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The potential for using flax (*Linum usitatissimum* L.) shiv as a lignocellulosic raw material for particleboard

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Abstract

Single-layer experimental particleboards were made from various wood chip/flax shiv mixtures bonded with urea formaldehyde resin. Flax particles were characterised by having higher length to thickness and length to width ratios and lower bulk density than industrial wood chip particles. Partial substitution of wood by flax shiv resulted in the deterioration of all key board properties. This was attributed to the cellular structure of the flax shiv material, giving rise to a weaker, more absorbent substrate. However, the strength properties of boards containing up to 30% flax particles still met the minimum EN requirements for interior boards. It is suggested that the application of alternative resins such as isocyanates, and/or a reduction in the size of particles comprising the furnish, could improve the properties of particleboards made with flax shiv.

Keywords: Agricultural residues; *Linum usitatissimum*; Flax; Particleboard

1. Introduction

World-wide economic growth and development have generated unprecedented needs for converted forest products such as pulp and paper, composite boards, plywood and lumber (Youngquist et al., 1993). This global demand started with the advent of the industrial revolution, resulting in aggressive deforestation and an increase in the concentration of global carbon dioxide (Adger and Brown, 1994). All indications are that the demand for forest products will increase steadily for the foreseeable future. This in turn will place increasing pressure on the wood supply.

Agricultural residues, e.g. cereal straws, or dedicated annual fibre crops grown using intensive agricultural management practices, e.g. flax (*Linum usitatissimum* L.) and hemp (*Cannabis sativa* L.), represent potential alternative sources of lignocellulosic raw materials which could supplement wood from natural and plantation forests. In Europe the interest in agricultural materials has largely been driven by agricultural policy, which has encouraged farmers to devote land to the growth of non-food crops rather than to food

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production. As a consequence, fibre crops have received a good deal of attention during the last 10–15 years, and the forest products industries, with their huge demand for raw materials, have been identified as potential consumers of the crop materials (Hague et al., 1998).

A wide range of agri-residues and annual fibre crops could potentially be used for manufacturing composites such as particleboard. Flax shiv (the woody core generated as a waste by-product from the flax fibre/linen industry) is one such material, and has previously been used on a commercial scale to manufacture panel products. The purpose of this communication is to report the results obtained in a study aimed at determining the technical feasibility of making single-layer experimental particleboards from mixtures of flax shiv and wood chips.

2. Materials and methods

2.1. Raw material

Flax shiv (*Linum usitatissimum*), derived from an experimental crop grown in the United Kingdom, and industrially produced wood chip furnish, comprising predominantly mixed softwoods, supplied by Kronospan Ltd, Chirk, UK, were the raw materials used in this study. Each furnish type was screened first through a mesh with 5 mm apertures to remove oversize particles and then through a mesh with 1 mm apertures to remove undersize (dust) particles. Oversize particles comprised around 20% (mass basis) of the flax shiv furnish and 10% of the wood chip furnish; dust comprised approximately 2% of each furnish type. After screening the shiv and wood chips were dried to 3% moisture content at 70 °C. After drying the bulk density of each furnish was determined. Samples of each furnish type were also further screened over a mesh with 3 mm apertures; the dimensions of particles comprising the fractions retained on and passing through the 3 mm mesh were then determined.

2.2. Board manufacture and testing

Five types of panel were made, consisting of varying mixtures of wood and flax shiv (wood to flax mass ratios of 9:1, 4:1 and 7:3) and wood and flax shiv alone. Pre-weighed raw material was placed into a resin blending chamber equipped with a rotary arm agitator. A commercial E1 grade urea formaldehyde (UF) particleboard resin (62.4% solids content), containing 2% (based on resin solids) ammonium chloride as hardener, was used for the manufacture of boards. Thirteen-percent resin (solids on oven dry mass of particles) was added in all cases. Where necessary, additional water was added to bring the furnish to the target moisture content level (10%); this was done after resin application. The total blending and mixing time was 3 min. Mattresses were hand-formed and hot pressed at 200 °C for 6 min using a maximum pressure of 3.4 MPa. Target board density was 0.75 g/cm^3 and target board thickness 17.5 mm. Three replicate panels were produced for each board type. The mat core temperature was measured during hot pressing using a 30-gauge type-K thermocouple.

After manufacture the boards were conditioned at 20 °C and 60% relative humidity. Values for internal bond (IB), modulus of rupture (MOR) and thickness swelling (TS) after 24 h water immersion were then determined according to procedures defined in the American standard for particleboards (ANSI A208.1-1998, ANSI, 1998) and European Union standards EN 310, EN 317 and EN 319 (European Standard EN 310, 1993; European Standard EN 317, 1993; European Standard EN 319, 1993).

3. Results and discussion

3.1. Particle dimensions and bulk density of furnishes

When screened over the 3 mm mesh, approximately half of the flax shiv furnish was retained on the mesh. This contrasted with the results for the wood chip furnish, where less than a third was retained on the mesh.

The dimensions of flax and industrial wood chips and their length to thickness and length to width ratios are presented in Table 1. Flax particles were typically longer, thinner and narrower than the wood chips. As a result, their length to thickness and length to width ratios were typically higher than those of the wood chips. The bulk density of the flax furnish was determined to be about half that of the wood chip furnish (Table 2).

3.2. Core temperature during hot pressing

Fig. 1 presents typical core temperatures in the flax particleboard mats and in particleboard mats made from industrial wood chips. It can be seen that the rate of heat transfer to the core was different in the two mats, being significantly slower in the flax panel. This is probably related to the lower bulk density of the flax furnish and consequent reductions in mat permeability upon densification during hot pressing. Previous workers have observed similar behaviour in particleboards made from coconut residues (Papadopoulos et al., 2002b).

3.3. Mechanical and physical properties of panels

The properties of the single layer experimental particleboards made from the various wood/flax combinations are shown in Table 3. It can be seen that higher flax content levels resulted in inferior board properties. IB and TS were more severely effected than the bending strength. Similar observations were made by Grigoriou (2000) in the case of straw-based panels. The significant reduction in IB is probably attributable to the fact that, compared with wood, flax shiv comprises relatively short, thin walled and weak cells. As a consequence the shiv particles themselves are relatively weak, giving rise to 'critical defects' in the panel structure and hence a rapid decrease in IB as the shiv content of the panel increases. The increase in TS associated with increasing shiv content can probably be similarly explained by the cellular structure of the shiv particles. However, as well as a reduction in particle strength, an additional factor is likely to be that the shiv material is more absorbent, which promotes more rapid uptake of water and hence increased swelling. Incidental supporting evidence for this hypothesis is provided by the fact that a key use for flax shiv is as livestock bedding, where absorbency is a key criterion of material performance. The fact that the bending strength of panels was least effected by the inclusion of shiv can in part be attributed to the fact that the flax particles had a high length to thickness ratio compared to the wood chips; such properties would be expected to enhance bending strength.

Table 2
Bulk density (g/cm^3) of flax shiv and industrial wood chips

Raw material	Bulk density
Flax chips	0.09 (0.002)
Industrial wood chips	0.21 (0.007)

The values shown are means from 3 samples. Standard deviations in parentheses.

Table 1
Dimensions of flax particles and industrial wood chips

Dimension	Flax	Wood	Flax	Wood
	Fraction retained on 3 mm mesh		Fraction retained on 1 mm mesh	
Length	18.2 (2.5)	13.2 (5.2)	15.4 (2.9)	10.2 (3.5)
Width	1.4 (1.2)	3.1 (1.1)	1.1 (1)	2.5 (1)
Thickness	0.5 (0.3)	0.9 (0.3)	0.4 (0.01)	0.8 (0.1)
Length:width	13	4.3	14	4.1
Length:thickness	36.4	14.7	38.5	12.7

The values shown are means from 50 samples. Standard deviations in parentheses.

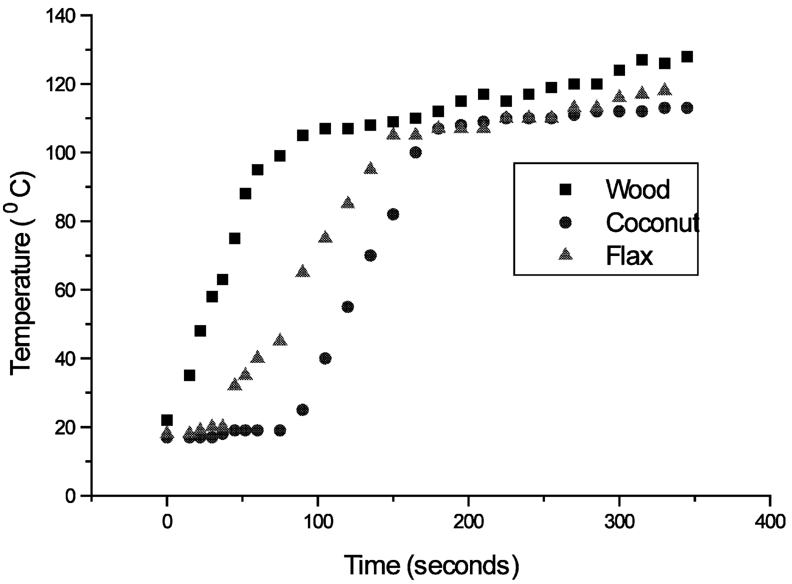

Fig. 1. Mattress core layer temperature during hot pressing of test panels. Data for coconut residues (Papadopoulos et al., 2002b) included for comparison.

Reference to Table 3 suggests that, although the inclusion of flax shiv does impair panel properties, in terms of strength many of the panels satisfied minimum requirements laid down in international standards for various grades of board. However, some caution needs to be used when drawing conclusions, as the resin loadings, press times and finished panel densities in this work were greater than those typically found in industry.

The results obtained in this study are in general agreement with those reported by other workers (Hague et al., 1998); these workers suggested that flax is possibly a more suitable raw material for MDF rather than particleboard manufacture. They also reported that improved properties could be imparted to particleboards made from raw materials such as wheat straw and miscanthus (*Miscanthus* sp.) when methyl di-isocyanate

Table 3
Mean properties of UF-bonded single-layer experimental particleboards

Wood:flax	Density (g/cm^3)	MOR (MPa)	IB (MPa)	TS (%)
100:0	0.751 (0.02)	16.92 (0.4)	1.21 (0.04)	13.5 (1.8)
90:10	0.748 (0.04)	15.51 (0.3)	0.89 (0.02)	19.4 (2.1)
80:20	0.744 (0.03)	14.54 (0.3)	0.65 (0.02)	25.2 (2.8)
70:30	0.739 (0.05)	13.22 (0.4)	0.43 (0.01)	37.5 (3)
0:100	0.748 (0.05)	11.72 (0.2)	0.09 (0.007)	62.9 (4.2)
ANSI A208.1-1998	Commercial use, shelving-M1	11.0	0.400	8
ANSI A208.1-1998	Industrial overlaying shelving, countertops-M2	14.5	0.450	8
ANSI A208.1-1998	Industrial overlaying shelving, stair treads-M3	16.5	0.550	8
EN 310 and EN 319	P2 general use	11.5	0.24	N/A
EN 310 and EN 319	P3 interior fitments	13.0	0.35	N/A
EN 310; 317; 319	P4 load bearing—dry	15.0	0.35	14

Standard deviations in parentheses.

(MDI) is used as the resin binder. Similar findings have been reported by many other workers for a range of agri-residues, and indeed commercial particleboard plants using cereal straws almost always use MDI as the binder in the production process. Hague et al. (1997, 1998) also reported that additional improvements in the properties of wheat straw and miscanthus particleboards were obtained when the mean size of particles comprising the furnishes was reduced.

MDI is believed to work well with agri-materials because it is capable in particular of overcoming the problems presented by the waxy coatings prevalent on the tissues of many materials. The resin is also reported to be capable of forming covalent bonds with substrates (Chelak and Newman, 1991). Smaller particles are believed to give improved performance due to an increase in 'sound' furnish surface area available for bonding (Hague et al., 1998). Whether the use of MDI resin and/or a reduction in mean particle size would be beneficial for panels made with flax shiv is unclear, since the shiv is largely free of any waxy coating. However, this would merit further investigation.

4. Conclusions

Flax particles were characterised by having higher length to thickness and length to width ratios and lower bulk density than industrial wood particles. Partial substitution of wood by flax in single layer particleboards bonded with UF resin resulted in the deterioration of all board properties. However, comparing the properties of the boards produced in this study to relevant European Standards, it was found that the experimental boards containing up to 30% flax particles met the strength requirements for standard interior boards. It is suggested that alternative resins, such as isocyanates, and/or a reduction in furnish particle size, might give improvements in panel properties (Papadopoulos et al., 2002a). Such strategies have been shown to be efficacious in laboratory studies with a range of agri-residues. The use of MDI has also been successfully employed in the commercial manufacture of panels from cereal straws.

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