Properties of Medium-Density Fiberboards from Bagasse Digested with Different Retention Times

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Abstract

The present work deals with studying the influence of different steam digestion retention times on properties of finished medium-density fiberboard (MDF). It aims to operate the defibration process with the minimum deterioration of stored bagasse-fiber strength. In this respect the wet-stored bagasse (WSB) samples were studied, parallel to dry-stored bagasse (DSB) samples, at different digestion retention times. Regression equations of quadratic order were used to optimize the independent variables (retention time and storage period).

The results obtained show that a relatively higher digestion time (353 s) reduced the hollocellulose and hemicellulose contents of WSB. In the case of DSB, the changes in chemical constituents as a function of retention time were not very significant because the mechanical properties of MDF (static bending, internal bond, and screw holding) produced from applying a higher digestion time do not fulfill the standard requirements of ANSI A208.2. However, digestion at a shorter retention time (253 s) is recommended for stored bagasse in order to produce a board that complies with the European standards on MDF. DSB fibers at all the examined retention times are recommended for comparison. The advantage of applying a shorter retention time is evident from preserving, to some extent, the chemical constituents of WSB fibers.

Agricultural wastes are the lignocellulosic material sources traditionally used in the wood industry. There are several advantages of using these kinds of fibers instead of natural wood. Some advantages include the preservation of forestry resources, the reduction of environmental pollution during the disposal of these wastes, and savings in energy. Moreover, using these fibers helps to overcome the raw material shortage that the panel industry is facing. Medium-density fiberboards (MDFs) are replacing solid wood, plywood, and particleboards in many furniture applications as a result of their properties, including strength, homogeneity, and machining performance (Akhtar et al. 2008, Halvarsson et al. 2008). They are also appropriate for interior and exterior construction, as well as industrial applications. The preparation of MDF at the mill scale started in the 1970s. The possibility of using available agricultural wastes (e.g., wheat, rice straws, peanut husks, and hazelnut shells) with urea-formaldehyde, melamine-modified urea-formaldehyde, and soybean–polymeric diphenylmethane diisocyanate adhesive systems in the production of MDF has gained the attention of many authors (Faraji 1998, Lee et al. 2006, Ye et al. 2007, Akgul and Toslughu 2008, Copur et al. 2008, Hossein 2009, Ciannamea et al. 2010, Abolfazl and Ahmed 2011).

In Egypt, agricultural waste accumulates in huge quantities, ranging from 30 to 35 million dry tones per year (El-Dorghamy 2010). Some of this waste is used as food for cattle and as fuel to produce energy. Another large amount of this waste remains unused. Therefore, the waste is burned outdoors, causing environmental pollution. Sugarcane bagasse is one of these wastes. It is the residue fiber that remains after the sugarcane is pressed to extract the sugar. This waste is the main substrate for the production of MDF and particleboards in Upper Egypt. In general, sugar extraction is an industrial seasonal process because sugarcane bagasse is harvested only once a year. For efficient industrial production, the storage of adequate

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Table 1.—*pH values, extractives, and chemical constituents of heat digestion bagasse at different times.*

Retention time (s)	pH	Extractives NaOH	Extractives MeOH-Bz	Holocellulose (%)	Pentosans (%)	α-Cellulose (%)	Klason lignin (%)
253	5.8	38.50	8.81	72.46	24.97	40.70	17.33
300	5.1	39.13	8.83	72.09	24.26	39.15	17.40
353	4.8	39.85	8.73	71.48	23.32	40.67	18.26

quantities of raw material must be thoroughly considered. There are different methods of bagasse storage (Atchison 1986), namely, dry, bale, and wet-bulk storage. This latter method is used at the NagHamady Fiberboard Co. for the storage of bagasse required for MDF production over the course of a year. Bagasse in the storage yard undergoes an undesired degree of prehydrolysis, which causes a deterioration in fiber strength and, consequently, a deterioration in the quality of wood products (Basta et al. 2010). Steam digestion is an inevitable step in the manufacture process because this operation allows for the individualization of the fibers, resulting in their successful MDF formation.

The present work deals with minimizing the deterioration effect of steam digestion process on wet-bulk–stored fiber by controlling the applied retention time. This approach was evaluated by following the chemical constituents of the produced fibers and, consequently, their effects on strength properties of MDF produced. Regression equations were used to optimize the applied retention and storage times.

Experiment

Raw material preparation and panel manufacture

Eight samples of wet-stored bagasse (WSB) were collected periodically (every 30 to 35 d of storage). The collected samples were softened by steam in a horizontal digester (Andritz horizontal digester type, with size 10 m, diameter 1 m, and pressure 800 to 850 kPa) and sent to atmospheric refiners. In the digestion stage, no sudden decompression occurred, but the pressure was gradually released.

The samples were then discharged, under the pressure from the digester section of the pressurized refiner, into the refiner section. The steam pressure was maintained at 800 kPa for different retention times (RTs), namely, 253, 300, and 353 seconds. In parallel experiments, eight samples of dry-stored bagasse (DSB) for the same periods as WSB were also subjected to the previous steam digestion RTs. The pH values and chemical constituents of bagasse subjected to steam digestion at different periods are reported in Table 1.

The previous digested WSB and DSB were mixed separately with urea-formaldehyde resin (12% of dry weight fibers) and ammonium sulfate (0.25% based on urea-formaldehyde as a hardener), as well as urea (0.5%) and ammonia (0.02%), both also based on dry fibers. In this stage, the resin was dosed by an IMAL blow line nozzle injection system. The resinated fibers were passed through a mat former (Siempelkamp-CMC mechanical mat former) and then prepressed into regular mats before being pressed into a final MDF panel (under a pressure of 30 bar and a temperature between 438 and 443 K for 325 s).

Characterizations of fibers and MDF boards

Chemical characteristic of fibers.—Parts of digested DSB and WSB fiber samples were subjected to pH measurement, milled by using sieves with mesh sizes of 250 and 400 μm, conditioned in polyethylene bags for 12 hours, and labeled to be ready for work. The pH values and chemical constituents (extractives, hollocellulose, α-cellulose, lignin, and pentosans) were determined by standard methods (Jayme and Sarten 1940; Wise et al. 1946; Technical Association of the Pulp and Paper Industry [TAPPI] 1978, 1998; ASTM International 2003).

Mechanical characteristic of MDF boards.—Board quality was evaluated by mechanical tests. Three-point static bending, modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), and face as well as edge screw holding (SH) tests were performed, in conformance with ASTM D1037 and ANSI A208.2

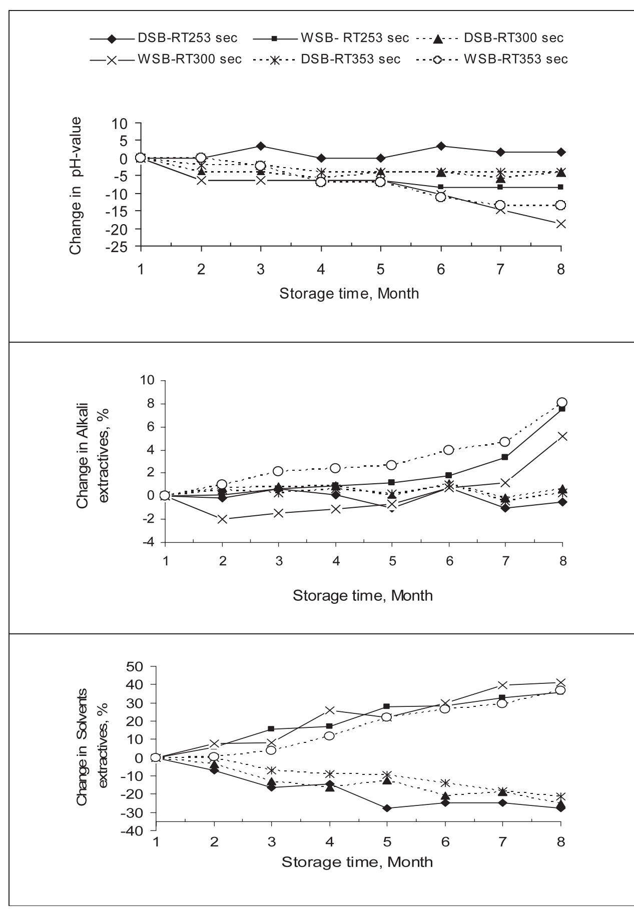

Figure 1.—Percent changes in pH values and extractives as a function of storage time and at different periods of heat digestion treatment. DSB = dry-stored bagasse; WSB = wet-stored bagasse; RT = retention time.

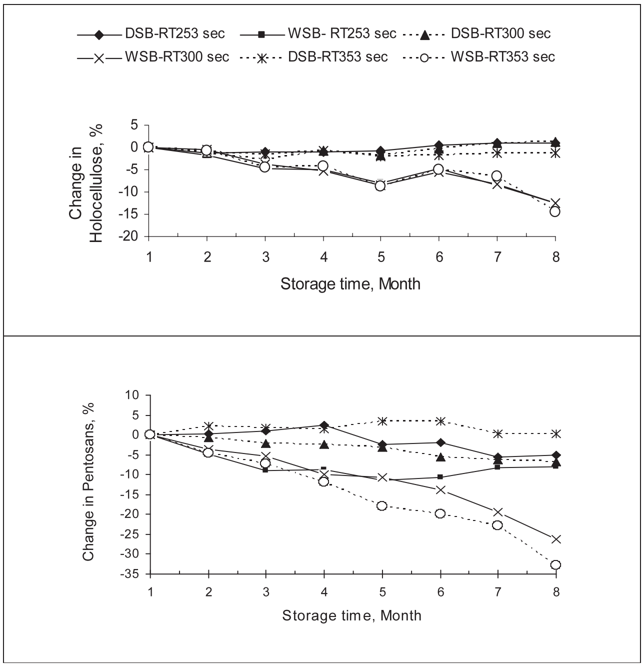

Figure 2.—Percent changes in holocellulose and pentosan contents of stored bagasse as a function of storage time and at different periods of heat digestion treatment. DSB = dry-stored bagasse; WSB = wet-stored bagasse; RT = retention time.

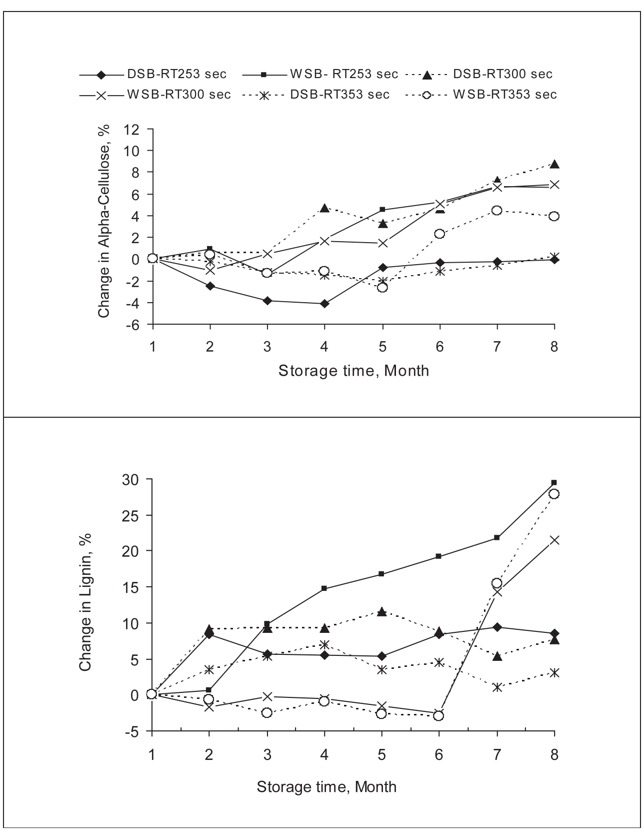

Figure 3.—Percent changes in α-cellulose and klason lignin contents of stored bagasse as a function of storage time and at different periods of heat digestion. DSB = dry-stored bagasse; WSB = wet-stored bagasse; RT = retention time.

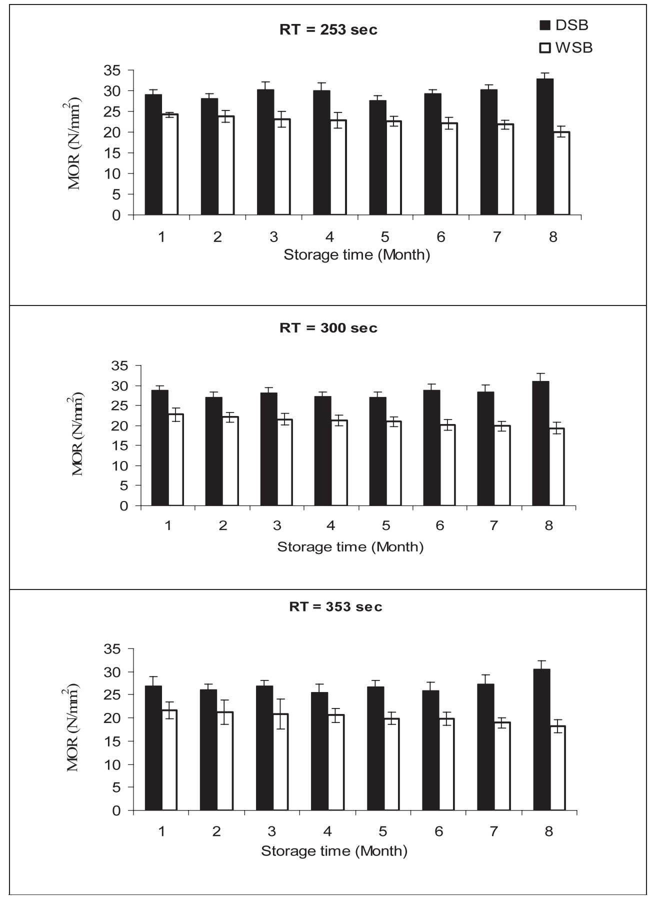

Figure 4.—Modulus of rupture (MOR) of medium-density fiberboard made from dry- and wet-stored bagasse (DSB and WSB) as a function of storage time and at different periods of heat digestion. RT = retention time.

standards (American Society for Testing and Materials [ASTM] 1994, Composite Panel Association 2002), using an IMAL IB500 testing machine. The results recorded were the average of four measurements.

Results and Discussion

The strength properties of bagasse-based MDFs were influenced by both the fiber geometry and storage process. Shorter fibers produce a weaker board; in addition WSB is a medium for fungi and bacterial attack. These microorganisms were isolated and identified in our previous study (Basta et al. 2010). It was reported that the deterioration in mechanical properties of MDF produced from stored bagasse increased when the storage period increased. The influence of RT on the performance of stored bagasse fibers, both for preserving to some extent its chemical constituents and quality of MDF produced, is illustrated graphically in Figures 1 through 8.

Chemical characteristics of digested bagasse fibers

This study was carried out to examine the influence of digestion RTs on chemical constituents of fibers produced. The results illustrated in Figures 1 through 3 show that the steamed WSB and DSB samples had different pHs and chemical constituents. For the WSB, it was observed that

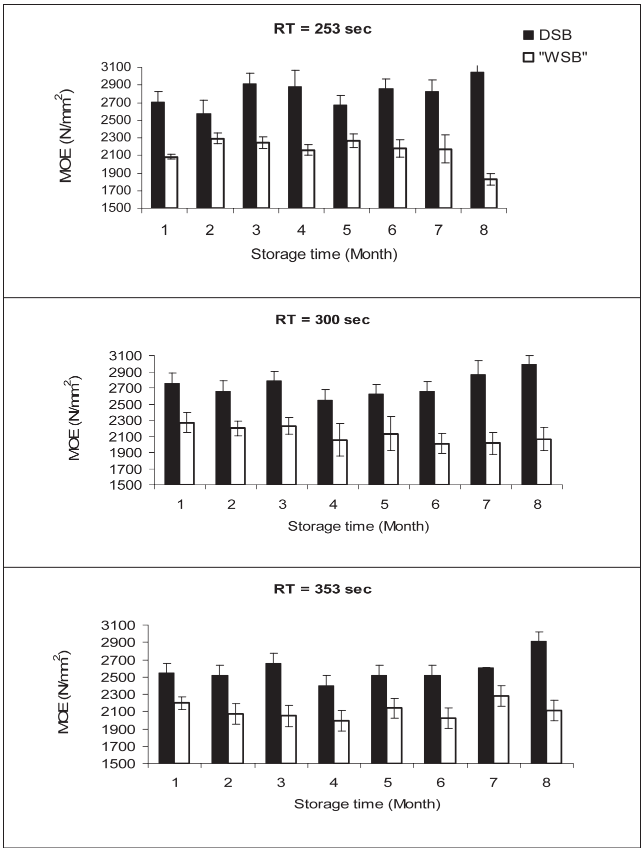

Figure 5.—Modulus of elasticity (MOE) of medium-density fiberboard made from dry- and wet-stored bagasse (DSB and WSB) as a function of storage time and at different periods of heat digestion. RT = retention time.

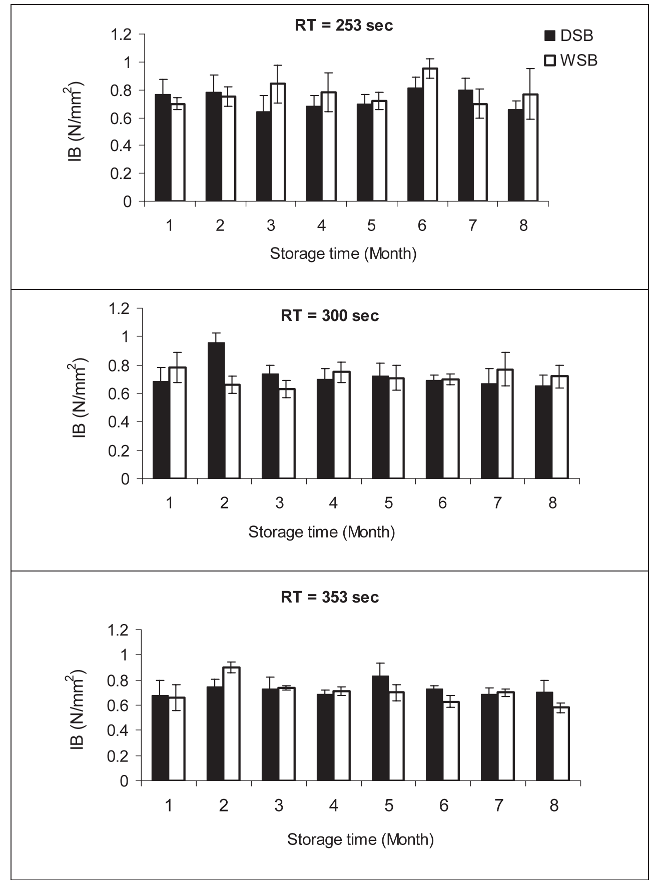

Figure 6.—Internal bond strength (IB) of medium-density fiberboard made from dry- and wet-stored bagasse (DSB and WSB) as a function of storage time and at different periods of heat digestion. RT = retention time.

the longer storage time led to decreases of the pH, the pentosans, and holocellulose contents and increases of the klason lignin, alkali solubility, and solvent extractives, which plays a large part in the reduction of the fiber's quality. However, there were fewer changes in chemical constituents under the effect of RT and storage period of dry bagasse.

After steam digestion, the changes in pH values as a function of storage period of wet and dry fibers were nearly the same. Both tend to become acidic fibers. The acidity of fibers increased with increasing storage period. Moreover, the acidity of wet-stored fibers was higher than dry-stored fibers.

The explanation of the above-observed data is probably related to pretreatment with high pressure steaming, which is referred as auto-hydrolysis, and the acid-catalyzed breakdown, or degradation of hemicellulose chains to its monosaccharide (e.g., xylose, mainly, and arabinos). However, the hemicellulose has less resistivity to hydrolysis than cellulose. The WSB is strongly affected by heating as a result of the fungus and bacterial decay of pentosans to soluble extractives (Wood 1991, Sun and Cheng 2003). The observed increase of the lignin content, especially at higher RTs, on heated WSB, with the increasing storage period is due to the decrease in the holocellulose content, as well as the fact that lignin is more resistant to hydrolysis by heat and/or microorganisms. Also, the increase in acidity of WSB indicates a potential increase in lignin content (Youngquist et al. 1996).

Mechanical characteristics of MDF boards

For the effect of RT of steam digestion on the properties of MDF made from WSB or DSB samples, Figures 4 through 8 reveal that for presteaming of bagasse at RTs of 253 and 300 seconds, the changes of MDF strength properties made from DSB were quite low. It can also be observed that at a relatively lower RT (253 s), the variability in MOR is bigger for boards made from DSB compared with boards made from WSB. This variability was increased when the storage time of bagasse was increased. The increase in the percentage of variation reached from 16.79 to 38.92 percent when the storage period was increased from 1 to 8 months.

It was observed that at a relatively longer digestion retention time (353 s), the MOR of WSB-based MDF tended to decrease from 21.65 to 18.12 MPa with increasing storage time of bagasse from 1 to 8 months. The lowering of MOR was associated with lowering of the MOE (Figs. 4 and 5). However, longer heating of MDF made of DSB slightly affected both MOR and MOE. At a lower digestion RT (253 s) and storage period of 5 months, the MOR and MOE (static bending strength) of MDF made from WSB were 23 and 2,268 MPa, respectively. These values met the standard specifications of MDF according to ASTM D1037. How-

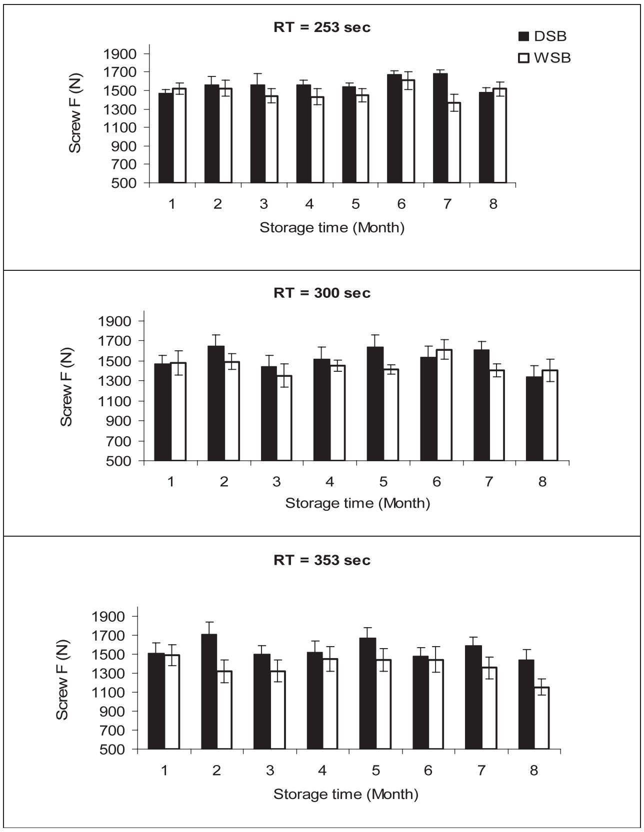

Figure 7.—Screw holding strength (on face) of medium-density fiberboard made from dry- and wet-stored bagasse (DSB and WSB) as a function of storage time and at different periods of heat digestion. RT = retention time.

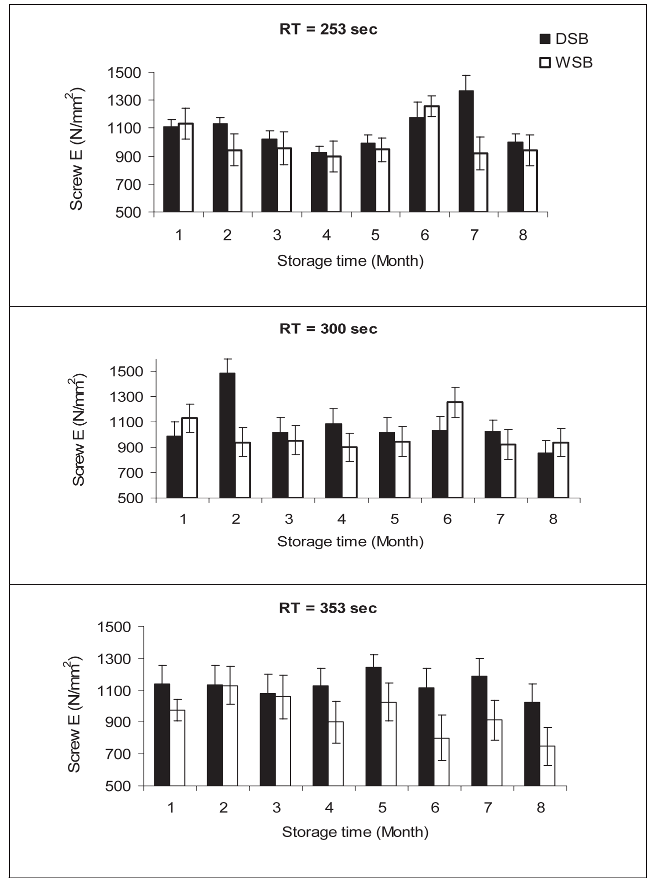

Figure 8.—Screw holding strength (on edge) of medium-density fiberboard made from dry- and wet-stored bagasse (DSB and WSB) as a function of storage time and at different periods of heat digestion. RT = retention time.

ever, for storage periods longer than 5 months and steam-digested bagasse RTs of 300 and 353 seconds, the resulting MDFs are not preferred.

For the MDFs made from digested DSB, the MOR and MOE were slightly affected by increasing both the heating period and storage period. Also, all static bending values of MDFs (MOR 26.9 to 32.9 MPa and MOE 2,543.5 to 3,044 MPa) exceeded the standard requirements of MDF as outlined in ASTM D1037

For the internal bond strength (IB), Figure 6 illustrates the changes in IB by changing the digestion RT from 253 to 353 seconds and increasing the storage period from 1 to 8 months, of both DSB and WSB fibers. It was observed that the IB of tested MDF boards made from WSB oscillated at 0.7 MPa, which was somewhat better than that of MDF made from DSB. The decrease in this property occurred with increased digestion heating time and reduced below the limited value of ASTM Standard D1073 at the end of the storage period and at the digested time of 353 seconds to become 0.58 MPa. The IB of MDFs made from all DSB and with digestion retention times of 253 and 353 seconds fulfilled the requirement of the ASTM standard. The same trend was also noticed in the case of SH property (Figs. 7 and 8)

The reduction in the static bending strength (MOR and MOE), IB, and SH on edge, on prolonging the heat digestion time of raw bagasse is due to the decomposition of hemicellulose to soluble acidic material. Increasing the acidity of fiber (pH 4.4 to 3.9) is undesired in the drying process of resinated fibers. However, the acidity of fibers led to accelerating the curing of binder (precuring of glue). Therefore, urea-formaldehyde lost its ability to bind the bagasse fibers during the hot press, leading to weakness of mechanical properties.

In order to correlate the dependence of the resulting MDF properties (Y), on both of the examined independent variables, digestion retention time (X_1) and storage period (X_2), the following second-order quadratic equation was selected. The design used was a two-factor rotatable design, with $\alpha = 1{:}414$ (Deming and Morgan 1987).

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2$$

The regression constant b_0 and the coefficients b_1 to b_{12} of the above model were obtained using multiple-regression analysis.

The multiple-regression equations in Table 2, the regression constant b_0, and the coefficients b_1 to b_{12} obtained prove that by varying both the digestion retention time (X_1) and storage period (X_2), the reduction of MOR, MOE, and SH are more significant in the case of WSB than DSB. The influence of independent variable X_2 (high b_2) is higher than X_1, while the reverse was noticed in the case of IB property.

Table 2.—Regression equations of medium-density fiberboard properties as a function of digestion retention time (x_1) and storage time (x_2).

Storage	Property[a]	Regression equation	R^2
Dry-stored bagasse	MOR	$y = 41.8 - 3.31x_1 - 1.31x_2 + 0.172x_1^2 + 0.187x_2^2 - 0.004x_1x_2$	0.801
	MOE	$y = 2,160 + 369x_1 - 77.2x_2 - 48.2x_1^2 + 14.3x_2^2 - 3.8x_1x_2$	0.87
	IB	$y = 0.82 - 0.028x_1 + 0.0037x_2 + 0.0019x_1^2 - 0.00196x_2^2 + 0.0012x_1x_2$	0.78
	SH (F)	$y = 784 + 284x_1 + 65.8x_2 - 29.8x_1^2 - 2.24x_2^2 - 10.9x_1x_2$	0.82
Wet-stored bagasse	MOR	$y = 45.0 - 7.32x_1 - 0.345x_2 + 0.576x_1^2 - 0.0245x_2^2 + 0.0167x_1x_2$	0.98
	MOE	$y = 3,189 - 277x_1 - 112x_2 + 15.1x_1^2 - 1.78x_2^2 + 21.6x_1x_2$	0.92
	IB	$y = 3.85 + 0.005x_1 - 1.28x_2 - 0.00329x_1^2 + 0.128x_2^2 + 0.0067x_1x_2$	0.82
	SH (F)	$y = 2,377 - 438x_1 + 141x_2 + 49.10016x_1^2 - 8.00x_2^2 - 14.3x_1x_2$	0.94

[a] MOR = modulus of rupture; MOE = modulus of elasticity; IB = internal bond strength; SH (F) = screw holding (face).

Conclusions

This article reported on controlling and characterization of MDF made from wet-stored sugarcane bagasse. The results show that a short duration of steam digestion of both DSB and WSB fibers resulted in significantly preserving their chemical constituents and consequently minimizing the deterioration in strength properties of MDF produced. DSB-based MDF exhibited slightly higher performance compared with WSB-based MDF. Retention time and storage period had higher effects on performance of WSB-based MDF, especially on static bending (MOR and MOE) and SH, than on performance of DSB-based MDF. The effect of RT on the IB performance of both stored bagasse-fiber MDFs was not significant. Steam digestion for RT 253 seconds was preferred in the case of WSB to prepare boards to comply with the EN 622-5 standard requirements (British Standards Institution 2009) for MDF.

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