EFFECT OF MIXING THREE LIGNOCELLULOSIC MATERIALS ON SOME PROPERTIES OF PARTICLEBOARD BONDED WITH UREA FORMALDEHYDE ADHESIVE

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ABSTRACT

This study investigated the effect of blending different proportions of three lignocellulosic materials available in Sudan on the properties of particleboards made using urea-formaldehyde. The three lignocellulosic materials used were sun sawdust (*Acacia nilotica*), bagasse and cotton stalks particles. They are waste materials of widely cultivated species in Sudan. They were collected at the beginning of 2004 from EL Suki sawmill, El Gunied sugar factory and the fields of El Kamlin state, respectively. Ten different mixtures of the three lignocellulosic materials (Nine homogenous, and one layered) of urea formaldehyde resin-bonded particleboards were manufactured under laboratory conditions at the end of 2005. Department of Forestry and Wood Technology, Faculty of Agriculture, Alexandria University, Alexandria, Egypt. The results of this study concluded that particleboard panels adequate mechanical and dimensional stability properties can be produced from each three lignocellulosic materials. The addition of bagasse particles to sunt sawdust or cotton stalks or to mixtures of them improved the properties of particleboards made of their mixtures. Mixing particles of the three lignocellulosic materials improved the properties of produced particleboard panels by increasing the values of mechanical properties and decreasing the values of dimensional stability properties. The particleboards made complied with the specifications of European standard and they fulfilled the requirement for general purpose boards for use in dry conditions, and for interior fitments (including furniture). Also they met the requirements for non-load bearing boards for use in humid conditions and for load bearing boards for use in dry conditions. These appears to be no problem in combining bagasse particles with sunt or with cotton stalks particles or blending those all in different proportions to produce homogeneous or layered resin-bonded particleboard. Further investigation about optimum conditions of particle geometry, adhesion and pressing condition of the three lignocellulosic materials are needed to improve the board quality, especially for boards from pure cotton stalks particles.

***Key Words*: Lignocellulosic materials, sunt, bagasse, cotton stalks, mechanical properties, dimensional stability, European standard.**

INTRODUCTION

Wood is the most commonly used natural raw material. It is still a widely used structural material in the world because it is comfortable for human life. It serves as a raw material for wood composites such as plywood, particleboard and fiberboard. However, since it is a natural material, it has several drawbacks, such as liability to checks, formation of knots, limited widths and variability in performance along and across the grain. In order to avoid such defects and to enhance the quality, wood composites or wood-based materials are developed.

A strong growth of the wood-based panels industry has been reported in the recent literature. **Cullity** (1988) mentioned that panel production has doubled during the period 1965-1985 from 42 million cubic meters to 109 million m^3. Particleboard in particular exploded from 9 million m^3 in 1965 to 44.5 million m^3 in 1985. The total production of wood-based panels was 24 million cubic meters in 1989 within the European Economic Community, of which 83% was particleboard. The total consumption of wood-based panels was 30 million cubic meters of which 70% was resin-bonded particleboard (**Dinwoodi.** 1979). **F.A.O.** (2002) reported that the production of particleboard in Europe for the year 2001 was 37.21 million cubic meters and for North America was 31.56 million m^3. The total production of particleboard by year is expected to be 41.63

million m^3 in Europe and 33.08 million m^3 in North America (**Anonymous**, 2004). The consumption of wood-based panels was projected to be 2375 thousands m^3 in Africa in the year 2010 and 6000 m^3 in the Sudan. The consumption of particleboard in Africa was projected to be about 562 thousands m^3 (**Anonymous,** 2003).

The supply of wood which so far has been the common raw material for particleboard manufacture has become problematic (**Vermass**, 1981). **Fuller** (1987) mentioned that the raw material prices are climbing due to decline in wood supply. Despite the extensive forest areas in many parts of the world, and the improved management of forests, the merchantable yield is still finite. Against the constantly increasing population and the resulting escalating demand for wood-based products, the supply may run short of meeting the demand. In particleboard industry efforts are being intensified to find other suitable substitutes for wood (**Lehmann** 1970, **Kandeel** *et al.* 1988, **El-Osta *et al.*,** 1988, **El-Mously** *et al.*, 1999, and **El-Johany *et al.*,** 2003). Apart from the utilization of biomass (hogged–up total bush and thinning produce including leaves) and bark, large quantities of agricultural residues and annual plants have been tried.

The main long–term trends according to **Fuller** (1985) have been for the non-wood lignocellulosic materials to substitute for wood. This substitution has been encouraged by either the cost of wood or the technological inability of wood to perform in certain end-uses. In recent years, following the reduction in timber resources and degradation of global environment, effective utilization of thinning, fast growing resources and agricultural residues such as bagasse has gained increasing importance. **Kozlowski *et al.*** (1994) stated that the shortage of wood together with a need for waste utilization and availability of an annual abundance of plant residues inspired the production of boards from plant residues. These residues are especially appreciated in places where wood resources are few or limited. One of the advantages of the boards produced from plant residues is the possibility of producing a wide spectrum of densities ranging from 300 to 750 Kg.m^{-3}.

For the production of particleboard from annual plant residues, urea-formaldehyde or urea-melamine formaldehyde synthetic resins are mainly used. Several attempts were made in the past to mix different types of raw materials for making particleboard (**Coleman and Biblis**, 1976, **and Hse**, 1983, **EL-Osta *et al.***, 1988 and 1991**, Wojcik *et al.***, 1989, **El-Mousely *et al.***, 1999 and **Ashori and Nourbakhsh, 2008**). This was done to make use of lignocellulosic residues and or to improve or modify the quality of particleboard. **Mohamed (1989)** reported that particleboard can be manufactured from non-wood lignocellulosic materials with excellent properties.

The objectives of this study were to evaluate the effect of mixing different lignocellulosic materials available in Sudan on the properties of urea-formaldehyde bonded particleboard and to compare their properties to the minimum property requirements specified in the commercial standards for mat-formed particleboards.

MATERIALS AND METHODS

Raw materials

Three lignocellulosic materials (LCM's), namely bagasse, cotton stalks and *Acacia nilotica* (sunt) sawdust were used in this study (from the beginning 2004 to the end 2005) as raw materials available in Sudan. Bagasse is a cellulose containing residue. It is a by-product of the sugar industry after extraction of sugar from the cane. Cotton (*Gossupium spp.*), is one of the oldest cultivated plants in Sudan. *Acacia nilotica* is a wide spread species in the northern part of tropical Africa. In the Sudan there are many small forests of *Acacia nilotica* along the Nile in the Blue Nile and Senar states. The LCM's used in this study are collected from EL Gunied sugar factory, northern Gezera. Kamlin state and EL Suki sawmills (age of the trees was ranged between 8-13 years) for bagasse, cotton stalks and sunt. respectively. Commercial urea-formaldehyde in solution (60% resin solid content) produced by Ratinj King Company. Alexandria. Egypt was used as adhesive.

Preparation of the lignocellulosic materials

In Sudan, sunt and bagasse were processed by a hammermill, while cotton stalks were processed first in a chipper then hammermilled. These lignocellulosic materials were screened using laboratory sieves to remove the oversize, fines and other impurities. The particles which passed a sieve hole size of 4-mm and were retained on a sieve size of 1-mm, were used for particleboard production (Fig. 1). One hundred kilograms were taken from each material of the dried particles, put in a polyethylene bag and transferred to the Wood Testing Laboratory, Faculty of Agriculture, Alexandria University, Egypt and stored until used for manufacturing of the boards.

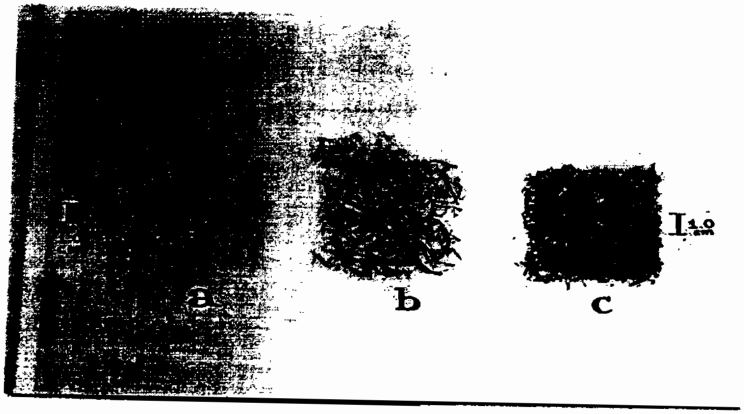

Fig. 1.The particle sizes of the three lignocellulosic materials used for resin-bonded particleboard manufacture (a-bagasse particles, b-cotton stalks particles and c- sunt sawdust.

Chemical analysis of lignocellulosic materials

The total extractive and lignin contents of the three lignocellulosic materials were determined according to ASTM Designation (ASTM D1037, 1989) at the Wood Testing Laboratory, Forestry and Wood Technology Department, Faculty of Agriculture, Alexandria University, Egypt.

Board manufacturing

To obtain a board (30 cm x 30 cm x 1.2 cm) with a target density of 700 Kg.cm^{-3}, 786.24 grams (oven-dry weight) of the lignocellulosic material were mixed with 126 grams of urea-formaldehyde resin using a laboratory type blender. The blender was designed and manufactured at Faculty of Agriculture. Alexandria University. To reach the final moisture content for the mattress (13%), the required amount of water was calculated and added. The mixture was blended for about 6 minutes to ensure thorough resination of the particles. Immediately, the resinated particles were hand felted into a wooden forming frame on a caul plate. Thereafter, the frame was removed and the mattress with its enclosed stainless steel caul plates (30 cm x 30 cm) were wrapped with aluminum foil and transferred to the hot press. The mat was pressed at 150 °C pressing temperature for 2.5 minutes using Carver laboratory press, model 2699. The pressure used was 27.8 Kg/cm^2. The boards were then placed at 65±5% relative humidity and 20 °C to reach equilibrium moisture content. Ten mixes of boards (Table 1) each replicated three times were manufactured (30 boards in total). Other manufacturing variables of resin-bonded particleboard in this study were:

1- Resin type: Urea-formaldehyde (UF), with resin solid content 60%.

2- Hardener: Ammonium chloride (1% of solid resin).

3- Pressure time: 12 seconds per mm of thickness, closure time: one minute.

4- Number of mixes and panel type: 10 (Nine homogenous and one layered).

Table 1. Different mixtures of the three lignocellulosic materials used in the study.

Board type	Bagasse %	Cotton stalks %	Sunt %
M1	100	0	0
M2	0	100	0
M3	0	0	100
M4	50	50	0
M5	50	0	50
M6	0	50	50
M7	25	25	50
M8	25	50	25
M9	50	25	25
M10	Core 50 % cotton stalks, face and back equal mixtures of bagasse (25%) and sunt sawdust (25%).		

Static bending test and internal bond:

The test specimens for static bending test were prepared and tested in accordance with the American Standard for Testing and Materials (**ASTM D-1037**, 1989) with some modifications due to the limited size of boards. The dimensions of the specimens were 25x5 x1 cm. The test was carried out using Lloyd testing machine. Modulus of rupture (MOR) and modulus of elasticity (MOE) were calculated from produced the curves.

The Internal bond (IB) specimens were 5x5 cm and had the same thickness of the boards. The samples were adhered with a hot melt adhesive from both their upper and lower faces with a couple of aluminum jaws. The jaws were manufactured to fit the accessories of the Instron Testing Machine (Model 1195) parts assigned for internal bond test.

All testes were carried out at the Wood Testing Laboratory, Forestry and Wood Technology Department, Faculty of Agriculture, Alexandria University, Egypt.

Specific gravity and moisture content of the boards:

After static bending test, specific gravity and moisture content sample from each replicate of boards were cut from the ends of the bending specimens. and then the samples were prepared and determined according to **EN-323** (1993) and **ASTM D-1037** (1989), respectively.

Dimensional stability of resin-bonded particleboard:

The dimensional stability tests i.e. water absorption (WA) and thickness swelling (TS) were evaluated from equilibrium condition to water soak condition after immersed in water for 2 and 24 hours. This test was carried out as specified by the European standard **EN 323** (1993). The test pieces were squares with a side length of 50 ± 1mm, which were immersed in a water bath at room temperature for two hours, then were taken out and weighed. The samples were then soaked again to complete 24 hours immersion time. The results of WA and TS after 2 and 24 hours were expressed as a percentage of the original **dimensions.**

Experimental design and statistical analysis

Representative samples of resin-bonded particleboard were randomly chosen from the manufactured boards. The specimens were chosen for testing their properties using the completely randomized design (**Steel and Torrie** 1989). Analysis of variance (ANOVA) and Duncan's Multiple Range Test were conducted to study the significance of the differences among treatments using Statistical Analysis System (**SAS**, 1990).

RESULTS AND DISSCUSION

Extractive and lignin contents

Average values of the results of the total extractive and lignin content determination of the three lignocellulosic materials are shown in Table (2). Bagasse particles attained the highest extractive content (16.81%) followed by cotton stalks particles (12.05%) and then sunt sawdust (5.44%). Although the extractive content of sun sawdust was low (5.44%), still it is in agreement with **Haroun** (1995). Table 2 indicates that there are no significant differences were found between the three lignocellulosic materials in lignin content. Since the lignin content of the three lignocellulosic materials is almost identical, it is more unlikely to have had serious effects on particleboard properties.

Table 2. Average values* of chemical analysis of the three lignocellulosic materials used in the current study.

Type of Material	Extractives Content (%)	Lignin Content (%)	Hot water solubility (HWS)	
			HWS (%)	pH
Bagasse particles	16.81^{a}	22.80^{a}	19.17^{a}	5.53^{a}
Cotton stalks particles	12.05^{b}	23.16^{a}	17.27^{b}	6.49^{b}
Sunt sawdust	5.44^{c}	22.50^{a}	7.41^{c}	5.87^{a}

Each value is an average of 6 samples.

* Means with the same letters in columns are not significantly different at 5% level of probability according to Duncan Multiple Rang Test.

Mechanical properties of the boards

The analysis of variance indicated that differences in MOR and MOE were highly significant (P= 0.0001). The averages of mechanical properties of particleboard made from different mixtures of wood and non-wood lignocellulosic materials are presented in Table 3. It can be noted from this Table and Fig. (2) that the highest MOR value (21.73 N.mm^{-2}) was observed with board type (M5), followed by board type (M10) of 21.3 N.mm^{-2}. The lowest MOR value (10.58 N.mm^{-2}) was reported with board type (M2). This low MOR value is probably due to the thicker flakes were used in this study (**Vital *et al.***, 1974 and **Shuler**, 1974). The values of modulus of rupture are in line with previous research results of **Gertjejansen** (1977), **Kozlowski *et al.*** (1994), and **El-Osta *et al.*** (1991). Nine out of ten MOR values of the boards made, complied with the specifications of European standard (**EN-312**, 2003). They fulfilled the requirement for general purpose boards for use in dry conditions (Type p1), for interior fitments (including furniture) for use in dry conditions (Type p2). Also they meet the requirements for non-load bearing boards for use in humid conditions (Type p3) and for load bearing boards for use in dry conditions (Type p4). The only one board type which is below this standard is board type (M2) which is 100 % cotton stalks particles. The result for boards made of pure cotton stalks particles in the current study is a disagreement with the finding of **El-Mously *et al.***, (1999) where they found that the MOR values of one-layer particleboard made of cotton stalks under different process parameters (board type, glue level and press level) ranged between 11.48 and 18.77 N.mm^{-2}.

With regard to modulus of elasticity (MOE) values, it is clear from Table (3) and Figure (3) that there are large variations among the ten board types produced, which ranged between 2199.05 and 5895.39 N.mm^{-2} for board type M9 and M1, respectively. MOE values of the entire laboratory fabricated board types are higher than the minimum requirements (2000 N.mm^{-2}) specified by the **EN-312** (2003). Some values are slightly higher than values were reported in previous research results of a similar nature. This can be explained as a result of the smaller observed board thicknesses as compared to the targeted thicknesses. Lack of thickness valves or suitable stoppers in the press has led to these variations.

Table 3. Mean values* of modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB), moisture content (MC) and specific gravity (SG) of one-layer particleboard made from mixtures of the three lignocellulosic materials.

Board Type**	MC at test (%)	SG+	Mechanical properties (N.mm-2)		
			MOR	MOE	IB
M1	8.413	0.898	18.82^{AB}	5895.39^{A}	0.60^{F}
M2	8.150	0.754	10.58^{D}	3017.88^{DE}	0.74^{EF}
M3	8.053	0.832	16.56^{B}	5372.79^{A}	1.99^{A}
M4	8.065	0.767	15.93^{BC}	3506.17^{CD}	1.28^{CD}
M5	7.143	0.901	21.73^{A}	5616.98^{A}	1.68^{B}
M6	8.303	0.831	19.66^{AB}	4463.12^{B}	1.52^{BC}
M7	7.483	0.860	16.46^{B}	4074.96^{BC}	1.48^{BC}
M8	8.590	0.816	16.17^{CD}	2862.65^{EF}	0.89^{E}
M9	7.540	0.840	18.27^{AB}	2199.05^{F}	1.21^{D}
M10	9.150	0.810	21.32^{A}	3511.53^{CD}	0.90^{E}

* Means with the same letters in columns are not significantly different at 0.05 level of probability according to Duncan Multiple Range Test.

** Board types from M1to M9 homogeneous and M10 layered. for legend see Table (1).

\+ Based on oven-dry weight and volume at test.

Each value is an average of 3 samples for mechanical properties and 6 samples for SG and MC.

As far internal bond (IB) is concerned, the analysis of variance showed that the differences in internal bond were highly significant (P = 0.0001). Table 3 gives the mean values of IB of different types of particleboard made from mixing the three lignocellulosic materials. It is clear from this Table that the highest IB values were noticed with boards having higher proportions of sunt sawdust. The pure sunt boards (type M3) attained the highest IB value which is 1.99 N.mm^{-2}, followed by (type M5), of 1.68 N.mm^{-2}. The boards types M1 (100% of bagasse particles) and M2 (100% cotton stalks particles). attained the lowest values (0.60 N.mm^{-2} and 0.74 N.mm^{-2}, respectively). This could be due to particle geometry. particle distribution and resin distribution. However, as had been mentioned by many researchers, the efficiency of the resin depends on its properties, but its distribution on the particles and its contact with adjacent particles are more practically considered to affect internal bond strength properties in particleboard (**Post 1958, Lehman** 1970, **Shuler** 1974 and **Generalla** ***et al.*** 1989). The effect of resin distribution was notable with bagasse particles. Since bagasse is light in weight, its bulky volume in the blender rendered the even distribution of the resin very difficult. Even when reduced volumes are blended in batches, several small balls are usually formed. The properties of boards produced can also be affected by factors other than the type of raw material. Among the major factors that affect the properties of particleboard are type and size of particles, type and amounts of binder, additive used, and board specific gravity. Thorough investigation of the various factors has led to a continuous improvement of particleboard quality (**Kollman** ***et al.,*** 1975).

The improvement in IB of the boards in this work is probably due to the increases in the bonding quality which resulted from reduction of the board density. The same result was reported by **El-Osta** ***et al.*** (1991) for particleboard made from mixing casuarinas particles with flax shives in the face and back layers, they found that mixing particles caused reduction of the density of the board and hence increase the bonding quality which in turn improves the properties of the board.

The internal bond strength of all board types exceeded the minimum standard specifications set by **EN-312** (2003) for general purpose boards, boards for interior fitments as well as boards intended for load and non-load bearing for use in dry and humid conditions.

Generally, from the obtained results it can be told that all particleboard panels manufactured from each pure of the three lignocellulosic materials (100%), satisfy the requirements of **EN-312** standards, except boards made of pure cotton stalks in MOR (10.58 $N.mm^{-2}$). So that particleboard panels with adequate mechanical and dimensional stability properties can be produced from each three lignocellulosic materials used in this study. Mixing particles of the three lignocellulosic materials improved the properties of produced particleboard panels by increasing the values of mechanical properties and decreasing the values of dimensional stability properties.

Boards made from mixing of bagasse and sunt particles (50% for each) resulted in a significant increase of all mechanical properties of the boards produced (MOR, MOE and IB) as compared to other pure mixtures. Other studies (**Kelly** 1977 and **Wojcik** ***et al.*** 1989) have also demonstrated the advantages achieved by mixing wood species. These improvements of particleboard quality by mixing the three lignocellulosic materials can be attributed to the density of raw material and compaction ratio (**Vital** ***et al.*** 1974 and **Geimer** 1982).

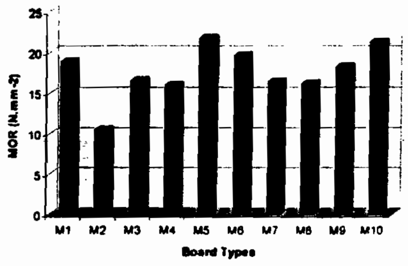

Fig. 2. Modulus of rupture* (MOR) for particleboard panels made from different mixtures of three lignocellulosic materials.

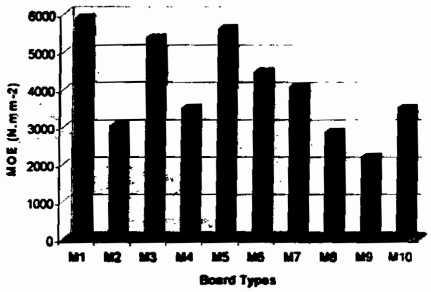

Fig. 3. Modulus of elasticity* (MOE) for particleboard panels made from different mixtures of three lignocellulosic materials.

*** For legend of board types from M1 to M10 see Table 1.**

Dimensional stability of the boards:

The analysis of variance revealed that the differences in thickness swelling (TS) and water absorption (WA) for both the 2- and 24-hours soaking tests, were highly significant at (P= 0.0001). Table 4 shows the results of the property testing of resin-bonded particleboard. It reveals that the average thickness swellings after two hours soaking are slightly higher in comparison with past research results.

It can be seen from Table (4) and Fig. (4) that the smallest value for thickness swelling after 2-hours water soaking test (7.14%) was observed with the layered board type (M10). The face and back layers of this board type were made from a mixture of equal weights of bagasse and sunt particles (25% for each). The core layer was made from cotton stalk particles (50%). This result complies favorably with the specifications outlined in the latest European standard (**EN-312**, 2003). Perhaps the smaller thickness swelling of this particular board type is due to the layering of the board. The smaller particles of the face and back layers may have restrained the swelling of the coarser cotton stalk particles. Another possible reason is that the lignin in the face and back layers may have been plasticized and hardened by the heat of the platens and therefore acts as a barrier (**El-Osta *et al.*,** 1991).

The highest thickness swelling was observed with the 100% bagasse boards (M1) as shown in Table (4) and Figure (4). Bagasse boards were anticipated to absorb more water than other boards. The value of thickness swelling after 24-hours compares favorably with most of the previous research results of **El-Osta *et al.*** (1991). The smallest values were observed in the 100% sunt board type (M3) and the layered board type (M10). In the mixtures where sunt is a predominant component (100% or 50% i.e., board type M3, M5, M6, and M7), thickness swelling and water absorption are reduced. This may be due to the presence of non-hygroscopic extractives which may be found in sunt, that serve as dimensional stabilizing agent, by either bulking the wood structure or limiting the absorption of water (**Kelly** 1977 and **El-Osta *et al.*** 1991). With exception of panels type M3 (100% cotton stalks) and type M10 (layered board), the other panel types were very high (poor) in TS after 24 h water soaking with compare to the maximum TS requirements (15%) for load-bearing boards after 24 h immersion. Thickness swelling after 24 h soaking for board types M3 and M10 were very close the required level of panels for general uses. As a consequence, panels would require additional treatments such as surface coating (**Nemli *et al*,** 2006) or using water repellent agents in particleboard manufacturing to improve this property.

Table 4. Average* of thickness swelling and water absorption after 2- and 24-hour water soak test of resin-bonded particleboard made from mixtures of the three lignocellulosic materials.

Board type**	Dimensional stability properties			
	Thickness swelling (%)		Water absorption (%)	
	After 2-hrs.	After 24-hrs.	After 2-hrs.	After 24-hrs.
M1	17.32^{B}	26.83^{A}	28.98^{CD}	47.23^{BC}
M2	22.64^{A}	25.51^{A}	49.72^{A}	69.59^{A}
M3	10.27^{CD}	13.33^{E}	32.44^{BC}	41.18^{C-F}
M4	16.60^{B}	24.58^{A}	28.18^{CDE}	45.82^{DE}
M5	11.40^{C}	16.61^{CDE}	23.65^{EF}	36.30^{FG}
M6	8.73^{CD}	20.06^{BD}	26.30^{DEF}	42.89^{C-E}
M7	10.41^{CD}	20.25^{BC}	21.50^{FG}	37.80^{EF}
M8	12.22^{C}	18.03^{CD}	18.48^{G}	34.65^{G}
M9	16.38^{B}	23.59^{AB}	36.44^{B}	51.80^{B}
M10	7.14^{D}	14.19^{DE}	23.45^{EF}	40.88^{D-F}

Each value is the average of three specimens.

* Means with the same letter in the same column are not significantly different at 0.05 level of probability according to Duncan Multiple Test.

** Board type from M1to M9 was homogeneous and type M10 was layered, for legend see Table (1).

The lowest water absorption value after 2-hours (18.5%) is attained by board type (M8) which is a mixture of 50% cotton stalks particles and 25% for each of bagasse and sunt sawdust particles, while the highest value (49.72%) was observed in board type (M2) which is 100 % cotton stalk particles (Table 4 and Fig. 5). These results are similar to the figures reported by **El-Osta** *et al.* (1988) but they are higher than the results reported by **El-Osta** *et al.* (1991) for a layered particleboard from a mixture of Casuarina wood and flax shives. After 24-hour water soaking, the highest absorption value (69.59%) was observed in board type (M2) which is 100% cotton stalks panel (Fig. 4). This may be attributed to the larger internal voids found because of large particle sizes (**Gertjejansen**, 1978). This result is higher than the values obtained by **El-Osta** *et al.* (1991). They reported values ranging between 24.3 and 35.7%. The (WA24) values obtained from the boards under investigation are in agreement with the values reported by **El-Osta** *et al.* (1988) on particleboard made from *Casuarina* spp. flakes (61.4 %).

In the current study, the lower values of water absorption and the relatively low thickness swelling values attained by boards type (M8) could be attributed to the modified fabrication conditions of this particular board type. Several attempts using ordinary fabrication conditions described in materials and methods, produced boards with split core layers. Most of produced panels did not satisfy the thickness swelling and water absorption requirements after 2- or 24- hours water immersion. This may be due to not using wax and hydrophobic substance in particleboard manufacruring (**Ashori and Nourbakhsh** 2008). Among the successful manipulation factors were the reduction of mat moisture content (from 13% to 8 %), addition of more resin (slightly greater than 10%), increased pressing time, and better resin blending.

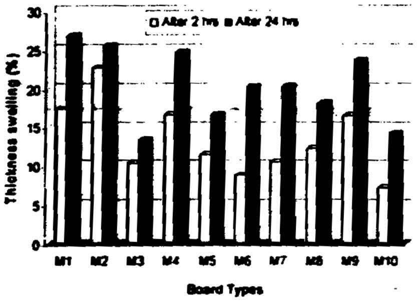

Fig. 4. Thickness swelling* (%) after 2-and 24-hours water soaking for particleboard panels made from different mixtures of three lignocellulosic materials.

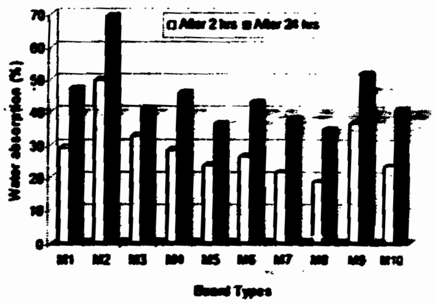

Fig. 5. Water absorption* (%) after 2-and 24-hours water soaking for particleboard panels made from different mixtures of three lignocellulosic materials.

*** For legend of board type from M1 to M10 see Table 1.**

CONCLUSIONS

Based on the obtained mechanical and dimensional stability properties of the present investigation, the following conclusions can be drawn:

1- There appears to be no problem in combining bagasse with sunt wood or with cotton stalks particles or blending those all in different proportions to produce homogeneous or layered resin-bonded particleboard.

2- The 10% resin content level of urea formaldehyde adhesive was found to be suitable for the production of panels with acceptable properties.
3- The addition of bagasse particles to sunt sawdust or cotton stalks or to mixtures of them improved the properties of particleboards made of their mixtures.
4- The smallest thickness swelling, for the two-hour water soaking test was attained by the layered board type.
5- Generally speaking, board properties are influenced by the proportion of the type of furnishes used (percent of bagasse, cotton stalks and sunt particles).
6- Minimum property requirements of the European commercial standard EN-312 (2003) for MOR, MOE and IB were met or exceeded by all board types except the MOR of the boards made of pure cotton stalks particles (100%).
7- Further investigation into the optimum conditions of particle geometry, adhesion and pressing condition of the three lignocellulosic materials are needed to improve the board quality, especially for boards from pure cotton stalks particles.

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الملخص العربى

تأثير خلط ثلاث مواد لجنوسليلوزية على بعض خواص ألواح الخشب الحبيبي الملصق بغراء اليوريا فورمالدهيد

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بحثت هذه الدراسة تأثير خلط نسب مختلفة من بعض المواد اللجنوسليلوزية على خصائص الخشب الحبيبي المصنع باستعمال اليوريا فورمالدهيد كمادة لاصقة. استعملت فى هذه الدراسة ثلاث مواد لجنوسليلوزية هى نشارة خشب أشجار السنط (*Acacia nilotica*)، البجاس (مصاصة القصب) وحطب القطن وهي مخلفا ت لأنواع من المحاصيل التي تكثر زراعتها في السودان. جمعت هذه المواد الجنوسليلوزية من مصنع السوكى لنشر الأخشاب، مصنع سكر الجنيد، وحقول القطن فى محافظة الكاملين بولاية الجزيرة بالسودان، علي التوالي.

معمليا تم عمل عشر خلطات بنسب مختلفة بين ٢٥، ٥٠ و١٠٠% من المواد اللجنوسليلوزية الثلاث (تسع خلطا ت منها متجانسة و خلطة واحده ذات ثلاث طبقا ت) لإنتاج ألواح خشب حبيبي ملصق براتنج اليوريا فورمالدهيد. وأوضحت نتائج الخواص الميكانيكية والثبات البعدي للألواح الناتجة انه باستثناء نوع الألواح المنتجة من حبيبات حطب القطن فقط (١٠٠% حطب قطن)، أوفت أو تعدت خواص الألواح المنتجة من الخلطات المختلفة الحد الأدنى للمواصفات التجارية الأوربية للخشب المضغوط (**EN-312**, 2003) وذلك من حيث معامل الكسر(MOR) ومعامل المرونة (MOE). وأوضحت الدراسة أن إضافة حبيبات البجاس لكل من حبيبات السنط أو حبيبات حطب القطن أو خليطهما، حسنت من خواص الألواح المنتجة وذلك مقارنة بالألواح المنتجة من أي من الحبيبات الغير مخلوطة (١٠٠% من أي من المواد اللجنوسليلوزية الثلاث). ونظرا للحاجة إلي مواد خام جديدة لاستخدامها في صناعة الخشب الحبيبي فانه يلزم إجراء المزيد من الأبحاث علي هذه المواد وخليطها حتي يتم تحديد الظروف المناسبة لتصنيع خشب حبيبي عالي الجودة.