduces the mechanical performance of the coconut husk boards. Increase in pressure time does not affect the board performance.
- Pressing of coconut husk boards at increased temperature reduces the mechanical performance of boards.
- Coconut husk boards with good mechanical properties can be manufactured in short pressin cycles of 3-4 minutes pressing at 180°C and 550 kN in a pre-heated mould.

3.7 Influence of relative humidity during conditioning of husk and board on board properties

It was shown that the dry matter content (DM) of the husk before hot pressing influences board properties strongly. It can also be expected that the DM of the board during testing influences the board properties similarly. For good comparison all tests of the manufactured boards have been performed after conditioning at 23°C and 50% relative humidity (RH). In tropical regions such as the Philippines, the RH in the open air may be as high as 95%. The influence of RH during conditioning of the milled husk before hot pressing and of the board before mechanical testing on the board properties is presented.

3.7.1 Results and discussion

The DM values of coconut husk and boards were measured at high and low relative humidity at 23°C and are presented in table 5.

Table 5 DM values of husk and board at two different relative humidity values at 23°C.

RH [%]	DM of husk, after cond. (press in) [%]	DM of board (press out) [%]	DM of board, after conditioning [%]
50	86	88	91
95	60	67	71

In the initial stage of hot pressing of the wet (95% RH) sample some water is pressed out of the husk and the DM increases from 60 to 67%. Together with the water, finely dispersed dark brown pith material flows out of the mould as well. After cooling, this material can be easily washed from the mould.

After circa 5 days conditioning of the board at 95% RH, some fungal growth can be observed. It is expected that these fungi do not significantly affect the mechanical performance after 7 days conditioning. After 10 days, the amount of fungi remains constant. The fungi can be easily removed from the board surface by wiping with a cloth. On the milled husk no fungal growth is visible, not even after conditioning at 95% RH during more than one month.

When the 95% RH board is conditioned at 50% RH, extensive warping (circa 20 mm) occurs. From the 50% RH sample only a small amount of water evaporates during hot pressing due to the high temperature, the DM changes from 86 to 88%. After a hot pressing cycle, the mould is clean and a new pressing cycle can be started up without any delay. After 7 days of conditioning at 50% RH, the board shows 45 mm warping. This strong warping is most probably due to a combined effect of differences in upper and lower mould thickness and changes in DM of the board during conditioning. When the 50% RH board is conditioned at 95% RH, after circa 5 days some fungal growth starts, comparable with the 95% RH board. This suggests the need for coating of the boards for outdoor applications.

During conditioning of the manufactured boards at 50 and 95% RH respectively, some more weight loss is observed). It can be concluded that coconut husk and board have different equilibrium DM values at one RH value.

Table 6 Mechanical properties and densities of boards, based on husk that is conditioned at 23°C and two different relative humidity values.

RH [%]	Strength [MPa]	Modulus [GPa]	Density [g/cm^3]
50	46 (2)	4.2 (0.1)	1.38 (0.01)
95	13 (1)	0.85 (0.02)	1.21 (0.01)

The mechanical properties and density of the boards are presented in table 6. The mechanical properties of the 50% RH samples are much better than of the 95% RH sample. The density of the 50% RH sample is higher as well. It is suggested that an excess of water in the husk hinders compaction and good interaction of the fibre and pith material.

3.7.2 Conclusions

- At a relative humidity of 95%, husk has to be dried for optimal board performance and optimal cycle times of board manufacturing.
- Husk conditioned at 50% relative humidity yields much higher performing board than husk conditioned at 95% relative humidity.
- At 95% RH, boards show fungal growth.
- Coconut husk and board have different equilibrium dry matter contents at one relative humidity value.

3.8 Chemical and thermo-gravimetric analysis: Comparison of fibre, pith and husk composition

3.8.1 Chemical analysis

The chemical composition of various coconut husk materials was analysed for contents of carbohydrates, lignin and extractable components. A clear difference in the chemical composition between fibre and pith was found (figure 14). Both the lignin content and the extractives are higher in the pith material. The content of neutral sugars in the fibre is higher. The difference in the composition between varieties is very small as shown for TAGT and CATD.

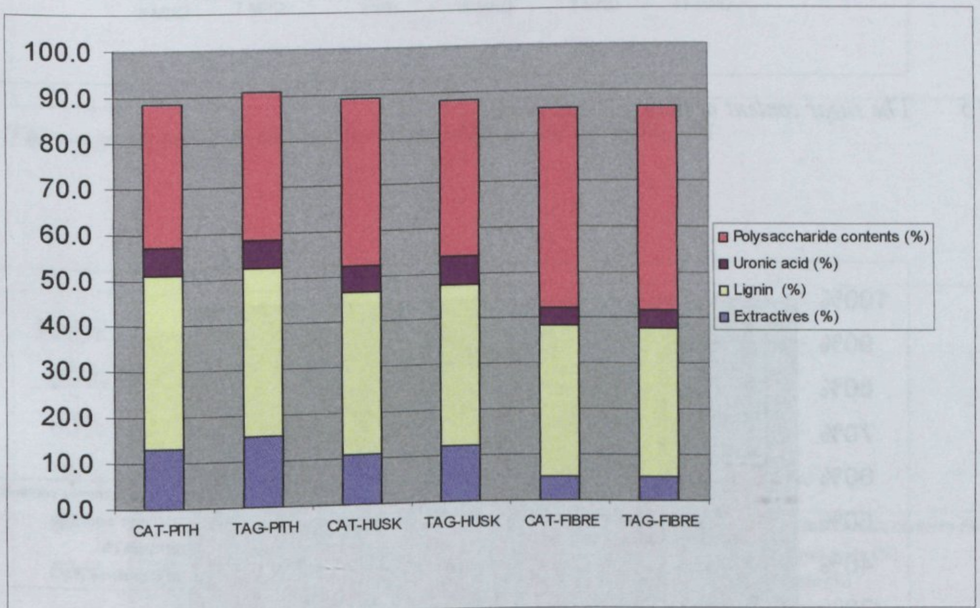


Figure 14 The chemical composition of fibre, pith and husk

Detailed analysis of the sugar composition reveals a difference between the sugar composition in pith and fibre. The higher glucose content in the fibre (29 vs 18%) is attributed to the higher cellulose content. Both fractions contain considerable amounts of hemi-cellulosic polysaccharides. The large amounts of galactose and arabinose in the pith suggests enriched arabino-galactan content.

The effect of maturity on the chemical composition of nuts and fibres is demonstrated in figure 15. The amount of extractives is clearly decreasing during aging of the nut. The relative amounts of lignin and sugars are increasing with maturing of the husk. The monosaccharides composition as function of the age of the nut does not change, except that the content of glucose (i.e. cellulose) increases with time (figure 16).

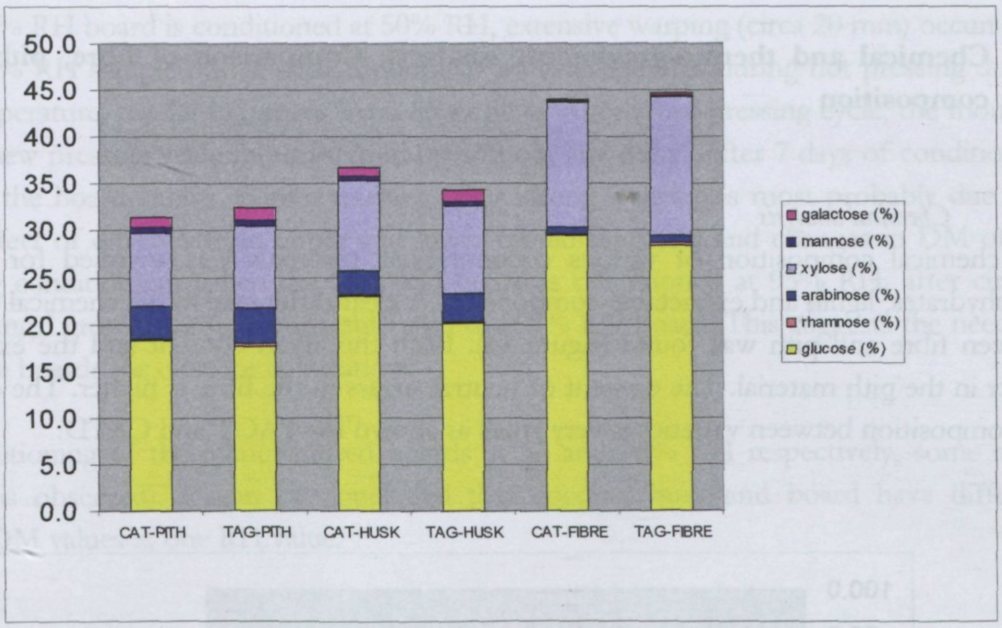


Figure 15 The sugar content of fibre, pit and husk

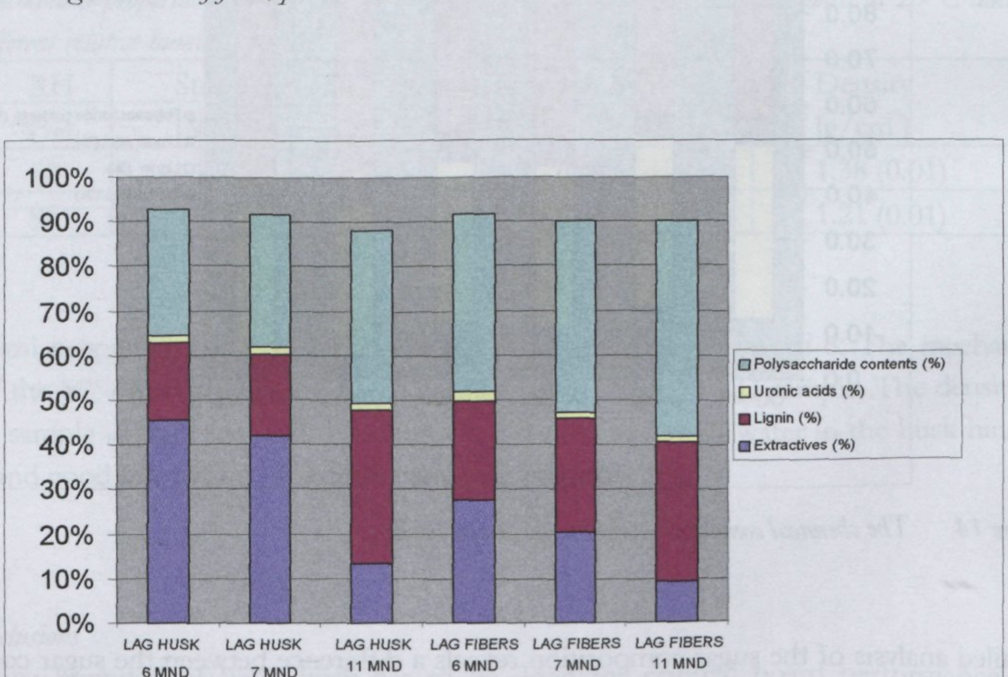


Figure 16 The chemical composition of husk and fibres of different age

The composition of boards as a function of the age of the nut (figure 17) runs parallel with the changing composition of the husk.

In figure 18 the different sugars present in the board are shown, which are very similar to the sugars present in the husk.

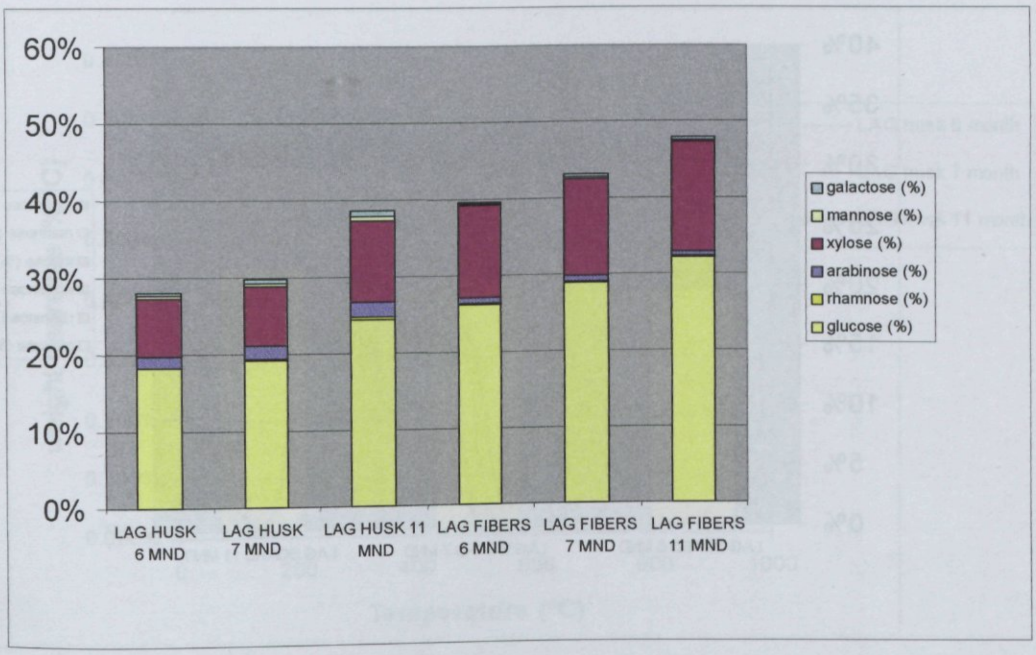


Figure 17 The sugar content of husk and fibre depending on the age of the nut

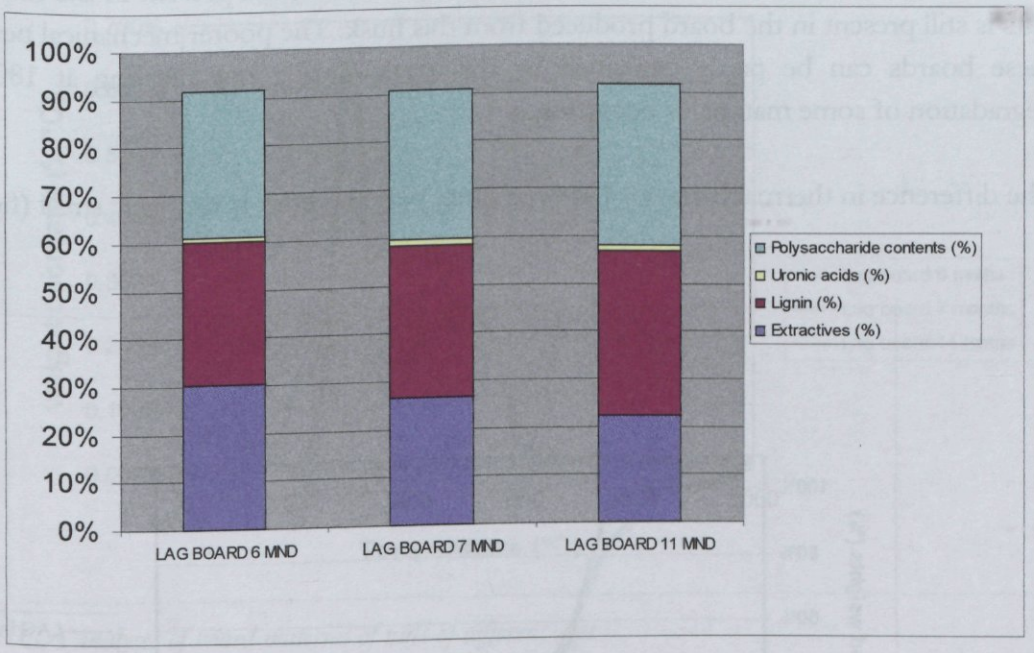


Figure 18 The chemical composition of boards produced by the milling process.

3.8.2 *TGA-measurements*

Comparison of the thermogravimetric analysis (TGA) between the husk of nuts of different ages is given in figure 20. The husk of the younger nuts starts to decompose at a lower temperature than the husk of the mature 11 months old nut. The same information is presented in figure 20. Here the first derivative of weight to temperature is given as a function of temperature. The first peak is only present in the younger nuts, most likely this peak is caused by extractable substances.

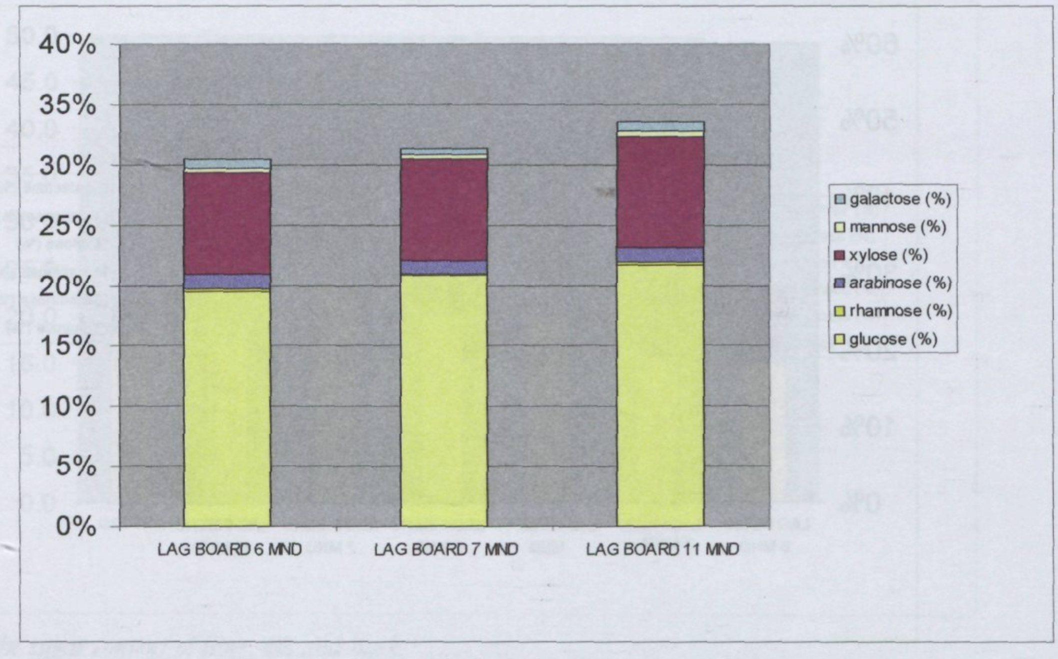


Figure 19 *The sugar content of board produced with the milling process as a function of the age of the nut.*

In figure 21 it is shown that the extra thermal degradation peak present in the husk of younger nuts is still present in the board produced from this husk. The poorer mechanical performance of these boards can be partly explained by this peak: during hot pressing at 180 °C thermal degradation of some material is occurring.

The difference in thermal behavior between fibre, pith and husk is relatively small (figure 22).

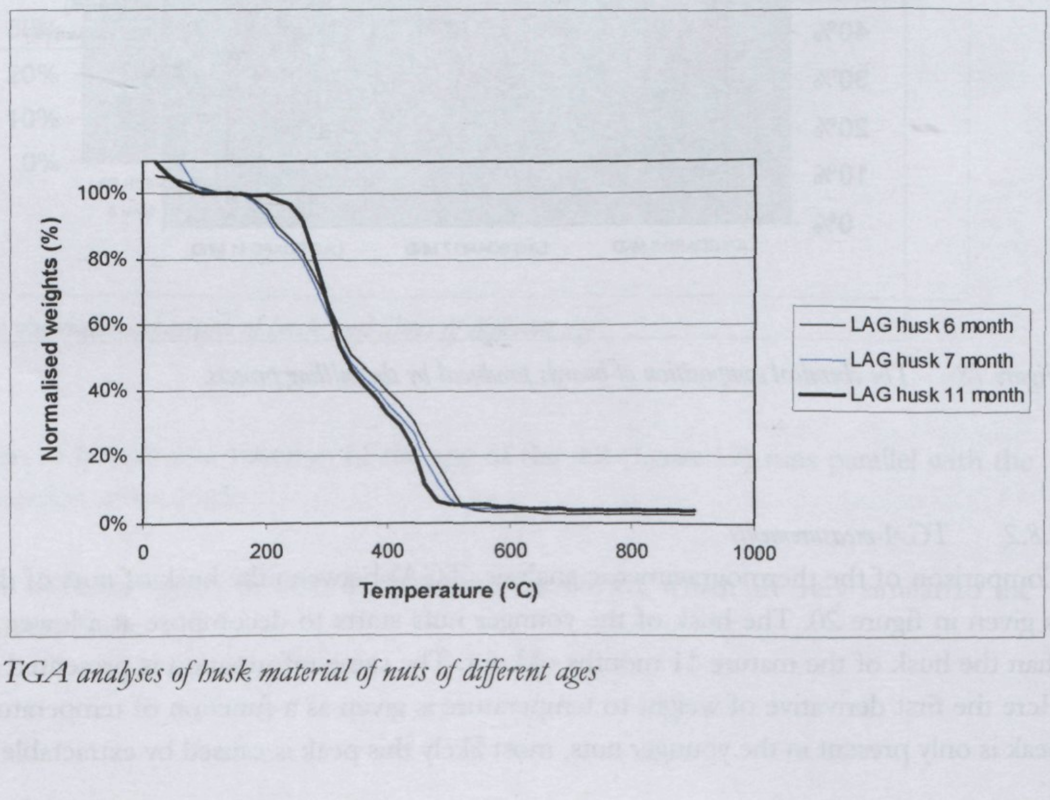


Figure 20 *TGA analyses of husk material of nuts of different ages*

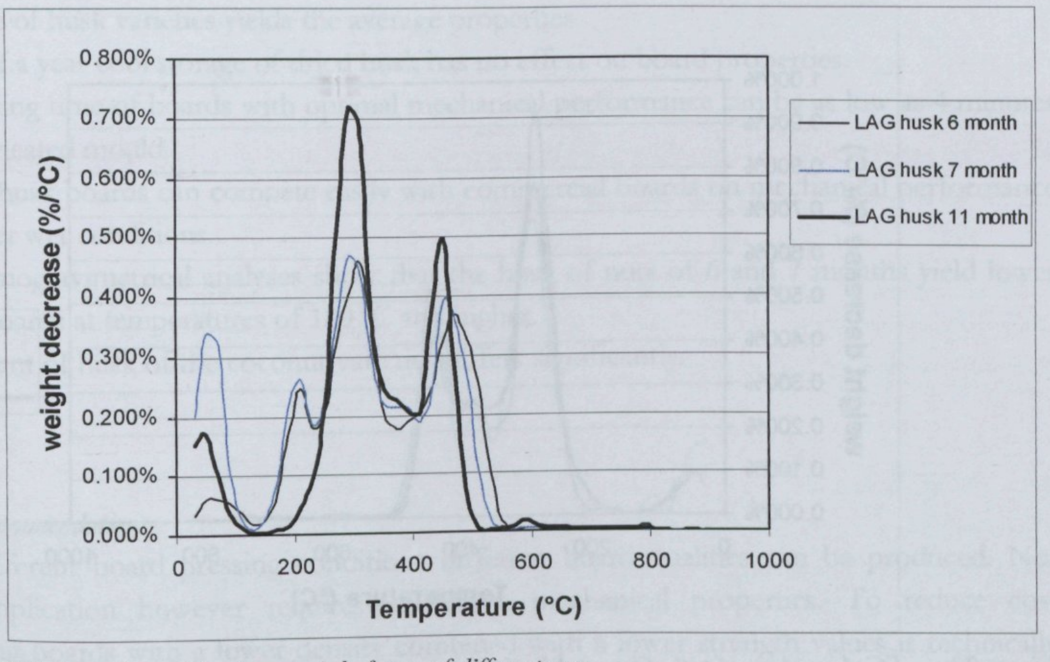


Figure 21 *TGA analyses of husk material of nuts of different ages*

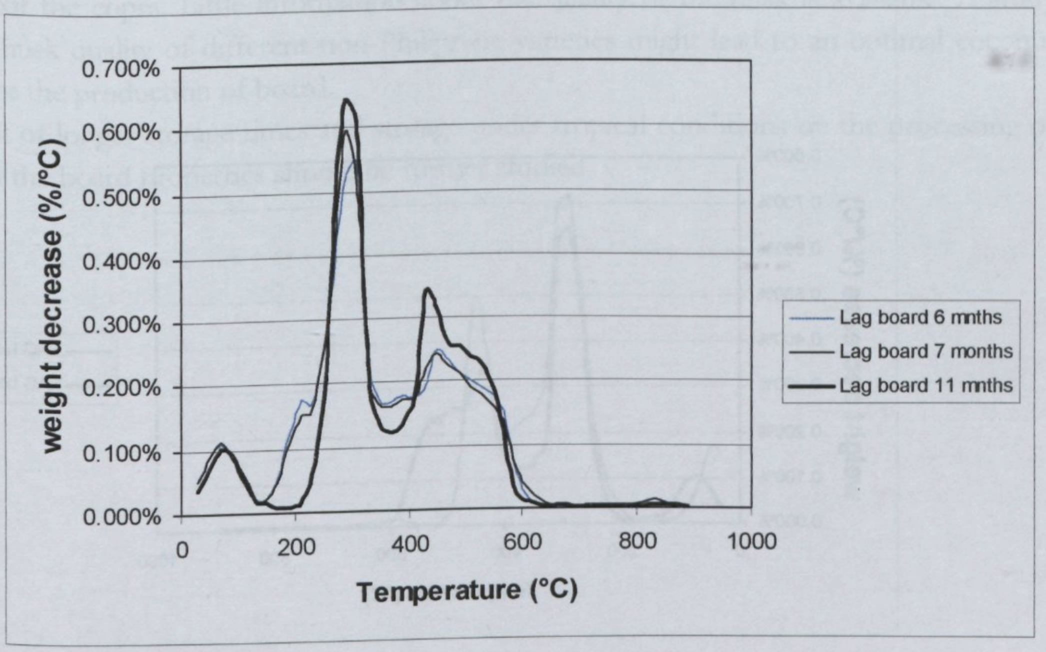


Figure 22 *TGA analyses of board material of nuts of different ages*

For comparison the TGA of both board and husk is shown. It indicates that the thermal degradation of the material as a function of temperature has changed. The decomposition of the hot pressed board starts at a slightly higher temperature (200 vs 180 °C), while complete conversion is only achieved at 600 °C.

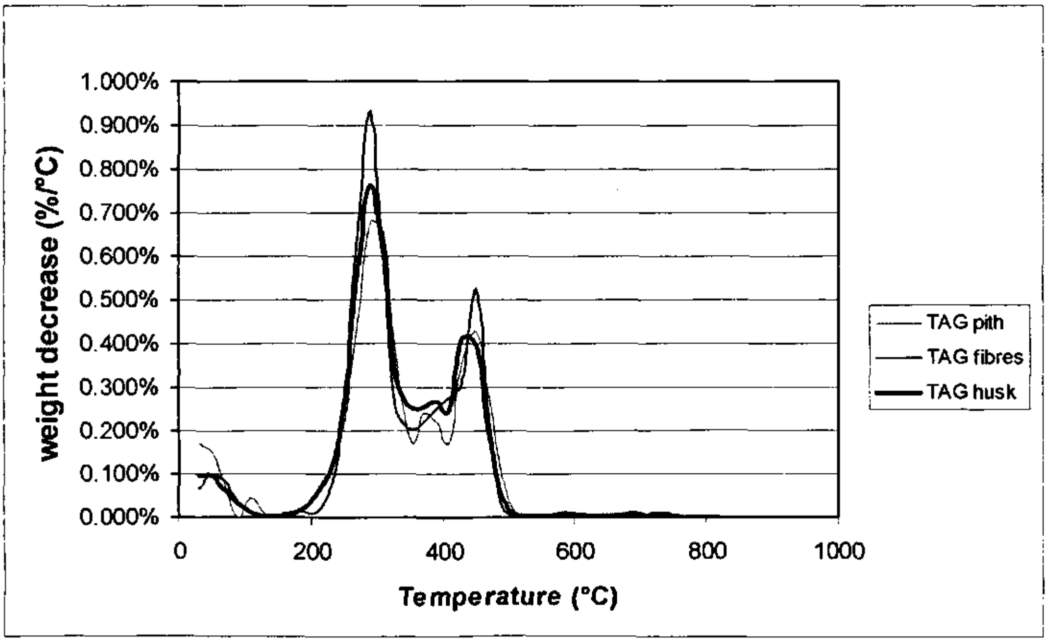


Figure 23 TGA analyses of pith, fibre and husk

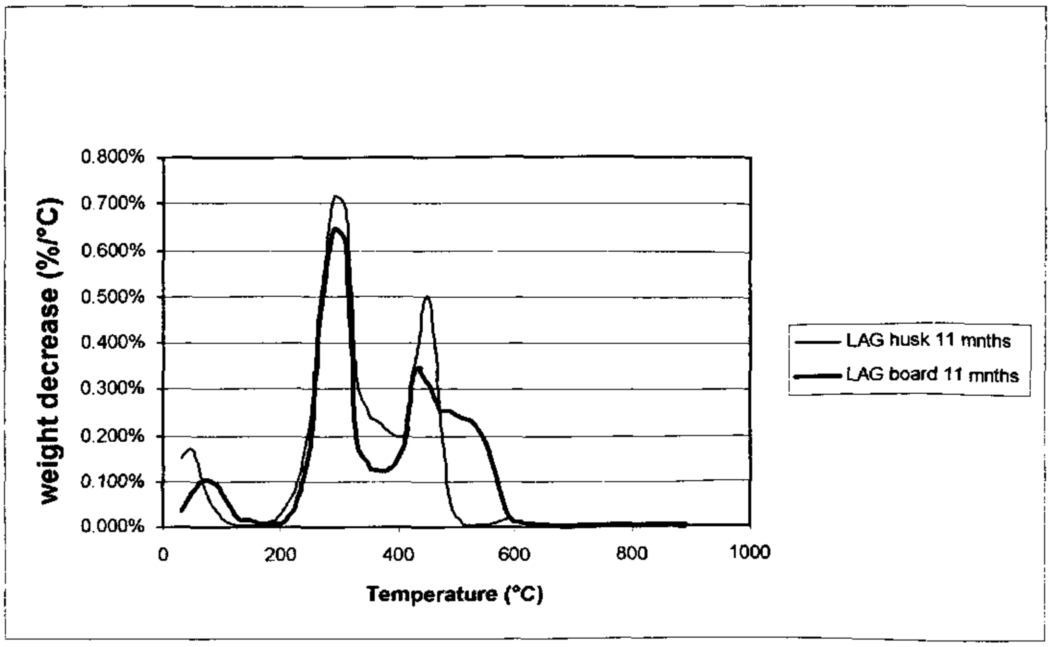


Figure 24 TGA analyses of board and husk material

3.8.3 Conclusions

- Binderless boards of excellent performance can be produced by subsequently milling and compression processes as demonstrated by the project.
- All husk raw materials, whatever freshness, variety or age can be converted to compressed boards of high performance. Younger nuts however (6-7 months) yield some lower quality boards.
- The coconut varieties Tagnanan Tall, Baybay Tall, Laguna Tall, Catigan green dwarf, Rennel Island Tall and Agta Tall yield husks that give very similar processing characteristics and board properties.

- A mixture of husk varieties yields the average properties.
- Up to half a year cool storage of dried husk has no effect on board properties.
- The pressing time of boards with optimal mechanical performance can be as low as 4 minutes in a pre-heated mould.
- Coconut husk boards can compete easily with commercial boards on mechanical performance and under wet conditions.
- The thermogravimetrical analyses show that the husk of nuts of 6 and 7 months yield lower quality boards at temperatures of 180 °C and higher.
- The amount of husk of the coconut varieties differs significantly.

3.8.4 Recommendations

- Using different board pressing conditions different board qualities can be produced. Not every application however requires maximum mechanical properties. To reduce cost producing boards with a lower density combined with a lower strength values is technically feasible; its economic impact is addressed in chapter 6.
- The main coconut varieties grown in the Philippines have been selected for the quality and quantity of the copra. Little information about the quality of the husk is available. A study into the husk quality of different non-Philippine varieties might lead to an optimal coconut variety for the production of board.
- The effect of longer storage times and storage under tropical conditions on the processing of husk and the board properties should be further studied.

4 Up scaling of the production process

This section describes the transition from producing on laboratory to producing on pilot scale. It is demonstrated that milled coconut husk can successfully be hot pressed into boards with quality as was achieved earlier on lab scale.
Processing conditions are described; in addition product specific properties like stiffness, strength, machine ability and fire resistance are provided. It turns out that when scaled up, coir-based boards again show better properties than their competing board materials.

4.1 Introduction

On lab-scale a variety of parameters in coconut husk binderless board manufacturing have been investigated and optimised. This resulted in high performance boards with properties close to that of MDF or even surpassing it. These promising results demand for a demonstration of the of manufacturing process at pilot scale of commercial sized boards in the Philippines. The effects of scaling-up were determined by a series of pilot scale experiments in the Netherlands (milling at A&F and hot pressing at Trespa bv, Weert) and in the Philippines (pilot-line at FPRDI).

4.2 Milling on pilot scale

During previous research, The dry-milling process was shown (Section 3.1) to yield refined husk material that very successfully can be used for the production of boards. For up-scaling of the milling process at A&F, a Pallmann PS 3-5 with a 3*38 mm sieve (the smallest mesh available) was selected. The principle of these 2 cutting mills is very similar. The Pallmann mill is compared to the Retsch mill with respect to: energy consumption, throughput and resulting particle size distribution.

Table 7 Milling characteristics of Laguna husk using a Pallmann PS 3-5 and a Retsch SM2000 cutting mill.

Mill type (sieve hole size)	Measured			Calculated	
	Weight of husk [kg]	Milling time [min]	Energy [Wh]	Throughput [kg/hour]	Normalised Energy [kWh/ton]
Retsch (2.5 mm)	0.5	5:26	77	5.52	154
Retsch (8 mm)	0.5	4:48	60	6.25	120
Pallmann, suction	10.7	7:57	440	80.8	41
Pallmann, no suction	3.5	4:40	120	45.0	34

The data of the Retsch mill confirm the expected effect of mesh size on throughput, specific energy and particle size: the throughput and husk particle size reduce with reducing mesh size, the specific energy consumption increases.

Table 8 Particle size distribution of milled husk.

Mill	> 5.6mm [g]	> 3.6mm [g]	> 2.36mm [g]	> 0.9mm [g]	> 0.71mm [g]	> 0.5mm [g]	< 0.5mm [g]
Pallmann, suction			0.7	41.7	7.6	12.3	37.12
Retsch, 8 mm	4.2	6	5.2	33.4	8.8	11.5	28.6
Retsch, 2.5 mm				5.9	8.3	17.4	66.5

4.3 Board manufacturing on pilot scale

To show the feasibility of the manufacturing of a high performance coconut husk binderless board with commercial dimensions, i.e. circa 1*2 m^2, pilot scale hot pressing experiments were performed at the testing lab facilities of Trespa bv, Weert, The Netherlands (www.trespa.com). Trespa is a commercial producer of high density fibre boards, applying phenolic resin with TMP-fibre (=Thermo-mechanical pulped wood chips). Board samples of circa 0.3 m^2 were produced succesfully.

4.3.1 Experimental

Milled coconut husk was evenly distributed in a square mould and pre-consolidated at 20-30°C and 20 bar pressure for 1.5 minutes in a Fontijne hot press with a platen surface of 60*62 cm^2. The amount of husk, the type of mill used, the dry matter content (DM) of the husk, the size of the mould and the thickness of the mat after pre-consolidation, h_{mat}, are presented in table 11. Subsequently, the mould was removed and the husk mat was put in the press again (figure 25). The mat was pressed to pressures as indicated in table 11 and heated to 180°C. The maximum pressure that the pilot press could handle was 120 bar. The temperature of the centre of the husk mat was determined using a thermocouple. After the husk mat reached a temperature of 175°C, the hot pressing was maintained for 5 more minutes before the press and the board were cooled under pressure. The temperature of the press platens and of the middle of the husk mat during hot pressing and cooling was monitored versus time.

For experiment 5, Trespa decoration-coating layers were placed on the 2 sides of the mat before hot pressing to demonstrate the effects of coating on board performance.

The edges of the boards were cut off using a circle saw. After 7 and 35 days of conditioning at 23°C and 50% RH, the warping was determined. After 35 days, specimens with 25 mm width were cut from boards 1–3 and density was determined. Subsequently, the specimens were subjected to flexural bending at a span length of 24 times the sample thickness, i.e. 108–117.6 mm (according to ASTM D1037). The cross head speed was 2.5 mm/min.

The use of commonly applied PP-release foil for phenol resinated boards was unsuccessful in this case, because it strongly adhered to the surface of the panel produced.

4.3.2 *Visual aspects and other observations*

Figure 25 shows pictures of the coconut husk boards pressed on the pilot scale press at Trespa. The boards 1–4 show small (< 1cm diameter) blisters immediately after opening the press. However, within a few minutes a number of larger blisters, up to 8 cm diameter, appear as can be seen from the right small board in the right photo of figure 26. Board 4, which has a 'double' thickness, showed blister formation up to 15 minutes after opening of the press.

Figure 25 Pilot press at Trespa.

Table 9 Pressing parameters

Nr	Mould size [cm*cm]	Amount of husk [g]	DM [%]	Pressure [bar]	h_{mat} [mm]	Milling equipment
1	58*58	2,350	11.6	105	3	Pallmann
2	58*58	2,350	11.6	105	3	
3	45*45	1,400	11.6	119	3	
4	45*45	2,800	11.6	119	6.5	
5	45*45	1,400	10.2	119	3	Retsch with 2.5 mm sieve

The formation of blisters was not directly understood since similar husk yielded boards without blisters at A&F. Therefore, a couple of additional experiments at A&F have been performed. Using a thermocouple in the centre of the husk mat during hot pressing experiments at a press platen temperature of 180°C showed that the husk mat only reaches a temperature of 160°C after 15 minutes heating in the A&F-mould. This is 20°C lower than during the experiments at Trespa. When pressing husk with a moisture content of 12% –close to the moisture content at the pilot press experiments- and at a press temperature of 200°C, boards with blisters were obtained. These experiments indicate that the actual temperature of the husk during hot pressing should be preferably 160–170°C instead of 180°C and that the moisture content of the husk should remain below 12% to avoid blister formation.

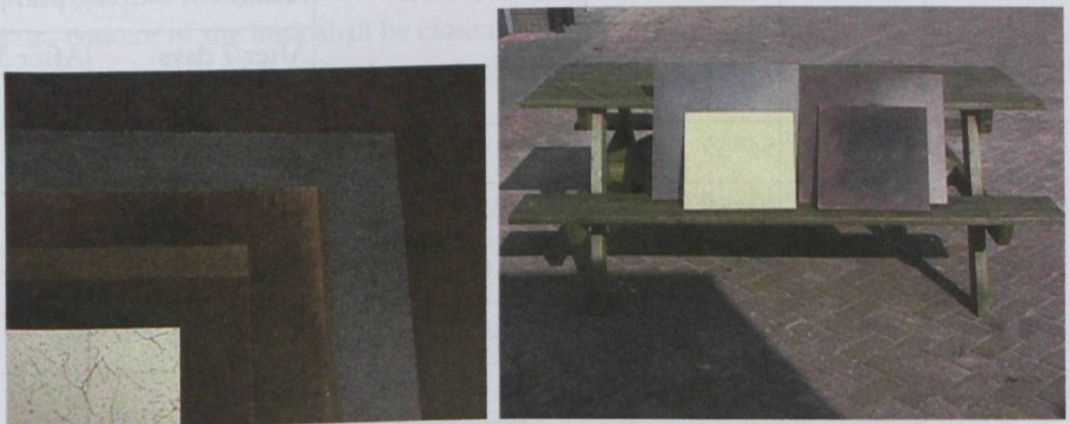


Figure 26 *Photograph of boards pressed. Left picture, from bottom-left to right: 5, 4, 3, 1 and 2. Right picture shows the relative dimensions in front of a garden seat+table.*

After hot pressing, only circa 2 cm from the edges had to be cut off in order to get a smooth board (table 10). The thickness of the boards was not constant, thus indicating either a range in density, a non-homogeneous distribution of the husk in the mould or a combination of these two parameters.

In experiment 1, polypropylene (PP)-sheets have been used to protect the press platens. The PP-sheets appeared to stick to the coconut husk board after pressing.

Board 5 showed that decoration sheets - commonly applied for coated MDF and HDF fibre boards - can be easily bonded to a coconut husk board during hot pressing. The decoration sheet maintains very smooth and sticks quite well. Moreover, board 5 does not show warping.

The maximum warping after 7 and 35 days is presented in table 12. Board 5 showed virtually no warping, boards 1–4 all show warping. The warping might be related to both the larger particle size and the higher moisture content of boards 1–4.. The warping has not come to equilibrium after 1 week of conditioning. It is not clear why board 4 with 10 mm thickness showed less warping than the thinner boards 1–3.

4.3.3 Performance of the pilot scale boards

The density, modulus and strength of boards 1–3 are presented in table 11. Surprisingly, the density of board 3 is slightly lower than of boards 1 & 2, while the pressure during hot pressing was higher, 120 versus 105 bar, respectively. Furthermore, the densities of all three boards is lower than values of 1.28–1.4 g/cm^3, observed for boards pressed on lab scale at similar pressures.

The modulus and strength of the board is similar to the lab boards pressed at similar pressure.

Table 10 Pilot scale board characteristics

Nr	Board size * [cm^2]	Board thickness range [mm]	Maximum warping [mm]	
			After 7 days	After 35 days
1	54*55	4.6 – 4.9	28	19
2	52*55	4.6 – 5.2	16	21
3	41*42	4.7 – 5.0	15	42
4	41*42	9.0 – 9.6	17	16
5	40*41	5.0 – 5.4	0	0

* After cutting off the edges.

Table 11 Density, modulus and strength of coconut husk boards that are manufactured on pilot scale; between brackets the standard deviation is given.

Nr	Density [g/cm^3]	Modulus [GPa]	Strength [MPa]
1	1.25	4.1	41
2	1.26	4.6	47
3	1.22	4.4	4

4.3.4 Conclusions

- On pilot scale, i.e. circa 0.3 m^2, milled coconut husk can be hot pressed into boards as was achieved earlier on lab scale (0.03 m^2).
- The temperature of the husk versus the press has been monitored during hot pressing. An exothermal effect is observed for the 10 mm thick board.
- One board showed no blisters and no warping, four boards did. The blisters and warping might be attributed to the large particle size and the high moisture content.
- The boards could be easily cut by using a circle saw.

- Decoration sheets can be bonded very well to coconut husk boards during hot pressing.
- The maximum pressure that could be applied was 120 bar, whereas on lab scale an optimum in between 120–150 bar was found.
- The performance of the pilot scale boards is similar to the boards manufactured on lab scale. The density is slightly lower.

4.3.5 Recommendations

For optimal manufacturing of board with pilot or commercial size, the husk shall have the following characteristics for the Dutch situation:

- The husk shall be milled to a particle size similar to that of the husk obtained after passing the Retsch cutting mill with the 2.5 mm screen.
- The moisture content of the husk shall be close to 10 %, i.e. not above 11%.
- The maximum temperature of the husk mat during hot pressing shall be in between 160–170 °C and not as high as 180°C.

The optimal manufacturing characteristics depend on, among others, the equilibrium moisture content of the finished board and should be determined for the Philippine situation.

4.4 Production in the Philippines

4.4.1 *Introduction*

Pilot scale manufacturing of binderless coconut husk boards was demonstrated at the industrial testing facilities of Trespa bv, the Netherlands. Demonstration of 2*4 feet boards manufacturing was performed at FPRDI, Los Baños, Laguna, Philippines. The milling of the husks was performed on a cutting mill, specially designed for milling coconut husk for application in binderless board manufacturing (see section 5.2).

4.4.2 *Experimental*

4.4.2.1 Preparation of husk

Coconuts (LAGT) of circa 11 months old were dehusked and sun-dried to an equilibrium MC of circa 17%. The dried husk pieces are milled in a specially designed pilot cutting mill (section 5.2 and figure 27), manufactured by M.S. Sazon of Yellow Bar Coircraft, Sariaya, Quezon, Philippines. The mill is powered by a 45 horse power Mitsubishi diesel engine. The screen used had 3 mm mesh. After milling, the husk was sundried to different MC (see table 3.1) and stored in plastic bags until hot pressing.

Figure 27 Pilot cutting mill, specially designed for milling coconut husk for application in panel boards.

4.4.2.2 Board manufacturing

Milled husk was uniformly distributed (ca 0.8 g/ cm^2) into moulds of 2*2 feet and 2*4 feet, respectively. The MC is checked using a UV lamp and a balance. The husk samples were hot pressed at conditions as indicated in table 12 (figure 28). After hot pressing, the boards are cooled to circa 30°C in the press under pressure. Subsequently, the boards were conditioned under load at local indoor conditions for at least 7 days.

Table 12 Processing conditions for pilot scale hot pressing experiments at FPRDI.

Ref nr.	Starting material Moisture content	Weight of husk	Size board	Pressing		
				Temperature *[1]	Pressure *[2]	Time
	%	Gram	Feet	°C	kg/cm²	Min
21	5	2,750	2*2	160	190	10
22	9	3,000	2*2	160	190	10
23	18	3,000	2*2	160	190	10
24	8	6,700	2*4	160	95	10
25	9	6,300	2*4	160	95	10
26	10	6,700	2*4	167	95	10
27	19	6,500	2*4	165	95	10

*1 The temperature indicated is for the upper platen, the temperature of the lower platen was 10°C lower.

*2 The indicated pressure was placed upon the entire board.

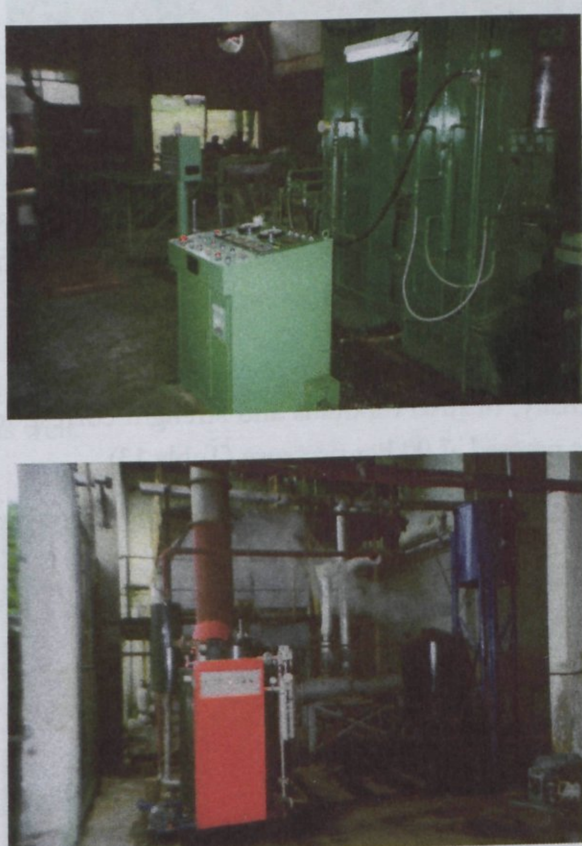


Figure 28 Pilot size hot press (top) and boiler to heat the press (bottom).

4.4.3 Results and discussion

The particle size distribution of the milled husk was very homogeneous and somewhat smaller than obtained for similar mesh sizes on the lab scale Retsch cutting mill. The homogeneous particle size is a result of the controlled feeding of husk in the mill by 2 rotating drums. The

throughput of the mill is circa 90 kg/hour at a MC of 17%. The throughput has not been optimised and could be improved substantially by accelerating the feeding drums, which also may result in a larger particle size.
The boards produced on pilot scale in the Philippines are homogeneously pressed and are very similar to the boards pressed on lab scale, both in the Netherlands and the Philippines (figure 29).

*Figure 29 Pilot scale boards of 2*4 feet hot pressed at FPRDI after trimming.*

The maximum load of the hot press, i.e. 700 tons, limited the pressure for a 2*4 feet board to 95 bar (Table 13). The resulting board density, flexural modulus and strength correspond very well to the properties of the lab scale boards pressed at 90 bar pressure (Table 13).

Table 13 Properties of pilot scale boards versus lab scale boards.

	Pilot scale board, FPRDI	Lab scale board, A&F
Pressure during hot pressing [bar]	95	90
Density [g/cm^3]	1.30	1.28 (0.01)
Warping [mm]	5-7	7
Flexural modulus [GPa]	3.9 (0.2)	3.9 (0.3)
Flexural strength [MPa]	35 (3)	37 (4)

The warping was measured to be 0, 5 - 7 and 20 - 45 mm for the boards produced of husks with 5, 8-10 and 18-19% MC, respectively. This warping is also partly due to the difference in temperature of the upper and lower press platens, both during heating as well as cooling.
The boards based on 18-19% MC husk showed blister formation.

4.4.4 Conclusions

- The cutting mill, specially designed to mill coconut husk for board manufacturing, yields very homogeneous particle sizes. The throughput is 2 times higher than requested and most probably, the throughput can be increased with another factor of 2.
- The experiments show that coconut husk boards can be very well pressed on pilot scale, i.e. 2*4 feet, without complications.
- The performance of the boards is as determined for boards pressed on lab scale, both in the Netherlands and the Philippines.

4.5 Machine ability

4.5.1 Introduction

Machine ability because of wear of machining tools may pose a practical problem since coir fibres are known to contain relative high amounts of silica. To determine the machineability of the binderless coconut husk boards was tested by detailed observation of the wear of common sawing blades

4.5.2 Experimental

Coconut husk boards of 2*4 feet and 7 mm thickness, consolidated at FPRDI at 160°C and 95 bar (boards 25 and 26 from table 3.1), were cut to strips of 5 mm width using a circular saw (figure 30) available at FPRDI (Los Baños, Laguna, Philippines). A new Suzuki Seikyo Tungsten Carbide tipped 12" blade with 100 teeth was used. The total cutting length was 100 m. At regular intervals of 25 m, the temperature of the blade, the knives and the cutting edges were evaluated.

As a reference, commercial hardboard (Lawanit) of 5 mm thickness was cut over 100 m using a new blade as well.

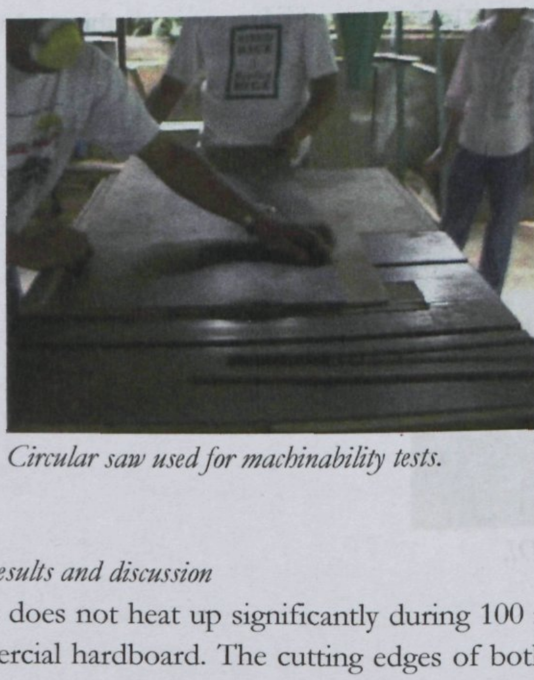


Figure 30 Circular saw used for machinability tests.

4.5.3 Results and discussion

The blades does not heat up significantly during 100 m of cutting, both for coconut husk board and commercial hardboard. The cutting edges of both types of board material are equally sharp for the first and the last meters. Both results indicate that coconut husk board can be cut very well. The sawing blade shows only negligible damage after 100 m of cutting coconut husk board. Furthermore, cutting coconut husk boards produces far less dust than cutting hardboard. The force needed to push the coconut husk board over the cutting saw was larger than for commercial hardboard.

4.5.4 Conclusions

Compared to commercial hardboard, cutting of coconut husk board:

- Yields similar smooth cutting edges after 100 m.
- Heating of the blades is similar after 100 m, i.e. negligible.
- Gives negligible damage on 1 out of 100 teeth.
- Yields less dust.
- Requires more force to push the board over the cutting saw.

4.6 Fire resistance

4.6.1 Introduction

Fire resistance is a critical property for building materials. Both at FPRDI (Los Baños, Philippines) and at SHR Timber Research (Wageningen, the Netherlands) binderless coconut husk boards were tested for their fire resistance and compared to commercial boards like hardboard, MDF and plywood.

4.6.2 Experimental at FPRDI

Coconut husk boards of 25*25 cm and 7 mm thickness, produced at FPRDI, was put at an angle of 45° above a 800°C flame (figure 31). The temperature of the flame was measured using a thermocouple. The time to ignition was determined.

As a reference, commercial hardboard (Lawanit) of 5 mm thickness was subjected to the same fire test.

Figure 31 Set-up of fire resistance test at FPRDI.

4.6.3 *Results at FPRDI*

The coconut husk board starts to ignite after 4 minutes, whereas the fire penetrates the board after 15 minutes. The hardboard, however, ignites within 1 minute and the fire penetrates the board within 2 minutes. Obviously, the coconut husk board has better fire retarding properties than commercial hardboard.

The coconut husk board, however, showed deformation during the fire test.

4.6.4 *Flame tests at SHR Timber Research*

Three different samples of coconut husk boards were tested for flame resistance at SHR. The experimental procedure for the fire resistance tests at SHR and the results are described in Appendix B. For these tests, the coconut husk boards were coded 1-3.

Sample 1 (11 months old coconut husk hot pressed at MC of 10%, d=1.4 g/cm^3); Sample 2 (7 months old coconut husk pressed at MC of 10%, d=1.4 g/cm^3); Sample 3 (11 months old coconut husk hot pressed at MC of 3%, d=1.1 g/cm^3). Compared to various commercial boards, the weight loss after the flame test was much lower (approximately 20%) for the coconut boards and charring was not observed on the top side of the samples and after removal of the flame only limited burning was observed. The flame retarding properties were considered to be very good.

4.6.5 *Conclusions*

- Without addition of fire retarding agents, coconut husk board shows better fire resistance than commercial MDF, hardboard and plywood.
- According to SHR, coconut husk boards perform comparable to solid wood treated with fire retarding agents.
- Coconut husk boards show deformation during the fire test.

5 Pilot trials

Pilot trials were performed at FPRDI, Los Banos, Philippines in April 2005. The rehabilitation and adaptation of the old particle plant to suit the needs of this process were carried out from August 2004 until April 2005. This section describes the individual componenents of the production facility - milling, drying, pressing and finishing. Process specific parameters are provided. The section ends by forecasting the industrial board production.

5.1 Description of the pilot facilities

A scheme of the pilot facilities is given in figure 32.

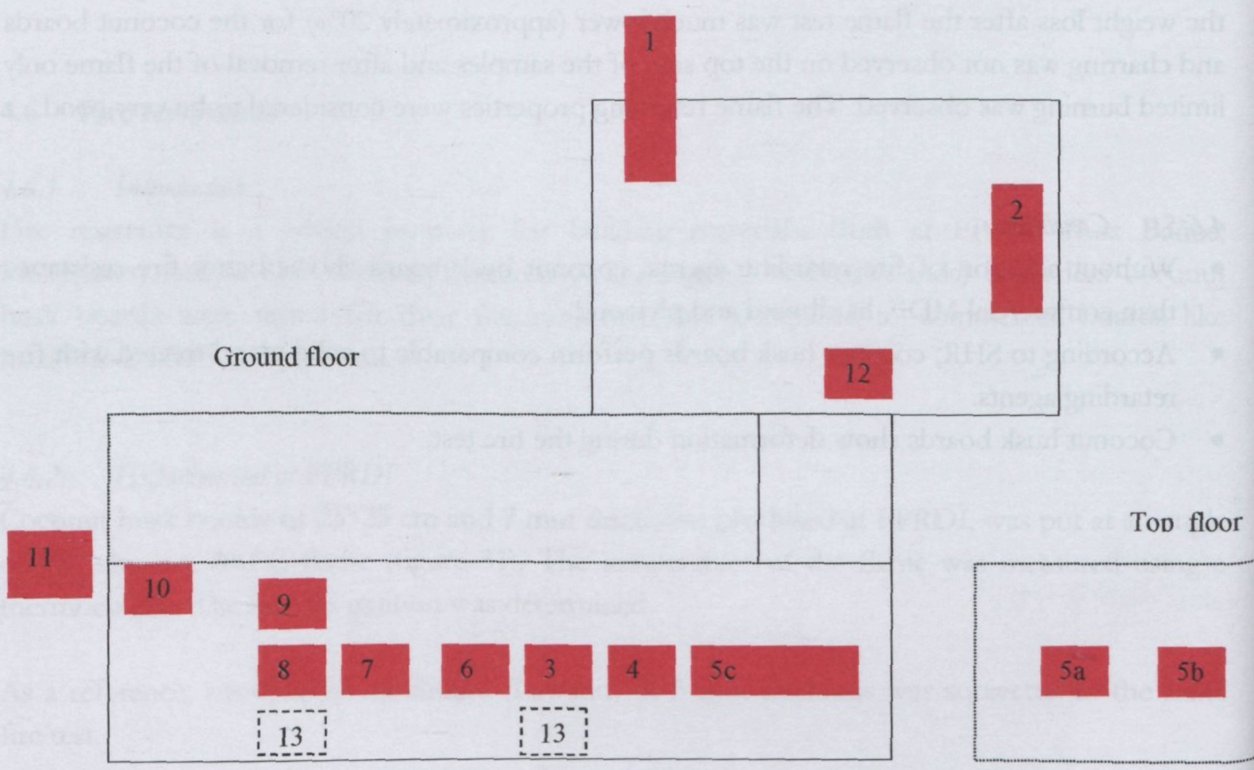


Figure 32 Schematic drawing of the FPRDI pilot facilities

1. Husk milling device
2. Dryer
3. Introduction of carrier sheet and transportation
4. Scale
5. a: Feeding station b: Feeding station c: Mat former
6. Press
7. Transportation
8. Removal of carrier sheet
9. Cooling carroussel
10. Sawing station
11. Central air cleaning system
12. Steam generator
13. Storage spaces carrier sheets

The production of a board consists of several consecutive stages. Firstly, the husk is refined by milling (1), The milled husk is then dried in the dryer (2) and transported to the two feeding stations (5a, 5b) on the top floor. The formation of the fibre mat takes place in the mat former. In this machine the material is dropped on a sheet of metal, because the mat is not strong enough to support itself. This metal sheet is hereafter referred to as carrier sheet. Mat formation is performed in a prescribed way:

A carrier sheet is put inside the board production machine (3). This sheet is transported to the scale (4). After weighing of the empty sheet the mat is formed by transporting the sheet through the mat former (5c) and by opening the feeder stations at the right moment. The sheet is passing through the mat former from left to right, stops at the end of the machine and passes through the mat former for a second time from right to left. Because of this double pass and the two feeding stations the matt consists of four layers: First (bottom) layer material from feeder 5a, second layer from feeder 5b, third layer from feeder 5b and fourth (top) layer from feeder 5a. However, in our system no difference was made between the material in feeding station 5a and feeding station 5b. After the formation step the mat and sheet are weighed on the scale (4) and transported to the press (6). After pressing the board is separated from the sheet (8) and cooled in the carrousel (9). The board is finished by removing the edges on the sawing station (10).

5.2 The milling device

5.2.1 Design and production

The milling device was developed during this project and manufactured by M.S. Sazon of Yellow Bar Coircraft, Sariaya, Quezon, Philipinnes in 2002. The milling device had to be rehabilitated in 2005. All parts in contact with the husk had to be protected against rust. The milling device consists of a diesel engine, a milling chamber (figure 34a), a husk feeder section (figure 34b), and a cyclone to separate the milled material from the air. A picture of the milling device is given in figure 33.

The milling is based on a cutting principle. After introducing the husk into the milling chamber the husk is cut into smaller pieces. Because of this cutting action fibers and pith are separated. Before leaving the milling chamber the pieces are screened. Different screens can be installed to control the size of the fibres and husk after milling. During the pilot trials a screen with a 3 mm mesh was used.

The average production rate of the milling device is 90 kg/hr. The milling device requires 13.9 liter diesel per ton husk. The energy consumption in this milling device equals about 130 kWh/ton.

Figure 33 The milling device in operation

Figure 34 The milling chamber before rehabilitation (a) and the feeder section (b)

An increase in the rotation speed of the feeder and an introduction of a second feeder section seems possible, this will increase the production rate significantly. The used amount of energy during the milling is comparable to the results found on lab-scale. However, both on lab-scale as on pilot-scale most energy is consumed by the stationary running of the mill. Only a minor amount is consumed during the actual cutting of the husk.

The current feeder section is safe to skilled workers. Contact between the worker and the cutting knives is impossible. However, if the feeder is jammed because of overload of husks, it is necessary to stop the feeder device before removing the husks, otherwise contact between the rotating feeder and the worker is possible.

The milled product of the milling device is well suited for this application. A screen with slightly bigger pores can be considered. This will also result in lower energy consumption.

5.3 The dryer

5.3.1 Design and production

The dryer (figure 37) was originally designed by FPRDI to dry palay. This dryer was slightly adapted for the drying of milled husks. Most importantly a transportation belt was added to be able to feed the milled husk from floor level. The transportation belt was completely covered to prevent dust in the air (figure 36). Several other minor adaptations were performed to prevent dust formation. The milled husk is dried by contact with hot air. This air is heated in a heat exchanger. The heat source is rice husk (figure 35). The residence time of the milled husk in the dryer is controlled by the rotation speed of the drum. Long residence times can be obtained because the drum is equipped with baffles that push the milled husk back to the inlet. Typical data of the dryer during the pilot trials is given in table 14.

Table 14 Data pilot trial milled husk dryer

Milled husk Drying		
Production time	min	112
Initial moisture content	%	11
Final moisture content	%	7
Feeding rate	Kg /hr	72
Minimum air temperature	ºC	70
Maximum air temperature	ºC	100
Rice husk used	kg	30
Drum rotation speed	1/min	2.4
Estimated residence time	min	27

Figure 35 The biomass fuel for the dryer

Figure 36 The covered transportation belt

Figure 37 The dryer during operation

5.3.2 Evaluation of the dryer

The dryer is operated using biomass (rice husk) as fuel. An experienced worker is necessary to control the fire. The change in air temperature during the different trials from 70 up to 100 ºC shows that the actual control of the amount of heat from the fire is very difficult. A different system for biomass burning is advisable. The dryer was capable to dry the milled husk up to the dry matter content that is necessary for this application. This specific dryer was selected by the FPRDI because it is more economic to use then imported dryers. The main setback of this dryer for the drying of milled husk is the creation of dust. A good sealing mechanism for the rotating drum should be applied.

5.4 The mat former

5.4.1 Design and adaptation

The mat former (fig 38 and 39) was originally designed as a formation stage for particle board with a core layer and a top and bottom layer. The mat former was rehabilitated for this project, however no specific changes to the design were made, except for a minor change in the feeding system.

After thorough mixing of the milled husks the material is dropped onto the metal carrier sheet. All excess material is removed by a special system and recycled to the original feeding unit. This recycle system is also supplying a low pressure area around the mat, thereby preventing dust formation around the mat former.

During the pilot trial mats of different heights and therefore different amounts of material were formed. Normally a mat with a thickness of around 10 cm and a surface of 3*6 feet was formed.

The mat former performed very well. Minor adaptations are necessary to distribute the material more evenly over the carrier sheet.

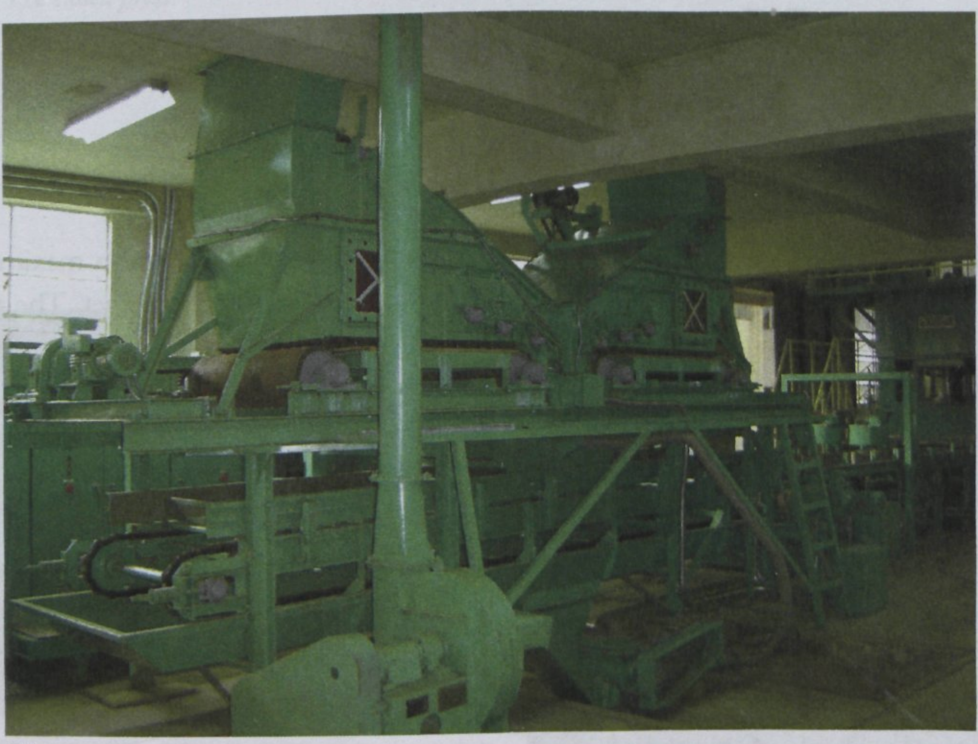


Figure 38 The mat former

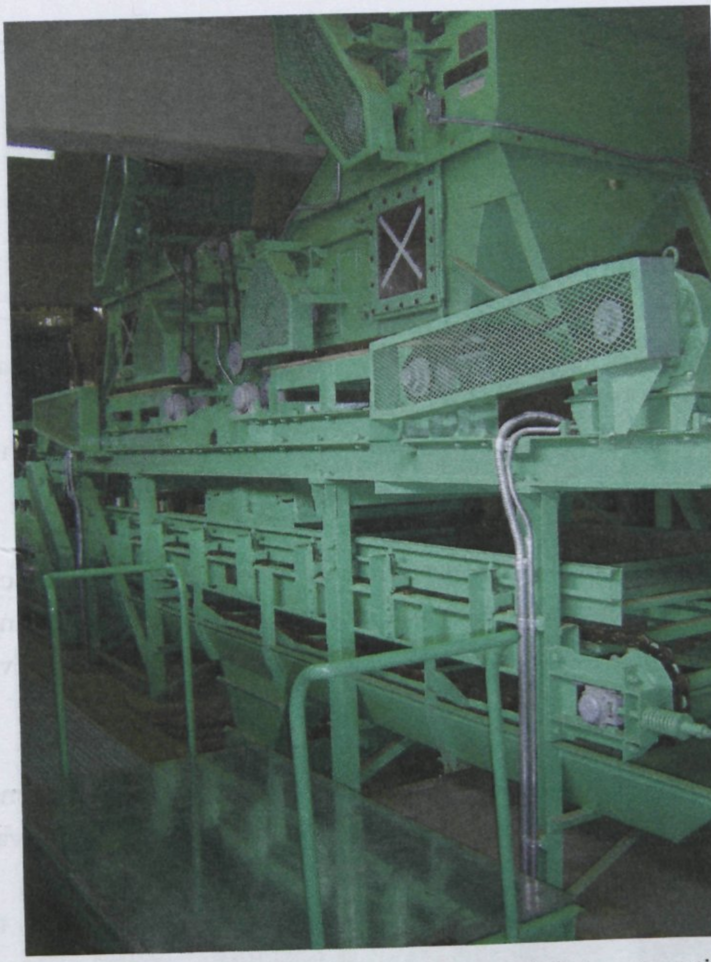


Figure 39 The mat former, showing the mixing section and the transportation section for the carrier sheet

5.5 The press

5.5.1 Description

The press (figure 40) has a maximum working temperature of 160ºC and a maximum working pressure of 600 tons. The maximum board size that can be made is 3*6 feet. The press can be operated at constant pressure, or by using side bars at a constant thickness of the board. For our application it is necessary to operate the press at constant pressure. The oil pumps that provide the pressure are working on electricity. The press platens are heated using steam. The contact area between the heated platens and the actual press is cooled by cooling water in order to avoid overheating of the press. The mat is automatically introduced into the press (figure 41). The steam is provided by a steam generator (figure. 42), which uses diesel as heating fuel.

Figure 40 *The closed press.*

Figure 41 *Introduction of the mat in the press*

Figure 42 *The steam generator*

5.5.2 *Evaluation of the press*

The temperature range and the maximum pressure of this particle board press are suited for the production of medium quality boards as described in section 4. The maximum size of these boards in this press is 2*4 feet. The surface area of boards with sizes of 3*6 feet, is too large at the given maximum pressure of the press to achieve the necessary specific pressure (pressure per area). One of the disadvantages of this press compared to a multi-daylight press - as commonly applied in fibre board manufacturing plants - is that cooling water is being used above the upper heating platen and below the lower heating platen to prevent the actual press from heating. A large amount of the available steam energy is wasted on this cooling water. In a multi-daylight press there is no need for this cooling water above and below each platen.

5.6 Miscellaneous equipment

5.6.1 *The cooling carousel and the sawing panel*

After the press the board is cooled down in a cooling carrousel (figure 43) and sawn. This cooling and sawing caused no problems. After the sawing the boards were stored on a flat surface on top of each other.

Figure 43 The cooling carousel

5.6.2 *The air cleaning system:*

The pilot facilities are equipped with a larger air cleaning system (figure 44), to collect dust. During the trials this cleaning system was seldom used, the amount of dust around the mat former, the press and the finishing section was limited.

Figure 44 The air cleaning system

5.7 Description of the pilot trials

In April 2005 pilot trials were preformed in Los Banos, Philippines at the FPRDI facilities. During these trials the different processing units were optimized for this application. The main items for optimizing were:

- Adaptation of the dryer, the milled husk created more dust then was to be expected from the dryer performance with rice palay. It was necessary to cover the feeding belt completely with a metal covering. Several other spots were air was vented together with the milled husk were also closed.
- The mat former was adjusted to give the right amount of material on the carrier sheet. This optimization will be necessary for every change in desired board thickness.
- The pressing regime was adjusted to create optimal boards for the press used.

At the beginning of a trial the feeder sections of the mat former were emptied. After storage for several hours in the feeder sections the milled husk has taken up water. Optimal boards cannot be produced using this moistened material. For this specific mat former a second problem was the recycling stream of the material that is falling from the carrier sheet. This material is recycled to only one of the two feeder sections (5b). A change in moisture content of the milled husk therefore resulted in a difference in moisture content of the material between the two feeder sections.

After the adjustments present above the pilot facilities were operated for a longer trial. The pilot plant was operated using 7 persons:

Three unskilled persons were operating the mill and were responsible for all transport of the husk, milled husk and end products. One skilled person was operating the dryer. The mat former and press were operated by two skilled persons. Another person was controlling the steam generator and acquiring energy data.

During the trials several other persons were present who supervised the trials and recorded data. Technicians of a local company who rehabilitated the pilot plant were present to be able to assist if any problems would occur.

The technical data of the trial is given in table 15.

Table 15 Data pilot trial board production

Pilot trial board production		Total	2*4	3*6
Duration of the production:	hours	3.5		
Board size	Feet*feet		2*4	3*6
Board size	M^2		0.74	1.67
Number of boards	[-]	8	2	6
Board thickness	mm		10	8
Pressing regime				
Time at maximum pressure	min	10		
Time for decreasing pressure	min	10		
Mat forming	min	3		
Applied pressure	Tons	600		
Applied pressure	Bar		81	35
Applied temperature				
Upper platen	°C	160		
Lower platen	°C	150		
Diesel steam production				
Start up	litre	24.0		
Continuous	litre	21.3		
Electricity	kWh	28		
Water use (steam and cooling)	litre	568		

5.8 Technical and technological summary: industrial forecast of coir-based board production

From the experiments, combined with some initial market research, it can be concluded that there are two promising types of board that can be produced from coconut husk without the addition of a binder. The main difference between the board types is the quality. The medium quality board has a lower density and lower mechanical properties, comparable to particle board. The high quality board has a higher density and higher mechanical properties, comparable to MDF. However, the production of medium quality boards is easier and cheaper then the production of high quality boards.

Table 16 overviews the main production parameters for the medium and high quality boards, in table 17 an overview is given of the quality of the boards.

Table 16 Main processing conditions for the two proposed board types

	Medium quality boards	High quality boards
Moisture content before pressing [%]	3	11
Pressing temperature [°C]	180	180
Pressing pressure [Bar]	120 – 150	120-150
Pressure during cooling of the board [Bar]	ambient	120-150

Table 17 Main properties of the two proposed board types

	Medium quality boards	High quality boards
Density [kg/m3]	1050	1350
Moisture content [%]	9	9
Bending strength [MPa]	13	47
Bending stiffness [GPa]	2	5
Water resistance	Poor	Good
Fire resistance	Good	Good
Handling properties		
• Sawing	Possible	Possible
• Sanding	Possible	Possible
• Painting	Possible	Possible
• Drilling	Possible	Possible
• Screwing	Possible	After pre-drilling
• Nailing	Possible	Not possible

6 Economic evaluation of industrial coir-based board production

Previous sections of this report described in detail many technical and technological aspects involved when producing coir-based binderless boards, both on laboratory and on pilot scale. Based on these results the economic outlook for industrial production of the board material can be estimated. This section describes the different economic aspects starting from coconut husk harvesting up to final board production. Like many industries production costs turn out to be highly dependent on raw material- and energy costs combined with production throughput. By evaluating the critical processing parameters it is demonstrated that industrial production of coir-based boards is potentially highly competitive with plywood and particle board.

6.1 Introduction

Estimations of production costs are essential in order to predict its market potential. This section aims to make an economic forecast for the industrial production of coir-based boards. Cost and production aspects of the individual components will be addressed first. Based on the suggested annual production rate as discussed in paragraph 6.2.2, for the for the sake of convenience, one typical industrial size board will be used to support the cost calculations. Next all investment and production cost aspects are integrated for the total production unit, resulting in data for annual floating- and fixed costs, working capital, total production cost and suggested F.O.B. and retail prices (paragraph 6.3). In addition similar tables for producing boards with others thicknesses are addressed. Sensitivity analysis furthers shows the processes' most critical cost factors and provides suggestions for cost reduction. Comparison with competing materials, as highlighted in paragraph 6.4.2 and 6.4.3 shows the economic potential of binderless coir-based board material.

6.2 Cost calculation of the individual components

6.2.1 Point of departure

The following individual components are taken into account for the production of industrial sized coir-based binderless boards and full-scale throughput:

- raw materials supply (i.e. coconut husk separation after nut harvesting, transport to factory for further processing)
- Husk milling
- Husk drying
- Husk hot-pressing

The factory is considered a stand-alone processing unit at an area of 10,000 m^2, holding a husk delivery unit, a husk milling unit including a series of milling devices based on the design as described in section 5, a series of drying facilities based on FPRDI's "Palay" (paddy rice) dryers[3], and a series of multi-daylight hot presses (incl. mat pre-forming, mat-pressing and board finishing). Transport of materials between the individual processing units is adjusted through

[3] *Pulmano et al, FPRDI Journal 27 (1&2), January - December 2001, 105*

conveyers. The number of machines per unit is determined by the projected annual production rate, which is further described in this section.

Pilot production has been successfully performed at the near-industrial processing site at FPRDI, UP Los Baños (detailed information on the process can be found in section 5). Critical costs, like product throughput and energy consumption, are calculated by using data derived from these pilot processing trials.

In general industrial production costs are highly dictated by raw materials' and energy consumption. Regarding this specific board production process, the energy consumption is process intrinsic: costs can only be reduced by using the equipment as efficient as possible. In order not to loose heating energy and production time due to frequent (daily) start-up the factory runs most efficiently when operating 24/7. This study however assumes operating 24/5 (no production in the weekend) which equals 260 labour days per year.
Raw material cost on the other hand is very much absorbed by transportation costs. This suggests that there is a limited economic distance from farm to factory. In addition, although economy of scale applies, the local farm sizes can be a limiting factor. For this reason it is practically not feasible to design an industrial facility having an annual production of 100,000 tonnes per year (which is a normal size for MDF production).

6.2.2 Raw material supply

In the Philippine situation many coconut production sites are hilly. In addition transportation is a time-consuming business. In order to keep raw material cost as low as possible the processing facility should preferably be near the coconut farms. First question then is: how much raw husk can be derived from neighbouring farms?

1. Western Mindanao coconut industry contains ~ 39,000 hectare coconut farmland.
2. Coconut husk yield is ~400 kg/ hectare /year.
3. Production of 10,000 tons of board material requires husk from ~77,650,000 nuts, which can be harvested from 25,500 hectares farmland; for the W. Mindanao situation this would be equal to ~65% of its total production.

→ This is equal to 255 km^2, or a circle with a diameter of 18 km.

Further calculation's on the industrial production costs are based an annual quantity of 10,000 tons of board product since this is an acceptable measure for raw material supply and since time-to-delivery is a major bottleneck. (higher production volumes would require more farmland than practically available in a typical coconut agricultural area.) The number of boards which can be produced depends on the boards thickness.
Raw husk is supplied to the FPRDI processing site for 0.3 peso/husk. Average distance from coconut farm to FPRDI is less than 50 km, therefore this price is realistic as a starting point and can decrease in case the board production site is situated closer to the coconut farms. Furthermore interviews with several husk processors in the Philippines learned that it's more economic to collect husk and to mill it centralised rather than have it milled *decentralised* first followed by transport to the factory.

Table 18 shows the influence of typical size boards (4 by 8 feet, equal to 1.22 by 2.44 meter) with different thicknesses on the weight of the product. Furthermore, by assuming an annual production of 10,000 ton, it shows the annual need of nuts/husks (~77,650,000) and how many boards are produced by using this number. For a typical size of 4 by 8 feet by ¼ inch this results in almost 400,000 high density boards (1.35 g/cm^3).

Table 18 Typical size boards versus husks need and resulting # plates at an annual production of 10,000 tons

Share [wt%]	Length [m]	Width [m]	Thickness [mm]	Weight [kg]	# boards -	# nuts/husks -	Waste [kg]
0	1.22 (4 feet)	2.44 (8feet)	3.18 (1/8 inch)	12.76	0	0	0
100	1.22	2.44	6.35 (1/4 inch)	25.52	391,871	77,647,138	1,263,101
0	1.22	2.44	7.62 (0.3 inch)	30.62	0	0	0
0	1.22	2.44	12.70 (1/2 inch)	51.04	0	0	0
0	1.22	2.44	19.05 (3/4 inch)	76.56	0	0	0
					Total # nuts:	77,647,138	
					Total husk weight (dry):	10,249,422	1,263,101

For comparison reasons Table 19 shows the numbers of boards which can be produced annually for each thickness from the same amount of husks. Ranging the thicknesses from 1/8 inch to ¾ inch results in ~780,000 to ~130,000 boards.

Table 19 Typical size boards versus husks need and resulting # plates at an annual production of 50,000 tons

Share [wt%]	Length [m]	Width [m]	Thickness [mm]	Weight [kg]	# plates -
100	1.22 (4 feet)	2.44 (8feet)	3.18 (1/8 inch)	12.76	783,742
100	1.22	2.44	6.35 (1/4 inch)	25.52	391,871
100	1.22	2.44	7.62 (0.3 inch)	30.62	326,559
100	1.22	2.44	12.70 (1/2 inch)	51.04	195,935
100	1.22	2.44	19.05 (3/4 inch)	76.56	130,624

6.2.3 *Milling of husk*

Milling of husk is preferentially performed by using milling devices from M.S. Sazon of Yellow Bar Coircraft, Sariaya, Quezon, Philipinnes, which are specifically designed for milling whole husks to fibre and peat material to desired dimensions. Figure 45 shows a mobile example at work; section 5 provides more detailed technical information.

For the annual milling of 10,000 ton husk the following data are determined:

- Annual throughput per milling device: 1,200 ton/year
- Needed number of devices → 9
- Required labour: 18 operators
- Investment: 140,000 US$ (~PhP 7,750,000)
- Annual energy consumption: ~ 140,000 liter diesel, cost 75,000 US$ (~PhP 4,100,000)

Figure 45 Pilot cutting mill, specially designed for milling coconut husk for application in panel boards.

6.2.4 *Conditioning/ drying of husk*

After milling the husk's fibre/peat material need to be dried to the desired dry matter content. Equilibrium moisture content of husk in the Philippines is too high. This needs to be reduced by drying the fibre/peat material. At pilot scale this was realised by using the FPRDI palay dryer. Figure 46 shows a schematic diagram, section 5 provides more detailed technical information.

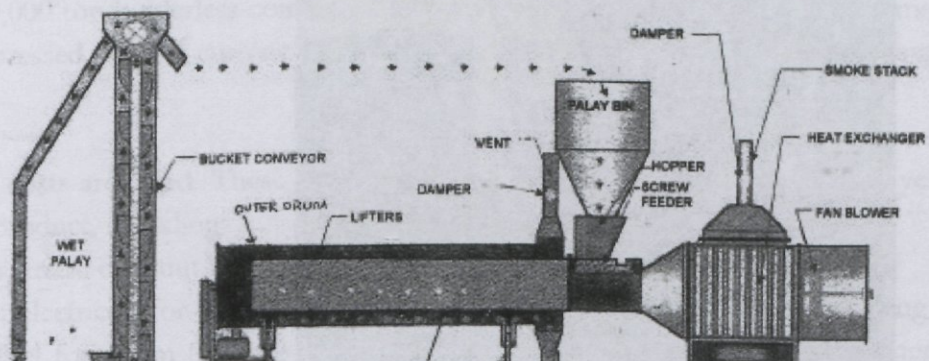


Figure 46 Schematic diagram of the FPRDI palay dryer

For the annual drying capacity of 10,000 ton fibre/peat the following data are determined:

- drying capacity per dryer: 1,250 ton/year
- Needed number of devices → 8
- Required labour: 8 operators
- Investment: 36,500 US$ (~PhP 2,010,000)
- Annual energy consumption: 105,000 US$ (~PhP 5,700,000)

6.2.5 *Hot pressing (incl. mat pre-forming, mat-pressing and board finishing)*

After drying the husk's fibre/peat material is conveyed to the mat pre-former and subsequently pressed to the desired thickness and transported to be finally trimmed to the desired board size (4 times 8 feet). At pilot scale these steps were linked in a continuous production line by using the FPRDI hot-press facility. Figure 47, 48 and 49 show the different actions; section 5 provides more detailed technical information. It should be noted that pilot facility hosted a single-press unit whereas industrial practice requires a multi-daylight press unit. Data provided below are extrapolations from single to multi-daylight press.

Figure 47 Pre-formed husk mat before pressing

Figure 48 Hot-pressed coir-board leaving the press

Figure 49 Coir-board transport

For the annual pressing of 10,000 ton fibre/peat the following data are determined:

Multi-daylight press		
Production hours	6240.0	hrs
Duration press cycle	10.0	min
Plates per cycle/ # daylights	11	
Plates/hour	66	
Plates /day	1584	

- Pressing capacity per unit: at least 5,000 ton/year (assuming 11 daylight/plates per cycle)
- Needed number of units → 2
- Required labour: 20 operators, 6 chiefs, 1 manager
- Investment: 110,000 US$ (~PhP 6,000,000), based on second-hand price or locally constructed
- Energy:
    - Electricity: 14,200 US$ (~PhP 7,800,000)
    - Fuel: 46,300 liter diesel, cost 25,250 US$ (~PhP 1,400,000)

6.3 Investment and production cost aspects for the total production unit

The integrated investment and production costs for the total production unit are calculated for producing 10,000 ton binderless coir-based board, with dimensions 4 times 8 feet times ¼ inch. Costs are expressed in local currency (PhP), Annex 3 lists similar tables with costs expressed in US$.

First floating costs are listed. These are scheduled as (1) cost per item, (2) cost per year and (3) cost per ton product, including:

- Raw materials: coconut husk and water (for steam and cooling).
- Energy: electricity for pressure at press and mat former, electricity for running conveyer belts, fuel for steam (heating the press), fuel to operate the mill and total energy to dry fibre/peat material.
- Direct labour (i.e. labour which is allocated to board production for 100%), including operators, chiefs and manager.

Next working capital is listed; these are based on working practices within the Philippines (see next paragraph). Costs are scheduled as (1) cost per year and (2) total cost per ton product, based on:

- Stock raw materials (4 weeks)
- Stock finished products (2 weeks)
- Suppliers Credit (2 weeks)
- Credit to Customers (4 weeks)

Fixed costs are next listed. These are categorised as:

- *onsite investment* (including all machineries needed for board production; write-off = 10 years),
- *allocated investment* (including Instrumentation, Tankage, Storage & Handling, Utilities, Offsites and Buildings; write-off = 20 years) and
- *additional annual allocated costs* (including Maintanance, Laboratory, Staff+Additional, Ground Rent, Tax, Insurance).

Investments are scheduled as (1) cost per item, (2) cost per year and (3) cost per ton product, allocated costs are scheduled as (1) cost per year and (2) total cost per ton product.

FLOATING COSTS			Unit	Cost/Unit [PhP]	total [PhP]	cost per ton product
Raw material	coconut husk	77,647,138	#	0.30	23,294,141	2,329
	water	18,518,519	liter	0.01	185,185	19
Required energy	electricity press + matforming (pressure)	1,296,296	kwh	6.00	7,777,778	778
	fuel press + matforming (steam)	52,910	liter	30.00	1,587,302	159
	fuel mill	136,878	liter	74,660.71	4,106,339	411
	rice dryer			103,053.28	5,667,930	567
Total					**42,618,675**	**4,262**
Labour						
Operator		46	man	47,500	2,206,372	221
Chief		6	man	62,500	375,000	38
Manager		1	man	180,000	180,000	18
Total					**2,761,372**	**276**
				TOTAL	**45,380,047**	**4,538**
				(US$)	**$825,092**	**$83**

Working Capital	weeks	cost/year	cost per ton product
Stock raw materials.	4	1,791,857	
Stock finished products	2	1,898,388	
Suppliers Credit	2	-895,929	
Credit to Customers	4	3,796,776	
	TOTAL	**4,799,236**	**480**
	(US$)		**$9**

FIXED COSTS					
direct investment	*depreciation time*	*10 years*			
allocated investment	*depreciation time*	*20 years*			
			cost	**cost/year**	**cost per ton product**
Milling Equipment			7,756,418	775,642	
Drying Equipment			2,008,887	200,889	
Multi-daylight Presses			6,000,000	600,000	
Lang Factor			7,882,652	788,265	
Total onsite investment			**23,647,957**	**2,364,796**	**236**
Instrumentation			472,959	23,648	
Tankage, Storage & Handling			236,480	11,824	
Utilities			709,439	35,472	
Offsites			236,480	11,824	
Buildings (P1000/m2)			10,000,000	500,000	
Total allocated investment			**11,655,357**	**582,768**	**58**
Maintainance				63,061	
Laboratory:				27,614	
Staff + Additional				276,137	
Ground Rent				157,653	
Tax, Insurance				101,624	
			TOTAL	**3,573,653**	**357**
			(US$)	**$64,976**	**$6**

Adding up all annual costs results in Cost Ex Works; further adding costs for Management-, Sales-, and Research Work gives the Total Production Cost (TPC). Annual Cost+ Return finally is calculated by multiplying TPC by a factor of 1.25.

Specific details for the annual production of 10,000 ton binderless coir-based board, with dimensions 4 times 8 feet times ¼ inch are given hereunder.

COST EX WORKS		**48,370,932**	**4,895**
Management-, Sales-, and Research Work		9,871,619	**987**
TOTAL PRODUCTION COST		**49,358,094**	**5,883**
Profit at 25% of production cost		**12,339,523**	
COST+ RETURN		**61,697,617**	**6,170**
	(US$)	**$1,121,775**	**$112**

Annual Cost+ Return in this example is ~PhP 61,700,000 (equal to ~1,122,000 US$). The number of boards of this specific dimension is equal to 391,871, which results in a suggested **F.O.B. price of PhP 157/board** (equal to 2.86 US$/board). Including price increases from the manufacturer to the wholesalers by as much as 31% and from the wholesalers to retailers by as much as 12% (see next paragraph) results in a suggested **Retail price of PhP 230/board** (equal to 4.17 US$/board).

Most important data for the annual production of 10,000 ton board, with dimensions 4 times 8 feet times ¼ inch are given hereunder

PRODUCTION	157	peso/board	$2.86	
RETAIL	230	peso/board	$4.17	
	391,871	# plates		1,507 plates/day
	9	# milling devices		
	77,647,138	# nuts		
	10,249,422	# kg dry husk		
	255	km2		[surface following Western Mindanao coconut industry]
	18	km		[circle following Western Mindanao coconut industry]

It shows that:

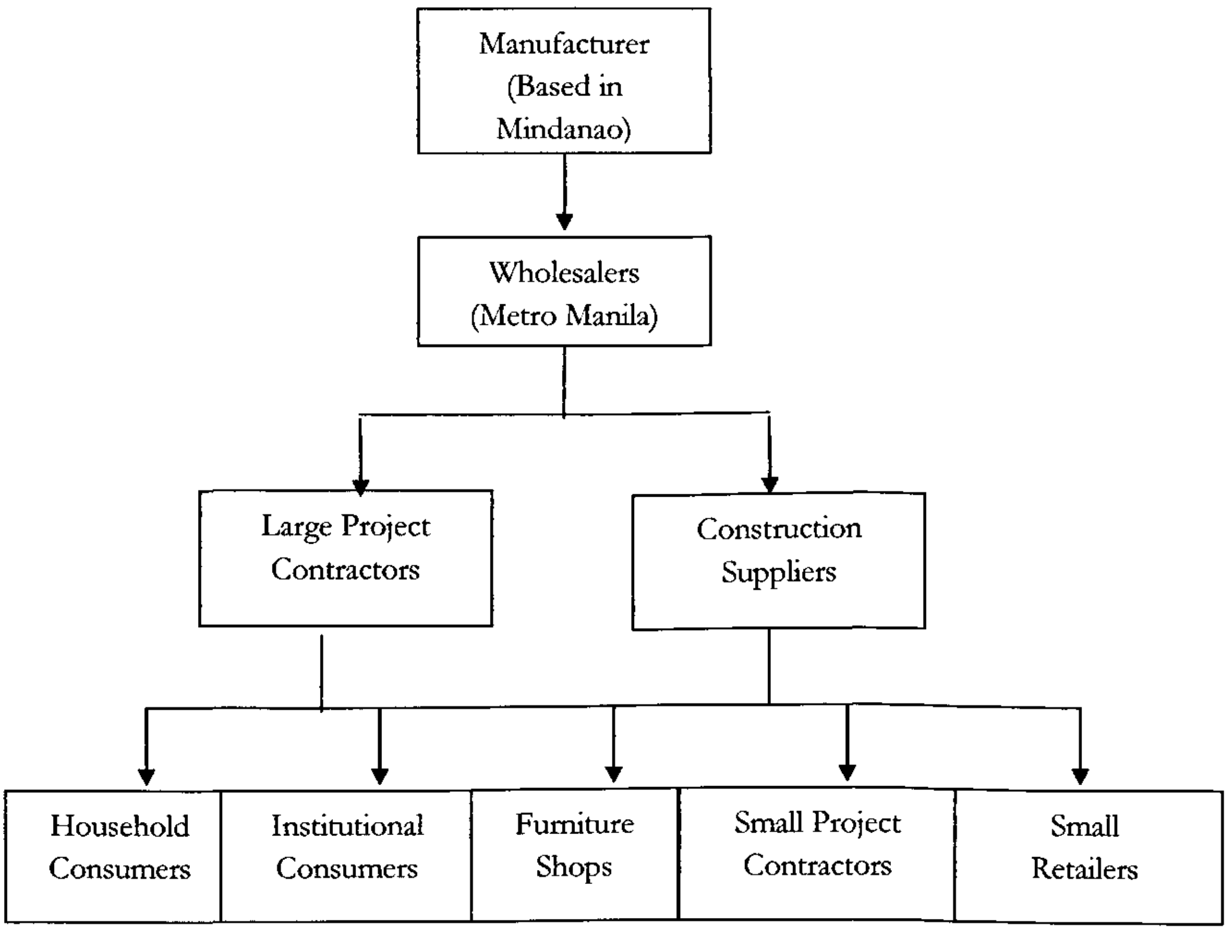
- nearby coconut farms in potential can supply a sufficient amount of coconut husk
- a board production unit nearby these coconut farms in potential ensures that husk transportation cost will not become too high that the suggested raw material price of PhP 0.3/ husk seems reasonable for the foreseen product

Price comparison with competing products is described in the next paragraph.

6.4 Comparison with competing products

The marketing channel plays a vital role in bringing the goods closer and accessible to the end-users. A typical plywood manufacturer surveyed in Mindanao sells its product mostly to wholesalers in Metro Manila. The wholesalers act as distributors to Large Project Contractors with capitalization of more than P10 million as well as to various Construction Suppliers in Metro Manila and nearby provinces of Luzon. The ordinary plywood flows into the market as shown on table 20:

Table 20 Typical production/supply chain for ordinairy plywood



Other plywood manufacturers also have their own hardware stores where they gather feedback regarding their products directly from customers. They also act as distributors, wholesalers and retailers, all at the same time depending on the customers they serve.

6.4.1 *Marketing Practices*

The plywood manufacturer sells its product on cash basis but he gives credit payable within 15 to 30 days to his trusted regular customers, the wholesalers or his distributors. However, the latter is required to issue post-dated check upon delivery of the goods purchased.

It is convenient for the manufacturer to deal with a few buyers like the wholesalers; however, he cannot maximize his profits since he cannot dictate the price. Besides, he has no alternative way of bringing his products to end-users. Although a manufacturer can establish his own distribution system, much of his time, effort and resources are required.

The wholesalers resell the plywood to large Project Contractors and Construction Supplies store warehouses. For his non-regular customers the sale is cash basis. For regular customers, the credit terms range from 30 days to 60 days. At this end, the plywood price will have an add-on of P5 to P10 per panel.

As in the case of ordinary/regular plywood, the prices of panel boards that are distributed through their marketing channels increase from one outlet to another. The price increases from the manufacturer to the wholesalers by as much as 31% while from the wholesalers to retailers, price increase by as much as 12%.

Notably, the wholesalers are in control of the prices of panel boards in the market. Since they maintain a large working capital, they have the bargaining power to get the product from manufacturers at a lower price and sell them at a higher price with huge profits. They have a great influence and a strong hold on the retailers since they continuously provide credit to the latter who maintain good credit standing with them. When the retailers default in payment, the wholesalers easily cut off this credit privilege. The retailers also strive to maintain good credit standing to be assured of available supply and maintain their stocks, and in turn, maintain loyal customers.

Large project contractors have project contracts with either the government or the private sector whether individuals or institutions. These companies are using all types of panel boards but the bulk of this consumption is plywood. The project contractors buy their panelboard requirements from the wholesalers or from distributors or directly from the manufacturers in bulk to avail of lower prices and discounts and save on materials and project costs. The easy credit term, ranging from 15 to 30 days given them by manufacturers or wholesalers help them improve in their business operations and in their cash flow.

Construction supplies stores/warehouses are companies engaged in trading and retailing of various construction materials. It carries different construction products along with panel boards such as different brands of paints, electrical parts, carpentry materials, etc. These are usually single proprietorship with capitalization below P1 million.

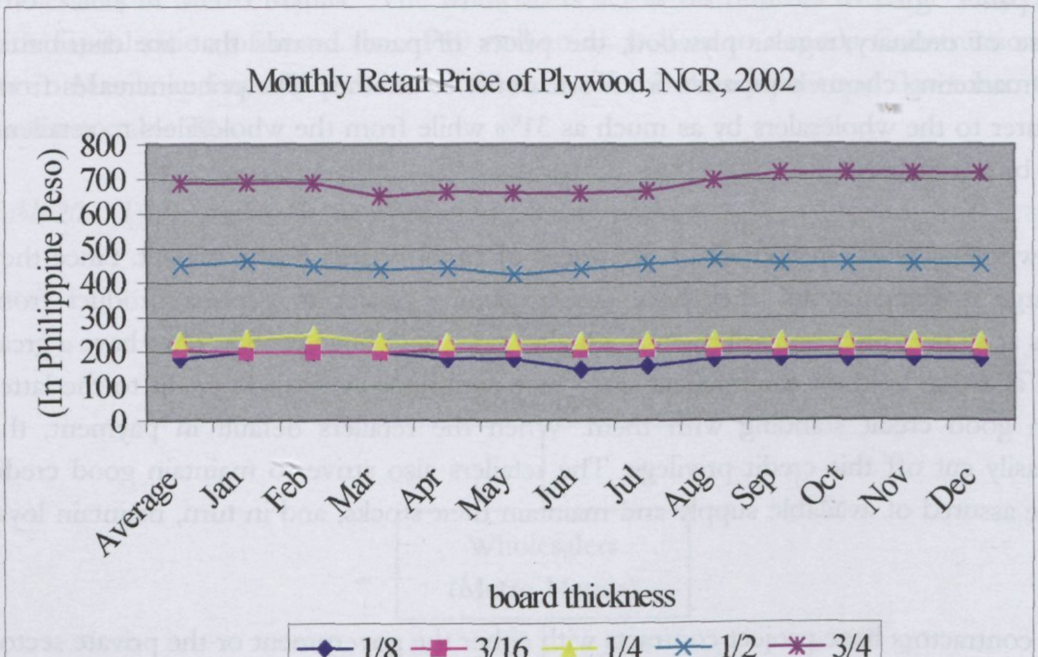
The panel board end-users are household and institutional consumers which buy their requirement from nearby construction supplies stores/hardwares. The end-users buy panelboards on need basis only, thus their utilization is limited. They usually buy on cash basis, either pick-up or delivered.

Other panelboard products available in the market like lawanit, particle board and MDF follow the same marketing system applied in marketing plywood.

6.4.2 Prices of competing products

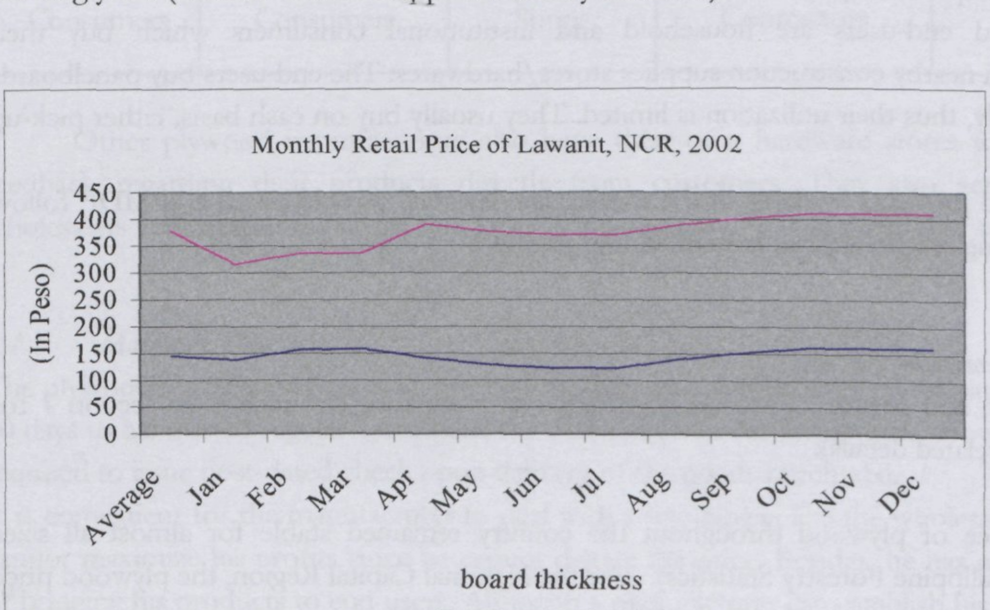
Plywood, lawanit, and particle board are considered as competing products (See section 7 for more marketing related details).

In 2002, the price of plywood throughout the country remained stable for almost all sizes (Source: 2002 Philippine Forestry Statistics). For the National Capital Region, the plywood price fluctuated almost flatly on a monthly basis except for ¾ size which price increased by five (5) percent at the end of year.



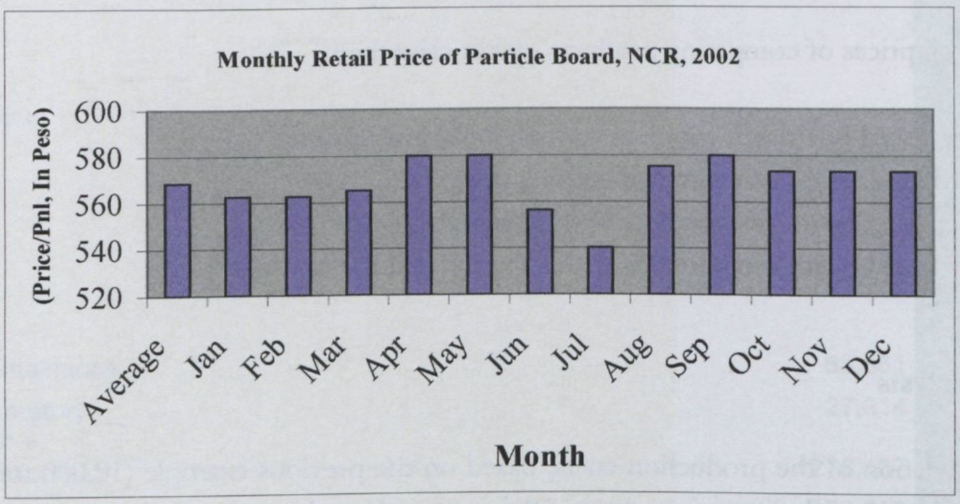
During 2002, the price of lawanit, both for 1/8 and 3/16 inches thick increased by 11% and 8%, respectively. This is attributed to depreciating Philippine currency affected by political instability that resulted from the change of government administration in early 2002.

Lawanit is strongly popular in the lower segments of the marketing hierarchy since it is cheap and affordably sold at wholesale price of P100 per panel (1/8inchx4 feetx8 feet) to Project Contractors and Construction Supply Outlets. Survey results showed that its price in the retail outlet range from P120 to P150 per panel. It is not expected to reflect a significant increase in the coming years (Source: 2002 Philippine Forestry Statistics).



Like lawanit, particle board supply in the country is augmented by imports. In 2002, the imported particle boards amounted to US$1 Million. The major suppliers are Malaysia, Australia and Thailand. There was no record of local production as per DENR records which was confirmed by FPRDI.

In general, the particle board retail price has been stable throughout the country. The survey revealed that in 2002, the price of the most commonly used size of ¾" x 4' x 8' fluctuated from a range of PhP 481 to PhP 723 per pane. In NCR, its price followed a seasonal pattern (Source: 2002 Philippine Forestry Statistics).



The graph depicts that the price increases during summer, April and May, since construction and furniture shop activities are at their peak due to conducive weather conditions. However, such price falls during rainy season, June and July; but it stabilizes on its average price level towards the end of the year. However, the average price per panel of particle board in year 2002 of P554 is lower by 2% in year 2001 and by 4% in year 2000.

6.4.3 Price comparisons

Data below shows the suggested production- and retail prices of coir-based boards of typical sizes, varying in thickness from 1/8 inch (equal to 3.18 mm) to ¾ inch (equal to 19.05 mm)

4 by 8 feet by 1/8 inch					
PRODUCTION	79	peso/board	$1.43		
RETAIL	115	peso/board	$2.08		
	783,742	# plates		3,014	plates/day

4 by 8 feet by 1/4 inch					
PRODUCTION	157	peso/board	$2.86		
RETAIL	230	peso/board	$4.17		
	391,871	# plates		1,507	plates/day

4 by 8 feet by 1/2 inch					
PRODUCTION	315	peso/board	$5.72		
RETAIL	460	peso/board	$8.35		
	195,935	# plates		754	plates/day

4 by 8 feet by 3/4 inch					
PRODUCTION	472	peso/board	$8.58		
RETAIL	690	peso/board	$12.53		
	130,624	# plates		502	plates/day

Comparison with retail prices of competing products makes clear that:

- At 1/8 inch coir-based board can compete with plywood and lawanit.
- At ¼ inch coir-based board can compete with plywood.
- At ½ inch coir-based board can compete with plywood.
- At ¾ inch coir-based board can compete with plywood and particle board.

6.5 Sensitivity analysis

Summary of the calculation of the production costs, based on the previous example (10,000 ton binderless coir-based board, with dimensions 4 times 8 feet times ¼ inch) is given below.

The latter column lists the relative contribution (percentage) to the cost+ return. This is the starting point for a sensitivity analysis:

- Raw materials and energy consumption contribute for almost 70% to the cost+ return, whereas direct labour contributes for 4.5% and write-off of the investments almost 4%. In other words, *the cost combination of raw materials and energy consumption is by far the most critical contributor to the cost+ return.*
- A closer look at the cost combination of raw materials and energy consumption reveals that husk contributes for ~ 40% to the cost+ return, whereas energy contributes for almost ~30%.

PRODUCTION COSTS + PROFIT

		total costs	% of turnover	
Raw materials [coconut husk]		23,294,141	37.8%	
water		185,185	0.3%	
Energy	*electricity press + matforming (pressure)*	7,777,778	12.6%	
	fuel press + matforming (steam)	4,106,339	6.7%	
	fuel mill	5,667,930	9.2%	
	rice dryer	1,587,302	2.6%	
	SUBTOTAL	**42,618,675**		**69.1 %**
Labour				
	Operator	2,206,372	3.6%	
	Chief	375,000	0.6%	
	Manager	180,000	0.3%	
	Total	2,761,372		
Maintainance		63,061	0.1%	
Laboratory:		27,614	0.0%	
Staff + Additional		276,137	0.4%	
Ground Rent		157,653	0.3%	
Tax, Insurance		101,624	0.2%	
	SUBTOTAL	**3,387,461**		**5.5 %**
TOTAL EXPENDITURE BEFORE PRODUCTION			**46,006,136**	
	DEPRECIATION	2,364,796		**3.8 %**
COST EX WORKS			**48,370,932**	
	Management-, Sales-, and Research Work	987,162		**1.6 %**
TOTAL PRODUCTION COST			**49,358,094**	
	Profit at 25% of production cost		**12,339,523**	
COST + RETURN			**61,697,617**	**100 %**

To make the influence of future price rises of individual cost components to the product price more manifest, a few examples are given below. Again starting point is as follows:

PRODUCTION	157 peso/board	$2.86
RETAIL	230 peso/board	$4.17

1. 50% cost increase of raw husk results in the following product prices:

PRODUCTION	195 peso/board	$3.55
RETAIL	285 peso/board	$5.18

2. 50% cost increase of electricity results in the following product prices:

PRODUCTION	170 peso/board	$3.09
RETAIL	248 peso/board	$4.51

3. 50% cost increase of diesel results in the following product prices:

PRODUCTION	167 peso/board	$3.03
RETAIL	243 peso/board	$4.42

In all cases suggested retail price becomes slightly higher than the retail price of it's direct competing product, which can only be compensated by accepting a lower profit. On the other hand, increase in energy prices will also impact the production costs of competing products but to a lesser extent. Only significant cost increase of raw husk requires negative compensation of the desired profit (down to 5%).

6.5.1 Suggestions for cost reduction

Sensitivity analysis of the suggestion production unit clearly shows that the cost combination of raw materials and energy consumption is by far the most critical contributor to the cost+ return. In addition these two components also seem to be most sensitive to (inter)national price fluctuations. (Furthermore market price of raw coconut husk is influenced by transportation costs, which is determined by energy cost.)

One direction for potentially significant cost reduction is by making the coir-based board production unit come a part of a larger industry. This industry could for instance combine the production of copra, consumer drinks and bio-fuel, *besides* panel production. By doing so, excess of energy (mostly steam) from one unit could be (partly) used by the other. In addition, cost of raw coconut husk can be distributed over different product units.

Second direction for potentially significant cost reduction is by producing high density coir-based boards which can technically compete with medium density fibreboard (MDF). Value addition is higher compared with penetration in tradition lawanit-, particleboard- or plywood markets. Furthermore MDF production based on coconut husk has export potential.
Provisions must be made towards altering the suggested production method: either combination of the hot-press' temperature and applied pressure must be increased, or addition of an addition binder must be considered. Without these technical requirements for competing with MDF cannot be met.

7 Marketing aspects of industrial coir-based boards

This section presents an extensive summary of the market study undertaken as part of the project. It was conducted to assess the acceptability of the binderless coir-based board in the domestic Philippine market and to conceptualize on the product lines where this new novel product can fit in. The study shows an overview of the domestic Philippine panelboard industry. Likewise it will show how the binderless coir board produced through the project can be a good material for other allied industries.

7.1 Introduction

Scope of the market study was to identify market sectors where coir-based panelboard could gain market shares.

Specifically, the research study was based on the following objectives:

- To identify the market sectors to be served by the coir-based product;
- To conceptualize product lines or identify product usages for which the coir-based panelboard can be used as a substitute raw material by its target markets;
- To forecast the demand for panelboard from the identified market sector(s);
- To gather certain critical industry information about the panelboard.

Relevant information was gathered from both primary and secondary sources. A market survey was undertaken. The list of industry association members were used as basis in selecting the target survey respondents; otherwise, the survey respondents were directly selected from the market. The respondents consist of contractors and construction business owners, engineers, architects, hardware store owners, furniture manufacturers and shop owners and casket manufacturers. Appointments with the respondents were obtained for their convenience. The questions asked were based on the questionnaire prepared prior to the interview.

Concerned government agencies such as the Department of Environment and Natural Resources (DENR), Environment and Management Bureau (EMB), Forest Product Research & Development Institute (FPRDI), Department of Public Works and Highways (DPWH), Department of Trade and Industry (DTI), National Housing Authority (NHA), Housing and Land Use Regulatory Board (HLURB), Housing and Urban Development Coordinating Council (HUDCC) and the Department of Education (DepEd) were the secondary sources of relevant information and statistics used in the study. Private agencies, i.e., the associations of private developers, constructors, engineers and architects and the chamber of furniture manufacturers, also served as secondary sources of information

The data gathered were carefully evaluated to assess its relevance to the study. These were summarized and analyzed to describe its impact. The purposive sampling method was used in the market survey which is applicable to the established and agreed target research area of Metro Manila and selected areas in Pampanga. Other research activities were conducted at the Forest Research and Development Institute (FPRDI) in Los Baños, Laguna.

7.2 Overview of the domestic panelboard market

Since 1920, panelboard products are sold in the domestic market and have significantly contributed to the national economy. Through its production, the natural resources are efficiently utilized because of the added value, aside from its economic impact to the labor market. The panelboard products served a wide market as major raw materials for household and industrial projects such as in construction, manufacturing of furniture and fixtures, tables and chairs, coffins/caskets or funeral boxes, packaging materials for heavy equipment & machines, appliances and other household accessories, interior partitions of vessels, among others.

In 2002, the domestic plywood production was 350,000 cubic meters which reflected an average growth rate of 10% for the past four (4) years. Production of veneer was placed at 200,000 cubic meters while Fiberboard, Particleboard and Blockboard registered production of less than 100,000 cubic meters each. Total volume of panelboard imports registered a volume of almost 1.5 million cubic meters with corresponding to an import value of US$34.7 Million. Exports for these products resulted to a foreign exchange earnings of US$12.9 Million.

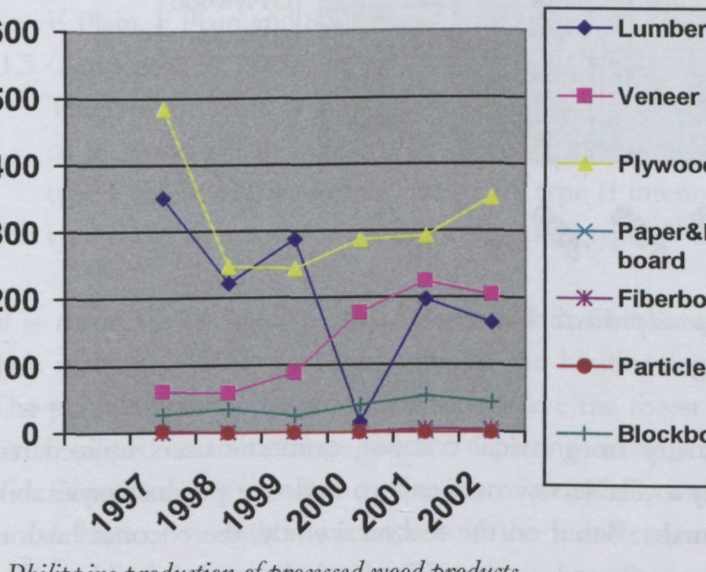


Figure 50 Philippine production of processed wood products

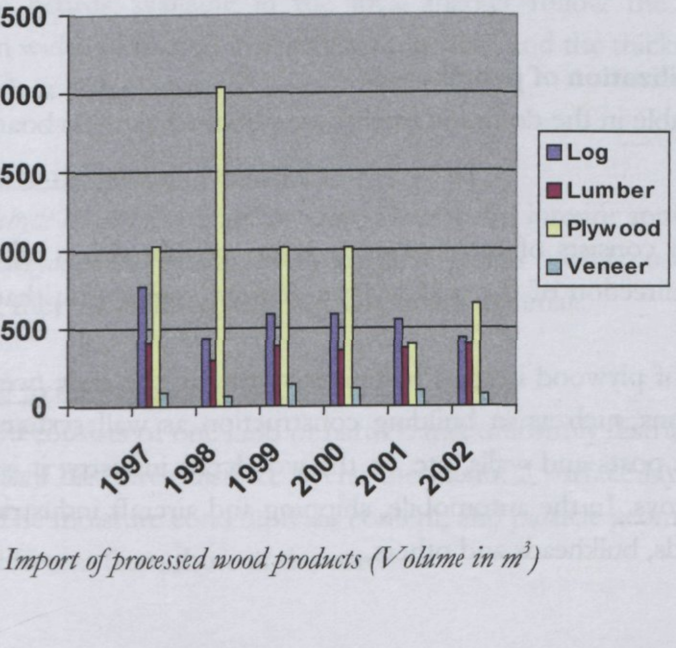


Figure 51 Import of processed wood products (Volume in m^3)

Wood is the main raw material in producing panelboard products. Due to fast depleting forest resources, the government issued Executive Order 277 in 1987 to strengthen the existing laws on illegal logging, and strictly regulate tree cutting from the remaining forests in the country. This resulted to the scarcity of raw materials supply. To address this supply gap, the panelboard manufacturers were forced to import logs and other wood products such as lumber, plywood and veneer from Malaysia, China, New Zealand and other countries. The problem on scarcity of logs was further compounded by a rapidly depreciating Philippine currency that resulted to declining profitability for panelboard products.

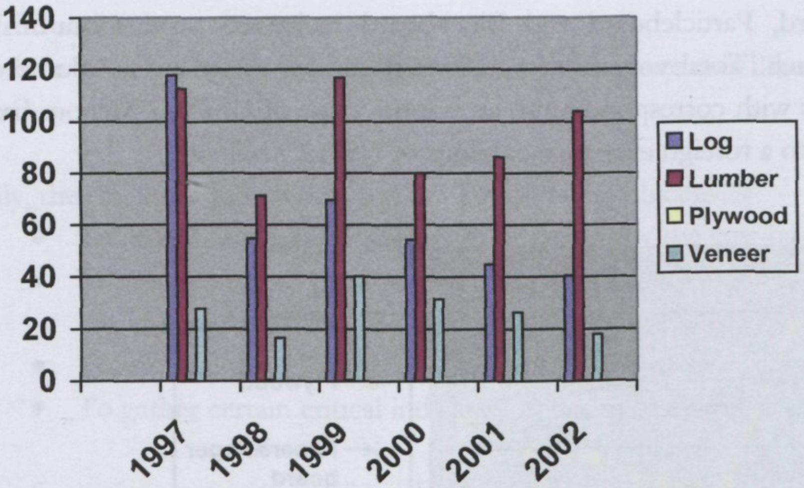


Figure 52 Import of processed wood products (Value in US$)

To save the panelboard industry from virtual collapse, domestic users utilized native, locally-grown, cheap and abundantly available raw materials to improve product profitability. Among these materials is **coconut husk**. Based on the technical study, the coconut husk is a potential and essential component for panelboard product. The binderless coir-based board produced has superior mechanical properties which surpass those of existing particle boards and medium density fiberboards (MDF).

7.3 Market rends on the utilization of panelboards

The panelboard products available in the domestic market are plywood, particle boards and fiber boards.

Plywood is a wood product that consists of three or more layers of thin sheets of wood firmly glued together with the grain direction of the middle layer at right angles with that of the two parallel outer layers.

The commercial manufacture of plywood in the Philippines started in the early twenties. It was used in a variety of applications such as in building construction as wall systems, floorings, forming materials for concrete posts and walls, etc. In the woodcraft industry, it is used in the manufacture of furniture and toys. In the automobile, shipping and aircraft industries, it is used for door liners, bulls, dashboards, bulkheads and others.

Several species of Philippine Mahogany are used in the manufacture of plywood. The most commonly used are red and white lauan, tangile, tiaong, mayapis, almon and bagtican. Other species used are dagang, palosapis, malaanonang, manggasinoro, and apitong.
Generally, plywood comes in different classes. It is classified according to its physical construction, appearance and the type of bond offered.

1.1 *Classification by Physical Construction* which is all-veneer panel that comes in odd-numbered plies such as 3-ply, 5-ply, 7-ply and so on, with increasing thickness, edge-glued lumber pieces, not exceeding three (3) inches in width and 5/8 inches in thickness make up the core of the lumber-core plywood and the particle board, which is a sheet of wood particles glued with a quitable binder.
1.2 *Classification by Physical Appearance* and quality of its veneer face. Some of the defects considered are open splits, stains, joints, knot holes, vine and mineral streaks, wormholes, and others. The different grades are as follows: Special, A Plain, AV-Grooved, B Plain, BV-Grooved, C Plain, CV-Grooved, Print, D Plain, E Plain, F Plain and SG (Shop Grade).
1.3 *Classification by Type of Bond* which dictates its use for interior or exterior purpose. The type of bond is dependent upon the durability of adhesive used. The types of plywood for this classification are (a) technical or fully-waterproof bond, (b) type I exterior or waterproof bond, (c) type II interior or water-resistant bond, (d) type III or moisture-resistant bond, and (e) type IV or dry resistant bond.

Particle board is made up of small particles from wood, fibrous agricultural wastes, and other lignocellulosive materials. It is produced through the binding together of small particles with adhesives. The particle board production helps conserve the forest resources because other raw materials can be tapped as an alternate use for depleting exotic woods. Its production creates great economic impact since it involves conversion of practically waste materials into high-quality processed wood. Interviews with some experts in the industry revealed that the production of particleboard is capital intensive since it requires a number of imported machinery and equipment.

The particle boards available in the local market follow the standard sizes of panelboard products, on width (4 inches) and length (8 inches), and the thickness as follows: ¼", 3/8", ½", ¾" and 1". It is classified as follows:

<u>a. According to the adhesive or binders</u>
Urea-formaldehyde-bonded boards are produced mainly for interior application.
Phenol-formaldehyde-bonded boards are structural panels mainly used as building materials. For exterior use, they are covered with water-resistant materials.

<u>b. According to the number of layers</u>
One-layer board consists of one kind of particle mix uniformly distributed throughout the board.
Three-layer Board has three distinct layers: the identical surface layers (top and bottom), and the core layer. The moisture content, resin content, and particle geometry at the surface of the board are usually different from those at the core.

c. According to particle geometry

Fine-surfaced board, usually a three-layer board made up of small, thin flakes/splinters at the core and a high percentage of fines at the surface; ideal for overlaying or lamination on account of its tight or high-density surface.

Flake/splinter board consists of small thin flakes/splinters and is constructed either as a one-layer or three-layer board.

Waterboard is made up of large flakes or wafers that are bonded mainly with powdered phenol-formaldehyde resin.

Oriented Strand Board (OSB) is made up of long, narrow, wood flakes or strands which are aligned parallel to each other and to the board length at the surface layers and perpendicular to the board at the core layer. The common binder is phenolic resin.

7.4 Current performance of the major industries that utilize panelboards

This section will show the performance of the major industries that utilize panelboards, among which are the construction, furniture manufacturing, casket/coffin manufacturing and the commodities export industries.

The national economy remained sluggish as a result of the 1997 regional financial crisis, which was further aggravated by various unfavorable circumstances like domestic political instability, local peace problems and the war in the Middle East. The country's gross domestic product (GDP) was forecasted to grow by 4.5% for the year 2004 and may reflect a slight increase compared to 4% GDP in year 2003 (Phil. Business Report, Oct. 2003, DTI).

The *construction industry*, which was badly affected by the crisis, has slowly recovered from this situation. In Metro Manila, a number of high-rise building projects were visibly constructed in major urban cities such as Makati, Pasig, Mandaluyong and Quezon City. This positive development in vertical construction was complemented by the continuous growth in horizontal construction. The government pushed for the construction of socialized housing units to narrow down the backlogs, estimated at approximately 3.4 Million[1] by the year 2004.

At present, the demand for construction materials, e.g. plywood, has sustained considering the current level of construction projects from both the government and private sectors. In choosing construction materials, the government follows the prescribed standards under the National Structural Code of the Philippines; while its price is determined through competitive bidding. The private sector, household and industrial consumers, look for price and quality in buying panelboard products.

The *furniture industry* has revitalized over the past years with the introduction into the domestic market of molded multi-dimensional furniture items, in various shapes and sizes, such as cabinets, beds, TV racks, office tables, chairs, computer tables, bookshelves, etc. Most of these are imported from Malaysia, Thailand, and Taiwan. In 2002, the imported furniture was valued

[1] *Source: NHA, Fast Facts on Philippine Housing and Population*

at US$5.0 Million[2]. These furniture are visible and available in shopping malls, retail outlets, showrooms, and other marketing outlets in Metro Manila and other key cities of the country.

In relation to the *coffin/casket industry*, registered deaths of 339,400 in 1997 continued to grow at an average rate of 1.4% per annum from 1993 to 1997. Using such growth rate, the calculated death is 368,926 by the end of year 2003, which is estimated to have generated close to PhP 1.0 billion revenue for the coffin industry. The minimum unit price is PhP 2,700 per casket in the domestic market. Some coffin manufacturers in Pampanga are likewise supplying caskets in Visayas and Mindanao other than Luzon.

7.5 Market sector identification

7.5.1 Government Sector, the National Housing Authority

The National Housing Authority is a government agency mandated to provide affordable and adequate housing for homeless low-income families in the country, thus it is conceived as one of the possible markets for the coir-based panelboard. It leads other line agencies in attaining the annual target for socialized housing projects nationwide. In performing its function, NHA creates demand for various types of construction materials like cement, steel, plywood, GI sheets, and many others.

The housing requirements in the country are classified into different categories such as National Capital Region, Large Cities, Urban Municipalities, Urban and Rural Areas. This indicates that there is demand for construction materials in various parts of the country during the implementation of these housing projects. As shown on table 21, the planned housing projects by year 2004 is 3,362,349 units which is broken down as follows:

Table 21 Planned housing projects in the Philippines for the year 2004 (Source: NSA)

Category	NCR	Large Cities	Urban Munici-Palities	Urban Areas	Rural	Total
Backlog						
Doubled-up	126,696	41,900	10,060	151,060	184,780	454,176
Replacement	432,450	18,260	5,970	87,740	142,960	662,960
Homeless	2,271		6,796	63,320		9,067
Household growth	488,454	197,391	258,478	722,673	556,743	2,223,739
Upgrading	7,385	3,545			1,477	12,407
Total	1,080,256	261,096	281,304	873,733	885,960	3,362,349

7.5.1.1 Trend in Socialized Housing

Housing projects in the Philippines started in the 1940s. The apartment-type unit was the first kind of a housing project built in different parts of Metro Manila, in Quezon City, Caloocan City

[2] *Source: 2002 Philippine Forestry Statistics*

and Manila. The rapid urbanization of Manila in 1960s triggered the influx of rural migrants which resulted to heavy congestion and problem on squatting. This led to the shift into multi-storey tenement housing project, such as in Pandacan, Tondo, Sta. Ana and Fort Bonifacio.

In the seventies, the Philippine population reached 40 million with the biggest concentration in Metro Manila. To address the housing problem and soaring real estate prices, NHA formulated and implemented three (3) housing program concepts, namely: construction of new housing units to meet the demand for housing brought about by household formation and immigration, slum improvement and upgrading of sites and services to improve slums and blighted areas and the sites and services development in growth areas where urban centers were connected by transport network to accommodate families displaced from danger zones and slum improvement projects. Towards end of 90s until this time, NHA has intensified the implementation of the resettlement program which addresses the shelter needs of urban poor families relocated from esteros, creeks and waterways and along the danger areas and those whose houses will be affected by the construction of government infrastructure and other development projects.

7.5.1.2 Basis for Selection of Building Materials

The national government has prescribed certain standards to be considered in selecting building materials for its projects. Basically, there are two (2) general requirements to be complied with, such as technical and price. For technical considerations, the building materials must satisfy the corresponding technical standards set under the National Structural Code of the Philippines for its product category. For the price aspect, it must follow the competitive bidding process, as required under the existing laws and regulations.

7.5.2 Government Sector, Department of Public Works and Highways

Department of Public Works and Highways (DPWH) is the primary engineering and construction arm of the government responsible for the planning, design, construction and maintenance of infrastructures such as roads and bridges, flood control systems, water resource development projects and other public works such as construction of school buildings, farm-to-market roads, rural development, food security projects and projects under the countryside development fund which are implemented throughout the country.

In 2003, it has completed the ground-break of 15 large projects worth P3 Billion and has continuously implemented 40 projects in Luzon, Visayas and Mindanao with an estimated total project cost of about P35 Billion[3]. A large chunk of its annual budget is allocated for its infrastructure programs from years 1999 to 2003 and for its projections for the year 2004, figure 53 (Source:DPWH)..

Based from its estimate, DPWH shall consume plywood in different thickness for a total of 28,000 cubic meters or approximately 1.4 million pieces approximately valued at PhP 407 Million for the year 2003, Table 22.

The DPWH utilizes plywood for concrete cement form to fix the foundation of buildings, roads, flood-control dikes, dams and other types of construction projects. In its projects, DPWH requires durable and highly water-resistant panel boards that withstand the changes in climate and temperature.

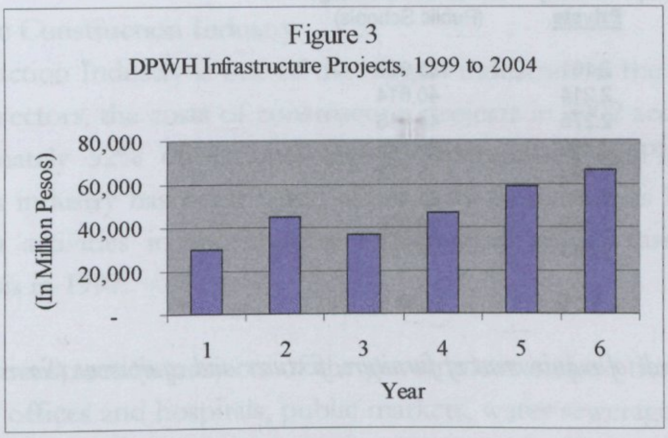


Figure 53 DPWH infrastructure Projects, 1999 to 2004

Table 22 DPWH plywood consumption (2003)

Project	Cubic Meter	Estimated Value
1. Highways and bridges	8,915	P131,824,520
2. Flood control	6,504	96,254,620
3. Various infrastructure	5,918	87,391320
4. National buildings	5,852	86,359,860
5. Other projects	347	5,187,190
Total	27,536	P407,017,510

7.5.3 *The Private Sector*

The Private Sector includes individual and institutional users/consumers of panelboard and panelboard products such as school administrators and investors on education business, furniture industries, project contractors, coffin/casket manufacturer and exporters of Philippine products. Since each consumer has its own requirements, the coir based product must be designed and technically produced to satisfy the requirements of these identified potential markets.

7.5.3.1 Individual Users/Consumers

Individual Users/Consumers are those who require housing units constructed privately or on their own. Majority of these are married people who build houses for their family residence which requires use of voluminous construction materials like panelboards and others. For housing purposes, panelboards are used for both exterior and interior parts such as ceiling, wall system and partitions, built-in cabinets, bedroom and kitchen doors, and many others.

The following table (23) is an indication of the magnitude of requirement of furniture, fixtures and equipments – desks, chairs, seats, laboratory and workshop counters, computers tables and chairs, etc. of both the private and public schools (in units per million). These are the identified potential users of the finished products that may be created with the binderless coir-based panelboard as major components.

manufacturers have been operating for the past 20 years, while the remaining three has been operating for less than 20 years. There was no existing industry association for this business. Previous attempts to organize such association did not materialize due to personal differences among the business owners.

Caskets produced in Sto. Tomas, Pampanga are classified as wooden and steel. Steel caskets are made out of plain galvanized sheets. The raw materials for wooden caskets consist of lumber, lawanit and plywood. The preferred thickness of the lawanit commonly used is 1/8 inch; while for plywood it is ¼ inch.

7.5.3.5 Exporters

With the advent of globalization, Philippine exporters must re-design their strategies to consider the international market. With globalization, trade barriers are significantly reduced or totally eliminated. Under these trade arrangements, the Philippine products shall be easily exported to both WTO member and non-member countries. This trade development is an opportunity for local establishments other than those located in the Export Processing Zones to enter the global market. This situation will trigger a significant increase in the demand for packaging materials. As pointed out earlier, the total Philippine exports stood at P35 Billion or $700 Million in year 2002. The bulk of such Philippine export represents non-traditional items such as electrical parts and telecommunication equipment. Almost one-half of it was shipped to Asia, 32% in America, and the rest to Europe and other countries.

Table 24 Non-Traditional Export Products, 2000 (Value in Million US$) (Source: 2001 Philippine Statistical Yearbook)

Electronics and electrical equipment	22,178
Machinery and transportation equipment	5,909
Garments	2,563
Furniture and fixtures	381
Textile yarn/fabrics	249

These export figures are seen to grow in the future as more companies in the country participate in the global arena.

Some exporters surveyed are corporations with capitalization between PhP 1 Million to PhP 3 Million. They use different panelboards such as plywood, MDF, fiberboard, lawanit and particleboard in packaging their products for export. Their preferred thicknesses are ¼, 3/8 and ½ inch depending on the usage requirements. The exporters are buying such panelboard from their suppliers with credit terms that range from 30 days to 90 days. Some buy made to order packaging materials.

The Philippine exporters have their own industry association with registered members of 208 companies.

7.6 Conceptualization of markets

The binderless coir-based product is a panelboard consisting mainly of pressed coconut husks held together by lignin, a resin-like adhesive. It is properly classified as fiberboard which is one among the panelboards currently traded in the local market. It joins other products made out of fibers like medium density fiberboard (MDF), cement-bonded sugarcane bagasse fiberboard and bamboo skin fiberboard. Particle board, on the other hand, is widely used as components for furniture products and house interiors.

The coir-based product was compared to *lawanit* by respondents in the survey. Apparently, it resembles lawanit in physical appearance. Lawanit, a panel board composed of wood/saw dust particles joined together by synthetic adhesives, is a popular product for interior house partitions that caters to the lower market segments. It is affordable with its low price. The survey results proved that lawanit ranks as the second most salable panel board among 30 construction supply outlets surveyed in Metro Manila, figure 55.

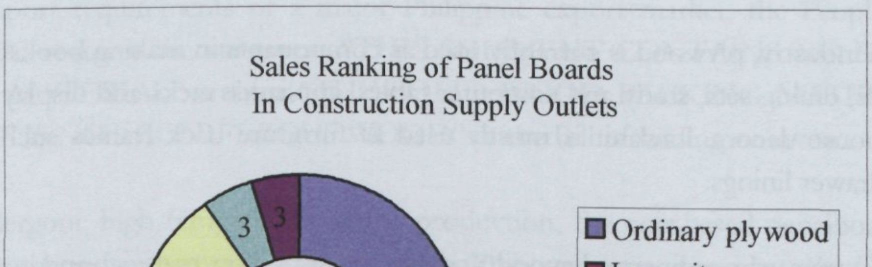


Figure 55 Sales Ranking of Panel Boards in Construction Supply Outlets

The popularity of lawanit in the domestic market will help the binderless coir-based product to penetrate the target market segments and to successfully take off in the competition. In this sense, this product may not need expensive advertisements and promotional strategies to push it aggressively in the market. Also, the product was readily accepted and was observed by survey respondents as possible replacement for lawanit, if certain product features improve. This is a welcome reaction for the coir-based board considering that it is a value-addition to coconut farm wastes. This product can likewise solve the problem on depleted forest reserves.

As this product can readily eat the market share of lawanit in the domestic market, it would definitely ease out the demand for logs, thus, importation of logs and other processed wood products such as plywood, particle board and furniture items will ultimately decrease.

As discussed earlier, the coir based product has technical advantage over some existing panelboards in the market. It has demonstrated its superiority in terms of strength, stiffness,

thickness swelling and density that may further be enhanced to meet the technical requirements for construction materials. These are the panelboard qualities which respondents from the construction sector require.
The survey showed that 30% of the respondents suggested that the product should be with varying thickness, i.e., 2 mm to 25mm, similar to those of plywood and with the standard size of 4 by 8 feet. Their preference for thickness and densities vary from 2 mm to 25 mm. According to the 30 construction suppliers in Metro Manila and Pampanga interviewed, the most salable panelboards in terms of thickness are those with 5 mm thickness.

The product is perceived *useful as interior parts of houses* such as ceilings and floorings, room partitions, panel doors, movable dividers and doors, built-in cabinets, living room organizer and other similar products.

Another interesting result of the survey among furniture shops and coffin manufacturers is that the binderless coir-based board is *considered as a substitute for ordinary plywood and lawanit* which are most commonly used panelboards in the furniture and coffin production.

In the furniture industry, plywood is currently used as components in making bookshelves, office tables and chairs, dining sets, study and computer tables, appliance racks and display cabinets for novelties and house decors. Lawanit is mostly used as furniture back frames such as those of cabinets or as drawer linings.

Coffin manufacturers use ordinary plywood and lawanit as siding material and top covers for caskets as this material can be easily curved and contoured.

Indeed, the binderless coir-based product can be a raw material for industries covered in the survey, especially if the selling price is lower than that of panelboards existing in the local market.

The coir-based product has the necessary strength and stiffness to suit the technical requirements of exporters for *packaging materials*. Exporters transport their goods to foreign destinations either through seafreight or airfreight, thus these goods must be properly packed to avoid any damage or shrinkage while on its way to the intended destination. Exporters need sturdy, firm and reliable packaging materials to protect their products from any breakage, pilferage, destruction and seepage of unnecessary moisture and heat to preserve the products' freshness and best qualities. The coir-based panelboard will allow these products' arrival to their respective markets and consumers with the same qualities they possess as they leave their production lines and quality control stage.

For large quantities or voluminous shipment, the export products are packed in wooden crates which are then stuffed in container vans. In this case, some property features of the binderless coir based product, e.g. firmness and stiffness, density and thickness, smoothness etc., can match the quality of packaging materials required by the exporters. However, since this product is highly dense, its weight may add to the weight of products packed.

Another interesting feature of the coir-based panelboard is its anti-termite property which is organic to the coconut husk. Being a natural and environment-friendly product it can comply with the requirements of the international standards for phyto-sanitary measures as packaging materials. The International Standards for Phytosanitary Measures (ISPM) has set the guidelines for regulating wood packaging material in international trade. Recent concerns over insects and diseases spreading across international boundaries has forced many countries to enact strict import requirements for pallets. New international wooden packaging guidelines have been established by the International Plant Protection Convention (IPPC) of United Nations member countries. The United States, European Union, Canada, Mexico, and Japan are among the more than 150 countries that plan on implementing the requirement as early as January 1, 2004. These regulations require that all wooden packaging must be heat-treated, fumigated or made from special materials. If treated, the wood packaging must be stamped by a certified manufacturer. Certified manufacturers are audited monthly by representatives controlled by the American Lumber Standards Committee.

Being a non-solid wood and a non- coniferous wood, the coir-based panelboard can also comply with the import requirements of a major Philippine export market, the People's Republic of China. PROC requires the statement "THIS SHIPMENT CONTAINS NO SOLID WOOD PACKING MATERIAL" and/or "THE SOLID WOOD PACKING MATERIAL IN THIS SHIPMENT IS NOT CONIFEROUS WOOD" in the Bill of Lading or invoice.

Having undergone high temperature in the production, the coir-based panelboard can likewise comply with the requirements of another major Philippine export market, the European Union for packaging. The European Union is delaying full ISTM 15 implementation until January 2005. This will continue with the Emergency requirements that have been in force since 2002. Currently, hardwood packaging will be accepted with a "NC-US" stencil on each pallet. Coniferous wood must be heat treated and stamped in accordance with ISTM 15.

The coir-based panelboard can also comply with the requirements of the United States of America, a major trading partner of the Philippines. All wood packaging materials arriving in United States of America (USA) after January 02, 2004 must comply with ISPM 15, the Guidelines for Regulating Wood Packaging Material in International Trade which requires that wood packaging must be heat-treated to achieve a core temperature of 56 degrees Celsius for 20 minutes, or fumigated with methyl bromide.

7.7 Issues and concerns

The following issues and concerns were gathered from the comments given by 75 survey respondents based on a piece of the coir-based panelboard product presented to them.

a. <u>Hardness/stiffness of the Coir-based board</u>

12% of the survey respondents commented that the product sample is very hard. It is not easy to cut through handsaw, and very hard to pound on with nail. The respondents suggested that such coir-based product be softened to make it more flexible and convenient to use.

b. Unattractive dark color

20% of the total respondents found the physical appearance unattractive and un-appealing. According to them, this unattractive dark color makes it more expensive in the end as compared to other panelboards since it requires the application of heavy coatings of paint. The respondents suggested a lighter colored product.

c. Limited Product Usage

Apparently, the respondents were indeed biased to the dark monotonous color since they consider this as a deterrent to the panelboard's multiple usage and application. They suggested that it should be produced in different colors so it can serve other purpose.

7.8 Conclusion and recommendations

7.8.1 Conclusion

Based from the analysis of data gathered, the binderless coir board has a bright prospect of penetrating several industries and markets, namely, the construction, furniture, commodities export, coffin/casket production and individual consumers. As discussed earlier, the revenue potential of panel board is calculated at PhP 6 billion per annum. With the depletion of forest reserves, the future production of plywood shall be reduced, thus the potential of the binderless coirboard is further enhanced.

Some respondents look at the product as a potential substitute for lawanit which is totally dependent on residue of sawn logs. Since lawanit is largely patronized by the lower price markets, it is expected that the coir-based product can easily penetrate such market segments and gain a solid ground.

Coconut husk, being the main component of the binderless coir-based board is indigenous, abundant in supply, replenishable and is a cheap farm waste. Assuming constant prices, the production cost of the coir board will be lower than other panelboards in the market which will make it distinct and will give its competitive advantage. This is on top of its superiority on mechanical properties over other existing panelboards in the market.

Although there is a strong likelihood for the product to succeed and find a niche market domestically there are certain critical issues that need to be seriously addressed and overcome. These issues are the product selling price, credit terms with customers and the strategies to be formulated for its effective and successful marketing and promotion and the marketing system to be applied in its distribution to the market. Such issues are some of the critical factors that will affect the success of the binderless coir board in the domestic market.

7.8.2 Recommendations

7.8.2.1 Coir-based Panelboard

The coir-based panelboard must be produced with the qualitative features and characteristics required and demanded by its target customers to effectively serve their needs. To ensure wide

acceptability, its physical qualities such as nailability, overall weight, hardness and dark color should be improved to cater to the needs and wants of the target market.
The technical requirements such as dimensions and thickness, smoothness, absorbability, etc. of each market segment must be carefully considered with the production of this product.

7.8.2.2 Market Penetration

Considering the technical superiority of this product over other competing products available in the domestic market, it can target to initially replace at least 5% of the latter in the market. This initial cut in the flow of imported panelboards will have a big impact in the country's economy.

7.8.2.3 Price

The coir-based panelboard producer must identify clearly the market segment it will serve since it will directly influence the price of the coir-based panelboard to be offered in the market. High end market segments are widely believed to look for quality in buying a product; while, lower end market segments are considered price sensitive. To serve wide market segments, the coir based panelboard must be produced in different product lines that will cater to the specific needs and wants of each market segment. Each product line will have different price structure.

7.8.2.4 Promotion

For the product to succeed in market penetration, the future manufacturer must offer competitive sales price and credit terms to its marketing outlets and design and implement effective and efficient marketing and distribution system. The existing panelboard distribution system can give a higher profit margin to the prospective manufacturer of the coir based product since it eliminates the multi-layered marketing structure.

8 Final conclusions

Coconut husk turns out to be an excellent material for the production of binderless boards. An innovative processing technique has been developed, which uses a smart combination of husk drying, milling and hot-pressing. Without using any additives (like chemical binders) the coconut husk is processed into industrial scale construction boards, which perform better than MDF.

The effect of the individual processing steps on final board characteristics has been evaluated. In summary, the following overall conclusions have been drawn:

- Binderless boards of excellent performance can be produced from coconut husk by simple milling and pressing/moulding processes.
- Coconut husk boards can compete easily with commercial boards on mechanical performance under standard and humid conditions.
- All husk raw materials, whatever freshness, variety or age can be converted to compressed boards of high performance. Younger nuts however (6-7 months) yield some lower quality boards.
- A mixture of husk varieties yields the average properties.
- Up to half a year cool storage of dried husk has no effect on board properties.
- The pressing time of boards with maximum mechanical performance can be as low as 4 minutes in a pre-heated mould.

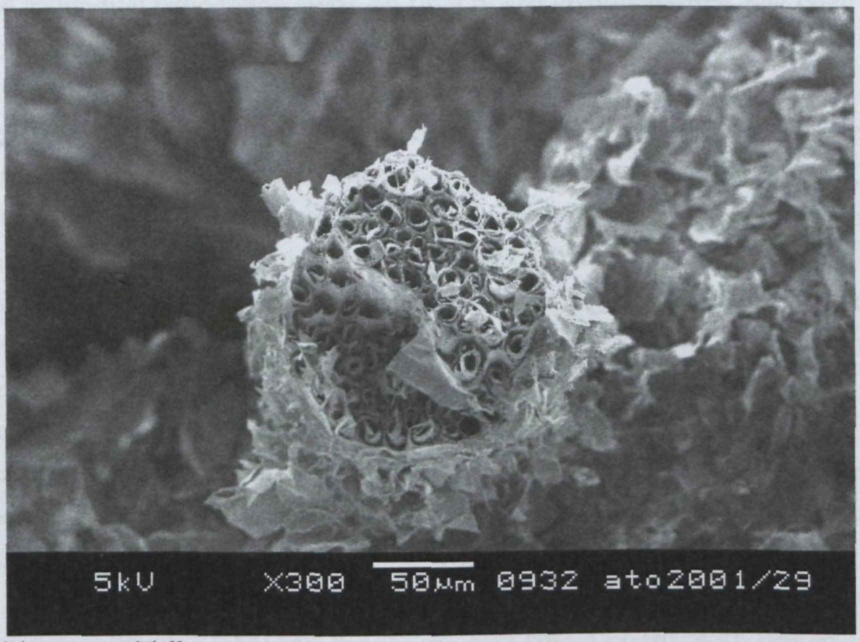
For the annual production of 10,000 ton binderless coir-based board, with dimensions 4 times 8 feet times ¼ inch, Annual Cost+ Return is ~PhP 61,700,000 (equal to ~1,122,000 US$). The number of boards of this specific dimension is equal to 391,871, which results in a suggested F.O.B. price of PhP 157/board (equal to 2.86 US$/board). Including price increases from the manufacturer to the wholesalers by as much as 31% and from the wholesalers to retailers by as much as 12% results in a suggested Retail price of PhP 230/board (equal to 4.17 US$/board).

The binderless coir board has a bright prospect of penetrating several industries and markets, namely, the construction, furniture, commodities export, coffin/casket production and individual consumers. Coconut husk, being the main component, is indigenous, abundant in supply, replenishable and is a cheap farm waste. Assuming constant prices, the production cost of the coir board will be lower than other panelboards in the market which will make it distinct and will give its competitive advantage. This is on top of its superiority on mechanical properties over other existing panelboards in the market.

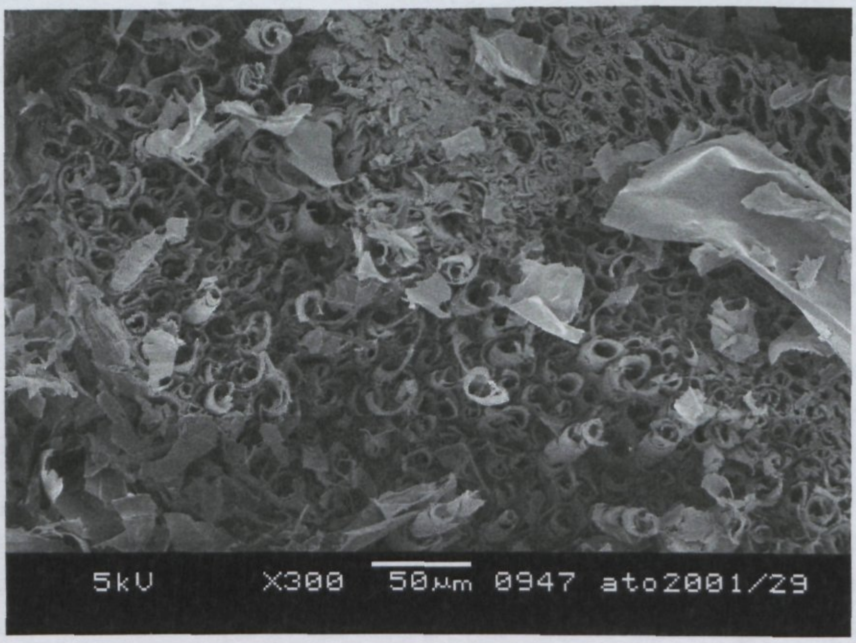
The coir-based panelboard producer must identify clearly the market segment it will serve since it will directly influence the price of the coir-based panelboard to be offered in the market. High end market segments are widely believed to look for quality in buying a product; while, lower end market segments are considered price sensitive. To serve wide market segments, the coir based panelboard must be produced in different product lines that will cater to the specific needs and wants of each market segment. Each product line will have different price structure.

Appendix 1 SEM micrographs of fibre and pith of different coconut varieties

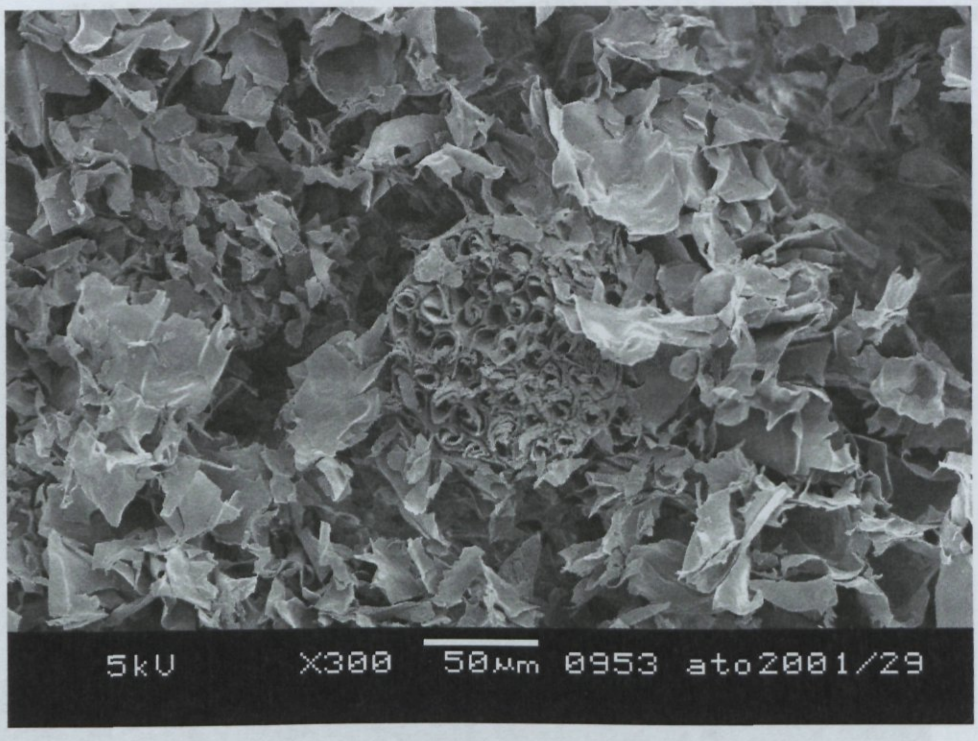
Figure A1: SEM micrographs of coir from the coconut varieties Tagnanan Tall (TAGT), Baybay Tall (BAYT), Laguna Tall (LAGT), Catigan Green Dwarf (CATD), Rennel Island Tall (RIT) and Agta Tall (AGAT).



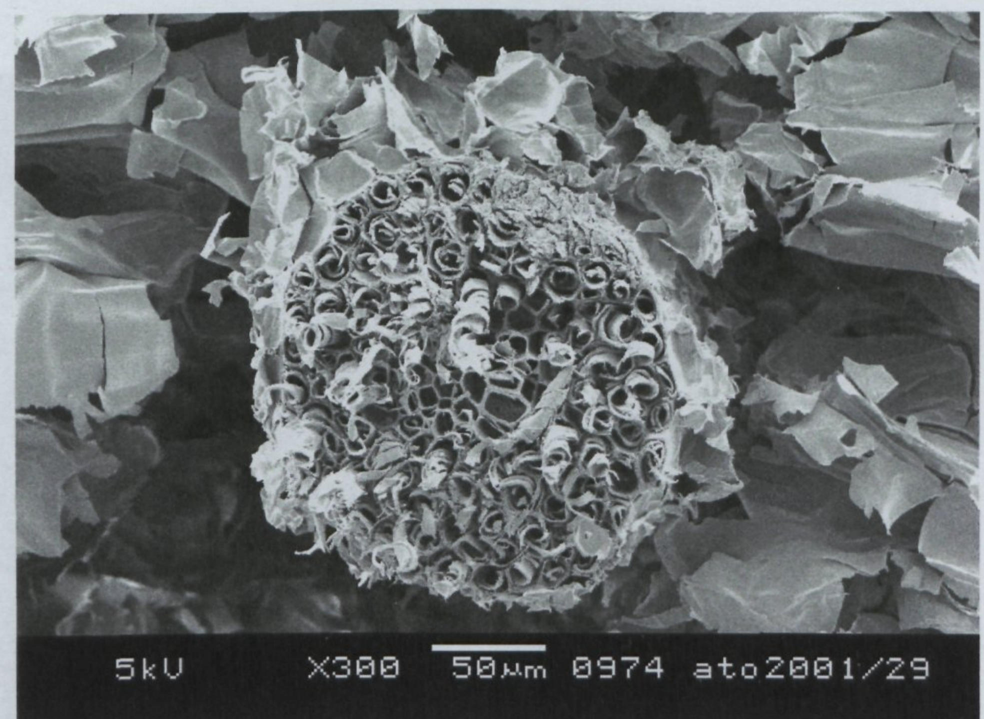
Tagnanan Tall



BayBay Tall



Laguna Tall

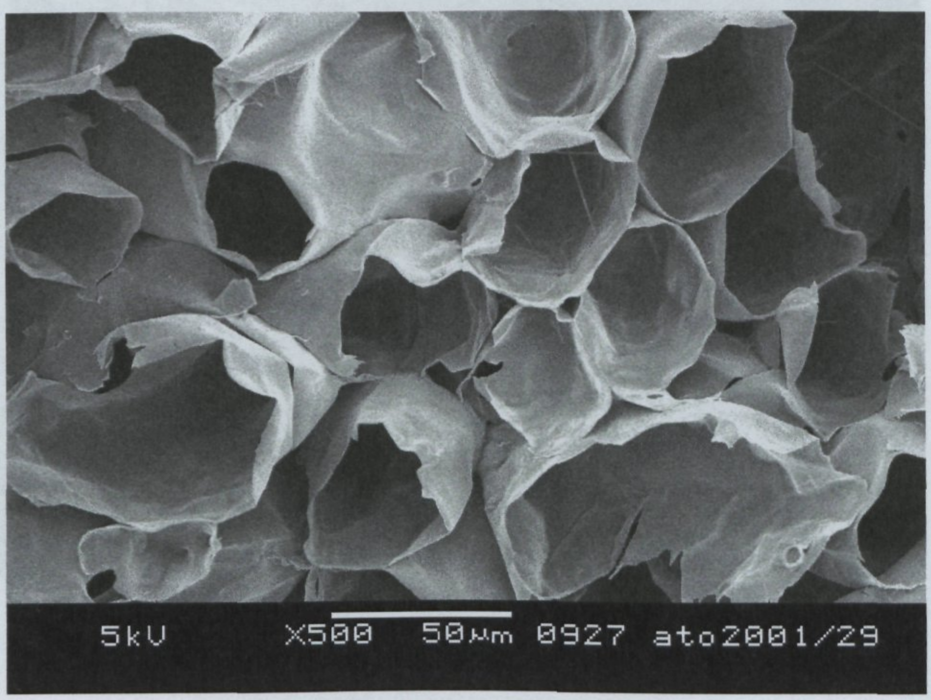


Catigan Green Dwarf

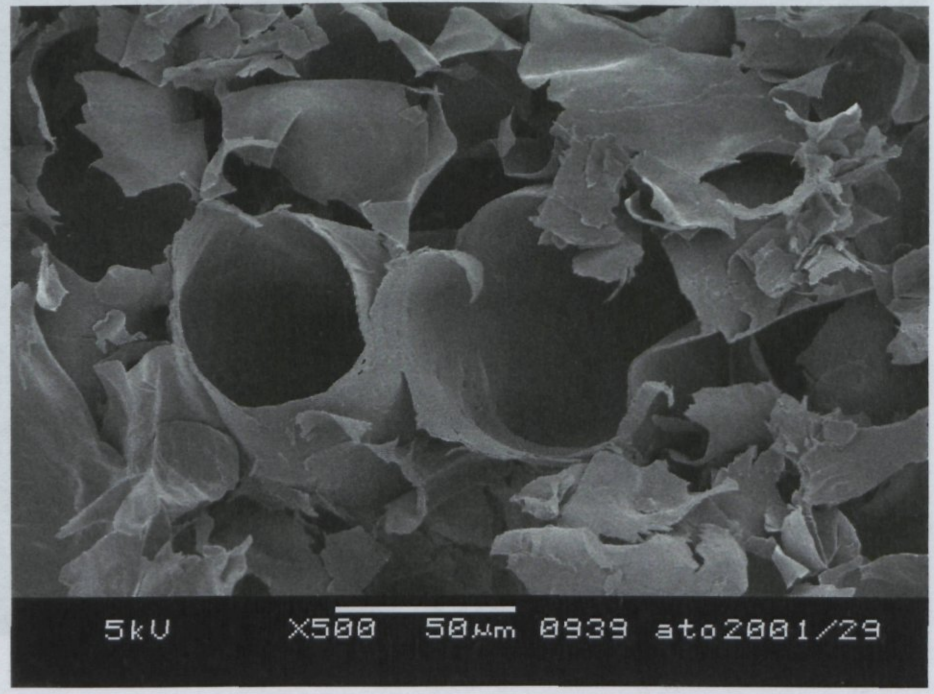
Rennel Island Tall

Agta Tall

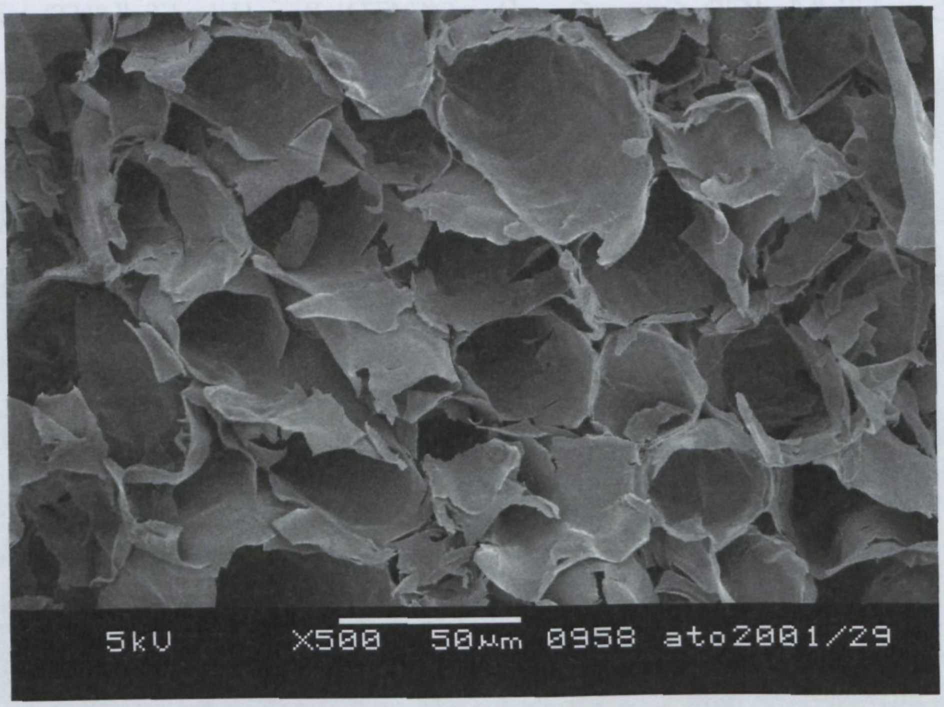
Figure A.2 SEM micrographs of pith from the coconut varieties Tagnanan Tall (TAGT), Baybay Tall (BAYT), Laguna Tall (LAGT), Catigan Green Dwarf (CATD), Rennel Island Tall (RIT) and Agta Tall (AGAT).



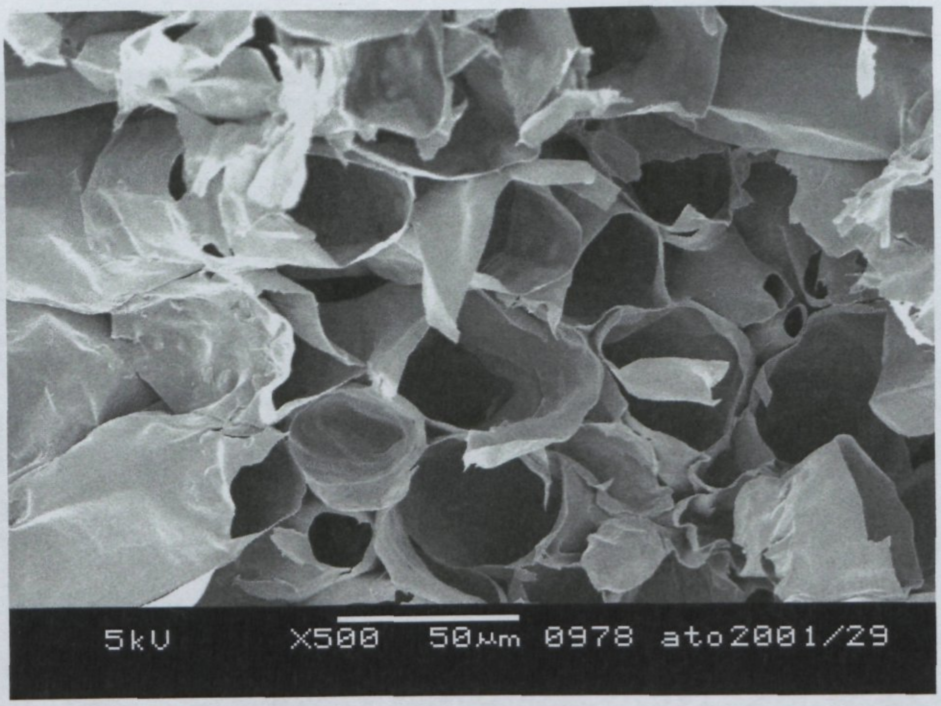
Tagnanan Tall



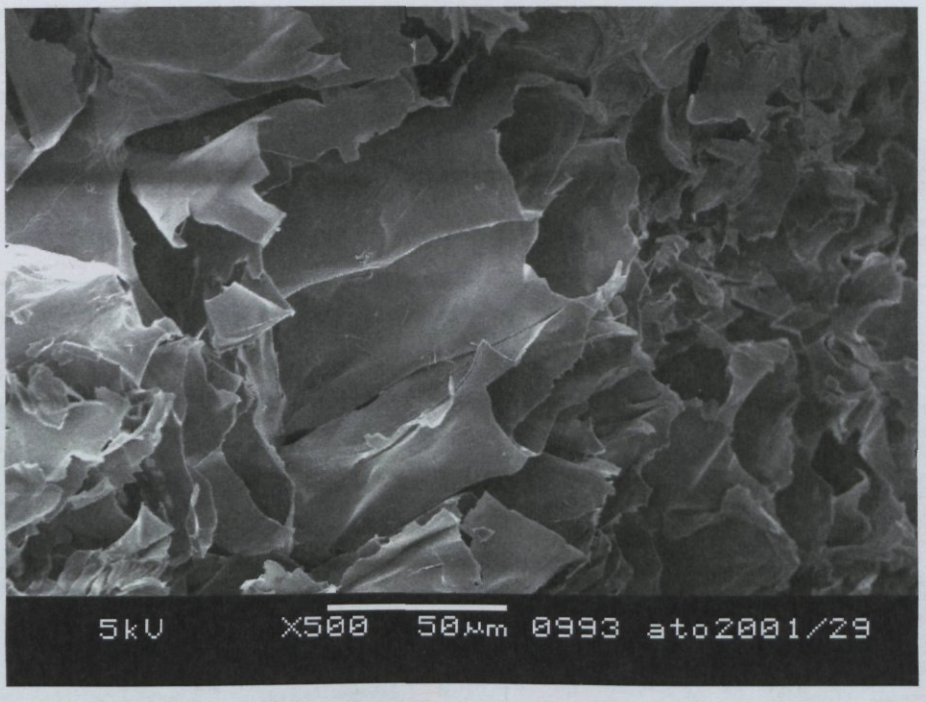
BayBay Tall



Laguna Tall



Catigan Green Dwarf



Rennel Island Tall

Agta Tall

Appendix 2 Fire tests on coconut husk materials

Fire tests on coconut husk board materials

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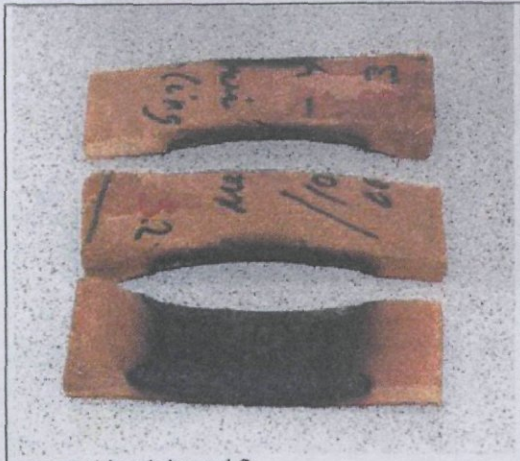

coconut husk board 3

Okoumé triplex

Title: Indicative fire test on coconut husk board materials

Report code: 3.577 **Date:** 2 december 2003

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Projectnumber: 3.577

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Entries: coconut husk board material,
indicative fire test

Summary

On November 14th 2003 SHR Timber Research was commissioned by Agrotechnology & Food Innovations (A & F) in Wageningen to perform a series of indicative fire tests on board material made of coconut husks.
The results show the coconut husk boards to have good fire retardant properties the weight loss was low. The charring on the top side of the samples was very limited with little burning after removal of the flame. However the boards became very hot and bent during the test.

Contents

1 Assignment

On November 14th 2003 SHR Timber Research was commissioned by Agrotechnology & Food Innovations (A & F) in Wageningen to perform a series of indicative fire tests on board material made of coconut husks.

2 Materials and methods

Three different coconut husk materials were supplied by A & F, numbered 1 to 3. The materials were compared to commercial products: hardboard, supplied by A & F, MDF and okoumé triples, supplied by SHR. Three samples (30 * 100 mm) were cut from the supplied materials and left to condition at 65% RH 20 °C. Photo's of the sample before testing are shown in annex 1. Description of the materials is given in table 1.

Table 1. Description of the tested materials

Number	Description	Thickness [mm]	Equilibrium moisture content [%]
1	Coconut husk board 1*	4,99 ± 0,084	9,9
2	Coconut husk board 2*	4,56 ± 0,178	9,8
3	Coconut husk board 3*	7,81 ± 0,057	10,9
4	Hardboard	3,20 ± 0,022	6,2
5	MDF	6,12 ± 0,007	6,4
6	Okoumé triplex	4,82 ± 0,004	11,2

*: sample identification by A & F.

Equilibrium moisture content (EMC) is calculated on samples conditioned till the weight differences between two measurements that are at least 24 hours apart are less than 0.1%
Drying of the samples is carried out at 103 °C for 24 to 48 hours.

EMC is calculated as:

EMC = (conditioned weight – dry weight) / dry weight [%]

Description of the fire test.
For three minutes the samples are placed horizontally 23 mm above a 25 mm high flame with a blue pit of 12 mm. The time till coal formation on the top side completely surrounds the samples is recorded. After 3 minutes the flame is removed and the samples are allowed to burn for another 2 minutes. If the samples ceases to burn, the time till all flames die is recorded, if the samples continue to burn the flames are extinguished after 2 minutes by water spray.

The wet samples are dried at 103 °C and the weight loss by the test is calculated from the weight after burning and the calculated dry weight of the samples before the test.

Weight loss by test = (dry weight before test – dry weight after test) / dry weight before test

3 Results

The equilibrium moisture content is calculated from the conditioned and the dry weight. The results are given in Table 1.

During the fire test the samples are supported by 4 metal pins. During the test all three types of coconut husk samples bent in the centre where the flame is positioned. This part of the samples bent upwards away from the flame so that the centre of the sample was more than 1 cm above the original horizontal plane. As a result the samples fell off the support pins and a new support had to be constructed by means of an aluminium frame. The 10 cm sides were left free as much as possible as not to interfere with the heat and flame spread around the sample. After removal of the flame and cooling of the sample the degree of bending became less. Accurate measurements of the bending angles were not possible.

The increased distance between sample and flame will influence the test results. The magnitude of the effect is unknown. However, as the boards became and remained very hot the burning after removal of the flame and the measured weight loss (see below) will not change dramatically if the boards remained flat.

The weight loss by the fire test is given in Table 2 and Figure 1. Other observations made during the test are also given in Table 2. Some board materials became so hot, water used to cool down the sample sizzled on the sample and evaporated before it could wet the surface.

The coconut husk boards did not char on the topside of the sample, whereas the others did. The burning of the samples after removal of the flame differed from board material. The hardboard and coconut husk board 3 did not burn at all after removal of the flame. MDF burned longest, the fire of two of the three samples needed to be extinguished with water after 2 minutes. Hardboard did not continue burning after the removal of the flame. However, as a result of the high temperature it completely turned into coal. The three coconut husk boards showed very good fire retarding properties, comparable to solid wood treated with fire retardant agents. The weight loss was remarkably lower compared to any of the other boards and the samples did not fall apart after the test as most samples of all other types of boards did.

Because of the difference in thickness it is not possible to give a rating of one coconut husk board being better compared to the others.

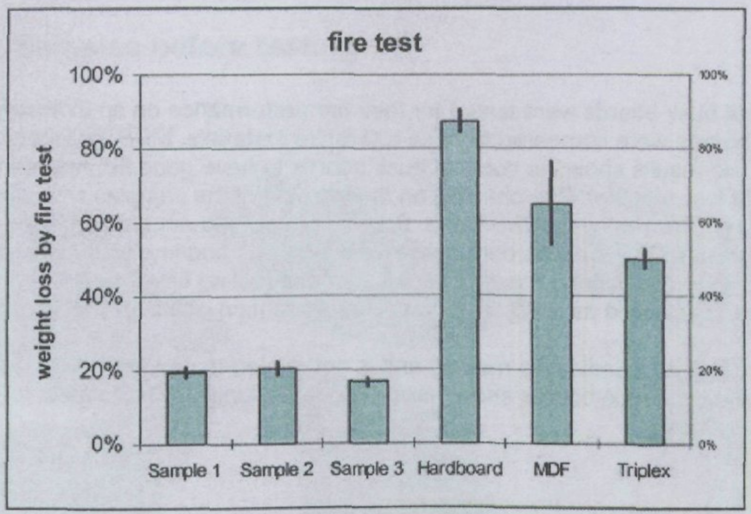


Figure 1. Graphic representation of the weight loss of the boards after fire test.

Table 2. Weight loss as a result of and observations during the fire test.

Sample	Weight loss by fire test [%]	Time till complete coal formation on top of sample [sec.]	Burning time after flame has been removed [sec.]	Bending during the test	High temperature of the sample after the test
1	19,5 ± 1,3	-*	5	Yes	Yes
2	20,5 ± 1,8	-*	35	Yes	Yes
3	16,6 ± 1,2	-*	0**	Yes	Yes
4	87,4 ± 3,0	60	0**	No	Yes
5	65,2 ± 11,2	150	100***	No	No
6	50,1 ± 2,6	77	77	No	No

* After the complete test, the samples were not charred over the whole width of the sample

** Samples did not burn after removal of the flame

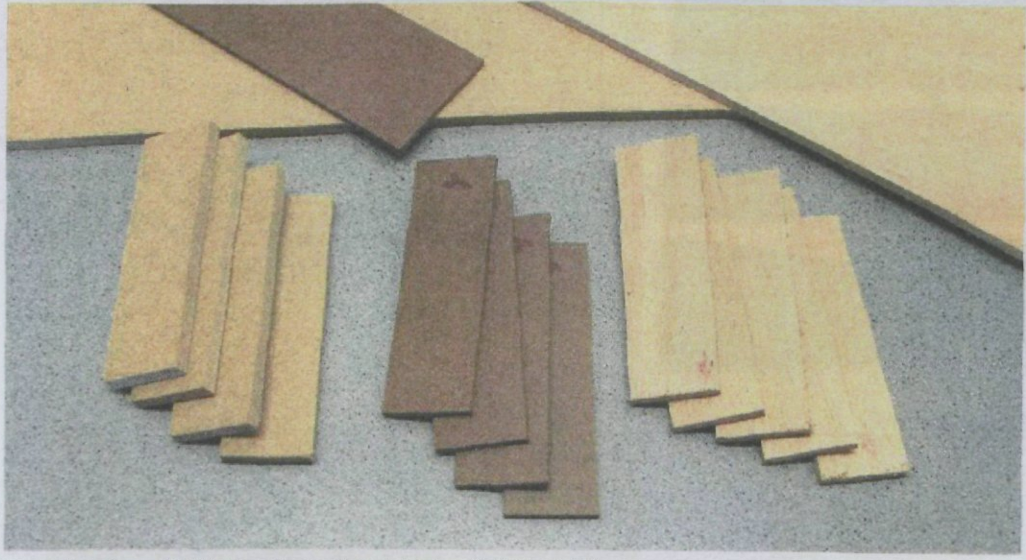
*** Two of the three samples did not cease burning two minutes after removal of the flame. The fire was extinguished with water.

Conclusions

Three types of coconut husk boards were tested for their fire performance on an indicative testing method. The boards were compared to three reference materials, MDF, hardboard, and okoumé triplex. The results show the coconut husk boards to have good fire retardant properties. The weight loss was low. The charring on the top side of the samples was very limited with little burning after removal of the flame. Board 3 did not remain burning at all, board 2 remained burning for 35 seconds only. However the boards became very hot and bent during the test. When considering these materials for constructing fire compartments, the bending should be considered as in fire it will cause the formation of fissures where boards meet.
Although the used fire test is an indicative method and is not related to any normative test, the comparison with the reference boards shows promising opportunities with respect to flame spread and mass loss.

Annex 1. Samples before testing

Samples from coconut husk boards 1, 2 and 3 (left to right)



Samples from MDF, hardboard and triplex (left to right)

Annex 2. Samples after testing

The photo's show the samples after burning. The top two specimen are shown from the top side of the sample, away from the flame, the bottom specimen is shown from the bottom side, the flame side.

coconut husk board 1

Hardboard

coconut husk board 2

MDF

Appendix 3 Production data, expressed in US$

FLOATING COSTS			unit	cost/unit [US$]	total [US$]	cost per ton product
Raw material	coconut husk	77,647,138	#	0.0055	423,530	42.35
	water	18,518,519	liter	0.0002	3,367	0.34
Required energy	electricity press + matforming (pressure)	1,296,296	kwh	0.1091	141,414	14.14
	fuel press + matforming (steam)	52,910	liter	0.5455	28,860	2.89
	fuel mill	136,878	liter		74,661	7.47
	rice dryer				103,053	10.31
Total					**42,618,675**	**4,261.87**
Labour						
Operator		46	man	864	40,116	4.01
Chief		6	man	1,136	6,818	0.68
Manager		1	man	3,273	3,273	0.33
Total					**50,207**	**5.02**
				TOTAL	**42,668,882**	**82.51**

Working Capital	weeks	cost/year	cost per ton product
Stock raw materials.	4	32,579	
Stock finished products	2	34,516	
Suppliers Credit	2	-16,290	
Credit to Customers	4	69,032	
Total working kapital		**87,259**	**8.73**
	TOTAL		**8.73**

FIXED COSTS

direct investment	*depreciation time*	*10 years*			
allocated investment	*depreciation time*	*20 years*			
			cost	**cost/year**	**cost per ton product**
Milling Equipment			141,026	14,103	
Drying Equipment			36,525	3,653	
Multi-daylight Presses			109,091	10,909	
Lang Factor			143,321	14,332	
Total onsite investment			**429,963**	**42,996**	**4**
Instrumentation			8,599	430	
Tankage, Storage & Handling			4,300	215	
Utilities			12,899	645	
Offsites			4,300	215	
Buildings (P1000/m2)			181,818	9,091	
Total allocated investment			**211,916**	**10,596**	**1**
Maintainance				1,147	
Laboratory:				502	
Staff + Additional				5,021	
Ground Rent				2,866	
Tax, Insurance				1,848	
			TOTAL	**64,976**	**6**

COST EX WORKS	**879,471**	**89**
Management-, Sales-, and Research Work	179,484	**18**
TOTAL PRODUCTION COST	**897,420**	**107**
(Profit at 25% RoI)	**(136,830)**	
Profit at 25% of production cost	**224,355**	
COST+ RETURN	**1,121,775**	**112**