INNOVATIVE FIREPROOF INSULATING PANELS FROM AGRICULTURAL WASTES

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ABSTRACT

To reduce pollution as well as energy consumption, new insulating and non-flammable bio-panels based on the combination of different reinforcements such as Miscanthus x giganteus particles and rice husk mixed with recycled textile fibres were prepared using Chitosan as a polysaccharide natural binder. Different formulations using one or more combined reinforcements and Chitosan (7 wt%) as an aqueous binder were prepared by a thermocompression process. Mechanical, thermal and fire behaviour of the panels were examined. Results showed that the mechanical properties vary according to the size and the nature of the used reinforcements. All the panels showed sufficient bending and compressive strength for thermal insulation uses, according to European construction specifications (DIN 4108-10). The highest mechanical strengths in bending and compression have been found for the formulation with small size miscanthus particles (0.48 MPa and 0.64 MPa respectively). Fireproof panels (E rating, according to standard NF EN ISO 11925-2) with an insulating behavior (thermal conductivity vary between 0.07 and 0.09 W/m/K) and a density range between 247 and 400 kg/m³ were successfully elaborated. The prepared bio-panels show promising results and great potential to compete with the conventional insulating materials used nowadays.

Key words: bio-panels, agricultural wastes, chitosan, thermal insulation, fireproof.

INTRODUCTION

Environmental pollution is one of the most important issues to deal with worldwide. Pollution reduction based on the replacement of the non-renewable materials by bio-sourced ones is a very considerable solution to this problem. Hence, the new trend is now to valorise and to use agricultural and industrial wastes to develop biobased materials useful for the building sector (e.g. insulating materials).

Natural fibres coming from Miscanthus (M), which is a perennial grass. or husks. as rice husk (Rh), are widely available. These two raw materials attracted the researchers to investigate their use as reinforcements in biobased materials.

M has been incorporated in PBAT, Mater-Bi matrix and bioplastics (Johnson et al. 2003; Muthuraj et al., 2015, 2017). Such as miscanthus, Rh has been used with glue (Buratti et al. 2018) and biodegradable Ecovio adhesive (Muthuraj et al. 2019) for the preparation of thermal insulation panels.

The most used natural fibre in clothes is cotton, which produces tonnes of wastes every year. Textile waste (Tw) were recently used in the development of bio-panels (Asdrubali et al. 2015; El Hage et al. 2018; Muthuraj et al. 2019).

Replacing synthetic binders by natural or biodegradable ones is also important to reduce pollution. Chitosan is an abundant biopolymer produced by the chitin deacetylation extracted for the exoskeleton of Crustaceans such as shrimps and crabs (Illum et al. 2001).

Thus, the present work is devoted to the development of new chitosan-based insulating and non-ignifuged panels using miscanthus fibres, textile wastes and rice husks in different formulations. The study seeks to compare the effect of fibre nature as well as particle size effect on the mechanical, thermal and fire behaviour of the prepared panels.

EXPERIMENTAL METHODS

MATERIALS

Miscanthus x giganteus (M) stems were provided by EARL Ar Gorzenn (France). After milling and sieving, three different particle size of miscanthus fibres were obtained and used: small (Ms) 2–5 mm; medium (Mm) 10–20 mm and large size (Ml) 30–60 mm.

Rice husk supplied by Silo de Tourtoulen (France) and textile wastes namely Metisse provided by Le Relais Co. (France) were used as received.

A commercial chitosan powder was purchased from Glentham Life Sciences (UK) and used as a binder after dissolution in glacial acetic acid.

PANELS MANUFACTURING

Eight formulations of bio-panels were manufactured with different components as presented in the Table 1.

Table 1: Designation of the bio-composite samples and their corresponding formulations

Name	Miscanthus particles (g)			Rice Husk (g)	Particles (M or Rh)/Tw (wt%)	Chitosan (wt %)
	Small	medium	large			
Ms	+	–	–	–	100/0	7
Mm	–	+	–	–	100/0	7
Ml	–	–	+	–	100/0	7
MsTw	+	–	–	–	60/40	7
MmTw	–	+	–	–	60/40	7
MlTw	–	–	+	–	50/50	7
RhTw	–	–	–	+	60/40	7
Tw	–	–	–	–	0/100	7

Chitosan binder solution was prepared by dissolving 4.5g of chitosan powder in 100 ml of glacial acetic acid solution 2% (w/v) at room temperature, using mechanical stirrer until a homogenous solution was obtained. Then, a net amount of textile waste, rice husk and miscanthus particles was weighted according to each formulation. For combined samples, particles and fibres were manually mixed before the addition of the chitosan binder. The mixtures were left to stand for 30 min, to ensure wetting of the reinforcements. Panels shaping was achieved by the mixtures compaction at room temperature using a 200 x 50 x 70 mm^3 tefloned mold. Compaction is maintained throughout the drying period. The compacted mixture was then placed in an oven at 60°C for 48 hours to obtain well dried panels while dismenting some of the mold edges during this period to speed up the drying step.

CHARACTERIZATION

1. Thermal conductivity

The specimen thermal conductivity was measured using a hot linear wire sensor (50 mm) branched on thermal conductivity analyser (FP2C-NeoTIM device).

2. Mechanical properties

The bending and compressive properties were measured on a Zwick TH010 testing equipment according to the standard ASTM D790.

3. Fire properties

Ignition time (T igns), flame spread height (Fs) and self-extinguishing time (Tself) were measured to some samples according to standard NF EN ISO 11925-2 using single flame source fire.

RESULTS AND DISCUSSION

1. THERMAL CONDUCTIVITY

Density (ρ) and thermal conductivity (λ) values of the prepared panels are presented in Table 2.

Table 2: Density (ρ) and thermal conductivity (λ) values of the bio-panels

Name	ρ (kg/m³)	λ (W/(m*K))
Ms	368	0.084
Mm	354	0.08
Ml	247	0.071
MsTw	357	0.08
MmTw	334	0.079
MlTw	284	0.079
RhTw	405	0.076
Tw	286	0.09

The density of the produced bio-composites ranges from 247 to 405 kg/m³. The density of the panels increases when the size of the miscanthus particles decreases. Moreover, the addition of textile wastes reduces the density of the composite having same size of miscanthus except for the panels having large miscanthus particles, where the addition of Tw increases the density from 247 to 284 kg/m³.

Having thermal conductivity lesser than 1W/(m*K) all the bio-panels of this study can be considered insulating materials (Jelle, 2011). Table 2 shows that composites with smaller particle size (2–5 mm) have higher λ than that of bigger particles (30–60 mm).

It seems also, that textile waste addition does not affect the conductivity of the panels. λ of the panels containing Rh is relatively low despite their highest density; this is partially due to the hydrophobic character related to the presence of approximately 20% of silica in amorphous form of the used rice husk and to their curved frames which leads to a more porous structure (Park et al., 2003).

2. MECHANICAL PROPERTIES

2.1. Flexural bending properties

Fig. 1 represents the bending Young's modulus of all panels. It shows that panels with small miscanthus particles (Ms) have a much higher Young's Modulus (68.8 MPa) than panels with medium (27.2 MPa) and long (28.3 MPa) miscanthus particles.

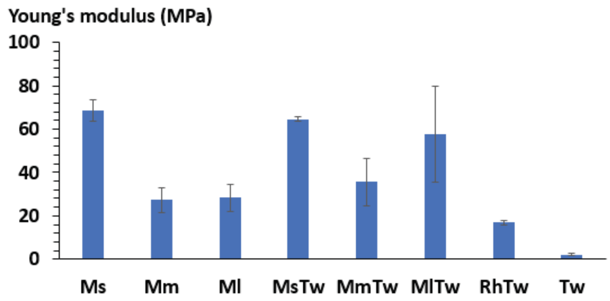

Figure 1: Bending Young's modulus (MPa) of the different panels

It can be noted that the replacement of small size miscanthus fibres by Tw does not impact the rigidity of the panels; whereas, the rigidity significantly increases while replacing the medium and large miscanthus by Tw despite the low Young's modulus of the Tw panels (2.1 MPa). This behavior indicates that Tw addition acts as compatibilizer leading to fiber-binder improving interface.

It can be also noted that RhTw panels feature the lowest modulus (17 MPa). This behavior could be related to the low wettability and adhesion problem of thehydrophobic nature of Rh (Park et al., 2003).

2.2. Compression properties

Young's modulus in vertical compressive mode are presented in Fig. 2.

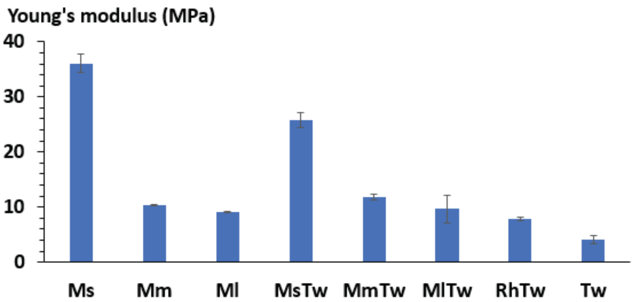

Figure 2: Compression Young's modulus (MPa) of the different panels

The modulus values are twice lower than those obtained in flexural mode while maintaining the same trend. Modulus increases with decreasing miscanthus particle size. The highest modulus is found for Ms (36 MPa) and the least modulus for Tw (4 MPa). Compressive rigidity increases for MmTw and MlTw in comparison with Mm and Ml which confirms again that the addition of Tw (40 wt% or 50 wt%) increases the fiber- matrix interface and thus the mechanical behaviour of the panels.

3. FIRE PROPERTIES

The fire test according to NF EN ISO 11925-2 was carried out on Ml, MlTw and Tw panels. Results are shown in Table 3.

All panels belong to Euroclass E rate because flame spread height Fs remains lesser than 150 mm after 60 seconds of flame application. It can be noticed that only Ml panels ignites but it extinguishes after 49 s. The flame spread significantly decreases with Textile wastes addition which is related to a char layer formation that appeared immediately when the flame reaches the surface of the samples. Thus, this char layer acts as a barrier layer inhibiting the sample ignition.

Table 3: Fire properties of the tested panels

Name	T igns (s)	Fs (mm)	T self (s)
Ml	3	120	49
MlTw	None	60	None
Tw	None	50	None

CONCLUSION

The main goal of this work was to develop new flame insulating panels based on miscanthus, textile waste and rice husk. Thermal, mechanical, and fire behavior of the developed boards were investigated.

It emerges from this study that the size and the nature of the used fibers influence the various final properties of the panels. It is demonstrated that the density of the panels increases when the size of the miscanthus particles decreases and thermal conductivity increases with density increasing. Furthermore, results in mechanical analysis confirm that highest rigidity is found for panels with small size miscanthus fibers, which decreased significantly in presence of bigger particles size and that the replacement of 40 wt% of miscanthus fibers by Tw increases the rigidity for the less wettable bigger fibers.

The different panels show an interesting fire behavior using chitosan as bonding material and deserve to obtain E Euroclass fire rating, using a standardized fire test according to NF EN ISO 11925-2.

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