Lignocellulosic materials from annual plants and agricultural residues as raw materials for composite building materials.

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Abstract

In this work various lignocellulosic materials of annual plants such as kenaf *(Hibiscus cannabicus),* mischanthus *(Miscanthus sinensis 'giganteus'),* reed *(Arundo donax L.)* and agricultural residues of cotton were evaluated as alternative raw material for the production of particleboards of low toxicity (low emission of formaldehyde). The results showed that the above materials if properly treated could be used satisfactorily in admixtures with poplar wood to manufacture both low and high density particleboards. Also, low density boards of the above materials proved to behave satisfactorily as basic components for manufacturing of building materials with good thermo-sound insulating properties.

Keywords: particleboards, lignocellulosic material, annual plants, agricultural residues, low formaldehyde emission, thermo-sound building materials.

Introduction and Literature Review

The global increase of population and economical development cause increased demands for wood products, particularly particleboards, fiberboards and paper (FAOSTAT 1998). Also, the social pressure for developing more ecologically friendly building materials (substitutes to plastic, metal, etc.) increases the demand for availability of more natural renewable raw materials. At the same time the capacity of world's forests to produce wood fibers for various reasons is decreasing (McNutt et al. 1992). The foreseen deficit in wood and wood fibers led to many research and industrial efforts to find alternative lignoccelulosic raw material sources. Agricultural residues, plantation of fast growing and annual plants and recycling of wood products have been looked up as very important sources (Bowyer and Stockman 2001; Ntalos 2000; Youngquist et al. 1994; Hesch 1968).

The interest in using agricultural residues for the production of fiber panels started at the beginning of the 20th century (Atchinson and Collins 1976) and numerous fiber and particleboard plants based on corncob, hemp, flax, and baggage operated in the 50's and 60's (Berns and Caljar 1999). Today research efforts are been focused mainly on the utilization potentials of wheat straw (Mantanis and Berns 2001; Grigoriou 1998; Dalen and Shorma 1996), cotton stems (Ntalos 2000; Padney and Mehta 1980) and kenaf (Pasialis et al. 1998 Grigoriou et al. 1997; Chow et al. 1992). Branches of pruning fruit trees, vine stems, sunflower, soya stems, etc., have also been look as particleboard raw material (Ntalos 2000; Grigoriou and Pasialis 1992).

Several publications (Youngquist et al. 1994; Mohan 1978; Durso 1949) have discussed the potentialities for producing insulation and other building materials from agricultural residues and annual plants and give technical descriptions for their manufacture.

In Greece there have been many efforts by CRESS and NAGREF to develop energy plantations from kenaf and several studies to establish productivity of the crops and conditions of proper cultivation and to access technical and chemical characteristics of the biomass produced (Alexopoulou et al. 2000; Kipriotis et al. 1998). Laboratory experiments have also been made to study the degree of suitability of kenaf in the production of conventional type particleboards (Pasialis et al. 1998; Grigoriou et al. 1997).

Except kenaf, reed and mischanthus appear to form very good plantations in Greece with satisfactory

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annual yield (Christou et al. 1998; Markidis et al. 1997; Dalianis et al. 1994, 1995). The biomass produced could be used for energy purposes as well as raw material for wood panels. Perdue (1958) describes the botanical, anatomical and technical characteristics of reed as well as its utilization for musical instruments and its suitability for paper making. Pasialis (1985) also studied the anatomical, chemical and technical characteristics of reed and suggested its possible utilization in particleboards and fiberboards. Dalianis et al. (1994, 1995) and Christou et al. (1998) studied the growing conditions and the yield of mischanthus in various places in Greece. The Handbook of Mischanthus (Wals M. 1997) describes the botanical, chemical and technical characteristics of mischanthus canes and presents its utilization potentials for a number of products including fiberboard and light sandwich building materials. Troger et al. (1998) give information on the utilization of mischanthus and flax fibers for the production of reinforced particleboards.

The aim of this work was to evaluate the degree of suitability of kenaf *(Hibiscus cannabicus),* reed *(Arundo donax L.)* mischanthus *(Miscanthus sinensis 'giganteus')* and cotton stems as supplementary raw materials for the production of low density and low formaldehyde emission of particleboard and of environmentally friendly building materials.

Materials and Methods

Twelve (12) series of three layered particleboards were made using as raw material particles from small sized poplar *(Populus sp.),* mixed with particles of kenaf *(Hibiscus cannabicus),* reed *(Arundo donax* L.), mischantus *(Miscanthus sinensis 'giganteus')* or cotton stems. The material composition of the boards is shown on Table 1.

TABLE 1. Composition of the lignocellulosic materials used for the production of the laboratory particleboards.

Board series No.	Interior layer		Surface layer		Density	U:F
	Species	%	Species	%	gr/cm^3	ratio
1a (PPa)	Poplar	100	Poplar	100	0.600	1:1
1b (PPb)	Poplar	100	Poplar	100	0.600	1:1.3
1c (PPc)	Poplar	100	Poplar	100	0.700	1:1
2 (PK1)	Poplar / Kenaf	50/50	Poplar / Kenaf	50/50	0.600	1:1
3 (PK2)	Poplar / Kenaf	50/50	Poplar / Kenaf	75/25	0.600	1:1
4a (PMa)	Poplar / Mischanthus	50/50	Poplar / Mischanthus	75/25	0.600	1:1
4b (PMbX	Poplar / Mischanthus	50/50	Poplar / Mischanthus	75/25	0.600	1:1.3
4c (PMc)	Poplar / Mischanthus	50/50	Poplar / Mischanthus	75/25	0.700	1:1
5a (PRa)	Poplar / Reed	50/50	Poplar / Reed	75/25	0.600	1:1
5b (PRb)	Poplar / Reed	50/50	Poplar / Reed	75/25	0.700	1:1
6 (PC)	Poplar / Cotton	50/50	Poplar / Cotton	75/25	0.600	1:1
7(PKM)	Poplar	100	Poplar/Reed/Mishanthus	50 / 25 / 25	0.600	1:1

Poplar material were selected from a particleboard industry in the form of flakes. Reed, mischanthus, kenaf stems and cotton were supplied by CRES and NAGREF. Shanks from the above plant material were dried, splintered and separated in order to obtain the proper dimensions. Although these materials were handled with the same way, their final form was different. Material from mischanthus and reed was constituted mainly from particles with good proportion of length and width. The interior layer material of kenaf had cubic or parallelogram form while the surface material was constituted from fine particles and fibers. The cotton material was darked color and constituted for both layers from particles mixed with fibers.

All particle furnish from the above material were separated in size fractions with a mechanical sieve. Particles with sieve dimensions ^{3} 0.4cm and £ 0.8cm were used for the manufacture of the interior layer and with dimensions £ 0.4cm for the surface layers. Particles were dried to final moisture content of 3%.

The boards were manufactured in the Laboratory of Wood Technology in Aristotelian University of Thessaloniki, under the same conditions: moisture content 8%, proportion of interior and surface layers 60:40, amount of glue 8 and 12 % solids based on dry particles for interior and surface layers, amount of catalyst 3% solids based on glue solids and paraffin 0.5% solids based on dry particles, pressing temperature 180°C and pressing time 4 min. The target density in three board series (1c, 4c and 5b) was 0.700 gr/cm^3 and in all the others. 0.600 gr/cm^3. Two types of urea formaldehyde glue were used. In two board series (1b and

4b) a glue with a molar ratio U:F 1:1.3 and in all the others with a molar ratio U:F 1:1 were used (see Table 1). Six boards (35x30x2.5cm) were made for each board series.

Three boards of each series were tested for their physical (moisture content, density and thickness swelling after immersion for 2 hours) and mechanical properties (internal bond and bending strength) according to DIN Standards, and emission of formaldehyde with the perforator method. The other three boards were used to construct the building materials. Four series of building materials were manufactured using particleboards with low density and low formaldehyde emission. The building materials with thermo or sound properties that were made are shown in Table 2.

TABLE 2. Types of laboratory building products.

Product series No	Usage	Particle board series used	Insulating material	Insulating property
A	roof	la	-	sound
B	wall	4a	-	sound
C	wall	3	glass fiber	thermo-sound
D	bulkhead	5a	mineral fiber	thermo

For the construction of the building materials with thermo-sound properties laboratory three layered particleboards of poplar and mixtures of poplar with kenaf, mischanthus and reed material were used (Table 1 - series la, 3, 4a, and 5a). As thermo-insulating materials glass fiber (density 13 kg/m^3) and mineral fiber (density 80 kg/m^3) were used.

Roof products (code A) were constructed from poplar particleboards which were drilled in one of their surfaces in order to become sound insulating. The density of drilling was *Vi* up to 1 hole per cm^2, and every hole had diameter and depth 2mm. Wall products (code B and C) were constructed from particleboards (mixtures of poplar with mischanthus or kenaf), which were drilled as mentioned above in order to become sound insulating. Also, in the non-drilled surface of the poplar/kenaf particleboards glass fiber agglutinated in order to obtain thermo insulating properties. Bulkhead products (code D) were constructed from particleboards (consisted of reed material and poplar) agglutinated in on surface with mineral fiber in order to become thermo-insulating products. Three specimens of each product were tested for their physical (moisture content and density) and thermal properties (coefficient of thermal escape according to DIN 4108).

Results and Discussion.

The physical and mechanical properties of the particleboard series tested are given in Table 3, as mean values of the tested specimens (the numbers in brackets give standard deviation).

TABLE 3. Properties of the materials tested.

Board Series No.	Moisture content (%)	Density (gr/cm^3)	Internal bond (N/cm^2)	Bending strength (N/cm^2)	Thickness swelling (%)	HCHO* (mg/lOOgr)
la(PPa)	*in*	0.618	38(7)	156(13)	*S2*	*15*
lb(PPb)	7.6	0.612	46(8)	161 (10)	5.4	21.1
lc(PPc)	8.3	0.711	50(8)	179(12)	7.8	8.0
2(PK1)	7.9	0.619	34(6)	135(13)	9.8	7.9
3(PK2)	8.0	0.622	35(7)	152(12)	8.9	8.3
4a(PMa)	7.8	0.618	37(6)	160(12)	7.8	8.0
4b(PMb)	7.8	0.609	43(8)	16510)	5.9	202
4c(PMc)	8.4	0.710	49(12)	186(11)	8.2	*15*
5a(PRa)	8.1	0.627	37(7)	159(13)	8.4	6.6
5b(PRb)	8.4	0.708	52(6)	184(13)	7.2	6.3
6 (PC)	7.7	0.615	36(8)	145(9)	8.8	7.8
7(PKM)	8.0	0.625	39(8)	185(13)	8.2	7.2
DIN	-	-	30	150	6	
CEN/TC112WC1	-	-	35	130	8	

* El < 10 and E2 between 10 and 30 mg HCHO/lOOgr.

As we can see on Table 3, all lignocellulosic material used (poplar alone or in admixtures with kenaf, mischanthus, reed or cotton) when glued with UF glue of low formaldehyde content, produced boards with very good mechanical and physical properties even at low board densities. Of course, increasing density from 0.600 to 0.700 gr/cm^3 and F:U molar ratio from 1:1 to 1.3:1, as it was expected, improved all properties of the boards.

Poplar comprises a very good particleboard raw material. Its low density and low hardness make poplar particles very compressive and compatible with particles from the other lignocellulosic materials. Boards made from poplar particles only (board series la, lb and lc) had internal bond and bending strength higher than the requirements of DIN and CEN standards at both density and U:F molar ratio levels. Thickness swelling of poplar boards made with glue of U:F molar ratio 1:1 (board series la and lc) almost met the requirements of CEN standards. Thickness swelling of the boards was much better when glue with high formaldehyde content was used (board series lb) and met the requirements of DIN standards.

Kenaf particles in admixtures with poplar (series 2 and 3) produced boards with good mechanical properties but with relatively poor thickness swelling. All properties of the boards were slightly inferior than those produced from pure poplar. The negative effect was smaller when kenaf particles were used in the surface layer at a proportion of 25% (series 3). This negative effect of kenaf on board properties, when mixed with conventional wood particles, was noticed also by other researchers (Chow et al. 1992; Grjgoriou et al. 1997). However, Grigoriou et al. 1997, noticed that addition of kenaf bast fibers in the surface layers improve the bending strength of the boards.

Mischanthus particles in mixtures with poplar in proportion 50:50 for the interior and 25:75 for the surface layers (series 4a, 4b and 4c), produced boards with at least as good properties as poplar alone at both density and U:F molar ratio levels. In fact, the use of mischanthus particles improved the bending strength at the board.

Reed particles in admixtures with poplar (series 5a and 5b) had the same behavior as mischanthus. All properties of the poplar-reed boards were slightly better than those of poplar boards, particularly, at the high density level. When both mischanthus and reed particles were mixed with poplar particles in the surface layer in a proportion of 50:25:25 (series 7) gave boards with similar properties.

Cotton particles in admixtures with poplar gave boards (series 6) with slightly lower internal bond and substantially lower bending strength than those of poplar boards. The negative effect on the properties of particleboard of substituting conventional wood particles by cotton particles at various levels was studied by Ntalos (2000).

It was interesting to notice that the urea-formaldehyde glue with U:F molar ratio 1:1 gave very low formaldehyde emission of the boards that allow them to be characterized as 'ecological boards' class El. These boards had also acceptable thickness swelling and good internal bond.

The building materials produced from the boards are shown in Figure 1. The physical and thermal properties of these products are given in Table 4, as mean values of the tested specimens.

TABLE 4. Properties of the tested building products.

Product code	Density (gr/cm^3)	Moisture content (%)	Coefficient of thermal escape (W/m^2K)
A	0.61	8.0	-
B	0.61	7.6	-
C	0.28	7.8	0.839
D	0.32	8.1	0.955

The construction of these products proved to be rather easy and their use in buildings could be very beneficial both economically and environmentally. However, much more research and development work is needed before industrial manufacture and use the above products in actual building conditions are realized.

Conclusions

The main conclusions we can draw from this study can be summarized as follow:

The lignocellulosic material of annual plants of kenaf, mischanthus and reed can be used very satisfactorily as alternative or supplementary to wood raw material for the production of particleboards.

- Admixtures of particles of the above material with poplar wood flakes (in proportion 50% in the middle layer and 25% in surface layers) give particleboards of low density (0.600 gr/cm^3) with very good mechanical and physical properties.
- Mischanthus and reed materials produced boards with properties at least as good as poplar flakes. Kenaf material had slight negative effect on the properties of the boards, while cotton had an intermediate effect.
- The above materials allow the use of urea-formaldehyde glue with low formaldehyde content and the manufacture of ecological (El formaldehyde-emission class) particleboards.
- Low density boards with low formaldehyde emission from the above lignocellulosic materials can be used as basic components for the construction of environmentally friendly building materials.
- Much more research is needed in this area before we could see an extensive industrial use of the lignocellulosic material from annual plantations and agricultural residues in the production of building materials. The results of this work give only some of the potentials there exist for a more environmentally sound utilization of our renewable resources.

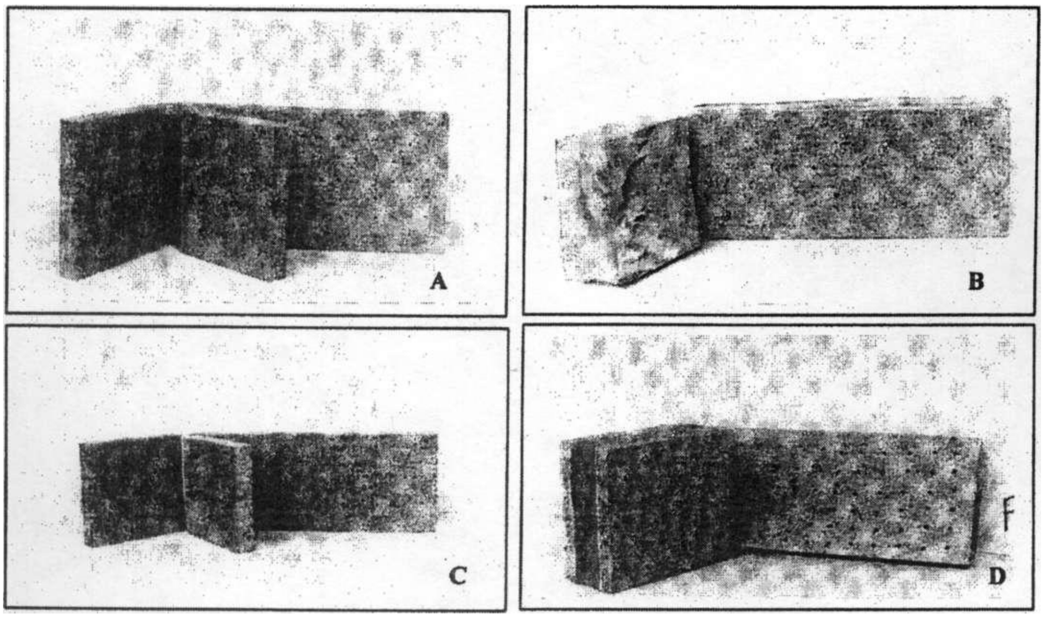

FIGURE 1. Building materials (A for roofs, B and C:for walls and D for bulkheads).

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