COMPARATIVE EVALUATION OF MECHANICAL AND PHYSICAL PROPERTIES OF PARTICLEBOARD MADE FROM BAGASSE FIBERS AND IMPROVED BY USING DIFFERENT METHODS

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This work aimed at evaluating the improvement in the mechanical properties of particleboard made from bagasse fibers. Two methods were investigated: treatment of bagasse fibers with NaOH and addition of *Eucalyptus camaldulensis* (EC) wood particles to the bagasse in different ratios (30 and 50% w/w). The initial pH of bagasse fibers was raised from 5 to 10 by soaking the fibers in a solution of NaOH of 3.5% concentration for one hour. The treated fibers were used to produce panels using two adhesive systems, UF and PUF (17%w/w). The obtained panels were tested for their mechanical properties (modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB) and physical properties (water absorption (WA) and thickness swelling (TS)) according to the relevant EN BS standard).
The results indicated that the panels produced from 100% treated bagasse fibers and PUF showed superior values for MOR and MOE, which well exceeded the performance level specified in EN312-3 standards for boards for interior fitments (including furniture). The values were slightly less than the standard value for load bearing boards (BSEN 312-4). The addition of *Eucalyptus camaldulensis* particles to the bagasse fibers in the proportions of 30% and 50% was found to improve the IB and the thickness swelling of the produced panels. The study concluded that the alkali treatment of bagasse could be more effective and beneficial, when compared with the addition of wood particles.

Keywords: bagasse, alkali treatment, *Eucalyptus camaldulensis*, PUF and UF

INTRODUCTION

Particleboard consumption increases every year. The demand for particleboard panels in the sectors of housing construction, interior decoration and furniture manufacturing has continued to increase. Its selling price is low. Besides, it has several other advantages, such as dimensional stability. Solid wood is prone to splitting and warping with changes in humidity, whereas composite particleboard is not. Particleboard manufacturing is ecologically sound, as the waste material will transform into useful products, thereby conserving natural resources.[1-4]

The rapidly expanding building and furniture industries in Sudan, on the one hand, and the diminishing supplies of sawn timber and plywood, on the other, are escalating; hence the demand for particleboard as a cheap modern substitute for these diminishing expensive products is increasing. The importance of particleboard stems from the fact that such a modern and valuable product can be produced from residues, which would otherwise go to waste.[5] Agricultural and industrial residues provide renewable and environmentally friendly alternative biomass resources for easing the huge demand for woody materials. As a result, much research has been focused on making particleboards using rice straw, cotton stalks, sugar cane bagasse, wheat straw, sunflower stalks, maize husks and cobs.[6] While the environmental benefits of these products are intuitive, the market viability of agrifiber composite panels depends upon their ability to successfully perform in intended applications.

Although most of the board properties made from agricultural and wood-based fibers are lower than fiberboard made from virgin wood fiber, the strength properties of composites can be improved by controlling resin types and the amount used in the composite formulation.[7] Urea-formaldehyde (UF) is an important wood adhesive, which is easy to handle and ideal for interior application panels, due to the virtually colorless glue line of the final panels after hot-press curing.[8] However, UF resin itself is less effective for binding agrifibers than other resins. Various resin systems have been developed to obtain increased strength properties and dimensional stability of agro-based composites. Adhesives were included in some UF modification research. Urea formaldehyde resins have been greatly used in the production of particleboard and other wood based panel industries.

The use of urea formaldehyde resin as a major adhesive by the forest products industry is due to the low cost, low cure temperature, water solubility, and lack of color and ease of use under a wide variety of curing conditions. However, it has high hydrolysis susceptibility and low water resistance.[9,10]

Osman and coworkers[11] reported that using PUF resin with bagasse could produce panels sometimes exceeding the specifications of European standards for panels for interior uses. Therefore, PUF could be a viable alternative to UF resins. Successful commercialization of bagasse-based panel products depends on the development of a cost-effective manufacturing process on a commercial scale and establishment of a market base for the products.

The production of particleboard from bagasse is a well-proven technology, but it has to compete with plywood and fiberboard. Its main difficulty is the high cost of imported synthetic resins, which serve as a binder to the bagasse fibers composing the board. Two important key research areas of bagasse particleboard are improving mechanical properties, while enhancing dimensional stability as well. Material (surface) treatments such as acetylation, polymer grafting, cyanoethylation, and conversion of bagasse into a thermoformable material through esterification have been applied to yield favorable results.[12-14]

Cao *et al.*[15] investigated the mechanical properties of biodegradable composites reinforced with bagasse fiber alkali treatments. They found that the mechanical properties of the boards made from the treated fibers were superior compared to those made from untreated ones. Improvements of approximately 13% in tensile strength, 14% in flexural strength and 30% in impact strength have been found. After alkali treatment, the increase in the strength and aspect ratio of the fibers contributed to the enhancement in the mechanical properties of the composites. SEM observations on the fracture surface of the composites showed that the surface modification of the fiber occurred and improved fiber–matrix adhesion.

Sugar cane is planted in small areas as food source for local consumption in Sudan. The actual commercial sugar cane production started in 1960.[16]

Eucalyptus camaldulensis is an exotic tree in Sudan and is planted as shelterbelt to protect crops such as sugar cane from blowing sands. Furthermore, most of these planted species are not utilized in the industry and in most cases they have very limited uses, such as shelterbelts and fence posts.

The main objective of this study was to investigate the best method for producing bagasse particleboards with improved mechanical and physical properties. The effect of alkali treatment on bagasse fibers and the optimum ratios of Eucalyptus particles to be added to the bagasse were studied.

EXPERIMENTAL

Lignocellulosic materials

Bagasse and *Eucalyptus camadulensis* were collected from Kenana Sugar Factory (Kenana farms), White Nile State, Sudan.

The bagasse fibers and eucalyptus wood were air dried and hammer milled into small particles using a laboratory hummer mill. They were then screened using different sieves. The particles retained on mesh size 20 (particle size ≈ 1 mm) were blended with the adhesives. The bagasse and eucalyptus particles (initial moisture content was 6%) were then oven dried in an industrial oven to decrease the moisture content (MC %) to 2.5%. The moisture content was determined using a moisture meter. Different ratios (50:50 and 70:30 w/w) of bagasse/*Eucalyptus camaldulensis* (B/EC) were mixed and used for particleboard manufacturing.

Chemical treatment of bagasse

The bagasse particles were treated with NaOH in order to remove the wax, oil traces and a certain amount of lignin. The method employed was described by Zheng *et al.*,[6] however it has been slightly modified.

The bagasse fibers with an initial pH 5 were soaked in (0 and 3.6%) (w/w) NaOH solution. The fibers were kept immersed for 1 hour. They were then washed with clean water several times till the pH was 10. The fibers were air dried at room temperature for 72 hours. They were then placed in an oven at 60 °C and kept there overnight. Their final oven dried moisture content was 2.5%.

Binding materials

Commercial phenol urea formaldehyde (PUF commercial code 10J227) was provided by Dynea Company (Austria) with 19.51% formaldehyde, phenol 16.49%, urea 28.13% and 30.07% water and was used in this investigation.

A commercial urea formaldehyde (UF) resin class E2 with formaldehyde concentration of 0.32%, viscosity = 2.24 p, specific gravity = 1.269 and solid content = 65.3% was also used in this study. Ammonium chloride 1% (NH_4CL) was added to UF resin as a hardener.

Particleboard preparation

Duplicate one layer laboratory particleboards of 340x310x10 mm dimensions were prepared by adding 17% of adhesives (PUF and UF resins) based on the oven dry weight of the particles. Higher levels of resin loading were needed to compensate for the lighter weight of the bagasse particles, which increased their volume and may have decreased board density. The panels were pressed at a maximum pressure of 180 bars. The pressing temperature was 185 °C and the pressing time was 10 min. All the panels had targeted densities comprised between 0.690 and 0.707 g/cm^3.

Mechanical and physical testing

The pressed boards were trimmed and kept in a conditioning room (humidity 65% and 20 ± 5 °C) for 2-3 days prior to testing. Test specimens were prepared according to BS EN (326: 1994). The mechanical properties were investigated in accordance with appropriate BS EN standards: modulus of rupture (MOR) and modulus of elasticity (MOE) – EN 310, 1993, and internal bond (IB) strength – BS EN 319, 1993. Physical properties, namely thickness swelling (TS) and water absorption (WA) were determined based on EN 317 (1993). Samples were immersed in distilled water for 2 and 24 h before thickness measurements.

RESULTS AND DISCUSSION

MOR and MOE

Tables 1 and 2 show the obtained results of MOR, MOE and IB values for particleboard made from UF and PUF, respectively. The panels made from untreated bagasse and treated bagasse with PUF exhibited higher MOR and MOE values than those recommended (14 N/mm^2 and 1800 N/mm^2) by the BSEN 312-3:1996 standard for particleboard manufacured for interior fitments, including furniture. Furthermore, the values obtained by the treated bagasse were slighlty lower than the value (2300 N/mm^2) recommended for load bearing boards according to the EN312-4 standard. The values obtained by the UF showed similar qualities. However, they were slightly lower than the values produced by PUF. It was observed that the increase in the pH of bagasse improved the mechanical properties of the panels produced by PUF adhesive, which set at alkaline pH, while raising pH to 10 did not improve the panels obtained by UF, which hardened at an acidic pH. The alkaline treatment of the fibers increased the mechanical strength of the panels produced by PUF by increasing the adhesion between matrix and fibers.[17] It also resulted in breaking the fiber bundles into microfibrils by removing part of the lignin and hemicellulose,[18] thus the treated fibers had better quality.[19] It should be noted that MOE and MOR values increased with the increase of the panels'densities.

When the eucalyptus particles were added to the untreated bagasse (50/%30%w/w), the panels produced with both types of adhesives showed low MOR and MOE values(11.16 N/mm^2) compared to the values obtained by the treated bagasse fibers. In the case of UF adhesive, the reason could be attributed to a decrease in the pH of the glued particles. It has been noted that the addition of EC particles dropped the pH.[20] It is also noteworthy that the addition of eucalyptus particles also reduced the panels'densities, which in turn resulted in a decrease in their mechanical properties.[6] However, although the obtained MOR and MOE values increased with the increase in the panels' densities, no significant corelation could be made as the density range was small.

Furthermore, it is also known that bagasse has a very low specific gravity, which results in more compression that causes better bonding between the particles and thus improves the overall bending strength and modulus of elasticity.[21]

The particle size used for preparing the panels in this study was 1 mm, which is considered to be small. It was also observed that smaller particle sizes give inedquate coverage for the same mass of the adhesives used due to the large surface area. It may therefore result in poor bonds.[22]

Table 1
Mechanical properties of particleboards made from UF adhesive

Lignocellulosic materials	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	Density (kg/m^3)
Bagasse	16.91	2100.61	0.34	722.07
Treated bagasse	17.75	2048.07	0.32	703.30
Bagasse:EC 70:30	11.16	1755.86	0.46	597.35
Bagasse:EC 50:50	11.19	1776.75	0.30	695.31
Eucalyptus camaldulensis	6.69	1316.62	0.41	667.96

Table 2
Mechanical properties of panels made from PUF adhesive

Lignocellulosic materials	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	Density (kg/m^3)
Bagasse	15.38	1909.75	0.26	776.04
Treated bagasse	19.32	2138.94	0.15	729.70
Bagasse:*EC* 70:30	12.97	1907.63	0.38	705.58
Bagasse:*EC* 50:50	11.79	1712.10	0.38	716.34
Eucalyptus camaldulensis	7.19	1215.65	0.85	722.23

It has also been reported that *Eucalyptus camaldulensis* usually needs high initial pressure due to its hard cell walls, which may fail to crack.[23] A similar observation has been made by Ashori and Nourbakhsh.[3]

To conclude, it has been noticed that bagasse and treated bagasse fibers gave MOE and MOR values that exceeded the norm when PUF was used as adhesive. The addition of EC decreased the MOE and MOR values obtained when both adhesives were used. This was found to correlate with the decrease in the panels' densities.

Internal bond (IB)

The results obtained for IB showed that all produced panels had higher or slightly lower values than the minimum ENBS requirements for boards for general uses (0.28 N/mm^2). An exception should be made for the panel made from treated bagasse and PUF resin (Tables 1 and 2), which produced panels with low IB value (0.15 mm^2). Furthermore, the highest value (0.46 N/mm^2) was achieved when a small ratio (30%) of eucalyptus particles was added to bagasse. The results indicated that the pH of the glued particles was suitable enough to give better adhesion property. It could also be explained by the observation that when EC was used alone or added to bagasse at 50% proportion with UF adhesive, the IB value (0.41 and 0.30 N/mm^2) decreased respectively. It is worth noting that there was no correlation between the board densities and the IB values, as it has been reported by Wu G.[24]

The results have shown that the treatment of particles by NaOH decreased the IB value, especially in boards made from treated bagasse and PUF resin. Generally, PUF resin is considered as a cheaper adhesive when compared with PMDI, but it gave properties that exceeded the ones obtained by PMDI resin with bagasse.[11]

To conclude, it could be stated that the overall results showed that most panels made from bagasse and the mixture of bagasse and eucalyptus particles achieved IB values that exceeded the ENBS standards for panels intended for general uses, and in some cases they were higher or slightly lower than the minimum requirements (0.40 N/mm^2) for boards for interior uses.

Thickness swelling (TS)

The panels made from bagasse and treated bagasse showed higher TS values (29, 26%), which slightly exceeded the accepted value (25%) according to BSEN 317:1993 standard. However, water repellent chemicals, such as paraffin, could be utilized to improve these properties of the panels. Similar results have been reported for the particleboards that were produced using agricultural residues, such as 60.7% for tobacco and tea leaves,[25] 35% for cotton stalks[26] and 19.6% for hazelnut hulls[27] after 24 hours water immersion time. The values obtained for the panels made from *Eucalyptus camaldulensis* (13.50% and 11.37% respectively for UF and PUF) were higher than the values required by the ENBS standards (Table 3).

Table 3
Physical properties of particleboards made from UF and PUF

Lignocellulosic materials	UF			PUF		
	TS% (2 h)	TS% (24 h)	WA% (24 h)	TS% (2 h)	TS% (24 h)	WA% (24 h)
Bagasse	23.08	43.43	87.84	29.17	46.53	85.63
Treated bagasse	23.62	45.96	86.78	26.40	41.42	85.68
Bagasse:*EC* 70:30	22.53	31.62	87.29	21.63	26.46	87.46
Bagasse:*EC* 50:50	23.38	38.75	87.06	26.65	26.65	85.53
Eucalyptus camaldulensis	13.50	18.87	61.13	11.37	19.25	66.59

Furthermore, the addition of *Eucalyptus camaldulensis* was found to decrease the TS when compared with the alkali treatment. It could be due to the fact that the eucalyptus particles are denser than the bagasse fibers, which increases the compressibility factor and makes a much denser system that prevents water from seeping in. It has also been noted that the type of adhesive has a pronounced effect on the quality of the produced panels: PUF resins gave small TS values when compared to UF. Similar trends were noted for the values obtained after 2 hours of soaking. Decreased TS values were observed when 30% of *Eucalyptus camaldulensis* particles were added to the bagasse/EC panels.

Water absorption (WA)

Most panels showed high water absorption values. It should be noted that the bagasse fibers were not depithed and therefore they contained a considerable amount of parenchyma cells, which are hygroscopic.

The addition of *Eucalyptus camaldulensis* chips in different ratios has no effect on the WA values (Table 3). Akyuz[28] found that the acidity of the particles was the main parameter affecting the physical and mechanical properties of the particleboard composite. Decreasing and increasing the acidity of particles below pH 4 or pH 5 negatively affected the particleboard properties. Therefore, the values obtained for both adhesive types were much higher than the one achieved when eucalyptus was used alone.

CONCLUSION

The results showed that it is possible to produce bagasse particleboards with improved MOR and MOE using alkaline treatment. The best results were obtained when PUF was used. Small ratios (30%) of eucalyptus particles could also improve the IB when UF was used. Therefore, most types of panels made in this study satisfied the MOE, MOR and IB requirements for interior fitments stated in the EN Standards. With regard to physical properties, it was found that TS was reduced by the addition of 30 and 50% of eucalyptus. However, the WA of these panels was very poor as the bagasse was used without depithing and no wax was added.

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