TURNING AGRICULTURAL STRAW RESIDUES INTO VALUE –ADDED COMPOSITE PRODUCTS: A NEW ENVIRONMENTALLY FRIENDLY TECHNOLOGY

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ABSTRACT

A new environmentally friendly technology for turning agricultural residues like straw into quality value-added composite products using conventional formaldehyde-based resins has been developed, and currently being scaled-up, within the framework of an EU funded project.

The new technology highly favours environmental protection and sustainable development by:

- Recovering and re-utilising organic wastes such as straw residues;
- Implementing a green solution as an alternative to straw burning and disposal into soil;
- Eliminating the release of carbon from decaying straw into air, which contributes to the global warming through greenhouse effect;
- Decreasing the constantly growing pressure over the forests for wood resources.

Straw has not been utilised before for board production with the use of conventional formaldehyde based resins because its fibre cells are surrounded by a layer of wax/silica. This layer prevents the water based formaldehyde resins - which are widely used today in the industrial fibreboard manufacture - from forming a sufficiently strong bond between the fibres. However, the new technology enables the destruction of the wax/silica layer by using mechanical high shear forces accompanied by a thermal and chemical treatment. This combined chemi-thermo-mechanical process subsequently refines straw and allows the formaldehyde resins to penetrate and adhere the individual straw fibres. The board produced known as strawboard matches MDF (medium density fibreboard from wood) in appearance, surface smoothness and strength.

In overall, the new process has two major advantages:

- It promises to be at least 20% cheaper compared to the existing processes; therefore, possesses the potential to have a huge impact on the market.
- It is an environmentally friendly process by which agricultural residues are recovered and transformed into value-added products.

Keywords: Prevention of waste, sustainable development, recovery and re-utilisation of agricultural residues, strawboard, formaldehyde-based resins.

INTRODUCTION

The paper and wood-based panels industries make use of forest wood as a raw material for their products. The use of other renewable resources such as agricultural residues (wheat straw, rice straw, etc.) in the production of composite panels (i.e. particleboards, fibreboards) and paper products has recently been considered attractive both from the economical and environmental point of view. The use of straw can by this way help to protect the virgin forests in regions where there is a shortage of wood. In addition, great quantities of straw residues are available today in other parts of the world where the burning of straw has been prohibited, and no proper (efficient) uses for these wastes have been found up to day.

An innovative environmentally friendly process for turning agricultural residues (agriwaste) like straw into quality boards suitable for use in the furniture and construction industries has been developed recently by a group of companies through a European innovation project.

THE EUROPEAN PROJECT

The work in this presentation has originated from the EU funded project "*Innovative Technology for Panel Manufacture from Fiberised Agriwaste*" (Innovation IN20551I) which is currently underway. The main objective of the project is the use of agricultural residues (e.g. wheat straw, rice straw, barley straw, etc.) as an alternative to wood in the production of composite products with the use of conventional urea-formaldehyde (UF) resins.

This project was actually the outcome of the initiative of a group of industrial companies who jointly had recognised the challenge posed by replacing wood with agricultural residues. A previous EU funded CRAFT project (CR-1638-91) had provided several SMEs with financial support in order to assign research organisations to carry out research on their behalf. Following, the continuation of the CRAFT project led to this ongoing innovation project whose consortium is composed of the following organisations:

WOODCHEM EUROPE S.A., Belgium, an industrial resin manufacturer, and co-ordinator of the project;

SIEMPELKAMP Co., Germany, the largest engineering manufacturer of industrial particleboard and fibreboard plants worldwide;

MARLIT Ltd., Greece, the company holding the international rights of the process, who is a small industrial company involved in the production of chemicals for the wood-based panels industry;

INP-ENSCT, France, a university chemistry institute based in Toulouse; and

AKRITAS S.A., Greece, a small industrial board manufacturer.

In the ongoing project, work is now underway in order to set up an industrial pilot production with the co-operation of SIEMPELKAMP and AKRITAS at the industrial facilities of PINDOS S.A., a Greek small size MDF manufacturer who is a subcontractor of AKRITAS. If everything goes as planned, this will happen by mid 2001, and enable the partners to demonstrate the technical and commercial feasibility of the new technology. The process has been patented in more than 30 countries and will be licensed worldwide. In particular, the partners are anticipating great interest from North America and Southern Europe as well as from countries such as China and India where wood is relatively scarce and straw is plentiful.

AGRICULTURAL STRAW RESIDUES

There are today huge unused quantities of agricultural (straw) residues around the globe. The estimated worldwide availability of wheat and rice straw in several countries is shown in Table 1. According to this, China, India and the USA appear to be at the present the major producing countries of straw residues (mainly wheat and rice straw).

Agricultural plants such as cereals (i.e. wheat, rice, barley, oats, rye), corn, cotton, etc. are naturally grown for the crop and not for the fibre. 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 manufacture, paper pulp and power generation applications. A compromise may be necessary to resolve the above, unless crops be specifically grown for industrial purposes, which may need some revision of government rules.

TABLE 1. Worldwide availability of wheat and rice straw residues (as in 1999)*.

Continent	**Country**	**Wheat straw residues** (in million metric tons)	**Rice straw residues** (in million metric tons)
Europe			
	France	47.8	
	Russia	32.3	
	Germany	23.8	
Asia			
	China	132.0	231.5
	India	79.2	146.6
	Turkey	25.2	
	Indonesia		55.5
Africa			
	Egypt	7.4	6.6
America			
	USA	83.3	9.8
	Canada	29.3	
	Argentina	12.1	
Oceania			
	Australia	26.1	1.6
World		709.2	673.3

*Source: Mantanis, G. (1999). Worldwide availability of agriwaste. MARLIT Ltd., Greece (unpublished data).

The majority of the agricultural crops are seasonal and in some regions are typically harvested annually over about a 100 day period. However, sugarcane is harvested twice a year in India, and rice three times in two years in the Philippines. For efficient industrial production, the storage of adequate quantities of raw materials (i.e. straw) should be thoroughly considered. Moreover, protection from the weather as well as control of fungal infestation have to be taken into account, when storing.
Dumping of agricultural waste in landfills or burning of straw residues have been considered unacceptable for environmental reasons. Forthcoming legislation within the EU is headed towards the prohibition of such disposal practices. For example, Germany has already enacted a law that forbids the dumping of materials containing more than 5% organic matter by the year 2005 (TA - Siedlungsabfall). It is therefore evident that new applications need to be found for agricultural residues.

CHEMI-THERMO-MECHANICAL TREATMENT OF STRAW

In the morphlogical structure, straw from wheat or rice is less homogeneous than softwoods or hardwoods. Straw contrary to wood contains a relatively large number of cell elements, that is, fibres, parenchyma cells, vessel elements and epidermic cells which comprise a high amount of ash and silica. In a cross section, the epidermic cells are the outermost surface cells and are covered by a thin waxy layer. This layer lowers the wettability of straw with water based formaldehyde resins. Also, straw has a quite different chemical composition compared to wood. Straw has a higher content of hemicelluloses, ash and silica, but a lower content of lignin compared with wood (Table 2). Straw has not been used before for board manufacture with the use of conventional formaldehyde resins (urea-formaldehyde, melamine-urea-formaldehyde, phenol-formaldehyde, etc.). The only adhesives being used today industrially for strawboard manufacture in Canada and the USA are polymethylene diphenyldiisocyanate (PMDI) based resins which are very expensive compared to UF resins. The new technology presented allows conventional UF resins, or other formaldehyde based resins, to penetrate and adhere the individual straw fibres. Thus, a continuous one-step process has been developed, which comprises the defibration of straw in an attrition mill, by innovatively combining thermal treatment by hot water at a temperature range between 40^{o}C and 100^{o}C with both mechanical treatment imposed by high shear forces and treatment with conventional chemicals. It is therefore a combined chemi-thermo-mechanical treatment. After such a treatment, the morphological structure of straw is opened and its affinity towards bonding increases tremendously. Following the chemi-thermo-mechanical treatment and subsequent defibration, the straw fibres can be dried using drum or flash dryers and then follow the conventional procedure as for the production of particleboard, medium or high density fibreboard.

TABLE 2. Main constituents of wheat and rice straw versus spruce wood.

Material	Wax %	Hemi-celluloses %	Cellulose %	Lignin %	Ash %	Silica %
Wheat straw	1.6	34.0	38.1	14.3	6.4	3.2
Rice straw	3.7	35.5	39.6	13.9	12.5	9.7
Spruce wood	1.8	23.4	54.1	30.1	0.2	-

BOARD PRODUCTION FROM 100% STRAW

Pilot trials have been performed using chemi-thermo-mechanically treated straw for the production of boards (strawboards) with the application of conventional UF resins. The boards obtained had significantly improved properties as compared to boards produced with raw (untreated) straw. The results showed (Table 3) that,

TABLE 3. Properties of boards made from treated wheat/rice straw and UF resin versus the European particleboard/MDF standard requirements*.

Property	**Wheat strawboard** (lab results)	**Rice strawboard** (lab results)	**Particleboard** (European std. requirements)	**MDF** (European std. requirements)
Internal bond strength (IB), N/mm^2	0.57	0.48	0.35	0.55
Modulus of rupture (MOR), N/mm^2	20	21	15	20
24-hour swelling, %	15	14	15	12
Density, kg/m^3	770	750	650	750

* Source: MARLIT Ltd. (2000), unpublished data.

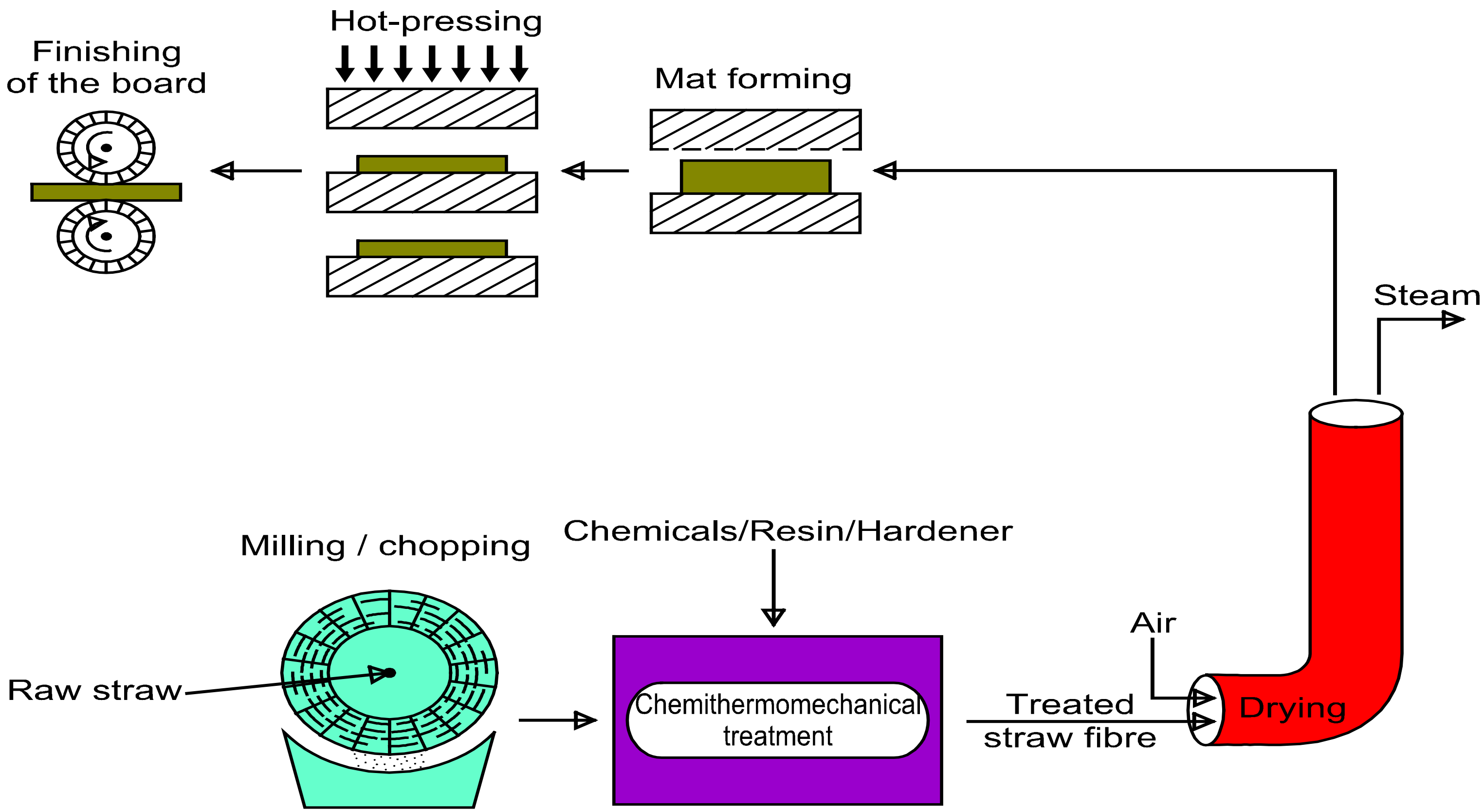

FIGURE 1. Schematic diagram of the strawboard production incorporating the new process.

not only the internal bond strength (IB) and modulus of rupture (MOR) of the boards had been greatly increased due to the treatment of straw, but also the thickness swelling had been significantly upgraded (reduced). From the results above, it can be concluded that this novel straw treatment enables the production of a good quality board. This strawboard matches MDF in appearance, surface smoothness and strength; its machinability is also superior than that of particleboard. Hence, the new method enables the production of MDF-like boards with use of conventional formaldehyde resins, which attests the innovative aspect of the new process.

ADVANTAGES

The new process offers various technical, environmental and economical advantages and benefits which are listed below:

Technical advantages

The technical advantages of the novel process are summarised as follows:

1. Low pressure machine (equipment) is needed
2. Low temperatures (40-100^{o}C) are applied
3. Conventional (dilute) chemicals are applied
4. No effluents are produced
5. Continuous one-step process
6. Straw and wood can be processed (combined) together

Environmental benefits

The new technology highly favours environmental protection and sustainable development by:

1. Recovering and re-utilising organic wastes such as straw residues;
2. Implementing a green solution as an alternative to straw burning and disposal into soil;
3. Eliminating the release of carbon from decaying straw into air, which contributes to the global warming through greenhouse effect;
4. Decreasing the constantly growing pressure over the forests for wood resources.

Economical advantages

From the economical point of view, the new process has a major economical advantage:

1. It promises to be at least 20% cheaper compared to the existing processes; therefore, it possesses the potential to have a huge impact on the present market.

CONCLUSIONS

A new environmentally friendly technology for turning agricultural residues like straw into quality value-added composite products using conventional formaldehyde-based resins has been developed and currently being scaled-up within the framework of an EU funded project. The implementation of the new technology will result in waste materials (agriwaste) being efficiently utilised as a sustainable resource for the industrial manufacture of commodity products like particleboards and fibreboards reducing the amounts of agricultural wastes and eliminating the pollution occasioned by the burning of such residues.

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