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Properties of Medium Density Fiberboard Made from Wet and Dry Stored Bagasse

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ABSTRACT

Medium Density Fiberboard (MDF) was produced using moist depithed bagasse stored dry or wet. The duration of storage for either method varied between 0 to 4 months. Two steaming temperatures of 175°C and 185°C were also used. MDF boards were produced in the laboratory and the common mechanical and physical properties were measured and compared. Results showed that an increased steaming temperature and storage time (especially for the wet storage method) have negative effects on the mechanical properties and positive effects on the physical properties (water absorption and Thickness swell). The mechanical properties of boards produced from bagasse as received (fresh bagasse) and at a steaming temperature of 175°C were superior to others. The modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Internal Bond (IB) of boards from fresh bagasse were 29.7 MPa., 3,127 MPa., and 0.52 MPa. respectively. However, the physical properties of boards produced from bagasse after 3 months' wet storage and a steaming temperature of 185°C were superior, and were measured at 44.3% and 63.9% for water absorption after two and 24 hours' immersion (WA_2, WA_{24}), and 11.5% and 17.6% for Thickness Swelling after two and 24 hours immersion (TS_2, TS_{24}) respectively.

Keywords: Bagasse, Dry storage, MDF, Mechanical properties, Physical properties, Steaming temperature, Wet storage.

INTRODUCTION

The wood and paper industries in the Middle East are faced with a limitation of wood fiber supply. In order to overcome this problem and fulfill the needs of society's demands, attention is focused on utilizing non-conventional raw materials such as agricultural residues. Even though the utilization of such residues has not been common in countries with abundant forests and wood supply, there have been attempts to use these residues in North America. However, for countries like Iran, agricultural residues show excellent potential and, among them, sugarcane residues which are by-product of sugar extracting operation are unique. Bagasse is abundant, unused, and can be obtained at low cost. Its lignin content is low and its open structure will facilitate liquid penetration. However, it possesses two drawbacks: its open structure will adversely affect the strength and integrity of the fibers, and it is a seasonal by-product that is available only during a short period of time (Habibi *et al*., 2002).

Sugarcane is a seasonal growing plant and its harvesting period varies between 4 to 8 months, usually five months in Iran. Therefore, in order to satisfy the raw material requirements of a board plant, it must be collected and stored for the rest of the production period. Raw bagasse, which is

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acquired from sugar extracting mills, contains almost 50% moisture content (wet basis), pith and some residual sugar. This bagasse at 50% moisture will provide an excellent growth environment for microorganisms (Kollmann *et al.,* 1975) and growth of these microorganisms will deteriorate the quality of fibers and therefore the quality of final products. For this reason, suitable storage methods must be foreseen to minimize such deterioration.

Any storage method employed must eliminate the growth conditions for deteriorating agents. This is usually accomplished either by the elimination of oxygen or by lowering suitable moisture content. Two main storage methods which are commonly employed in the MDF and paper industries are dry or wet storage methods (Atchison, 1971). In the dry method, the elimination of moisture needed for microorganism growth is foreseen and, in the wet method, bagasse is soaked in water after moist depithing and compressed and consequently, the availability of oxygen is limited.

Either method possesses its limitations and advantages. The dry method requires prior drying of moist depithed bagasse to about 20% moisture content (MC) which requires energy and its space requirement is high. On the other hand, the wet storage method needs more water with its associated water pollution and expensive water treatment facilities and operational costs. The quality of the bagasse is preserved but some deterioration will occur.

The wet storage method is preferred in the paper industries and this preference is also applicable in MDF production facilities. However, because of the limited application of this method in MDF plants, some doubts still exist. Therefore, in this study, the influence of dry and wet storage methods on the quality of bagasse MDF is investigated.

MATERIALS AND METHODS

Sampling

Moist depithed bagasse was collected from the MDF moist depithing plant at Imam Khomeni Agro-Industrial Site near Shoshtar, in Southwest Iran. Sufficient bagasse was delivered to the MDF laboratory at the Wood and Paper Science and Technology Department in the Faculty of Natural Resources, University of Tehran.

Two storage methods (A) and five storage periods (B) of 0, 1, 2, 3, and 4 months and a total of 10 combinations of these two variables were investigated. Hence, the received bagasse was divided into ten equal weight batches, each sufficient to produce the fibers required for one combination of variables. Four batches were baled and kept under saturation conditions in fiberglass containers and, to avoid drying, the surface of the bales was frequently sprayed with fresh water. Another four batches were dried under laboratory conditions (to about 50% MC) and then baled. One batch was immediately used (zero storage time) without any drying or soaking. Other samples were used after the assigned storage periods and methods.

Board Making

Each bagasse sample was defibered according to the usual procedure in MDF plants as described below.

A laboratory steaming system which consists of one steaming vessel and one steam generating vessel was used for steaming the bagasse. A sufficient quantity of bagasse was transferred into the steaming vessel (dry bagasse was water sprayed to facilitate heat transfer) and saturated steam was then injected. After a short presteaming time to equalize the steam pressure and temperature inside the steaming vessel, the exhaust valve was closed and steam pressure built up at the start of steaming pressure and temperature. The steaming time started after reaching the

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steaming temperature and continued for 5 minutes. Two steaming temperatures (C) of 175°C (P= 6 bar) and 185°C (P= 8 bar) were used.

Cooked bagasse was discharged from the vessel and defibered using one 25 centimeter single disc laboratory atmospheric refiner. The refined fibers were air dried under laboratory conditions to reach equilibrium moisture content and then fluffed using a hand mixer. Final drying to 1.5% moisture content was achieved by drying at 110°C in an oven. Dried fibers were stored in sealed plastic bags until used.

Laboratory MDF boards of a 750 kg m^{-3} density and dimensions of 350×350×10 mm were produced using urea-formaldehyde resin (pH: 7.1, density: 1.28 gr cm^{-3}, viscosity: 15 seconds (>100 cp) and 55% solids). Dried fiber (1.5% MC) was blended with 12% resin (dry basis) and then carefully hand formed using a wooden forming frame. Fiber mats were pressed at 175°C for five minutes at a maximum press pressure of 35 kg cm^{-2}. Press closing time was kept constant at 4.5 mm s^{-1}. All boards, after leaving the press, were cooled and stored at room temperature until trimmed to their final dimensions of 300×300 mm.

For each combination of variables (storage method, storage period, and steaming temperature), three boards and a total of 60 boards were made.

Testing

Test samples were prepared from each board and tested according to the following standards.

All mechanical tests, including static bending (MOR and MOE) and internal bond (IB), were performed based on DIN 67863 (DIN 1965) test methods using an Instron Model 4486 universal testing machine. The measurements of physical properties ($WA_{2,24}$ and $TS_{2,24}$) were performed according to ISO 16983 (ISO 2003). The average value for each property and each combination of variables was calculated and reported.

Statistical Analysis

A factorial experiment with a completely randomized design was used for the analysis of variance (ANOVA) of the data and Duncan's Multiple Range Test (DMRT) was used for differentiation and classification of the averages.

RESULTS AND DISCUSSION

The results of the ANOVA test on the effect of different variables including the storage method, storage period, and steaming temperature on both the mechanical and physical properties of bagasse MDF are summarized in Table 1, which shows the significance at either 5% or 1% level. In the following sections, the mechanical and physical properties of these boards will be presented separately.

Mechanical Properties

Table 1 shows that the influence of storage method (A) and storage period (B) and the combined effect of A and B on MOR and MOE of bagasse MDF is significant at a 1% level. However, the effect of the storage method and period on IB is not significant and only the combined effect of these variables on IB was significant at a 1% level.

The results of the MOR and MOE measurement of MDF produced from either dry or wet stored bagasse is shown in Figure 1, which indicates the higher values for both MOR and MOE of boards produced from dry stored bagasse since, after baling, dry stored bagasse loses its moisture and dries rapidly. Therefore, sufficient moisture is not present to cause the deterioration of bagasse.

In the wet storage method, the outer parts of the bales lose moisture to below saturation. This level of moisture will provide sufficient oxygen for the growth of microorganisms. For this reason, the dete-

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Table 1. The results of ANOVA test on the effect of variables on bagasse MDF properties.

S.O.V	Df	Mean squares						
		MOR[d] (MPa)	MOE[e] (MPa)	IB[f] (MPa)	WA (%)[g] (2 hrs.)	WA (%) (24 hrs.)	TS (%)[h] (2 hrs.)	TS (%) (24 hrs.)
A[a]	1	153.6**	557384.8**	0.008n.s	48.7n.s	38.6n.s	4.8n.s	31.9**
B[b]	4	126**	1155410**	0.112**	233.9**	76.4*	54.3**	15.7**
A×B	4	43.4**	220163.8**	0.015n.s	67.4n.s	31.7n.s	8n.s	9.1**
C[c]	1	754.9**	6286254**	0.017n.s	138.5+	28.8n.s	37.9**	15.4**
A×C	1	21.2*	366132.8*	0.006n.s	2.4n.s	7.7n.s	0.14**	0.1n.s
B×C	4	15*	88949.4n.s	0.005n.s	215.6**	67.6+	42.6**	11.3**
A×B×C	4	5.9n.s	105801.2n.s	0.016n.s	117.8*	40.9n.s	23**	7.5**
Error	40	4.9	57207.6	0.007	39	28.2	3.8	1.8
C.V%		10.1	10.47	25.26	11.03	7.3	11.23	5.82

[a] Storage method; [b] Storage period; [c] Steaming temperature; [d] Modulus of Rupture; [e] Modulus of Elasticity; [f] Internal Bond; [g] Water Absorption, [h] Thickness Swelling.

n.s= non significant; += Significant (10%); *= significant (5%), **= Significant (1%).

Table 2. Means comparison[a] of the effect of storage time on bagasse MDF properties.

B[b] (month)	Investigated properties						
	MOR (MPa)	MOE (MPa)	IB (MPa)	WA (%) (2hrs.)	WA (%) (24hrs.)	TS (%) (2hrs.)	TS (%) (24hrs.)
0(B_1)	27.65 a	2828 a	0.49 a	62.44 a	76.63 a	19.29 a	22.95 b
1(B_2)	20.85 b	2115 b	0.31 b	58.51 a	73.79 ab	19.41 a	24.72 a
2(B_3)	20.37 b	2132 b	0.33 b	52.17 b	70.56 b	16.26 b	23.07 b
3(B_4)	19.74 b	2091 b	0.3 b	52.25 b	71.01 b	14.37 c	21.55 b
4(B_5)	20.97 b	2254 b	0.23 c	57.89 a	71.51 b	17.11 b	22.58 bc

[a] The means with minimum common letter are not significantly different (p<o.o5) according to Duncan's multiple range test.
[b] Storage time.

rioration rate with the wet storage method is higher than with the dry storage method.

The storage time is an important factor in the industrial utilization of bagasse. For this reason, the result of the means comparison (DMRT) test for storage times is summarized in Table 2, and shown in Figure 2. It shows the higher strength values for boards produced from fresh bagasse (non-stored bagasse) and that storage will reduce these properties. However, the storage period of 1 to 4 months did not influence MOR, MOE or IB and all values remained statistically similar. Steaming temperature significantly reduced both MOR and MOE and increasing the steaming temperature from 175°C to 185°C adversely affected both MOR and MOE (Figure 3), but not IB.

In addition, the results show that MOR and MOE of MDF made from fibers prepared at 175°C were higher than those of MDF made from fibers prepared at 185°C (Figure 3). Increasing the steaming temperature will accelerate hydrolysis reactions of chemical components and reduce the degree of polymerization of cellulose and hemicelluloses (Faraji, 1998; Habibi *et al.,* 2002; Widsten *et al.,* 2003). Therefore, fiber yield decreases and fiber strength reduces which, as a result, decreases the MOR, MOE and IB of MDF.

Table 3 and Figures 4, 5 and 6 show that the highest MOR (29.7 MPa.), MOE (3,127 MPa.) and IB (0.52 MPa.) of MDF is achieved by using fresh bagasse and a steaming temperature of 175°C. At the other extreme, the lowest values for MOR (11.2 MPa.), MOE (1349 MPa.) and IB (0.21 MPa.) correspond to wet bagasse stored for 3 months and a steaming temperature of 185°C.

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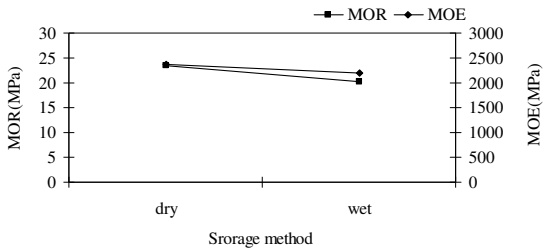

Figure 1. Influence of storage method on MOR and MOE of MDF panels.

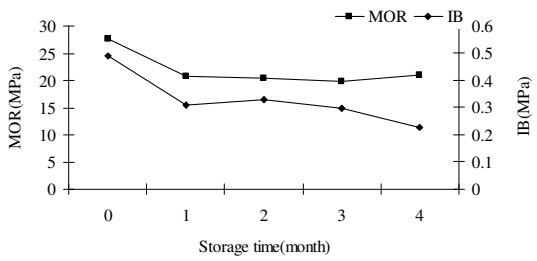

Figure 2. Influence of storage time on MOR and IB of MDF panels.

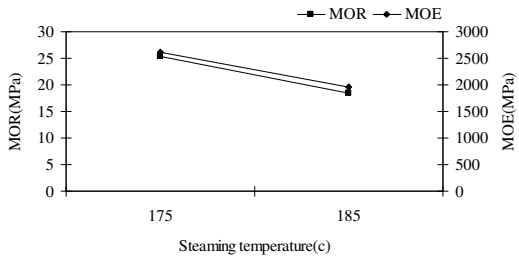

Figure 3. MOR and MOE changes with the increased steaming temperature.

Physical Properties

Table 1 also shows the effect of variables on the physical properties of the boards. The influence of storage method on both water absorption and thickness swelling was not significant, but the effect of storage time on thickness swelling after two hours was significant at 1% level (Table 3 and Figure7). The maximum TS was related to MDF made from fresh bagasse and increasing the storage time reduced water absorption of the boards.

The influence of storage method on water absorption was not significant, but the influence of storage time on WA_2 was significant at a 1% level and on WA_{24} at a 5% level (Table 2). Bagasse fibers, because of their high sugar, cellulose and hemicellulose content contain many hydroxyl groups which absorb water. In fresh bagasse and at the beginning of storage, more carbohydrates are present and therefore the rate of water absorption and thickness swelling of boards will be higher, but the reduction of the amount of these compounds in fibers upon

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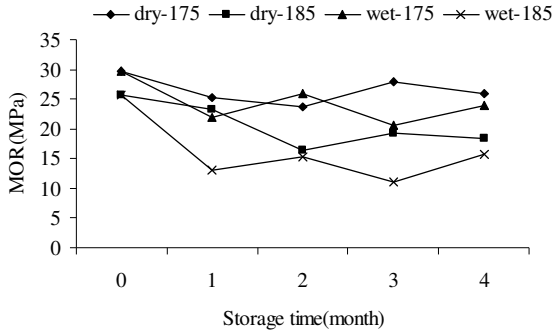

Figure 4. Influence of storage method, storage time and steaming temperature on MOR of MDF panels.

storage and of microorganism activities will decrease WA and TS.

Table 2 shows that there is significant difference between wet and dry storage methods on TS of MDF. The TS of MDF made from wet stored bagasse is lower than those of MDF made from dry stored bagasse (Figure 8). Wet stored bagasse was water sprayed regularly, and this causes washing out of part of the pith. Furthermore, because, dry stored bagasse loses moisture and dries rapidly and, for a short time after baling, wet stored bagasse also loses moisture to a point lower than saturation point and this phenomenon creates appropriate conditions for microorganism attack. Therefore, because of fiber deterioration and reduction in carbohydrate content, the WA and TS of MDF made from wet stored bagasse is lower than those of MDF made from dry stored bagasse.

Table 2 shows there is a significant difference between the two steaming temperatures. TS of MDF made from fibers prepared at a steaming temperature of 185°C is lower

Table 3. The results of DMRT of all combinations of variables on bagasse MDF properties.

treatments			Investigated properties						
A[a]	B[b]	C[c]	MOR (MPa)	MOE (MPa)	IB (MPa)	WA (%) (2hrs.)	WA (%) (24hrs.)	TS (%) (2hrs.)	TS (%) (24hrs.)
Dry	0	175	29.7 a	3127 a	0.52 a	59.7 abcde	72.4 abc	19.7 abcd	23.6 bcd
		185	25.6 abc	2528 b	0.46 ab	65.2 ab	80.9 a	18.9 bcd	22.3 cdef
	1	175	25.2 bc	2313 bc	0.34 bcde	59.2 abcde	75.2 abc	20.8 abc	26.2 a
		185	23.2 cde	2393 bc	0.42 abc	48 ef	69.1 bc	16.1 defg	22.9 cde
	2	175	23.7 bcd	2413 bc	0.31 bcde	45.2 f	72.2 abc	14.5 efgh	24.3 abd
		185	16.4 gh	1787 de	0.29 cde	57.6 abcde	72.5 abc	19.3 abcd	23.2 bcd
	3	175	27.9 ab	2714 ab	0.27 cde	52.9 cdef	70.5 abc	14.7 efgh	24 abcd
		185	19.3 efg	1964 cd	0.33 bcde	51.2 cdef	74.6 abc	15 efgh	23.1 bcd
	4	175	25.8 abc	2563 b	0.31 bcde	53.2 bcdef	72 abc	14.5 efgh	22.7 cdef
		185	18.3 fg	2002 cd	0.18 e	65.3 ab	75.7 abc	22.3 ab	24.7 abs
Wet	0	175	29.7 a	3127 a	0.52 a	59.7 abcde	72.4 abc	19.7 abcd	23.6 bcd
		185	25.6 abc	2528 b	0.46 ab	65.2 ab	80.9 a	18.9 bcd	22.3 cdef
		175	21.9 cdef	2319 bc	0.26 cde	59.7 abcde	74.2 abc	17.9 cde	24.2 abcd
		185	13 hi	1435 ef	0.23 de	67.1 a	76.7 ab	22.8 a	25.6 ab
	[illegible]	175	26 abc	2577 b	0.35 bcd	51 cdef	71.3 abc	14 fgh	24.3 abc
		185	15.3 gh	1750 def	0.36 abcd	54.8 bcdef	66.3 bc	17.3 cdef	20.4 ef
	[illegible]	175	20.6 def	2339 bc	0.40 abc	60.6 abcd	73 abc	16.3 defg	21.6 def
		185	11.2 i	1349 f	0.21 de	44.3 f	65.9 c	11.5 h	17.5 g
	[illegible]	175	24 bcd	2586 b	0.21 de	50.1 def	67 bc	12.9 gh	20.2 f
		185	15.7 gh	1867 d	0.21 de	62.9 abc	71.4 abc	18.8 bcd	22.7 cdef

[a] Storage method; [b] Storage time, [c] Steaming temperature.

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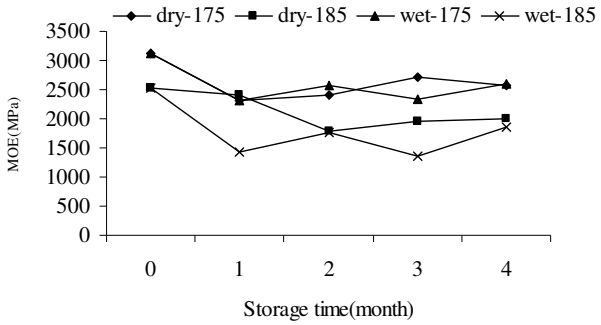

Figure 5. Influence of storage method, storage time and steaming temperature on MOE of MDF panels.

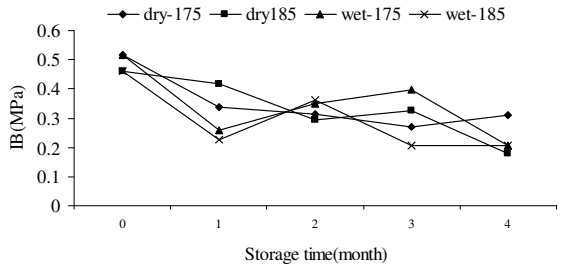

Figure 6. Influence of storage method, storage time and steaming temperature on IB of MDF panels.

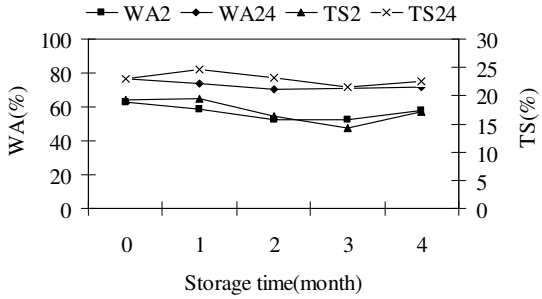

Figure 7. WA and TS (after 2 and 24 hours) changes with the increased storage time.

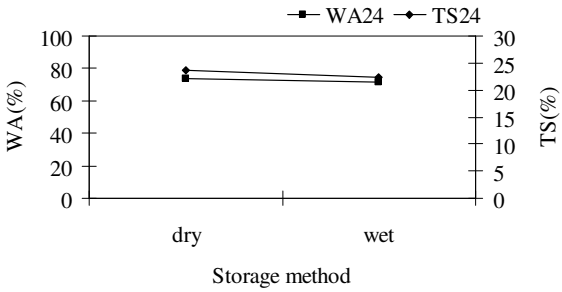

Figure 8. WA and TS (after 24 hours) changes with the changed storage method.

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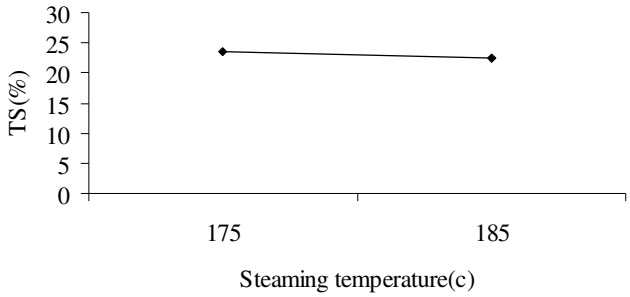

Figure 9. TS (after 24 hours) changes with the increased steaming temperature.

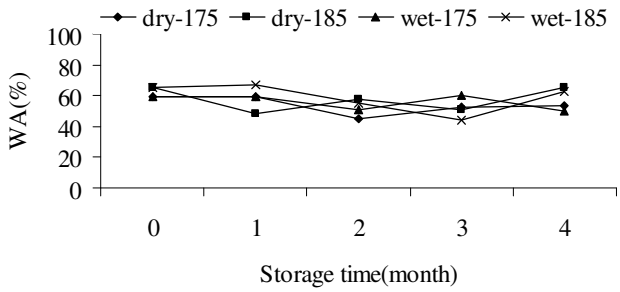

Figure 10. Influence of storage method, storage time and steaming temperature on WA after two hours.

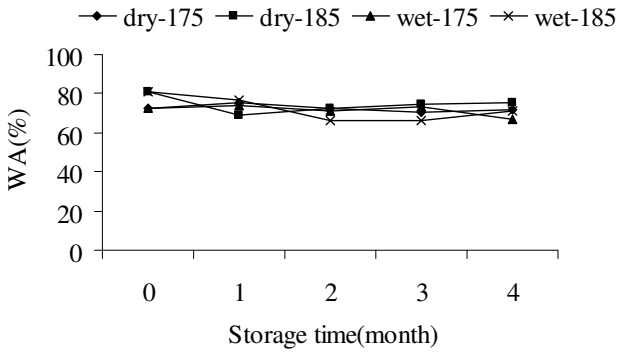

Figure 11. Influence of storage method, storage time and steaming temperature on WA after 24 hours.

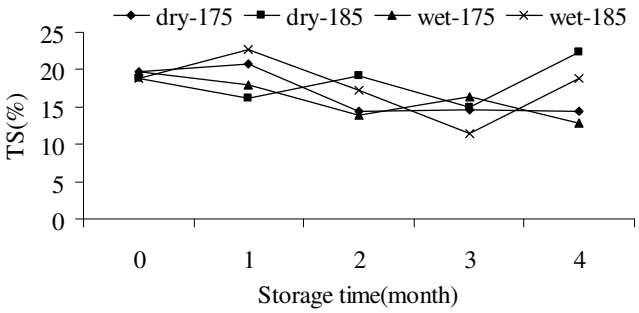

Figure 12. Influence of storage method, storage time and steaming temperature on TS after two hours.

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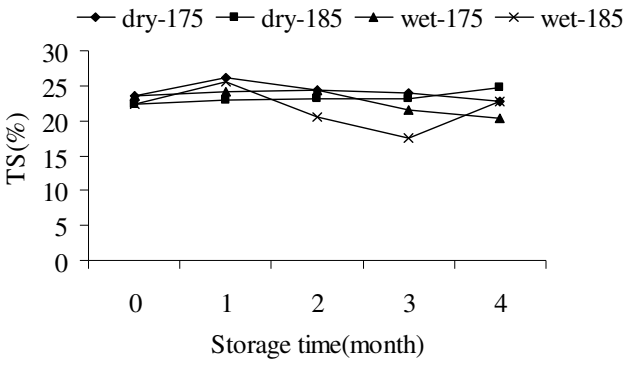

Figure 13. Influence of storage method, storage time and steaming temperature on TS after 24 hours.

than those of MDF made from fibers prepared at a steaming temperature of 175°C (Figure 9). Increasing steaming temperature causes an increase in hydrolysis and carbohydrate deterioration (especially hemicelluloses) which plays the most effective role in WA of wood panels (Faraji, 1998; Habibi 2002; Widsten *et al.,* 2001).

In addition, Table 2 shows there is a significant difference between the effects of storage method, storage time and steaming temperature on WA and TS of MDF. Minimum WA after 2 and 24 hours (44.4% and 65.9%) and minimum TS after 2 and 24 hours (11.5% and 17.5%) were related to MDF made following wet storage for a three-month and 185°C steaming temperature combinations (Table 4 and Figures 10, 11, 12, 13). These results are in conformity with results attained by Faraji (1998), Habibi *et al.* (2002) and Lee *et al.* (2004).

CONCLUSION

MDF made from fresh bagasse and fibers prepared at a 175°C steaming temperature showed the highest MOR (29.7 MPa.) which is higher than the values of 23.4, 12.2 and 13.0 MPa obtained by Faraji (1998), Habibi *et al.* (2002) and Lee *et al.* (2004), respectively.

MDF made from fresh bagasse and fibers prepared at a 175°C steaming temperature also showed the highest MOE (3,127 MPa.). This is also higher than 1,936, 1,370 and 1,578 MPa measured by Faraji (1998), Habibi *et al.* (2002) and Lee *et al.* (2004), respectively.

Furthermore, MDF made from fresh bagasse and fibers prepared at a 175°C steaming temperature had highest internal bond (0.517 MPa.), which was higher than 0.38, 0.13 and 0.311 MPa. for MDF made by Lee *et al.* (2004), Habibi *et al.* (2002) and Faraji (1998), respectively. Therefore, the best variable combinations to reach highest mechanical strength will be fresh bagasse, or that dry stored at the shortest storage time, and the lower steaming temperature (175°C).

However, MDF made from wet stored bagasse showed better physical properties than those of dry stored bagasse. Furthermore, the physical properties of MDF were improved by increasing storage time and also by increasing the steaming temperature. Therefore, if better water resistance properties are desired, the best combination of variables will be the wet storage method, longer storage time and higher steaming temperature.

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ویژگیهای تخته فیبر دانسیته متوسط ساخته شده از باگاس ذخیره شده به روش خشک و تر

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چکیده

با استفاده از باگاس‌های مغززدایی شده ذخیره شده به روش خشک‌وتر، تخته فیبر با دانسیته متوسط (MDF) ساخته شد.در این بررسی از مدت زمان ذخیره‌سازی ۰ تا ۴ ماه و دمای بخارزنی در دو سطح ۱۷۵ و ۱۸۵ درجه سانتیگراد استفاده گردیده و بعد از ساخت تخته‌های MDF، خواص مکانیکی و فیزیکی آنها مورد بررسی و مقایسه قرار گرفت. نتایج نشان داد که خواص مکانیکی تخته‌های ساخته شده از باگاس تازه (بدون ذخیره‌سازی) و دمای بخارزنی ۱۷۵ درجه سانتیگراد نسبت به بقیه تیمارها بالاتر بوده و مقادیر ۲۹/۷ Mpa ، ۳۱۲۷Mpa و ۰/۵۲ Mpa بترتیب برای MOR، MOE و IB آنها بدست آمد. اما بهترین خواص فیزیکی برای تخته‌های ساخته شده از باگاس ذخیره شده به روش تر به مدت سه ماه و دمای بخارزنی ۱۸۵ درجه سانتیگراد به دست آمد که مقادیر آن نیز برای WA_2، WA_{24}، TS_2 و TS_{24} به ترتیب برابر با ۴۴/۳۴ ٪ ، ۶۳/۸۹ ٪ ، ۱۱/۴۸ ٪ و ۱۷/۵۵ ٪ محاسبه شد.

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