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Properties of Nipa- and Coconut Fibers and Production and Properties of Particle- and MDF-Boards made from Nipa and Coconut

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1 Objectives, methods, material, recent experiences

1.1 Objectives

The project „Utilization of Nipa- and Coconut fibers in Vietnam“ (concise title) comprises the amount, harvest, utilization and market aspects of non-forest fibers and/or wood in Vietnam. The reasons why this potential sector of resources might be important for Vietnam are presented in detail in a study by Fink (1999a, 1999b). Investigations carried out in advance showed the large extent to which Nipa panicles and Coconut fibers can be harvested and utilized. Fink explains these facts in detail including the organizational structures for the fiber preparation and the costs for the industrial utilization. As it is shown in preliminary studies, the future demand for board shaped materials (e.g. particleboards, medium density fiber boards) for furniture, the interior and the general construction sector is expected to grow in Vietnam.

The objective of the successive study is to test the feasibility to produce particleboards and MDF (medium density fiber) boards with Nipa- and Coconut fibers. In addition, the study will give information about production parameters, board properties and the final sector of utilization of the boards.

1.2 Methods

The following investigations were necessary:

- Evaluation of experiences displayed in the literature
- Procurement of the sample material
- Characterization of the sample material with focus on properties that are crucial for the future sector of utilization
- Production and evaluation of the particle- and MDF boards
- Evaluation of the board properties and conclusions for the future sector of utilization

The methods of investigation are described in detail in each chapter.

1.3 Material

In cooperation with the company *Applicatio* a procurement plan for the sample material was developed. *Applicatio* received the material in Vietnam and air-dried the material in preparation for the shipment to Germany.

Nipa: To explore possible variations between grow sites (growing conditions, soil conditions), sample material from four different sites (about 1000kg fresh weight per site) in the Ben Tre province was selected and investigated accordingly. The site names are displayed below.

TP = Than Phu	MC = Mo Cay
GT = Giong Trom	BD = Binh Dai

The shipment contained leaf panicles, lengthwise cut to about 1.20 m. The position of the cut sections within the leaf was determined by comparing the section diameters. Details can be found in a study conducted by Kastler (1999). The material was air-dried in preparation for the container transport to avoid molding.

Coconut: details of procurement:

a) Coconut fibers (the length usually exceeded 100 mm), the fibers were packed relatively loose in bags (to avoid damage of the fibers) with a density of 50 - 100 kg/m^3 and compressed to bales (density 100 - 200 kg/m^3)

b) Coconut dust (screened material derived from the fiber preparation process), the dust contained short fibers as well (mainly up to a length of app. 10 mm). The dust was packed either loosely in bags or compressed to bales. Coconut fibers were already pre-dried along with the preparation process. Therefore no extra drying was necessary in Vietnam.

1.4 Recent experiences with Nipa- and Coconut fibers for the production of fiber boards

a) Literature

No specific studies concerning the suitability of Nipa- and Coconut fibers for fiber boards could be found in the literature.

Extensive literature addressing the production of fiber boards from Oil palm-panicles can be found (see Choon et al. 1991). One reason could be the extraordinary difficulties faced with the preparation of Nipa panicles for boards. A large fraction of the Oil palm-panicle consists of parenchyma (like the panicles of other palm species as well), which is not suitable for the production of fiber boards due to its cell geometry and properties. The same can be expected from Nipa. Another problem are the vascular bundles (often in combination with a high ash content) that are in general very hard to process. These are reasons for the difficulties that are faced in a mechanical as well as thermo-mechanical preparation process. A detailed description is given in a study by Hassan et al. (1991) and Jalil et al. (1991).

b) Experiences from other sources

Experiences are available from a well known manufacture of wood based panel production systems that are based on laboratory tests of Coconut fibers for the production of fiber boards. The resulting yield of the material during the preparation process was very low due to a high fraction of dust. Cutting the fibers to a defined length was problematic as well. The resulting properties of the boards (with relatively high glue content) ranged between 50 % and 80 % of standard fiber board properties produced from wood fibers.

No attempts are known for the industrial investigation of Nipa.

2 Characterisation of the sample material

To obtain fundamental knowledge about the suitability, the processing, the production parameters and the final properties of boards some basic material parameters are of importance. The investigation comprised in detail the following parameters (the process steps, for which the parameters are of importance are displayed in parentheses):

a) Moisture content on delivery (processing of the board)

b) Ash content (preparation, glueability, processing of the board)

c) SiO_2-content (preparation, processing of the board)

d) Salt content (glueability, thermal processing)

e) pH-value (glueability)
f) Buffer capacity (glueability)
g) Screen analysis (yield, glueability)
h) Velocity of moisture uptake (preparation) – Coconut only

2.1 Moisture content on delivery

Method: oven-dry method according to DIN 52 183

Results

a) Nipa

The moisture content of 20 randomly selected specimen from each growing site was tested. The results are displayed below:

Growing site	Moisture content averaged [%]	Var.coefficient [%]
TP	21.8	19
MC	16.4	12
GT	20.2	25
BD	19.4	28

Table 1: Moisture content on delivery (in Hamburg) of Nipa panicles

Despite the differences in average moisture content it is unlikely that systematic differences exist between the average moisture content of material from different growing sites.

b) Coconut

The moisture content of a total of 30 samples comprising the ranges fibers/dust, compressed and loose was tested.

Material	Moisture content averaged [%]	Var.coefficient [%]
Fiber loose	14.8	7
Fiber compressed	16.7	8
Dust loose	32.5	12
Dust compressed	31.6	18

Table 2: Moisture content on delivery (in Hamburg) of Coconut fibers and -dust

The reason for the high moisture content of the dust is probably that the dust was packed into plastic bags or compressed to bales right after the formation of the dust (processing of the nut, screening), whereas the fibers were able to continue to dry before packing.

2.2 Ash content

Method: Burning with temperatures of more than 550 °C in a high-temperature oven after the material reached the oven-dry state at temperatures of 103°C, ash content (in %) with regard to dry weight

Results

a) Nipa

The ash content of a total of 80 moisture samples (20 per site) was tested.

Growing site	Ash content averaged [%]	Var.coefficient [%]
TP	8.9	13
MC	8.5	22
GT	8.6	16
BD	11.8	15

Table 3: Ash content of Nipa panicles

The ash content of Nipa in comparison to other materials (wood, also from palms) is very high. It is necessary to specify in detail the constituents of the ash (SiO_2-, salt analysis (refer to chapter 2.3 and 2.4)). The high ash content will probably interfere negatively with the glueability and will have an impact on the mechanical and thermal processing.

b) Coconut

The ash content of 30 moisture samples was tested. The results are displayed below:

Material	Ash content averaged [%]	Var.coefficient [%]
Fiber loose	0.86	16
Fiber compressed	3.20	5
Dust loose	5.42	13
Dust compressed	5.92	15

Table 4: Ash content of Coconut fibers and -dust

Apparent differences can be found between fibers and dust. One reason could be a high contamination of the dust, another reason could be the separation and application of mineral compounds during the processing of the nut or the fiber. That could explain a higher ash content in compressed fibers with high dust content in comparison to loosely packed fibers. No explanation was found for differences between compressed fibers and loosely packed fibers. For detailed information refer to the results of the SiO_2-analysis.

2.3 SiO_2 (silicium dioxid) content

Method: Determination of the ash content, successively the ash was mixed twice with HCl (density 1.19 g/ml + aqua dest., 1:1 mixture) and evaporated. Dilution of the solution with HCl and dest. water in a row, filtration and washing, drying, scorching in an oven at 550 C. SiO_2 as the remainder (in %) in reference to the oven-dry material weight.

Results

a) Nipa

The SiO_2-content of 80 moisture/ash content samples was determined. The results are displayed below:

Growing site	SiO_2-content averaged [%]	Var.coeffcient [%]
TP	0.51	25
MC	0.41	30
GT	0.44	27
BD	0.67	28
completed MDF board	0.37	
max. value	0.61	
min. value	0.17	

Table 5: SiO_2 contents of Nipa panicles and complete MDF boards

The SiO_2 contents are low in comparison to the ash content. A high ash content usually refers to a high SiO_2 content (site BD). The absolute SiO_2 contents are high in comparison to „standard wood species“, there values of > 0.1 % are very rare. The results lead to the conclusion that processes, which involve cutting (sawing, profiling, drilling) of the material require specific tools (carbide-tipped, ceramic-tipped).
The question for further specification of the anorganic compounds that result in the high ash content was not addressed. (refer to 2.4 salt content).

b) Coconut

The SiO_2 content of 30 moisture/ash content samples was determined. The results are displayed below:

Material	SiO_2 content averaged [%]	Var.coefficient [%]
Fiber loose	0.55	9
Fiber compressed	0.31	80!!
Dust loose/compressed[1)]	1.71	11
1) max. value 2.62 %, min. value 1.42 %		

Table 6: SiO_2 content of Coconut fibers and –dust.

The SiO_2 content of the fibers is comparable with results derived for Nipa. Certain consequences are the result (refer to chapter a) Nipa).

On the one hand the increased values of the dust could be the result of a contamination with soil/dirt. On the other hand it is possible that the high SiO_2 contents found in the dust indeed derive from the Coconut fibers. **In both cases the SiO_2 content of the dust is too high for the utilization as board component (particleboard or MDF board)! In MDF boards, the SiO_2 that is concealed in the fibers will be preserved throughout the production process and can be found in the final board.**

2.4 Salt content

Method: Determination of elements (sodium for NaCl, potassium, magnesium, sulfur, phosphor)

Objective was the determination of sodium to calculate the content of NaCl. It is assumed that the NaCl content is relatively high because natural growing sites of Nipa are regions with brackish water (the results are sometimes differences in NaCl content).

The following results contain the sodium content calculated for the sodium salt content NaCl (salt).

Results

a) Nipa

The investigation comprised 1) the end sections of the palm-panicles 2) the lower end sections of the panicles and 3) blended samples of different panicles of one growing site – containing only lower end sections.

Growing site	NaCl content averaged [%]		
	Panicle upper end section single value	Panicle lower end section single value	Panicle lower end section blend
TP	3.5	4.6	4.6
MC	7.1	4.4	4.2
GT	4.7	7.1	7.8
BD	5.5	6.8	7.8

Table 7: NaCl content of Nipa panicles

Despite different growing sites the salt contents differ only marginally; the absolute values are nevertheless high. The average value is 6.1%. Certain impacts on the polymerization of resins can be expected but these problems seem to be controllable with a suitable resin formulation. Apparent are high potassium values for the growing site TP, which also can be found as solid salt formations.

b) Coconut

Material	NaCl content [%]
Fiber loose	0.07
Fiber compressed	1.55
Dust loose	0.86
Dust compressed	1.45

Table 8: NaCl content (average value) of Coconut fibers and -dust

The NaCl content (Na^+ calculated as NaCl) is low and has no impact on the utilization of Coconut fibers and -dust.

c) Fiber boards (MDF)

If the Na^+ content in produced fiber boards is calculated as NaCl, the following NaCl contents (averaged) can be determined in the boards (Nipa boards):

Board type (number)	NaCl content [%]
Reference (Spruce)	0.07
03	5.00
04	4.80
09	3.70
11	4.70

Table 9: NaCl content (averaged) in MDF boards from Nipa

The average NaCl content is 4.5%. Thus, the NaCl content of the boards is approximately 25% lower than the value derived for Nipa panicles. The explanation could be that NaCl was partially extracted from the pulp by in the refiner process (and successively moved into the squeezed-out water). At least that was expected for Cl^-. In preparation for the start of the industrial production it is necessary to determine whether Na^+ really exist mainly in form of NaCl and whether it is of importance for the glueability or has a negative impact on the burning process.

<u>d) reduction of minerals by water storage</u>

For initial tests whether minerals of Nipa can be reduced by water storage only, simple trials were carried out. Nipa chips and Nipa particles were stored for 24 h in water basins having different temperatures (20°C, 50°C). Effect of stirring was tested as well (for 20°C only).

Results show that even storage at 20°C reduces minerals content significantly. Reduction by up to 70% was possible, especially for minerals showing high initial content (Na^+, K^+). Reduction was higher for particles which is related to greater surface areas. Increasing temperature from 20°C to 50°C reduction could be improved by about 10% (chips) and 2% (particles). Stirring improved reduction by about 5% for chips and particles.

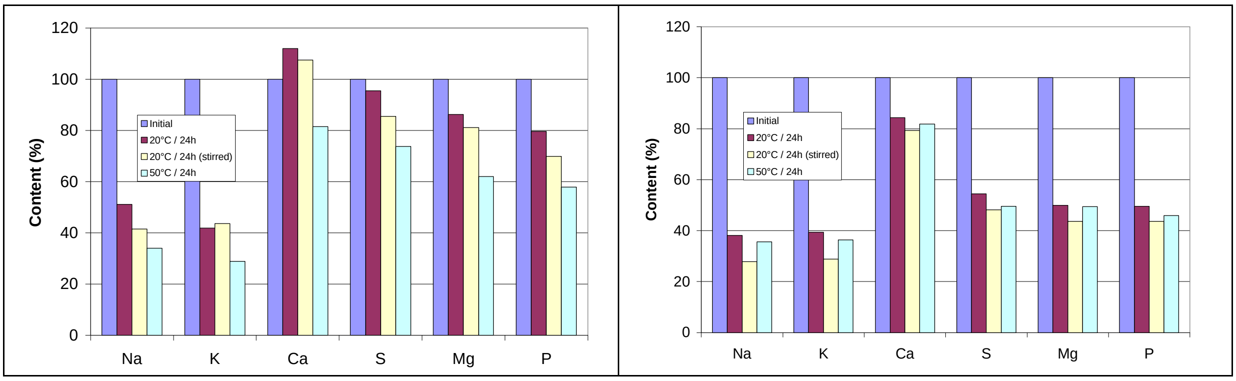

Table 10: Reduction of minerals by water storage (left: chips, right: particles)

2.5 pH value

Method: Production of wood powder by means of an oscillating grinder Herzog SHM 100 P. About 10 g of the powder was mixed with 150 ml aqua dest. and shaked for 24 hours. Successively the pH-electrode was submerged for 5 minutes (magnetic stirrer) and the pH value determined (measurement took place in blended phase).

Results

<u>a) Nipa and b) Coconut</u>

The results are determined separately for the upper and the lower end section of the Nipa panicle („upper end“, „lower end“).

Growing site			pH value	
			1. measurement row	2. measurement row
Nipa	TP	upper end	5.5	6.1
		lower end	5.5	6.1
	MC	upper end	5.7	6.2
		lower end	6.0	6.3
	GT	upper end	5.6	6.5
		lower end	6.4	6.4
	BD	upper end	6.0	6.3
		lower end	6.5	6.1
Coconut	Fiber	loose	5.4	5.3
		compressed	5.0	5.9
	Dust	loose	4.4	5.5
		compressed	4.9	5.5

Table 11: pH values for Nipa panicles and Coconut fibers and -dust

The variance of pH values for Nipa and Coconut is relatively small and ranges in the magnitude of „standard wood“. Specific problems concerning the glueability due to the pH values are not expected. Specific resin formulation do not seem to be necessary.

2.6 Buffer capacity

Method: Preparation of wood powder and mixing with aqua dest., stirring of the mixture for 24 hours as outlined in chapter 1.5. Addition of buffer solution to the mixture and determination of the buffer capacity with an accuracy of 1 g wood powder.

The buffer capacity is defined as the amount of hardener acid or alkali that is necessary to change the pH value of the resin/wood system to pH 3 (for amino resins) or pH 8 (for phenolic resins). The buffer capacity is an important factor for the polymerization reaction of resins in fiber boards.

Results

1) Nipa and b) Coconut

The measurements for Nipa were conducted separately for the upper and the lower end section of the panicles („upper end“, „lower end“).

Growing site/material			Buffer capacity (pH determined with Schott-electrode) for pH 3 [mg/g]	Buffer capacity (pH determined with Schott-electrode) for pH 8 [mg/g]
Nipa	TP	upper end	0.3	2.8
		lower end	0.4	2.2
	MC	upper end	0.6	2.6
		lower end	0.7	2.4
	GT	upper end	0.4	2.8
		lower end	0.7	2.3
	BD	upper end	0.5	2.4
		lower end	0.5	2.9
Coconut	Fiber	loose	0.2	0.8
		compressed	0.3	2.0
	Dust	loose	0.3	1.7
		compressed	0.3	2.5

Table 12: Buffer capacity (for pH 3 and pH 8) for Nipa and Coconut

The Buffer capacity for pH 3 corresponds to „standard wood" (ref. Boehme et al. 1989), for pH 8 the buffer capacity is slightly increased. Overall the variance is small, thus problems will be easily solvable by adjusting the resin formulation.

2.7 Screen analysis

Refer to chapter 3.

2.8 Velocity of moisture uptake of Coconut fibers

During the processing of the Coconut fibers it was apparent that below a fiber moisture content of 20 % the dust fraction will be very large. The processing of the pellets was done by means of pellet iron with matrix puncher. It is advised to process the material at a higher moisture content, thus the material should be moisturized in advance.

Method:
a) Test experiment: 250 g of fibers submerged in water for 6, 12 and 24 hours; determination of the moisture content.
b) Main experiment: Submersion of an entire bag with loosely packed fibers in water for 0.1, 3, 6, 14, 24 and 36 hours; determination of the moisture content.

Results

From the main experiment

Submersion time [hours]	Moisture content [%]
0 (initial)	12
0.1	61
3	92
6	97
14	110
24	128
36	131

Table 13: Moisture uptake of Coconut fibers after submersion in water

The results show that the fibers uptake the moisture rapidly. Moisture contents of 60 % and more (Submersion of 10 to 30 minutes) are sufficient to realize a thorough cutting of fibers with just a small fraction of short fibers.

2.9 Summarizing conclusions of the fundamental physical and chemical material properties

a) Nipa

According to the anatomical constitution of the fibers, specific problems during the processing of the material (wet and dry) can be expected. The relatively hard vascular bundles will result in high abrasion of the tools and high cutting and defibration forces. These high forces will cause an increased cutting of the parenchyma and thus result in a large fraction of short fibers. The consequence will be a reduced yield of fiber material. The processing of dry material (e.g. wing-beater milling after chipping) is tolerable if the parenchyma dust fraction is screened and separated before gluing to avoid an increasing resin demand. The resulting material yield will be reduced accordingly. The separation of the parenchyma fraction in a thermo-mechanical processing (for MDF) is difficult and only possible to a small extend. The consequence is a large resin demand (if the resin-spread is done by means of a blow-line). One alternative could be the dry resin-spread method (rarely practiced in the industry) after screening of the material. The consequence of the high processing expenditure (processing and drying) is the resulting high price of the remaining raw fiber material.

The ash content is sometimes high enough to result in problems with the final processing of the boards. Even if the ash content does only contain a small amount of SiO_2, these SiO_2 amounts of about 0.6 %, in reference to oven-dry fibers, are high enough to require specific tool bits (carbide-tipped, ceramic-tipped). The salt contents vary a little bit but are high in comparison to "standard wood“. No specific problems are expected for the further processing of the material due to the salt contents.

The pH values and buffer capacities range among values for different wood species, therefore the glueability is not expected to be problematic.

In reference to the fundamental properties of Nipa, the production of particleboard appears feasible – with minor restrictions in the processing of particles, the processing of the particleboard and the yield of the fiber material (cost factor). Because of the reduced tool abrasion and the higher material yield in a thermo-mechanical defibration process, the production of MDF appears to be more advantageous.

b) Coconut fibers and Coconut dust

The sole or fractional utilization of Coconut(fiber-)dust in boards is not feasible because of the grain-like structure of the dust (the consequence is a reduced bending strength of the boards). Only the blending of small quantities of dust with fibers seems reasonable. These small quantities of dust can even improve some of the board properties (tensile strength perpendicular to the surface) – under the condition that sufficient amounts of resin are applied. For other board properties the extra amount of dust can be disadvantageous (e.g. danger of board rupture caused by spring back). The utilization of dust in fractions of more than 10 % in the boards are neither for technological nor economical reasons justified.

The processing of Coconut fibers in a thermo-mechanical process (MDF) could be problematic because of the hardness of the fibers. If a suitable mechanical process is employed the results can be expected to be good or at least satisfying for the production of fiber boards (e.g. fiber cutting by means of a perforated drum pellet puncher).

The ash content, especially the SiO_2 content, of the fibers is not extraordinary high. In comparison, the ash content of the dust is discernibly increased probably in parts but not solely because of contamination with dirt. For that reason the utilization of the dust could be problematic.

The pH value and buffer capacity are not expected to impose specific problems for a good gluing technology.

For all these reasons, the utilization of Coconut fibers for the production of particle boards and MDF boards in general appears suitable. The utilization of Coconut dust is not justified because of its grain-like structure and the resulting increase in resin demand, problems with the processing of the board and final board properties. The alternative could be the utilization of the dust as a filler for polymers (e.g. compressed plastics).

3 Production of Nipa particleboard

3.1 Preparation of the panicles

The Nipa panicles were ground to particles with two different moisture contents. One fraction of the panicles remained at the same moisture content as the moisture content on delivery (u ≈ 30 %). A second fraction of the panicles was dried to a moisture content of u ≈ 10 % after grinding.

3.2 Chipping

The production of chips and particles was done in the technical laboratory of the company *Pallmann.* The panicles were chipped in a conventional drum chipper (PHT 120x500).
During the chipping of the panicles, the creation of large amounts of dust was apparent. The installation of an extra exhaust system was necessary in the vicinity of the chipper. The exhaust system was also employed for the chipping of the panicles with higher moisture content but will not be absolutely necessary in the future.
The results of the chipping and the analysis of the chips are displayed in Table 14. The bulkdensities and chip production capacities range below values known for softwood. The consequence is an slightly increased demand in chipper capacity and storage space.

In a comparison of different **screening fractions of chips** it is apparent that the chipping of dry material produced a large fraction of dust. In addition the analysis shows that after suitable screening of the fractions in the production process the dust fractions > 0.5 and > 1.0 mm can be used directly in the surface layer of the boards. The fractions > 2.0 to > 4.0 mm can be used in the core layer (=> app. 50 %). After chipping of the panicles with higher moisture content only the particle size between < 0.5 and > 3.15 mm can be used in the core layer of the boards (=> ca. 10 %). If parts of the chips are used directly as particle material, the capacities of succeeding processes for the particle production can be reduced accordingly. These potential reductions are opposed by increased investments for necessary screens and kiln dryers.

Figure 1: Nipa panicle, chips and particles

Parameter	**Dry u » 10%**	**Air-dry u » 30%**
Current [A]	40 – 45	40 – 45
Capacity [kg oven-dry/h] incl. 20% reserve	3900	3000
Bulk density [g oven-dry/l]	65	115
Screen fractions [mm]	Portion [%]	Portion [%]
> 10.0	30.0	74.6
> 8.0	19.9	5.3
> 4.0	25.4	9.1
> 3.15	4.7	2.0
> 2.0	6.5	3.3
> 1.0	6.2	3.0
> 0.5	3.9	1.5
< 0.5	3.4	1.2

Table 14: Chipping results for Nipa (drum chipper).

3.3 Particle production

The production of particle from chips was done with a range of different devices.

The use of a mill for surface layer particles produced a large fraction of fine material that is neither suitable for particleboard nor for MDF boards.
The employment of a cutting mill showed satisfactory results for dry chips. The cut of chips with high moisture content did not display acceptable results (cubical cracking).
Best chipping results could be achieved with a hammer mill (PHMS). Here the chipping of dry chips as well as chips with high moisture content showed a very good particle quality. Results of the screen analysis can be found in Table 15.

The results for particles produced from dry chips show that these particles are entirely useable. Because of the installed exhaust system, even the screen fraction < 0.5 mm contains only a negligible amount of dust. The fibers of the screen fractions < 0.5 to > 1.4 mm are *pin-shaped*, the screen fractions > 2.0 to > 6.3 mm *planar*. For the surface layer the fractions < 0.5 and > 0.5 mm (45%) can be used. These particles display a very good trickling performance but also have a sufficient tackiness after formation of the fiber mats.
The particles produced from chips with high moisture content appear optically as best fraction (planar, small dust fraction). In contrary the screening displays a large fraction of very coarse particles (>6.3 mm) even after drying. Because of interlocked particles, the material is only spreadable to a limited extent (refer to chapter 3.5.2). The fractions < 0.5 and > 1.0 mm (35%) are suitable for the surface layer of the board. The core layer of the board can be sparse to improve the venting of the board and to reduce the pressing time.

Parameter	Dry u » 10%	air-dry u » 30%
Current [A]	100	100
Capacity [kg oven-dry/h] incl. 20% reserve	2700	1700
Bulk density [g oven-dry/l]	48	42
Screen fraction [mm]	Portion [%]	Portion [%]
> 6.3	2.5	39.3
> 3.15	12.9	8.8
> 2.0	7.6	5.6
> 1.4	19.5	8.2
> 1.25	6.2	2.5
> 1.0	6.3	4.0
> 0.5	25.3	18.4
< 0.5	19.7	13.2

Table 15: Chipping results for Nipa (hammer mill)

3.4 Optimum configuration of the particle preparation tools

The production of particles from Nipa panicles is easy and without problems. Simple and conventional production devices can be used, without changes in the configuration of the devices. For that reason the following particle production process is preferred:

1. Chip production
   Moisture content: 30 – 50%
   Drum chipper: chip length 30 mm, screen perforation size 60x60 mm
   Feeder: conveyor app. 30 – 50 m long
   Exhaust system: probably not necessary, if necessary cap. app. 10.000 m³/h

2. Particle production
   Drying: moisture content app. 10%
   Hammer mill: screen perforation size 5x50 mm, slots mortised
   Feeder: vibrating chip conveyor
   Exhaust system: if necessary cap. app. 30.000 m³/h

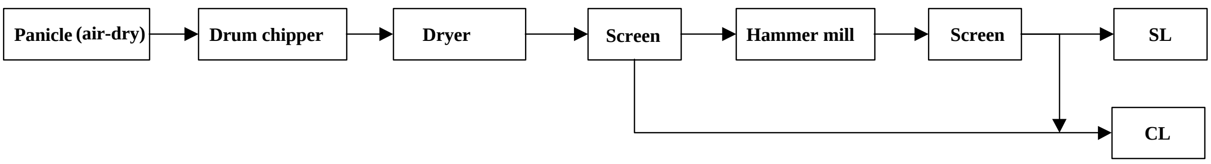

Figure 2: Particle production process for Nipa

3.5 Particleboard production

In the laboratories at the University of Hamburg one-layered and three-layered particleboard were conventionally produced from Nipa. In advance the *dry* particle fraction and the particle fraction with *high moisture content* were dried to a uniform moisture content of u ≈ 10% by means of a laboratory-scale kiln-dryer. Before the application of resin to the particles for the three-layered particleboard, the particle were screened and separated into core layer particles and surface layer particles (core layer particles > 1 mm, surface layer particles < 1 mm). No screening and separation was necessary for the one-layered particleboard. The density of the particleboard ranged between 530 and 750 kg/m³. The one-layered board was produced with a thickness of 12 mm, the thickness of the three-layered board was 19 mm. The pressing time factor was 10 or 15 s/mm.

Experiment	One-/Three-layered	Thickness [mm]	Target density [kg/m³]	Press. time factor [s/mm]
01	One	12	550	10
02	One	12	530	15
03	One	12	650	15
04	One	12	750	15
05	One	12	650	10
06	One	12	750	10
07	Three	19	650	10
08	Three	19	650	10

Table 16: Experiment plan for particleboard from Nipa

3.5.1 Gluing

The application of a conventional urea-formaldehyde resin (BASF Kaurit 350) to the particles was performed with a resin blender. The solid resin content was 8% for the one-layered boards, 7% in the core- and 12% in the surface layer of the three-layered boards. All boards were produced with the supplemental addition of 1% paraffin. Due to a calculation error only 0.4% instead of 1.0% of hardener solution was added.

During the separate application of resin to the surface layer particles the creation of large amounts of dust was apparent, therefore it is advised to separate the dust fraction from the particles before the application of resin. In addition, the occurrence of inhomogeneous resin spread was visible. Apparently some of the interlocked particles got excess resin loads, whereas single particles displayed low resin loads or no resin application at all. The solution is either a thorough separation of particles in the resin blender or a specific processing of the particles in advance (entangling).

3.5.2 Formation of the mats

The mats were manually formed with the resin-coated particles. A thorough separation of the particles was sometimes difficult. Many of the particles were found interlocked and entangled (see above). These entangled particles got separated manually. In all cases the formation of mats with particles produced from dry chips was easier but the separation of entangled particles more difficult. A higher moisture content of the resin-coated particles improves the separation.

3.5.3 Pressing

The mats (50 x 70 cm²) were pressed to particleboard by means of a single-daylight press at a temperature of 220°C.

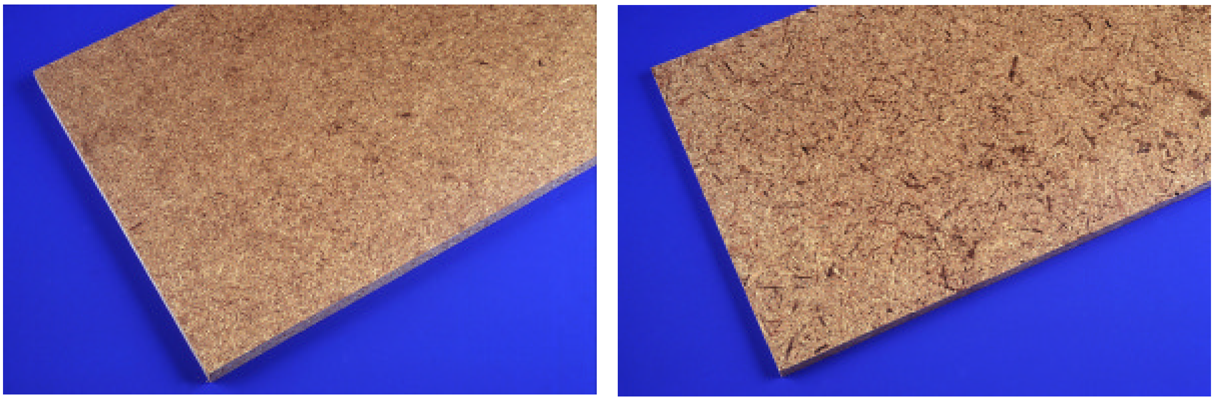

Figure 3: Particleboard produced from Nipa (right side with resin spots).

3.6 Board properties

After hot-pressing the boards were edged, cut into samples and stored in a standard climate room (20°C, 65% r.h.) for at least 4 weeks.

The following board properties were determined:

Density	EN 323	19 samples/board
Density profile	γ-ray measurement	2 samples/board
Bending strength	EN 310	2 samples/board
Bending-modulus of elasticity	EN 310	2 samples/board
Internal bond strength	EN 319	5 samples/board
Thickness swelling 24 hours	EN 317	6 samples/board
Dimensional stability	EN 318	2 samples/board
Surface soundness	EN 311	3 samples/board
Screw retention strength	EN 320	3 samples/board

The results of the board property tests are displayed in Table 17, Table 18 and Table 19. In the following discussion the obtained results are compared to the requirements stated in the EN 312 standard. The requirements stated in different chapters of the EN 312 standard are tailored to specific areas of final utilization of the boards:

EN 312-2	General purpose
EN 312-3	Interior finish (incl. furniture)
EN 312-4	Load-bearing constructions in dry conditions

3.6.1 Mechanical properties

Board	Density	Bending-MOE	Bending-strength	Tensile-strength	Surface soundness	Screw withdrawal retention	
						In plane	Edge
	[kg/m³]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	[N]	[N]
01	531	1057	6.0	0.16	0.31	662	n.d.
02	509	1300	6.8	0.07	0.24	568	n.d.
03	663	2188	13.9	0.15	0.52	887	n.d.
04	706	n.d.	n.d.	0.23	0.51	1162	n.d.
05	655	1780	11.4	0.26	0.49	977	n.d.
06	742	2204	13.9	0.37	0.63	1145	n.d.
07	632	2034	11.2	0.18	0.65	977	444
08	648	2208	12.6	0.19	0.68	1078	448
n.d. not determined							
Requirements							
EN 312-2			11.5	0.24			
EN 312-3		1600	13	0.35	0.80		
EN 312-4		2150	15	0.35			

Table 17: Mechanical properties of particleboard from Nipa.

The requirement for the bending-MOE for the three-layered particleboard are met without difficulties. The values even meet the requirements for particleboard for structural application. The required bending strength for particleboard used in furniture are met from the three-layered Nipa board only with difficulties. It is feasible to improve the bending strength for example by adjusting the density profile of the boards. The internal bond strength of the Nipa boards does not meet the requirements of the EN 312-3 and scarcely the requirements of the EN 312-2 standard. The reason is probably the low hardener amount added in the experiments. In an industrial production process this problem is easily solvable. Some remarks concerning the pressing times are necessary at this point, press time factors of 10 s/mm resulted in improved internal bond strength in comparison to a press time factor of 15 s/mm. Partial hydrolysis of the resin during to longer pressing time is probably the reason for the finding. The surface soundness of Nipa boards ranges closely below the requirements for furniture particleboard. The screw withdrawal retention of Nipa particleboard is 40% below the former value for MDF furniture boards required in norm EMB (1993). The reason for the low value is found in the internal structure of the board.

The conclusion derived from the results is the possibility to produce particleboard for the furniture sector from Nipa. Only minor technological adjustments are necessary to meet the mechanical property requirements of the EN 312-3 standard:

The average density of the board should be at least 680 kg/m³. The density profile of the board needs adjustment (Figure 4). The surface layer should have a maximum density of app. 930 kg/m³ to comply with the required bending strength. To meet the minimum tensile strength the density of the board should not fall below app. 590 kg/m³. The amount of hardener needs to be increased (to about 1%). The pressing time of 10 s/mm can probably be further reduced. These measures will most likely improve the surface soundness and the screw withdrawal retention values required in the standard.

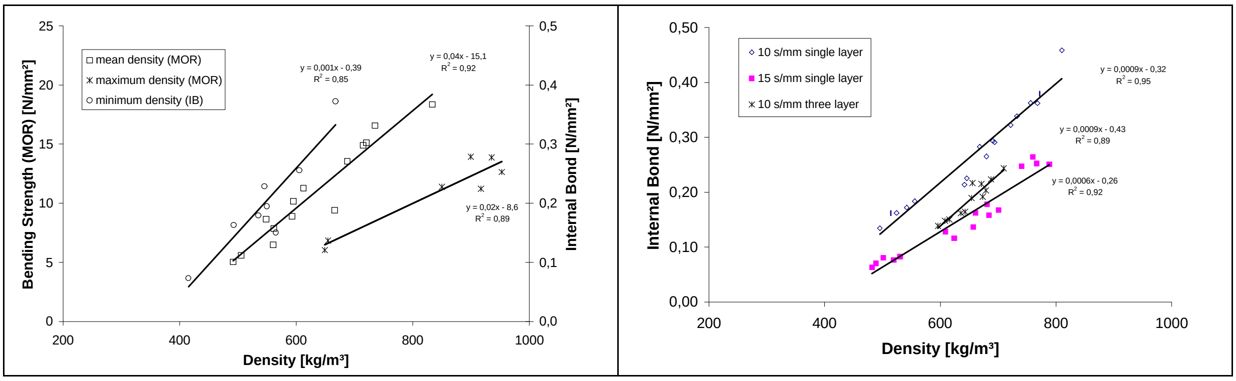

Figure 4: Bending strength and Internal Bond in dependency of the density profile (Nipa-particleboard).

3.6.2 Properties under the influence of moisture

The thickness swelling values (24 hours) of Nipa particleboard are acceptable. The three-layered Nipa particleboard even meets the required standards for particleboards for the construction sector that are stated in EN 312-4.

The dimension in longitudinal direction for Nipa particleboard is reduced by 0.13% after a climatic change from 20°C/65%r.h. to 20°C/35%r.h.. The dimension in longitudinal direction is increased by about 0.29% if the climate is changed to 20°C/85%r.h.. From the observation a dimensional change in longitudinal direction of 0.36% can be calculated for a climatic change from 20°C/35%r.h. to 20°C/85%r.h.. In comparison, the observed change in longitudinal dimension is larger than values derived from particleboard conventionally glued with UF resin (Schwab et al. 1997).

The equilibrium moisture content of Nipa particleboard in all 3 standard climates (20/35, 20/65, 20/85) is also notably increased in comparison to particleboard glued with UF and PF resin (Schwab et al. 1997). The boards stored in moist climate showed the beginning of molding after 4 weeks. Molding is a consequence of an increased moisture content of the boards. The reason for the high equilibrium moisture content is probably the high salt content of the fibers, which can be found in the boards as well.

	Thickness swelling	Water Uptake	Changes in dimension DL35	IL85	35-85
	[%]	[%]	[%]	[%]	[%]
Average	13.6	63.8	-0.13	0.29	0.42
Min	18.8	80.1	-0.10	0.21	0.33
Max	24.3	114.5	-0.15	0.37	0.52
V	16.5	20.2	13.2	17.2	13.2
EN 312-4	15				

Table 18: Thickness swelling, water uptake and change in longitudinal dimension of Nipa particleboard.

	Climate 20/35	20/65	20/85
Average	7.3	11.4	32.4
Min	6.8	11.0	26.3
Max	7.6	11.8	35.0
V	4.0	2.0	6.6

Table 19: Equilibrium moisture content for Nipa particleboard in different climates.

3.7 Conclusions

In general it is feasible to produce particleboard from Nipa. Further investigations to improve the glue-spreading and the mat formation are necessary. It is possible to meet the requirements for interior application (furniture) with few technological adjustments (increase in board density, pressing program). The changes in dimension upon the influence of moisture are major. For that reason and because of molding the final utilization in moist climates is reduced.

4 Processing of Coconut fibers and Coconut dust to particles for particleboard

4.1 Material and Methods

Due to the composition and structure of the different Coconut fractions *fiber loose, fiber compressed, dust loose, dust compressed* it was impossible to employ a conventional particle process (chipper, mills etc.). Instead, the fibers were cut by means of perforated screen matrixes (perforation diameter app. 10 mm). The material for the screens was high-grade steel. The Coconut material was transported to the screens by means of a vibrating chip conveyor and forced through the screen with a conventional roller press at a pressure of 30 bar. The moisture content of the material at the moment of processing was app. 20 %.

Investigations regarding the bulk density of the material reveal that the density increases notably with further processing due to a shortening of fibers (Table 20). The bulk densities of both fiber fractions are naturally reduced in comparison to the dust fractions.

Material		**Bulk density [kg/m³]**
Original	Fiber	20
	Dust	107
Processed	Fiber	157
	Dust	365

Table 20: Bulk density of Coconut fibers and –dust.

Only the grain size was determined for all Coconut material fractions by means of screens with different square wire netting.

4.2 Results and conclusions

The results are displayed in Table 21 and Figure 5. Apparent is that both fiber fractions contain similar grain size distributions. The same applies for both dust fractions.
On average the dust contains a larger amount of coarse screen fractions than the fiber material. The reason is a compaction of dust to bigger pellets. These pellets can easily be ground and separated between the fingers. The dust as well as the fiber fraction contain a large amount of very fine material after processing. In both cases about 30-40% of the entire material (screen fractions ≤ 0.2 mm) can be specified as dust or powder and is not suitable for the particleboard production. A range of slightly coarser fractions can be added to the dust fraction as well. These coarse remains of the pellets are created by the handling of the pellets and disintegrate to dust as well. All these dust fractions can be excluded from the particleboard production process.

40% of the entire material weight comprises fibers that are useable for the surface layers of the boards. 22% of the weight can be used for the core layer. The entire material yield is 62%. A particleboard produced with this material mix would have a dense core layer and smooth surface layers.

Material	**Screen fractions [mm]**									
	8	**6**	**4**	**2**	**1**	**0.5**	**0.4**	**0.2**	**0.1**	**0.05**
Fiber loose	2	1	2	9	11	28	13	20	8	4
Fiber compressed	2	1	2	9	13	27	11	23	7	4
Dust loose	11	8	9	21	14	14	4	9	6	4
Dust compressed	12	2	5	13	15	20	7	16	7	3
Fiber fractions	*Oversize*		*Core layer*			*Surface layer*		*Dust*		

Table 21: Screen fractions (%) of Coconut fibers and –dust after cut with a perforated screen matrix

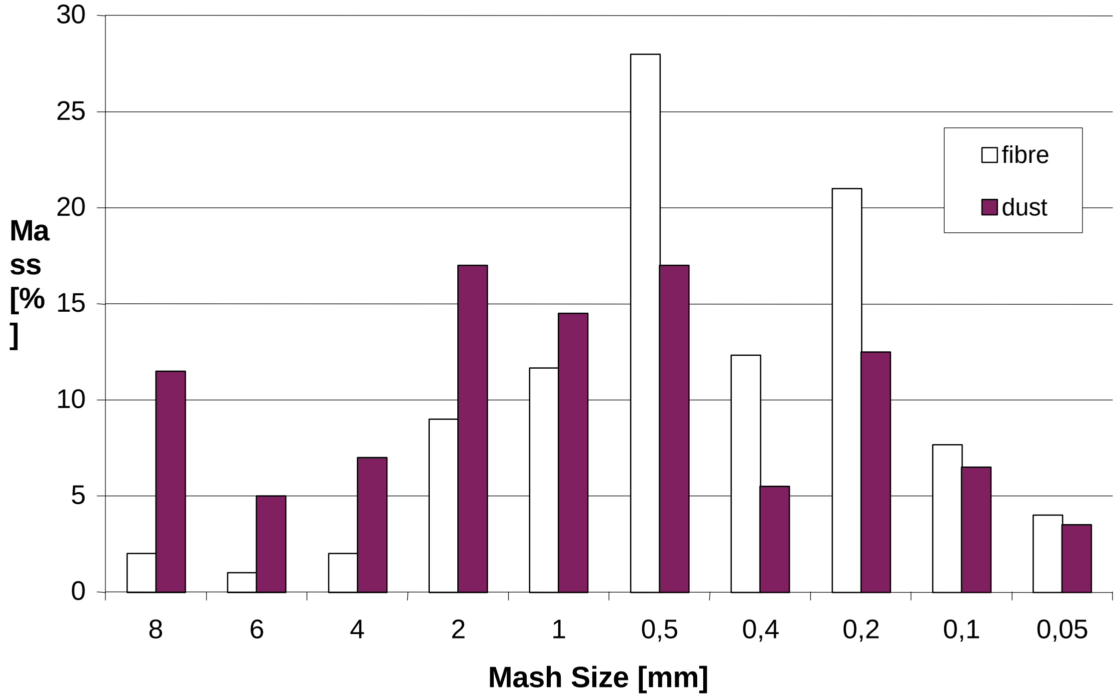

Figure 5: Screen fractions of Coconut fibers and –dust after cut with perforated screen matrix.

5 Production of MDF boards from Nipa

5.1 Preparation of the Nipa panicles

In Hamburg the Nipa panicles were cut into sections 2.5 cm by means of a band-saw. About 180 kg of the cut sections were put into plastic bags and shipped to the BioComposites Centre in Bangor.

5.2 Production of MDF boards

In Bangor a pilot MDF plant was available using the following process components and process parameters.

5.2.1 Fiber production and drying

The raw material was transported to the pre-heater (height 2.6 m) by means of a screw conveyor. Subsequently the cooked material was fed to a digester with 60 liter volume. A 12‘‘ Andritz Sprout Bauer refiner disintegrated the fiber material. The fibers were glue-coated in a blow-line (length 9 m) and subsequently dried in a tube drier (length about 112 m).
The Nipa MDF boards are produced with the following process parameters:

Pressure in the degister:	6 bar
Retention time:	ca. 5 min
Refiner energy req.:	ca. 13 KWh
Spec. refiner energy req.:	ca. 0.173 kWh/kg
Refiner-disk distance:	0.12 mm
Resin:	UF (E1)
	14 and 18% solid resin content per oven-dry wood
Paraffin:	0.8% emulsion
Dryer:	intake temperature 155°C
	outlet temperature app. 92°C

5.2.2 Fiber production results from Nipa

The initial cooking pressure of 8 bar was chosen too high and no sufficiently tight fiber plug could be developed with the plug screw. A lower cooking pressure of 6 bar solved the problem. Simultaneously the produced fiber quality could be improved by a significant reduction of the short fiber fraction (Figure 6). The screen fraction > 2 mm contained mainly fiber bundles. These fiber bundles are advantageous because they improve the venting of the fiber mat during pressing and have a positive impact on the mechanical bond properties. The specific energy required for the production of the fibers was 0.18 kWh per kilogram fibers.

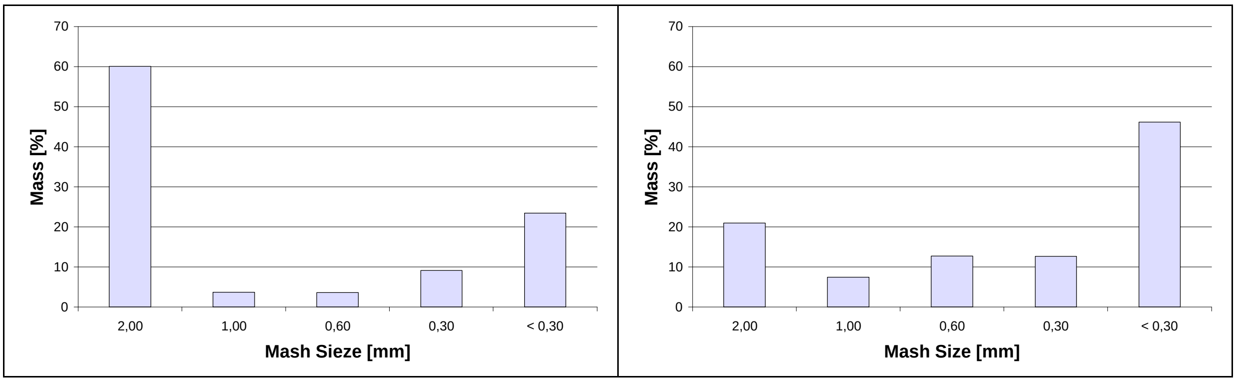

Figure 6: Screen fractions from Nipa fibers (left: 6 bar, right: 8 bar cooking pressure)

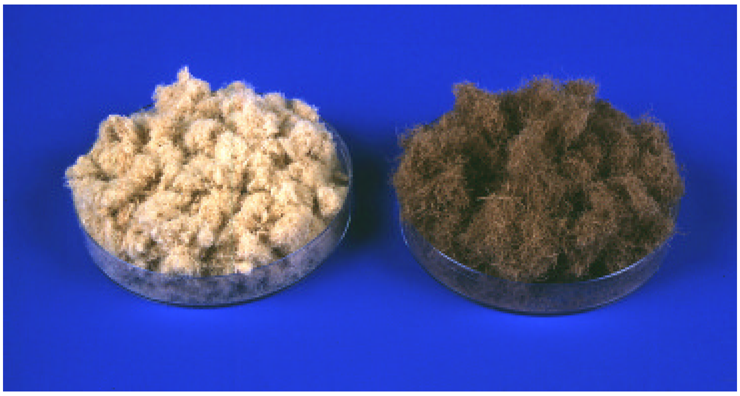

Figure 7: Fibers from Spruce and Nipa

5.2.3 Mat formation and pressing

The formation of the fiber mat was done by means of a mechanical spreading machine (Bison). The moisture content of the fibers was determined gravimetrically with an IR measurement device (IMAL UM200). The mat was cold pre-compressed and subsequently hot-pressed to MDF boards.

Moisture content of the fiber mat:	11-12%
Pressing temperature:	180°C
Pressing time factor:	15 s/mm
Board size:	600 x 600 mm^2

Board variations

A variety of different boards were produced to explore the effect of different densities and solid resin contents on physical and technological board properties. Additionally the produced MDF boards comprised a representation of different sectors of final utilization of the boards.

Thickness [mm]	Density [kg/m³]	Solid resin content [%]	Sector of potential utilization	Board No.
4	820	14	HDF	01, 02
12	700	14	Furniture	03, 04
12	800	14	HDF	05, 06
12	750	18	Impact of solid resin content, density	08, 09
12	800	18	Impact of solid resin content, density	07
18	500	14	Interior construction	10
18	700	14	Furniture	11, 12
18	750	14	Furniture	13, 14
18	800	14	Furniture	15

Table 22: Experiment plan for MDF boards from Nipa

After the production strips with a width of 8 cm were cut off the edges of the boards. Subsequently the samples for the physical and technological property tests were stored under standard climate conditions (20°C, 65% r.h.).

To allow comparisons 3 Spruce MDF boards were produced as well. The thickness of the Spruce boards was 18 mm with a density of 730 kg/m³. The solid resin content was 14%. The production parameters (refiner, dryer, press etc.) were identical to the parameters chosen for Nipa MDF boards.

Figure 8: Spruce and Nipa MDF boards.

5.3 Board properties

The processing of the fiber material did not reveal any significant problems during drying, mat formation and subsequent hot-pressing. The board surfaces before sanding appeared a little rough.

5.3.1 Mechanical and technological board properties

The following properties were tested on MDF boards:

Density	EN 323	16 samples/board
Density profile	γ-ray measurement	2 samples/board
Bending strength	EN 310	2 samples/board
Bending modulus of elasticity	EN 310	2 samples/board
Internal Bond strength	EN 319	6 samples/board
Thickness swelling 24 hours	EN 317	4 samples/board
Dimensional stability	EN 318	2 samples/board
Surface soundness	EN 311	4 samples/board
Screw withdrawal retention	EN 320	3 samples/board
Ash content		3 boards

The results of the mechanical tests are displayed in Table 23 as averaged values for each single board.

As displayed below, the Nipa MDF boards already meet with the chosen process parameters in main parts the requirements of the EN 622-5 for furniture MDF produced in a semi-dry process.

Thin boards with a thickness of 3.5 mm meet the requirements without any problems. The required Internal Bond strength as well as the bending modulus of elasticity are met with ease. To reach the required bending strength either the board density can slightly be increased to about 820 kg/m³ or the pressing program can be adjusted.

For thick board with a thickness between 12 and 18 mm a more specific investigation is necessary. In general the average density of the MDF boards should be at least about 750 kg/m³ to meet the requirements for furniture fiber boards. Regarding the single board properties the following picture can be drawn: to reach the minimum bending property requirements the density of the maximum surface layer density should be at least 980 kg/m³. The minimum density of the core layer should not fall below 700 kg/m³ to reach sufficient internal bond strength (see Figure 9). The surface soundness reached with these parameters (density profile, solid resin content) is about 0.88 N/mm².

A significant impact of the solid resin content on the mechanical board properties is not apparent.

Board	Thickness	Density	Bending strength	Bending MOE	Internal Bond	Surface Soundness	Screw withdrawal retention	
	[mm]	[kg/m³]	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]	Plane [N]	Edge [N]
01	3.6	823	27.3	3184	1.05	1.28	223	n.d.
02	3.7	817	20.8	2658	0.74	0.77	160	n.d.
03	12.6	697	16.6	2146	0.53	0.58	1090	n.d.
04	12.6	692	15.3	2015	0.59	0.60	1153	n.d.
05	12.6	739	16.0	2071	0.66	0.70	1133	n.d.
06	12.6	744	17.1	2281	0.62	0.72	1325	n.d.
07	12.5	752	24.2	2915	0.70	0.86	1130	n.d.
08	12.5	723	18.6	2190	0.75	0.80	1135	n.d.
09	12.5	738	19.9	2251	0.64	0.76	1295	n.d.
10	17.1	562	6.6	1081	0.21	0.35	610	285
11	17.9	671	14.7	2072	0.19	0.64	963	322
12	17.8	749	22.2	3271	0.24	0.80	1168	465
13	18.2	776	21.3	2688	0.15	0.79	1253	422
14	18.2	714	21.8	2937	0.23	0.94	1065	396
15	18.2	802	n.d.	3368	0.18	1.01	1285	472

n.d. not determined

Requirements

EN 622-5	2.5 – 4.0 mm		23		0.65			
	12.0 – 19.0 mm		20	2200	0.55			

Table 23: Mechanical properties of MDF boards from Nipa

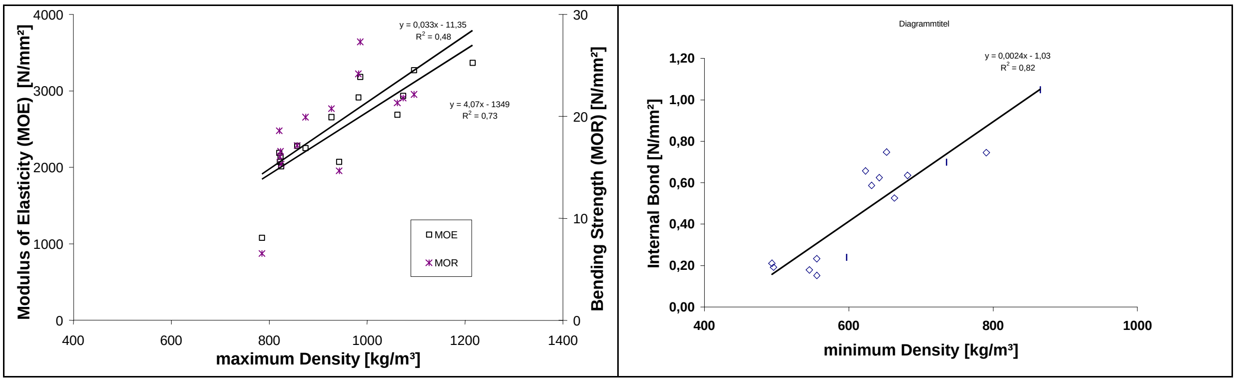

Figure 9: Bending and Internal Bond in dependency of the density profile (MDF board from Nipa)

5.3.2 Properties under the influence of moisture

The properties of Nipa MDF boards under the influence of moisture is displayed in Table 24 and Table 25.

	Thickness swelling (24 hours)		Moisture uptake	Change in dimension		
	2.5 - 4.0mm [%]	12.0 - 19.0mm [%]	[%]	DL35 [%]	IL85 [%]	35-85 [%]
Average	23.2	13.7	63.0	-0.17	0.43	0.60
Min	21.7	11.4	48.2	-0.13	0.25	0.41
Max	24.8	17.4	92.4	-0.21	0.64	0.79
V	6.6	12.3	17.2	9.5	37.0	24.2
EN 622-5	35	12				

Table 24: Thickness swelling, water uptake and change in longitudinal dimension of MDF-boards from Nipa

	Climate		
	20/35	20/65	20/85
Average	7.2	10.5	33.2
Min	6.8	9.8	27.7
Max	7.7	11.5	36.9
V	3.5	4.8	8.2

Table 25: Equilibrium moisture content of Nipa MDF boards in different climates

The values for the thickness swelling (24 hours) of Nipa MDF boards are satisfying in comparison to the standard requirements. With the chosen process parameters the thin boards already meet the requirements. The thickness swelling of the thick boards usually range slightly above the requirements of the norm. The swelling can be reduced to a norm value by addition of an extra amount of water-repellent.

A change in longitudinal dimension of 0.60% in plane of the Nipa boards under the influence of different climates (35→85) is very high and noticeably increased in comparison to Spruce MDF boards (see chapter 7.2). The increased dimensional change is a consequence of the discernibly increased equilibrium moisture content in general and the extremely increased equilibrium moisture content of 33.2% under the influence of increased humidity (20°C/85%r.h.). Another consequence of the increased equilibrium moisture content is the appearance of mold after 4 weeks of storage in very humid climate (20°C/85%r.h.). After 8 weeks of storage fungi covered the samples entirely with a bluish overlay.

For the final utilization of the Nipa boards the big dimensional change under the influence of different climates and the possibility of molding needs to be taken into account (see chapter 8). Further investigations are necessary either to reduce the salt content of the boards or to improve (chemically) the molding resistance of the boards.

Figure 10: Nipa MDF board covered with fungi after storage in very humid climate

5.4 Conclusions

In general, MDF boards produced from Nipa can meet the requirements for furniture MDF boards with minor adjustments in the technological process (increase in board density, pressing program). The dimensional change under the influence of moisture is major. For that reason and for the potential danger of molding the final utilization of the boards in humid climates is limited. This consequence applies especially for tropical climates.

6 Production of MDF boards from Coconut

6.1 Preparation of the Coconut fibers

A bale of compressed fibers (app. 90 kg) was shipped to Bangor. Parts of the Coconut fibers were cut into sections of about 2 cm in advance by means of a guillotine.

6.2 Production of fibers and boards

Because of the low bulk density of the Coconut fibers (original length) the inlet of the cooker was equipped with an extra screw conveyor to increase the fiber input. During the feeding the screw conveyor showed huge variations in electrical power demand up to the limits of the device. In the transition zone between the cooker and the refiner the material created very often a plug in front of the refiner disks that reduced or even stopped the material flow. As a consequence the production of fibers with Coconut fiber in original dimensions were impossible and got finally terminated.

A second experiment was started to investigate the possibility to produce fibers from cut Coconut sections. For that reason the Coconut fibers were cut into sections of 2.5 cm by means of a guillotine. The bulk density of the fibers was very low. The problem of plugging of fibers in the feeder and in the cooker process was apparent as well. Additionally the fibers could be extremely densified by the screw conveyor and created a very compact fiber plug. As a consequence only small amounts of fibers could be fed to the refiner and very often the plug stopped the screw conveyor and subsequently the entire process. The produced fiber material contained a large fraction of very short fibers. The amount of fibers was sufficient to produce 2 MDF boards (cooking pressure 6 bar, 18% solid resin content).

6.3 Board properties

Unfortunately, the boards got lost on their way from Bangor to Hamburg, therefore the board properties are described on the basis of visual and manual investigations.
The color of the boards was very dark and the odor very intense, comparable with the odor of hot lignin. No resin spots could be detected even if the amount of the resin added to the fibers was comparable high. The board surfaces appeared to be rough in comparison to standard boards. The mechanical properties appeared manually and visually comparable to fiber boards produced from Spruce. Due to the high content of short fibers it seems likely that the mechanical properties range below the values for Spruce boards. These low values could be relatively easy improved by increasing the board density and the amount of resin. Regarding the properties under the influence of moisture, the thickness swelling after 24 hours will probably range below the values for Spruce boards because of a reduced water penetration into the board. The dimensional change upon a climatic change will also be reduced in comparison to the Nipa board due to the low content of mineral constituents but will range above the values of Spruce boards. The danger of molding in very humid climate is very low.

6.4 Conclusions

The investigations show that it is not possible to produce MDF boards from Coconut fibers with conventional techniques. The cutting of fibers could only marginally improve the process but fundamental problems (bridging, plugging) remain unsolved.
As a consequence of the very low bulk densities of the Coconut fibers and the creation of fiber bridges in the process the throughput was very low. The costs of investment in relation to the production capacity are significantly higher than for other resource materials.
For these reasons and for the technological problems the production of MDF boards from Coconut fibers is not advised.

The utilization of Coconut fibers in low density fiber boards should be investigated in additional tests. In order to make the processing possible, a binding agent needs to be added to the fibers and the fibers subsequently compressed to *non-woven mats*.

7 Comparison of particle- and MDF board properties made from Nipa and Spruce

Subsequently the properties of Nipa and Spruce MDF boards and Nipa particleboard will be compared. In Table 26 the properties of similarly produced boards are compared.

	MDF-Nipa	MDF Spruce	Particleboard Nipa
Thickness [mm]	18	18	20
Density [kg/m³]	760	730	645
Solid resin content [%]	14	14	CL 7 SL 12

Table 26: The characteristics of the compared particle- and MDF boards

7.1 Mechanical properties

Figure 11 displays graphically the mechanical properties of Nipa and Spruce MDF boards and Nipa particleboard. The required values for the EN standard are shown if exist.

The mechanical properties of Nipa MDF boards are always below the values for Spruce MDF boards. The bending properties (MOE, MOR) Nipa MDF boards meet the requirements for EN 622. The required EN values for the internal bond strength can be met with a suitable adjustment of the pressing program.

The values for Nipa particleboard already range close to the required values for furniture particleboard. One exception is the low internal bond strength value that is caused by the low amount of hardener used in the experiments.

In general it is assumed, that mechanical properties of boards made of Nipa range below the properties of boards made of softwood. Subsequently the Nipa boards require a higher density to achieve the same properties. Nipa boards for static purposes e.g. structural application in buildings can not or only with significant difficulties be produced.

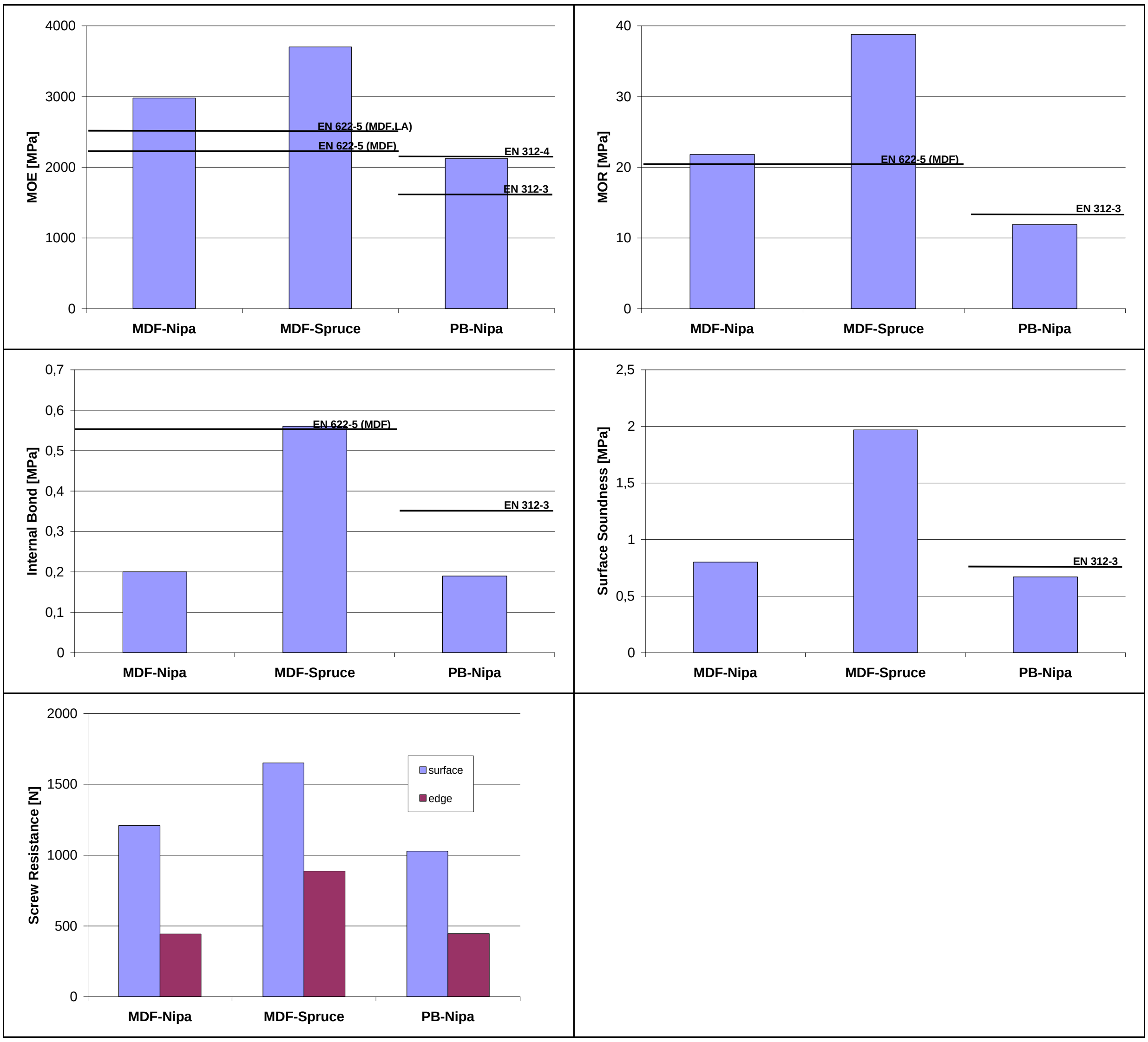

Figure 11: Comparison of particle- and MDF boards (mechanical properties)

7.2 Moisture resistance

Generally MDF and particleboard produced from Nipa show a clearly negative performance under the influence of moisture in comparison to Spruce MDF boards.

The thickness swelling (24 hours) of Nipa boards is significantly increased in comparison to Spruce boards. The required standard values are not or only with difficulties met from the Nipa board.

The chance in longitudinal dimension in the plane of the board upon a change in climate is much bigger for Nipa MDF boards in comparison to Spruce boards. The dimensional change of Nipa particleboard is slightly reduced in comparison to the MDF boards but still increased in comparison to Spruce MDF boards. A climatic change from 20°C/35r.h. to 20°C/85r.h. causes a dimensional change in longitudinal direction in Nipa boards between 0.42 and 0.58%, whereas in Spruce boards the longitudinal dimension only increase by 0.30%.

The change in thickness upon a climate change is slightly increased for Nipa particleboard in comparison to Nipa MDF boards which could be related to the increased thickness of the particles in relation to the MDF fibers. Upon a change in climate from 20°C/35r.h. to 20°C/85r.h the thickness of the Nipa boards changes by 25%, the thickness of Spruce boards only by about 8%.

The equilibrium moisture content of the Nipa boards is considerably higher in comparison to Spruce MDF boards. This result applies especially for high humidities. The equilibrium moisture content of u ≈ 33% in Nipa boards under very humid climatic conditions is almost double the equilibrium moisture content of Spruce boards (u ≈ 13%). As a consequence of the large amounts of water the dimensional changes are considerable and the danger of molding of the Nipa boards is high.

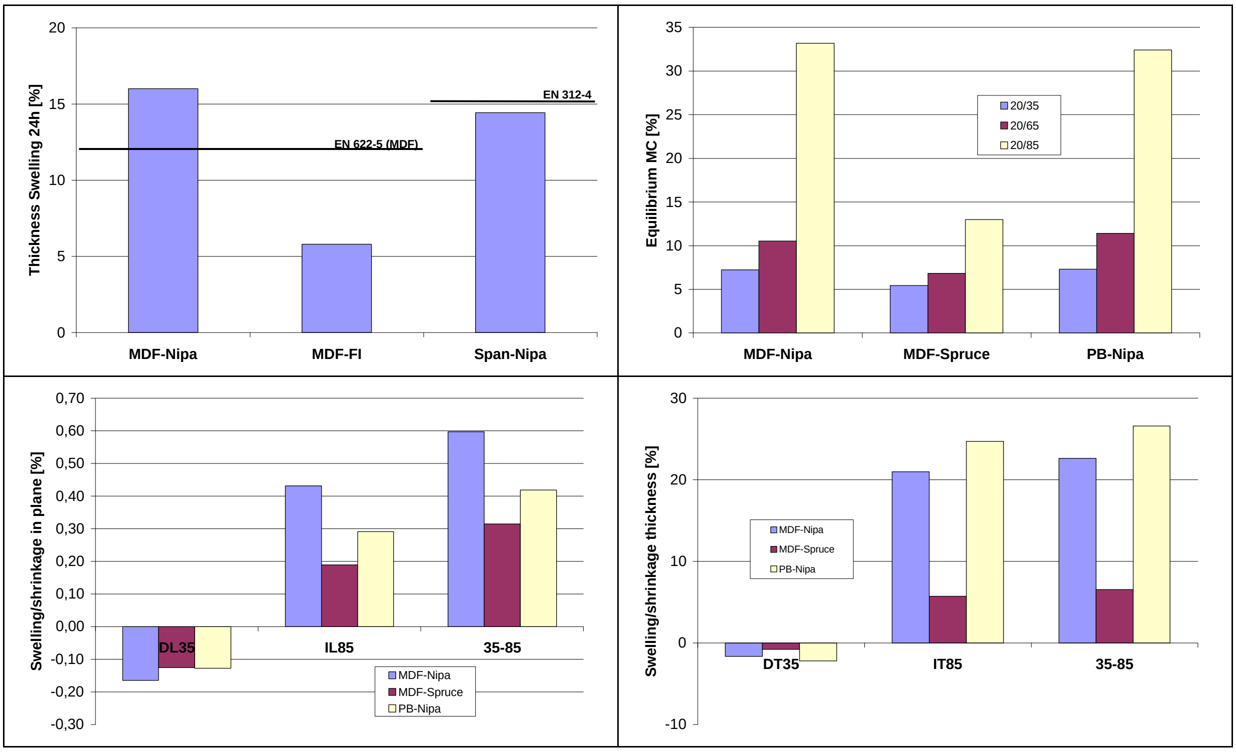

Figure 12: Comparison of particle- and MDF boards produced from Nipa and Spruce (moisture resistance)

The Nipa boards started molding after 2-4 weeks of storage in very humid climate (20/85). The reaction under the influence of moisture is of importance because the stored Spruce MDF boards did not show any mold under the same conditions.

The main reason for all these different aspects is the extremely high salt content (refer to chapter 2.4) of the Nipa panicles and subsequently the produced boards. The sodium content of Nipa boards is about 80 to 100 times higher than the content in Spruce MDF boards. After the calculation to NaCl the sodium content amounts to about 4 mass% in reference to oven-dry wood. These values are even very high for tropical trees (refer to Schmidt et al. 1999). As a consequence of the increased salt content the boards are highly hygroscopic and the resulting equilibrium moisture content of the boards is increased in comparison to MDF boards produced from Spruce. Due to the large amounts of bound water the changes in dimension are high and the growing conditions for fungi ideal.

Salt content (refer to chapter 1.4)

The fraction of Na^+-ions with about 3 mass % is the biggest constituent of all mineral components of the Nipa panicle. The extreme enrichment of these ions is probably a result of the growing conditions in brackish water with a high content of mineral components that are assimilated from the roots. Monocotyledons contain a large fraction of parenchyma cells that store mineral components to maintain a metabolism. For the same reason bigger amounts of other mineral components (K, Mg, etc.) can be found in Nipa panicles in comparison to tropical soft wood. The stem of *Swietenia macrophylla* for example contains only about one third of K, Mg and S-ions in comparison to Nipa panicles (Schmidt et al. 1999).

As a result of the production process the salt content of the Nipa MDF board is slightly reduced in comparison to the panicles and the Nipa fiber board. Parts of the salt (app. 25%) could be extracted in the pre-steaming and cooking process, squeezed out together with excess water in the screw conveyor or in the drying process. Consequently differences in equilibrium moisture content in different climates are the result (Figure 12).

The high salt content is of importance for the further processing of the fibers to MDF boards because the salt can dissolve and attack the components of the production process for example the inner sheath of the digester, the blow-line and the dryer. These components need to be made of resistant materials.

First tests showed that mineral content can be reduced by water storage of chips and particles. Further trials are requested for adaptation in industrial conditions.

8 Conclusions for the production and utilisation of particle- and MDF boards from Nipa and Coconut

8.1 Nipa

The high salt content is of special importance for the production of MDF boards because parts of the salt can be extracted and washed out. Therefore the components of the production process for example the inner sheath of the pre-heater, degister, blow-line and the dryer need to be build corrosion resistant.

The final utilization of the Nipa particle and MDF boards is restricted due to the high equilibrium moisture content and the resulting large changes in dimension upon climatic changes and the danger of molding. The high equilibrium content is probably a consequence of the high salt content of the Nipa panicles and subsequently the particle and MDF boards. If the salt content could be reduced the combined effects could be minimized of even inhibited. Some of the possibilities to reduce the salt content are displayed below:

1. Before further processing and drying, the panicles could be submerged for some time (hours/days) in a (warm) water basin.
2. During the washing of the chips parts of the salt is extracted. To improve the extraction of the salt the washing could be intensified and the washing temperatures increased.
3. The reduction of the salt content during the wet processing of the fiber boards needs further investigations.

To allow the utilization of Nipa products in areas with high humidity (e.g. tropics, kitchen, bathrooms) or for decorative purposes the molding of Nipa products needs to be inhibited during the production process. If the (complete) reduction of the salt content is impossible (see above) the addition of fungicides to the boards is necessary but these additives do not improve the dimensional stability of the boards upon climatic changes.

The dimensional changes also reduce the utilization of Nipa fiber and MDF boards even if the boards will be laminated later on. Thin and light foils are not suitable because of their tendency to crinkle and crack upon dimensional changes. The coating material should have good mechanical properties (elasticity, crack resistance). PVC foils are probably very suitable. The use of heavy papers (>200g/m²) or veneer could also be possible. The used resin is required to convey the occurring forces from the board. EPA and APAO are not suitable. PUR-resin could be an applicable choice (Brückner und Erb 1999).

During the construction of wood products the change of dimensions needs to be taken into account. For example, if the boards are used as backings for furniture the grooves and rabbets need to be cut accordingly. The easiest way to avoid problems is the choice of sectors of final utilization where changes of dimensions are not relevant.

If the boards will be painted later, the use of water-based paint is not advised. Accordingly the influence of the high salt content on other paint systems needs to be taken into account as well.

The mechanical properties of Nipa boards are in general significantly below the values known for Spruce MDF boards. The utilization of the boards in sectors with permanent static loads (construction sector) is not advised. The use in the furniture sector appears to be suitable. According to the mechanical properties the machining (sawing, cutting, laminating (veneer, laminate)) of the Nipa boards in general seems feasible but eventually with increased tool abrasion. To meet the required properties for coating and fastening, the board density needs to be increased to improve the mechanical board properties.

2 Scenarios can be derived from the conclusions.

Scenario 1: The salt content can not be reduced.

The utilization of Nipa products is restricted to areas where the humidity is below app. 70%. At the same time measures are necessary to compensate the significant changes in dimension. The utilization of the products for decorative purposes and in sectors with static loads is not possible.

Potential sectors of utilization:

- packaging (non food)
- palettes

Scenario 2: The salt content can be reduced.

In regards to humidity, the utilization of the Nipa fiber and MDF boards is not restricted. The dimensional changes are significantly reduced but still large in comparison to other materials. It is still necessary to take compensation measures. The utilization for decorative purposes seems possible. Due to the low mechanical properties the use in sectors with static loads is questionable. The production of MDF boards with conventional process methods is possible; maybe with a lighter construction (reduced steam pressure). In general the production of particleboard is possible as well. Further investigations concerning the particle preparation are necessary to improve the formation of the particle mats.

Potential sectors of utilization of Nipa particle- and MDF boards:

- packaging
- backings for furniture
- drawer bottoms
- panels

8.2 Coconut

Coconut fibers are not suitable for the production of MDF boards. Even a modified production process did not show satisfactory results. The production of particleboard from Coconut is possible only with significant efforts. The yield of useable fibers of app. 65% is too low. It is advised to use the Coconut fibers directly to produce *non-woven mats*. With *non-woven mats* shaped parts or insulation boards could be produced.

Coconut dust is neither suitable for the production of MDF nor particleboard. It is recommended to investigate the use of the dust fraction as filler for compressed plastics (polymers). The utilization as soil replacement for plants would be an innovative way as well.

9 Summary

The physical and chemical properties of Nipa panicles, Coconut fibers and Coconut dust from different growing sites in Vietnam were investigated at the department of wood technology at the University of Hamburg (OHt) and the department of wood physics and mechanical technology of wood (BFH). The fiber preparation process for the production of particle- and MDF boards was conducted at The BioComposites Centre, Pallmann company and Kahl company. The mechanical and technological properties of the boards were investigated at the OHt and the BFH.

Nipa panicles

Nipa panicles contain a large fraction of hard fiber bundles that results in an increased tool abrasion and high cutting and defibration forces. As a consequence of the SiO_2 content specific tool-bits (e.g. carbide-tipped) are necessary. The material yield is reduced due to the large fraction of parenchyma cells that develop very short fibers upon cutting/defibration. The pH values and buffer capacities range among values known for wood.

The preparation of Nipa panicles to particles and fibers is easy and without problems. Simple and conventional tools can be used without changes in configuration. The investment cost is low. Fibers can be produced in the refiner process with reduced steam pressure/energy demand.

During the production of particleboard the blending and the formation of the mat was problematic. The Nipa particles tent to interlock and to agglomerate. Before the formation of the mat these agglomerations needed to be disintegrated to yield a uniform board weight. The production of MDF boards did not reveal any problems but due to the high salt content the process components need to be planned and constructed corrosion resistant.

Particle- and MDF boards can be produced with acceptable pressing times. The mechanical properties of the boards are generally satisfying. To meet the requirements for furniture boards minor adjustments in the technological process (increase in board density, adjustment of the pressing program) are possible. The properties under the influence of moisture (thickness swelling 24h, dimensional changes) are not sufficient. The change in dimension upon a climatic change are major. All Nipa boards molded after 2-4 weeks of storage in very humid climate (20°C/85%r.h.).

The utilization as packaging material is already possible. If the molding can be inhibited the use in higher-grade products is possible as well. Due to the low mechanical properties the use for purposes with static loading (construction sector) is not feasible. In general the utilization in the furniture sector is possible. Under the premise of an inhibition of molding and a reduction of the dimensional changes, the laminating of the boards and the use for decorative purposes seem possible. For that purpose the salt content of the Nipa panicles needs to be reduced during processing.

Coconut

The ash and SiO_2 contents of Coconut fibers are not exceedingly high; the amounts contained in the Coconut dust are slightly increased due to contamination with dirt. The pH values and buffer capacities range among values known for wood.

Coconut fibers are not suitable for the production of MDF boards. Even a modified preparation process did not show satisfactory results. The production of particleboard from Coconut fibers is only possible with great efforts. The material yield of app. 65% is too low. It is recommended to use the Coconut fibers for *non-woven mats*. These mats can be used as shaped parts or insulation boards.

Coconut dust is neither suitable for the production of MDF boards nor for particleboard. It is recommended to investigate the utilization of the material as filler for compressed plastics (polymers). The former use as soil replacement substrate for plants etc. is also innovative.

10 Bibliography

Boehme, C.; Roffael, E.; Beyer, S.; Miertzsch, H.: Extraktstoffgehalte, Pufferkapazitäten und pH-Werte verschiedener Holzarten. In: WKI-Kurzbericht Nr. 7/89 (1989)

Brückner, P.; Erb, A.: Die Sieben-Prozent-Regel. MDF-Magazin (HK) Oktober 1999.

Choon, K.; Mansor, H.; Sudin, R.; Poh, K.; Shaari, K.: Proceedings of the National Seminar on Oil Palm Trunk & Other Palmwood Utilization. 4-5. March 1991, Kuala Lumpur. Oil Palm Tree Utilization Commitee of Malaysia.

Fink, D.: Final Report *Utilization of Coconut Palmwood from Vietnam for the Timber and Construction Industry*, December 1999, GTZ PN 98.4203.0-244.81.

Fink, D.: Final Report *Utilization of Nipapalm leaves and Coconutfibres for Production of Panles in Vietnam*, December 1999, GTZ PN 98.4203.0-244.80.

Hassan, K.; Hassan, A. H.; Ramli, R.; Jusoh M. Z.: Improvement of the brightness of unbleached chemithermomechanical pulps from oil palm frond. In: Coon et al. 1991, S. 219-230.

Jalil, A. A.; Kasim, J.; Ramli, R.: Fibre properties and chemical constitutions of oil palm fronds at different ages. In: Coon et al. 1991, S. 12-18.

Kastler, J.: Aufkommen und Bereitstellung von Kokosfasern und Nipa Palm Stalks in Vietnam für eine industrielle Vewertung. Diplomarbeit Universität Hamburg, 1999, 135 S..

Schmidt, P.; Lieberei, R.; Bauch, J.; Gasparotto, L.: Biomass production and mineral element content of *Swietenia macrophylla* King in the juvenile phase under plantation conditions in Central Amazonia. In: Mitteilungen der Bundesforschungsanstalt für Forst- und Holzwirtschaft Nr. 193 (1999), Hamburg.

Schwab, E.; Steffen, A.; Korte, C.: Feuchtebedingte Längenänderung von Holzwerkstoffen in Plattenebene. Holz als Roh- und Werkstoff 55 (1997) S. 227-233.

11 Annex

List of figures

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