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Composite Materials Symposium

Panels from Annual Plant Fibers Bonded with Urea-Formaldehyde Resins

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Abstract

Panel manufacture is traditionally based on raw materials derived from forest wood. The rate of global deforestation and its impact on the environment has led manufacturers to search for alternative feedstock, especially in countries where timber is less available compared to other cellulosic natural products. A recent European research project studied the effective use of agricultural residues and annual plant fibers as an alternative to wood for producing composites such as particleboard and fiberboard. In the process, a novel technique was developed that comprises the chemithermomechanical treatment of such materials in conventional devices and at moderate operating conditions. By applying this technique, fibers are obtained for producing 100 percent straw fiberboard and particleboard. In addition, furnish may be blended with wood to produce panels bonded with all commercially available binders. The raw materials used are agriwaste or plant fibers, which are annually renewable and available in abundant volumes worldwide. Employing the new technology will result in better utilization of waste products, reduced environmental impact, and ease the wood deficit confronting the panel industry. The 2-year project did not provide sufficient data for a complete financial analysis; however, certain observations indicate potential commercial value. Manufacturing costs of medium density fiberboard were estimated at 10 to 20 percent less than conventional production processes. Start-up capital is assumed at only 5 to 10 percent of an original capital investment. The opportunity thus exists to enter a lucrative market with a very low investment and provide existing plants the flexibility to open new markets by producing new products.

Introduction

The United Nations Conference on Environment and Development, the Earth Summit, held in Rio de

Janeiro in 1992 focused on biodiversity, global warming, and sustainable development. However, world leaders did not agree on effective actions to slow the rate of global deforestation. In fact, the deforestation and global trade in forest products have been allowed to escalate virtually uncontrolled, driven by excessive consumption and the operation of hugely powerful transnational companies.

It is widely believed that the current rate of deforestation and forest degradation has widespread, damaging, and potentially irreversible repercussions. The impact on global biodiversity has reached staggering proportions. Approximately 27,000 species are estimated to become extinct in the earth's tropical forests each year.

Also widely acknowledged is that forest loss is exacerbating the worldwide problem of global warming. The diminishing earth's natural forests and expansion of the trade in forest products is unsustainable. The forests provide habitat to half of the earth's species, regulate climate, and protect soils and water systems. A mature forest ecosystem evolves over many hundreds of years. It is a complex system of interacting plants, animals, and fungi, which cannot be easily replicated if lost.

The paper and wood-based panel industries make use of forest wood as raw material for their products. The use of other renewable resources such as annual plant fibers and agricultural residues to augment wood in the production of composite panels (particleboard, fiberboard) and paper products is now considered attractive for economical and environmental reasons. This supplement could help to reduce the rate of deforestation and provide manufacturers with the ability to produce boards even if wood becomes scarce.

The European Project

In this framework, the European research project entitled "Advanced Environmentally Friendly Composite Materials for the Furniture and Construction Industries" (EC Project CR-1638-91, Contract BRE2-CT94-1535) was implemented. The main objective of this project was the use of plant residues and annual plant fibers (e.g., wheat straw, rice straw, rice husks, flax, bagasse) as an alternative to wood in the production of composite panels, particleboard, and fiberboard, in combination with urea-formaldehyde resins.

This project was the result of a group of industrial companies who have jointly recognized the challenge posed by replacing wood with agricultural fibers and identified a solution. The CRAFT Action of the Brite-Euram Program has provided these companies with financial support, assigning research organizations to conduct work on their behalf. The primary step for the accomplishment of the project objectives was the collaboration of those who proposed it with research and technological professionals.

The group of industrial companies includes:

- Marlit Ltd., Project Coordinator, involved in the production of chemicals for the wood-based panels industry, established in Thessaloniki, Greece;
- Sapemus Chemie GmbH, a company affiliated with Marlit working in the same field, established in Springe, Germany;
- Bresfor LDA, a Portuguese chemical company producing formaldehyde-based resins;
- Bison-Werke GmbH & Co. KG, established in Germany, among the world leaders in design and construction of equipment for the wood-based panels industry;
- Compak Systems, established in Great Britain, is an equipment manufacturer with particular expertise in the production of low-cost small plants using annual plant fiber as a raw material;
- Valentin & Söhne KG, a wood-based panels producer in Germany; and
- Placolin N.V., a Belgian manufacturer of wood-based panels using flax waste as a raw material.

The group of research and technological development performers includes:

- University of Wales, BioComposites Centre, Great Britain. The Centre has much experience working with wood-based composite materials, chemical modification of plant materials, and urea-formaldehyde resin chemistry;
- École Nationale Supérieure de Chimie de Toulouse, Laboratoire de Chimie Agro-Industrielle, France. The Laboratory works on adding value to plant materials as industrial feedstock; and
- University of Göttingen, Institut für Forstbenutzung, Germany. The Institute is one of Germany's three main university centers for research on wood-based materials.

The project spanned 2 years beginning in January 1995 and ending in January 1997. The outcome was an innovative technique for the production of strong composites from renewable resources. Although the objective of the development of this new technique was the use of urea-formaldehyde resins in the production of boards from agriwaste, the technique is applicable to all types of resins that are commonly used in the field.

Although this paper is presented by only three co-authors on the very positive outcome achieved, the work is the result of the collaborative effort of all project participants. Also notable is that the partners involved came from six different European Union (EU) member states speaking six different languages, but all fluent in English. This experience was very fruitful in all possible ways. The different cultures and backgrounds made the collaboration even more interesting and enjoyable, highlighted by an acute sense of humor.

Fibrous Agricultural By-Products

There are large unused quantities of a variety of annually renewable agricultural fibers worldwide (Table 1). The extent of concentration of availability of each fiber type depends on the region and country, while climate and weather variables also affect yield and quality.

Agriwaste fibers are by definition grown for the crop and not for the fiber. Therefore, current trends in harvesting, such as the use of dwarfing chemicals to limit straw heights, run contrary to the requirements of those requiring straw for board making, paper pulp, and power generation applications. A compromise or development of other strains may be necessary to resolve this, unless crops are specifically grown for industrial purposes, which may need some revision of government rulings.

The majority of fiber crops is seasonal and in some regions typically harvested annually over a 100-day period. However, sugarcane is harvested twice annually in India and rice is harvested three times in 2 years in the Philippines. For efficient panel production, the storage of adequate quantities of raw material should be considered. Moreover, climatic conditions, protection from moisture, and control of fungal infestation has to be taken into account when storing the product.

The low bulk density of agricultural residues imposes limits on both the economic radius of their collection and the size of fibers processed, which is associated to the board production operation. In industry, a radius of straw collection of approximately 50 km is considered practical. However, this measurement is not a rule. Studies have shown that it corresponds to a plant capacity of 25,000 to 35,000 tons per year.

The average market price of agricultural fibers in the EU during the period 1990 to 1995 is given in Table 2. Concerning price and availability, one has to select cereal straw with a price of US$54.80 per ton, which is very competitive compared to wood prices (e.g., US$203.90 per ton for poplar and US$124.60 per ton for eucalyptus wood).

Table 1.—Worldwide availability of agricultural fiber residues in year 1994.

Country	Wheat	Rice	Barley	Oat	Rapeseed	Bagasse
	(million tons)					
Africa	32	30				7
North and South America	153					
United States		12		4		7
Canada			14	5	7	
Brazil		14				69
Asia	282					
China and Japan		42				
Philippines		13				7
India					6	58
Europe	192		74	13		
France and United Kingdom					3	
Russia	46		32	14		
Australia	11		3			8

Source: FAO Production Yearbook.

Dumping agricultural waste in landfills or burning crop residues have been considered unacceptable for environmental protection reasons. Forthcoming legislation is headed toward prohibition of disposal methods. For example, Germany has enacted a law that forbids the dumping of materials containing more than 5 percent organic compounds by the year 2005 (TA - Siedlungsabfall). It is therefore evident that new applications need to be found for agricultural fibers.

Straw versus Wood as Raw Material for Panel Manufacturing

Wood is the major raw material used in the composite board industry, which is due to its availability in most countries that produce panels. Wood, especially softwood, is homogeneous in morphological structure and easy to bond with common adhesives such as acid-curing urea-formaldehyde resins, alkaline-curing phenol-formaldehyde resins, and binders based on polyisocyanates (PMDI).

Some annual plant fibers (e.g., bagasse, cotton stalks, hemp) were used in the past and continue to be used, especially in countries like China and Egypt, to effectively produce boards by applying inexpensive adhesives such as urea-formaldehyde resins. Conventional urea-formaldehyde resins, however, are not able to bond cereal fibers (e.g., wheat straw). The only adhesives currently being used are isocyanates.

Straw from annual plants like wheat and rice is less homogeneous than softwood and even hardwood in the morphological structure. It is differentiated into stems and leaves and the stem is divided into internodes. The leaves are differentiated into two parts, the sheaths and blades. The sheath is inserted in the node, encircling the stem.

Table 2.—Average market price of fibers in the EU in the period 1990 to 1995.

Material	Market price
	(US$/ton)
Cereal straw	54.8
Rapeseed straw	54.8
Flax	203.9 to 273.8
Whole stalk hemp	81.5
Linseed straw	95.5
Eucalyptus	124.6
Poplar	203.9

Source: Meeusen-van Onna and Boers 1996.

Morphologically, straw is much more complicated than wood. Straw contains a relatively large number of cell elements. It includes the actual fibers, the parenchyma cells, vessel elements, and epidermic cells, which contain a high amount of ash and silica. In a cross-section of straw, the epidermic cells are the outermost surface cells, covered by a very thin waxy layer. This surface layer deteriorates the moisture absorbency of straw from water-based resins like urea-formaldehyde. Since it is soluble in an alkaline medium, it also acts as a barrier to the gluing of straw with acid-cured urea-formaldehyde resins. The different cell types in a cross-section of wheat straw are shown in Figure 1. However, this is not the case for flax, which has a more open morphological structure than wheat straw, and thus is more accessible to bonding.

Though lignocellulosic in nature, straw has a completely different chemical composition than wood. Wheat straw possesses higher hemicellulose, ash, and silica contents but lower lignin content compared to wood (Table 3). The wax content of straw is higher than that of wood; and the percentage of wax in rice straw is even more so, which corresponds to the ash and silica contents. The chemical composition of straw, especially the high ash content, has a negative impact on the use of straw as a starting material for making boards.

Many developing countries, however, do not have adequate wood reserves to cover their needs for wood-based composite materials. On the other hand, many of these countries do have relatively large quan-

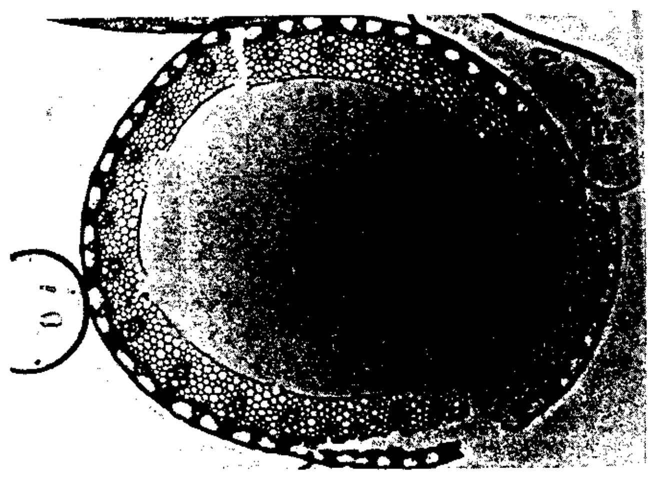

Figure 1.—Cross-section of wheat straw stem. (Source: Institut für Forstbenutzung).

Table 3.—Main components of wheat and rice straw compared to spruce wood.

Material	Wax	Hemicellulose	Cellulose	Lignin	Ash	Silica
	(%)					
Wheat straw	1.65	34.03	38.09	14.13	6.38	3.19
Rice straw	3.72	35.50	39.63	13.92	12.51	9.68
Spruce wood	1.47	23.40	54.09	30.15	0.24	- -

Source: BioComposites Centre and Institut für Forstbenutzung data.

Figure 2.—Disintegrated straw particles. (Source: Institut für Forstbenutzung).

Figure 3.—Untreated wheat straw. (Source: Institut für Forstbenutzung).

tities of lignocellulosic materials available in the form of agricultural residues which can be used as a raw material for composite boards.

Therefore, the main objective of this work was to find a practical method for improving the bonding ability of straw toward adhesives, particularly toward acid-curing aminoplastic resins. These resins are used worldwide as a binder for particleboard, medium density fiberboard (MDF), and moulded products.

Treatment of Straw Fibers

Preliminary studies showed evidence that the bondability of straw can be improved if its morphological structure is opened and thus made more accessible to wetting with water-based adhesives. Based on these results, a simple but novel method has been developed. It comprises the defibration of straw in an attrition mill by combining thermal treatment by hot water at a temperature range between 40°C and 100°C with both mechanical treatment imposed by high shear forces and treatment by addition of appropriate chemicals. It is therefore a chemithermomechanical treatment. After this treatment, the morphological structure of straw is opened and its affinity toward bonding increases tremendously (Fig. 2).

Defibration in this sense means disruption of the morphological structure of straw, leading to the creation of individual fibers (Figs. 3 to 6). In the original structure of straw, the waxy and silica layer encircling the cells inhibit sufficient direct contact between the binder and the straw fibers. The combined chemithermomechanical treatment disrupts the original straw structure leading to higher accessibility of individual fibers to the binder, which is a resourceful technique for use in board production. What is more extraordinary is that some chemicals added during the process can be the glue mixture itself, which is sprayed on the particles/fibers for panel manufacture. This situation allows the straw fibers and adhesive to mix, reducing the number of processing steps. Thus, thermal, mechanical, and chemical processing usually carried out as separate stages in traditional panel manufacturing are combined in one step.

This technology based on the "grinder-defibrator-mixing device" allows:

- the continuous processing of straw with a controlled residence time;
- the shearing/defibration of straw to obtain a controlled granulometric distribution (Fig. 7); and
- the injection of water and reagents in one or several points of the machine.

After the chemithermomechanical treatment and defibration, the straw fibers can be dried using conventional dryers used in board production plants (e.g., a drum dryer or a flash dryer used in MDF mills). From then on, the dried fibers follow the conventional procedure for the production of particleboard, MDF, or high-density fiberboard (Fig. 8).

The bulk density of treated fibers was higher than expected: 70 to 99 kg/m^3 for wheat straw, 81 kg/m^3 for rice straw, and 148 kg/m^3 for flax. In comparison, standard chopped wheat straw had a bulk density of 56 kg/m^3 (Compak Systems data).

Important process parameters are comprised of the following:

- device configuration;
- number of injection points;
- type of reactants for fiber treatment;
- treatment conditions (temperature, concentration of reactants, flow rates);

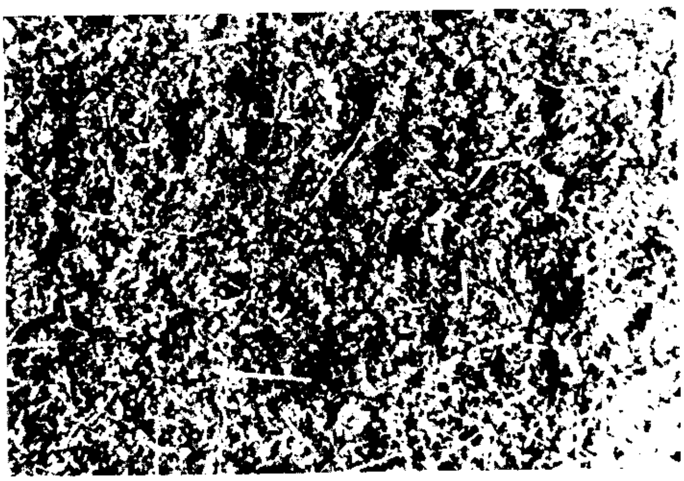

Figure 4.—Treated wheat straw. (Source: Institut für Forstbenutzung).

Figure 5.—Untreated rice straw. (Source: Institut für Forstbenutzung).

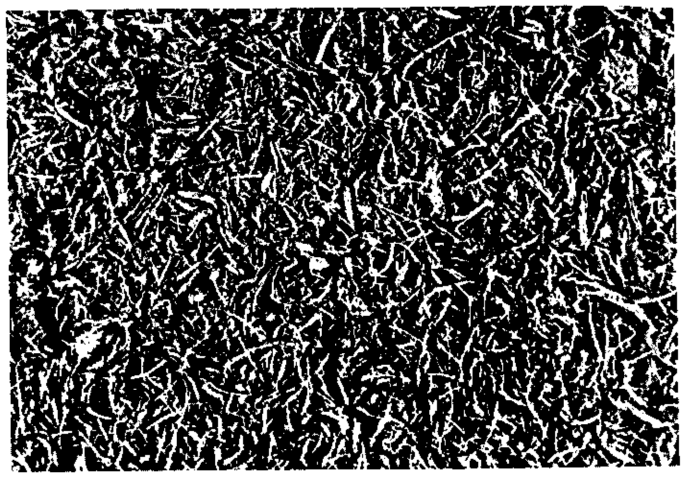

Figure 6.—Treated rice straw. (Source: Laboratoire de Chimie Agro-Industrielle).

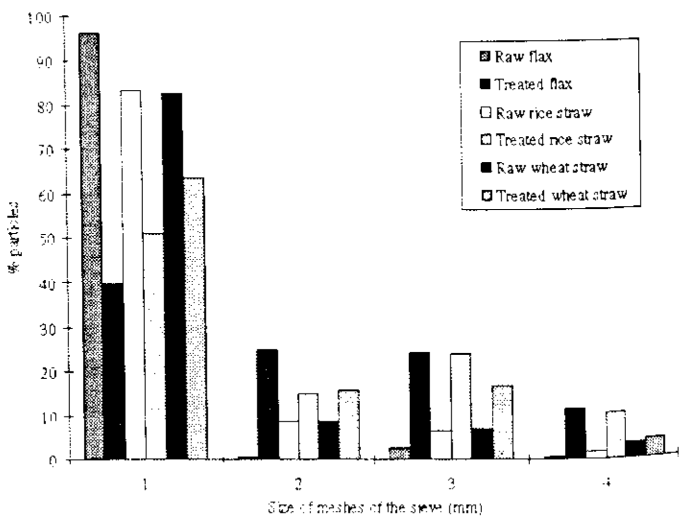

Figure 7.—Granulometric distribution of various treated and untreated annual plant fibers. (Source: Laboratoire de Chimie Agro-Industrielle).

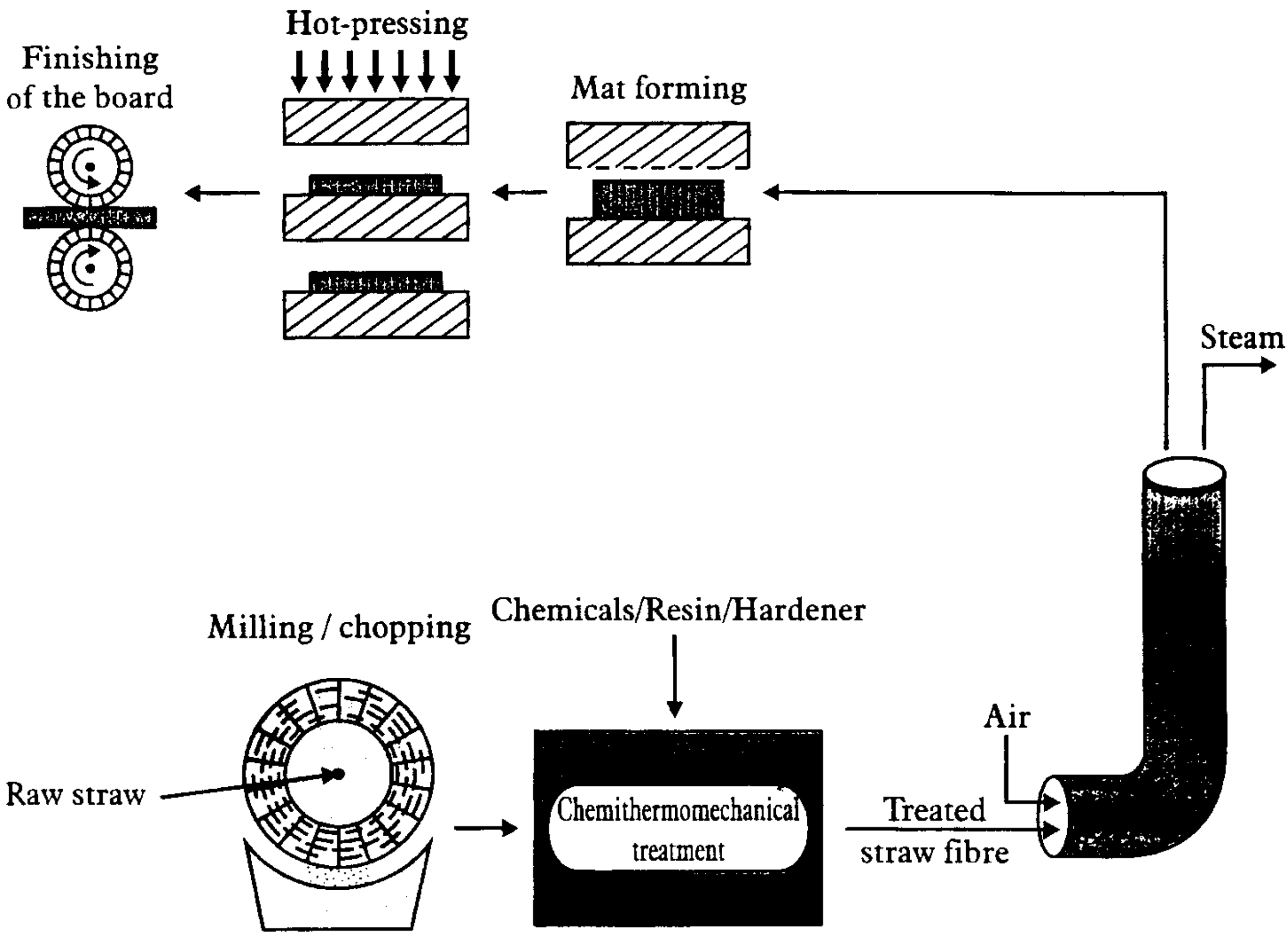

Figure 8.—Schematic diagram of the board production procedure incorporating the novel process.

- type of reactants needed for subsequent board production (resin, hardener etc.); and
- requisite mechanical energy for the treatment.

The optimization of operating parameters has revealed that the process is very flexible:

1. With a mild treatment and subsequent low mechanical energy consumption (100 to 150 kWh/ton of treated straw or 360 to 540 J/ton of treated straw), the treated material is more like particles, with a minimum of fine ones (Fig. 9). Then the machine works as a grinder, mixer, and reactor, modifying the particles' surface and soaking the reagents.
2. With hard shearing conditions, the mechanical energy consumption is more important (250 to 350 kWh/ton of treated straw or 900 to 1,260 J/ton of treated straw) and the treated material is like fibers, with a higher proportion of fine particles (Fig. 10). The machine then works more like a

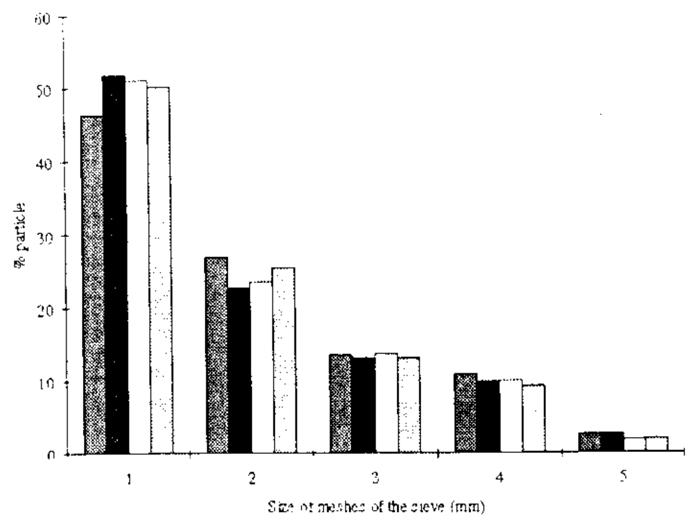

Figure 9.—Granulometric distribution of treated straw with mild conditions and various reagents. (Source: Laboratoire de Chimie Agro-Industrielle).

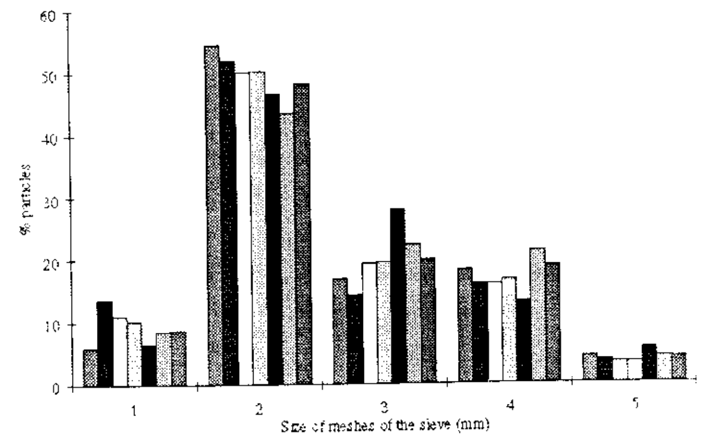

Figure 10.—Granulometric distribution of treated straw with hard conditions and various reagents. (Source: Laboratoire de Chimie Agro-Industrielle).

pulping device, but with a high ratio of dry matter and no effluents (Figs. 11 to 15).

In spite of energy consumption appearing to be quite high in this case, the overall energy consumption of the process is actually not because of the reduced heat input requirements of this unique system.

This very versatile process has been applied to the treatment of various agricultural or annual plant fibers like wheat straw, rice straw, and flax, and can be further adapted and optimized for use with a series of others like bagasse, jute, barley, oat, coconut husks, and cotton stalks.

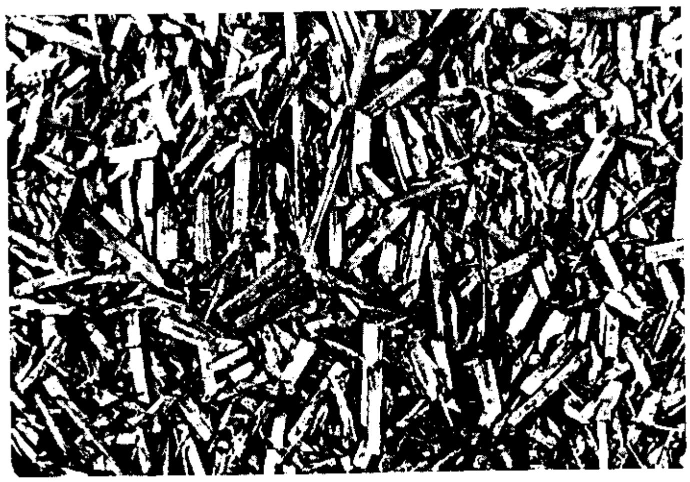

Figure 11.—Wheat straw treated under mild conditions. (Source: Laboratoire de Chimie Agro-Industrielle).

Figure 13.—Flax straw untreated. (Source: Laboratoire de Chimie Agro-Industrielle).

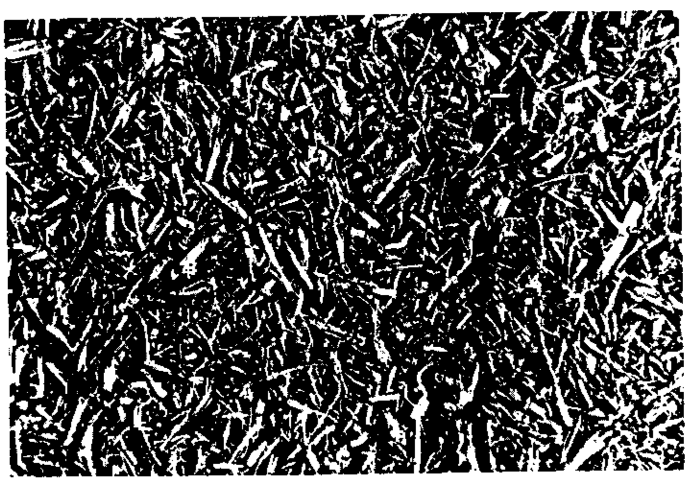

Figure 12.—Wheat straw treated under hard conditions. (Source: Laboratoire de Chimie Agro-Industrielle).

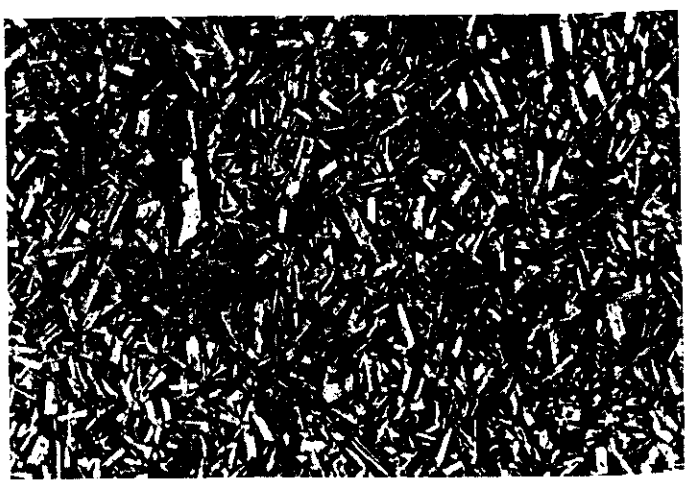

Figure 14.—Flax straw treated under mild conditions. (Source: Laboratoire de Chimie Agro-Industrielle).

Board Production from Treated Straw Fibers

By using this new straw treatment, it was possible to produce fine quality boards from 100 percent treated fibers of annual plants or agricultural waste. Moreover, boards were also produced using a mixture of wood chips and treated straw fibers or other similar products.

Board Production Using 100 Percent Treated Straw

Laboratory-scale board trials were performed using treated straw fibers with all commercially available resins. Boards were produced with urea-formaldehyde, melamine urea-formaldehyde, phenol-formaldehyde, tannin formaldehyde, and isocyanate binders. The boards obtained had significantly improved properties compared to boards produced with untreated straw. The analysis showed that not only had the internal bond (IB) strength of the boards greatly increased, due to the treatment of the straw, but also the thickness swelling of the boards was significantly upgraded (Figs. 16 to 25). The formaldehyde emission (HCHO) of the boards was at low levels (i.e., E1 grade without the use of formaldehyde scavengers).

It was hence concluded that the straw treatment increased the bondability of straw fibers toward bonding with both conventional and nonconventional binders. When trials were performed using rice and flax residues as starting materials, the application of the novel process in a variety of agricultural fibers was proven (Tables 4 and 5).

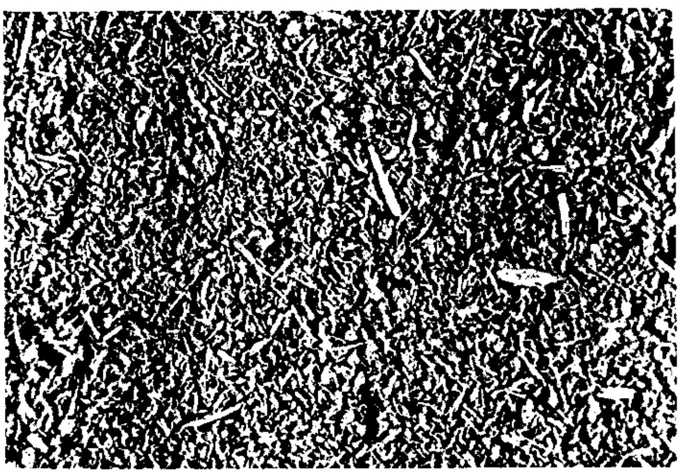

Figure 15.—Flax straw treated under hard conditions. (Source: Laboratoire de Chimie Agro-Industrielle).

The effect of chemical addition during the processing of the straw was also investigated by producing boards from straw treated with various chemicals (Table 6). It was then possible to identify the best conditions for chemical treatment. In combination, the effect of various operating conditions was tested. The aim was to provide feedback on the optimization of the straw treatment as well as to identify optimum board production parameters (press temperature, press time, resin molar ratio, hardener level, etc.), so that straw boards with acceptable properties were obtained.

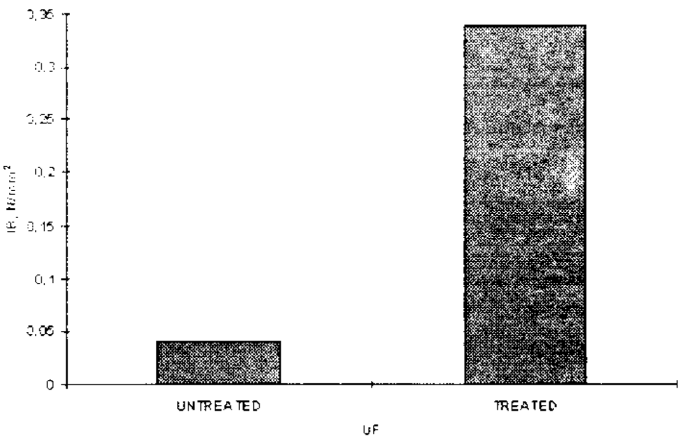

Figure 16.—Internal bond strength of the boards produced from untreated and treated wheat straw and urea-formaldehyde resin. (Source: Marlit Ltd. data).

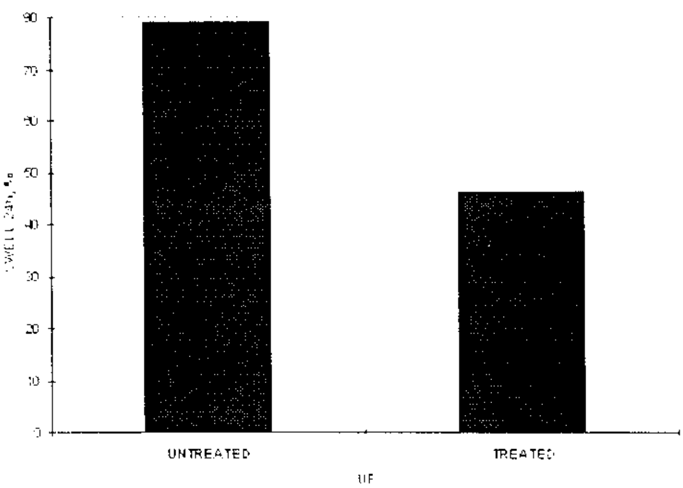

Figure 17.—Thickness swelling after immersion in water of the boards produced from untreated and treated wheat straw and urea-formaldehyde resin. (Source: Marlit Ltd. data).

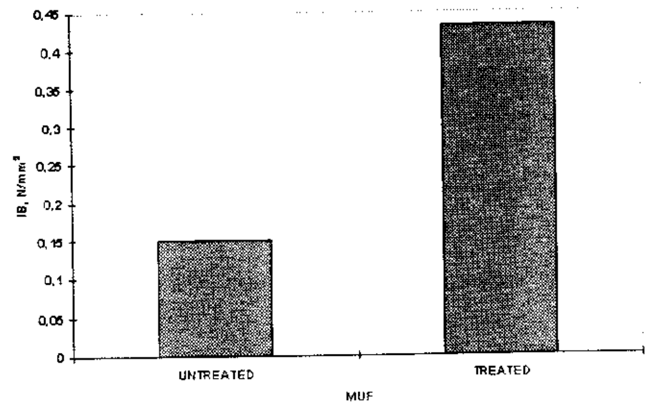

Figure 18.—Internal bond strength of the boards produced from untreated and treated wheat straw and melamine urea-formaldehyde resin. (Source: Marlit Ltd. data).

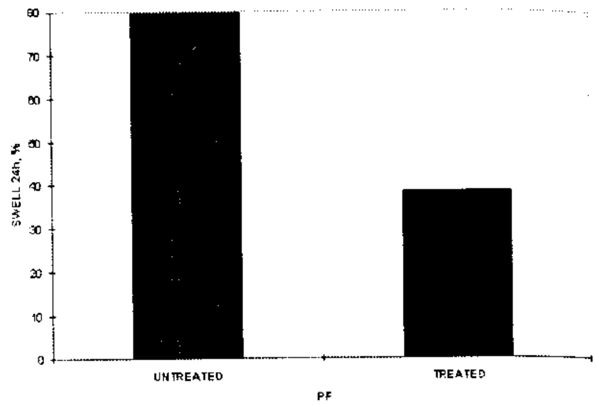

Figure 21.—Thickness swelling after immersion in water of the boards produced from untreated and treated wheat straw and phenol-formaldehyde resin. (Source: Institut für Forstbenutzung data).

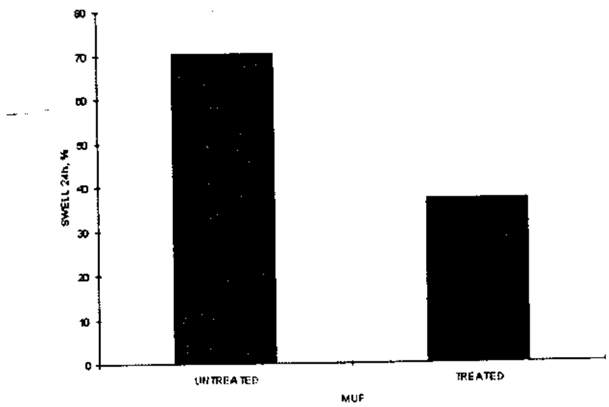

Figure 19.—Thickness swelling after immersion in water of the boards produced from untreated and treated wheat straw and melamine urea-formaldehyde resin. (Source: Marlit Ltd. data).

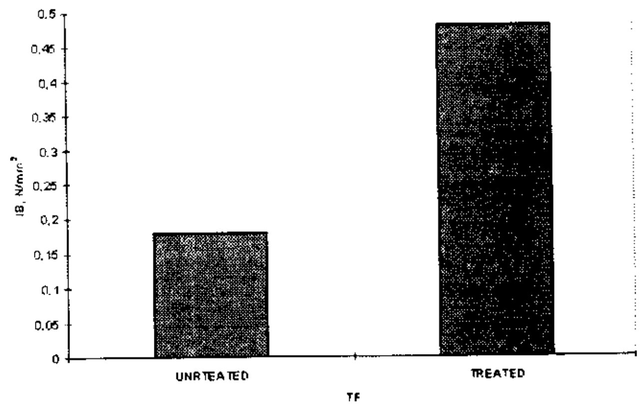

Figure 22.—Internal bond strength of the boards produced from untreated and treated wheat straw and tannin formaldehyde resin. (Source: Institut für Forstbenutzung data).

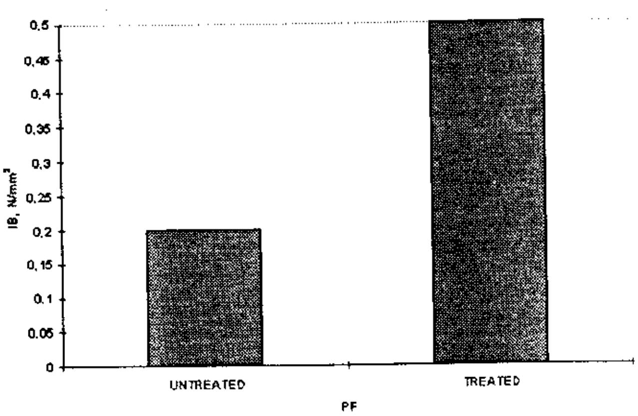

Figure 20.—Internal bond strength of the boards produced from untreated and treated wheat straw and phenol-formaldehyde resin. (Source: Institut für Forstbenutzung data).

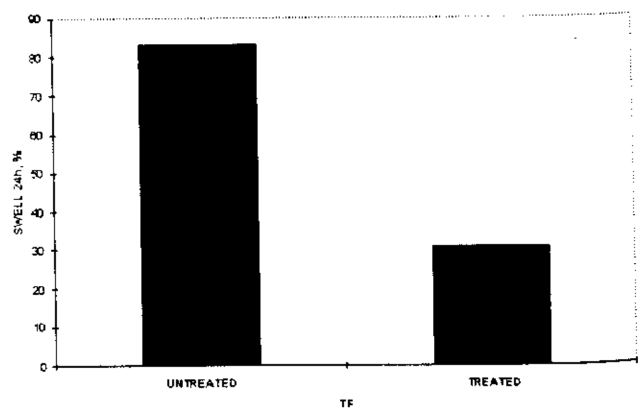

Figure 23.—Thickness swelling after immersion in water of the boards produced from untreated and treated wheat straw and tannin formaldehyde resin. (Source: Institut für Forstbenutzung data).

Further trials using either mild or hard shearing conditions for the straw treatment revealed that the treated fibers produced very different boards from the standard chopped straw. In the case of hard treatment, the board appearance, surface smoothness, and core density profile were far superior, approaching the quality of MDF. Increased mat stability and reduction of off-cuts was also of benefit. High-density boards were produced without the need to use excessive board forming pressure (Table 7). In the case of mild treatment, however, board surface finish was closer to particleboard rather than MDF, because the treated straw was less fibrous.

From all of these results, it can be concluded that this novel straw treatment enables the production of strong urea-formaldehyde-bonded strawboards.

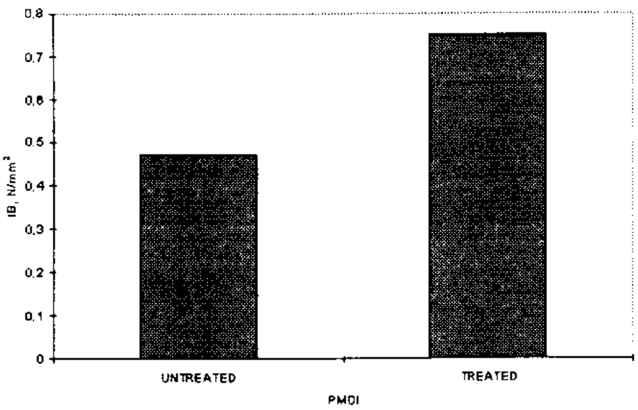

Figure 24.—Internal bond strength of the boards produced from untreated and treated wheat straw and PMDI binder. (Source: Compak Systems data).

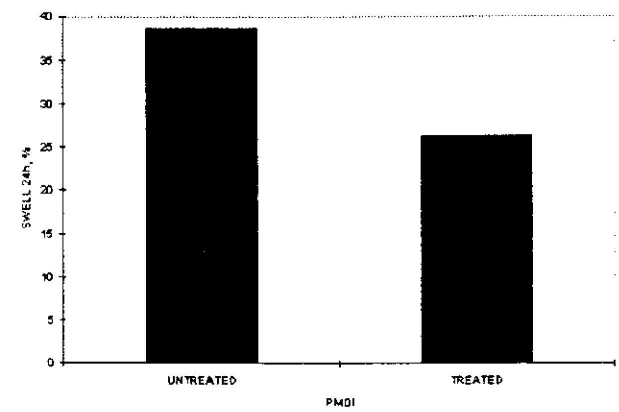

Figure 25.—Thickness swelling after immersion in water of the boards produced from untreated and treated wheat straw and PMDI binder. (Source: Compak Systems data).

Table 4.—Production of 6-mm boards from treated wheat, rice, and flax fibers and PMDI resin.

Property	Wheat	Rice	Flax
IB (N/mm^2)	0.83	0.52	1.19
Modulus of rupture (N/mm^2)	18.7	6.0	11.3
Modulus of elasticity (N/mm^2)	2,676	923	1,906
Density (kg/m^3)	700	700	700

Source: Compak Systems data.

Table 5.—Production of 16-mm boards from treated wheat and rice fibers and urea-formaldehyde resin.

Property	Wheat	Rice
IB (N/mm^2)	0.28	0.34
HCHO (mg/100 g)	8.4	11.9
Swell, 24-hr. (%)	40.8	33.7
Density (kg/m^3)	685	699

Source: Marlit Ltd. data.

Table 6.—Production of 16-mm boards using wheat straw treated with various chemicals and urea-formaldehyde resin.

Property	Chemical 1	Chemical 2	Chemical 3
IB (N/mm^2)	0.30	0.38	0.45
HCHO (mg/100 g)	5.3	7.1	6.4
Swell, 24-hr. (%)	40.5	38.9	31.5
Density (kg/m^3)	686	684	683

Source: Marlit Ltd. data.

Table 7.—Production of 6-mm boards with varied density from treated wheat straw and urea-formaldehyde resin.

Density	IB	Modulus of rupture	Modulus of elasticity
(kg/m^3)	(N/mm^2)		
600	0.35	8.6	1,397
700	0.50	13.1	1,974
800	0.65	17.7	2,551

Source: Compak Systems data.

Moreover, the straw morphological structure is destroyed and the fibers obtained show totally different chemical characteristics and bonding behavior compared to the original material. Hence, such a treatment is a new method for the production of MDF-like products, but also for particleboard.

Board Production Using Mixtures of Straw with Wood

This new approach allows the production of four categories of products:

1. 100 percent straw MDF.
2. 100 percent straw particleboard.
3. Partial replacement of wood fibers or particles wherever wood is not available in sufficient quantities or to decrease the cost of raw material.
4. Incorporation of straw fibers into conventional particleboard to improve its density profile and the machineability of the product.

The potential benefit of partially substituting wood chips with treated straw to obtain particleboard was also investigated both at pilot plant and at industrial scale. At a pilot scale, different kinds of wood chips and both treated and untreated straw were used. Results indicated that up to 20 percent substitution of wood chips with treated wheat straw has no harmful effect on board properties.

Pilot scale production of treated wheat straw enabled the industrial implementation of the process at the Valentin particleboard plant in Germany. Particleboard was produced by substituting wood chips with a quantity of straw fibers. Two resin types were used for the board production: a melamine urea-formaldehyde resin and straight urea-formaldehyde resin. The wood substitution levels employed for each type of glue were:

- melamine urea-formaldehyde: 10 and 20 percent; and
- urea-formaldehyde: 10 and 15 percent.

The assessment of board properties indicated that particleboard can be effectively produced by substituting part of the wood chips with extruded straw fibers (Table 8). The advantage is an improvement of board general appearance and of the corresponding board properties, as well as of board machineability.

Advantages

The advantages of this chemithermomechanical technique are:

- low-pressure equipment is needed;
- low temperature 40° to 100°C;
- conventional chemicals are added;
- no effluents;
- continuous processing of straw material;
- shearing/defibrating and simultaneous blending of the fibers with the binder; and
- controlled fiber granulometric distribution according to the needs of the product.

The generic system can be applied to all types of agriwaste and annual plant fibers using all types of commercially available resins. Even when formaldehyde-based resins are used, free formaldehyde emission is controlled to meet the most stringent regulations. The system can process simultaneously wood and straw and is applicable to four main categories of products:

- 100 percent straw fiberboard;
- 100 percent straw particleboard;
- partial replacement of wood fibers or particles wherever wood is not available in sufficient quantities or to decrease the cost of raw material; and
- addition of straw fibers to conventional particleboard to improve the density profile of particleboard and machineability of the product.

This chemithermomechanical equipment may be introduced to existing particleboard plants with a comparatively low investment, allowing such plants

Table 8.—Industrial production of 18-mm boards from treated straw and wood chips.

Resin	Wood substitution	Density	IB	MOR	24-hr. swell
	(%)	(kg/m^3)	------ (N/mm^2) ------		(%)
Melamine urea-formaldehyde	0	666	0.67	19.3	2.5
Melamine urea-formaldehyde	10	657	0.69	17.0	2.8
Melamine urea-formaldehyde	20	642	0.60	16.7	3.6
Urea-formaldehyde	0	633	0.49	14.1	5.1
Urea-formaldehyde	10	633	0.47	15.3	5.1
Urea-formaldehyde	15	622	0.46	14.1	5.6

to produce apart from standard particleboard production, all other categories mentioned above, including:

- either combined wood/straw board;
- 100 percent straw MDF-like board; and
- 100 percent straw particleboard.

Financial Aspects

It was not possible within the 2-year project to collect enough data to provide a financial analysis. However, a very rough estimation was carried out based on certain assumptions to provide the following information:

1. Straw MDF via the new method described in this project costs less to produce than conventional wood MDF by approximately 10 to 20 percent for a plant of approximately 300 m^3/day capacity. The smaller plants favor this method, while the larger plants favor the conventional method. The cost of wood was assumed to be $US28/ton at 50 percent moisture content, while the cost of straw was assumed to be $US24/ton at 85 percent moisture content. This price difference will become more significant as wood becomes less available.
2. Investment is approximately 5 to 10 percent less.

The main financial advantage is assumed however, for a particleboard plant to invest approximately 5 to 10 percent of a capital investment to produce straw fibers for either wood/straw boards or straw MDF boards.

The 5 to 10 percent of the original investment is calculated on the basis of a particleboard plant producing 100,000 m^3/year and the addition of extra equipment to produce straw fibers at approximately 25,000 m^3/year.

This possibility offers an opportunity to enter a lucrative market with only a minimal investment. Above all, it provides the existing plant with the flexibility to develop new markets by means of production of new products.

Conclusions

The new technology resulting from the European research project has proven that products can be obtained over a wide range of specifications conforming to the international standards expected of MDF and standard particleboard. However, a major benefit of the technology is that the raw materials used for board manufacture are agriwaste or annual plant fibers, such as cereal straws. These materials are annually renewable and available in abundant volumes in many regions of the world. Therefore, employment of the new technology will result in waste products being utilized as a sustainable resource for the mass manufacture of commodity products, reducing the impact on the environment, and the wood deficit that board industry is facing.

Test work has shown that the technology may be applied worldwide and can be used to convert a variety of agriwaste and annual plant fibers. Both traditional and sophisticated binders can be used effectively for the bonding of the resultant fibers.

The new process uses proven technology and machinery in a unconventional manner to produce fibers. The energy costs of processing the agriwaste material into suitable fiber are comparable to those of traditional wood-based methods. As a material, the cost of the annually renewable feedstock is a fraction of timber prices; however, the factory price is dependent upon its collection and storage. As machinery is developed for this purpose, this factor is no longer the concern it once was, and therefore the cost of prepared feed furnish to a board plant should be extremely competitive.

As this innovative technology becomes a means of preparation of furnish for board manufacture, its adoption by incumbent manufacturers will allow them to utilize their existing board production equipment by installing revised fiber preparation devices.

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