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Renewable Egyptian lignocellulosic materials as alternative raw material for particleboard manufacturing

Salem E. Zayed[1], Abdel Baset A. Adam[2], Entesar A. Hassan[1], and Mohamed A. El-kady[3]

[1]Chemistry dep., Faculty of Science, South Valley University, Qena, Egypt

[2]Nag Hamady Fiberboard Co., Quality manger & WBP consultant, Egypt

[3]MSc. Student, Chemistry dep., Faculty of Science, South Valley University, Qena, Egypt

ABSTRACT: The purpose of this study is to evaluate the suitability of renewable Egyptian biomass for full-scale manufacturing process to produce particleboards of requested quality. The tested raw materials are based on Sesbania aegyptiaca plant (Sesbania Sesban), Banana pseudo-stem and grain Sorghum stalks. For evaluating these raw materials, the chemical properties of the selected materials and sugarcane bagasse (the conventional raw material in Egypt) were compared including holocellulose, Alfa-cellulose, lignin , ash contents, alcohol-benzene extractives, hot water extractives and solubility in dilute alkali (1% NaOH). In addition, the physical properties were determined including fiber length, diameter and cell wall thickness, scanning with SEM, estimate of α-cellulose degree of polymerization (DP) and pH of lignocellulosic materials.
Three layers particleboards were made from the selected materials and sugarcane bagasse using urea formaldehyde (UF) as a binder. The physical and mechanical properties of the manufactured panels such as density, thickness swelling (TS), modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) were measured and compared with those panels which were manufactured from sugarcane bagasse.
Both of physical and mechanical properties of panels which are manufactured from Sesbania Sesban and grain Sorghum stalks are closed to those from sugarcane bagasse and all of produced panels met the requirement of European standard **(EN 314-2010)**: the Load bearing boards for use in dry conditions type (P4), but panels which are manufactured from Banana pseudo-stem do not meet the requirement of European standard.

KEYWORDS: Alphacellulose; Bending strength; Holocellulose; Klason Lignin; Modulus of elasticity Modulus of rupture; thickness swelling   Sesbania Sesban, Banana pseudo-stem and grain Sorghum stalks.

1 INTRODUCTION

The shortage in natural wood resources due to the continuing & increasing demand for wood products because of population growth makes the international attention focuses on utilization of agro-residues or recycling of wood waste for manufacture of wood based panel. Nowadays, many researchers are highly interest in utilization of agro-residues materials, e.g. **(El-Juhany, L. I. *et al.* 2003) [1], (Ye, X. Philip *et al.* 2007) [2], (Akgül, Mehmet *et al.* 2010) [3], (Halvarsson, Soren *et al.* 2010) [4]** and **(Amirou, Siham *et al.* 2013) [5].**

Egypt as the most of African & Arab countries are very rich in agricultural residues and natural fibers, only few amounts of these residues are used for animal bedding or bio fuels and the rest are lifted on the fields lands or burned, i.e. the required quantities of these materials are available for wood based panel manufacturing. In addition, lignocellulosic residues are naturally abundant and renewable raw materials; they are suitable alternative raw materials for wood based panel industries because their manufacturing processes can be easily adapted to various types and forms of wood based panel.

Most of these natural fibers have excellent physical and chemical properties and can be utilized more effectively in the development of composite materials for wood based panel manufacturing production. Recycling these residues adds some money value for these wastes, saves our environment from pollution, shares in solving our shortage in natural wood resources, and introduces new jobs to the local market. Finally, from both the economical and environmental point of view, Using of lignocellulosic residues protects the environment, protects the virgin forests in some regions, adds a money value to this residues, and decrease the shortage of wood in other hand.

1.1 CHEMICAL COMPOSITION OF LIGNOCELLULOSIC MATERIALS

The lignocellulosic material is a woody material that consists of four major components: cellulose (α- cellulose), hemicellulose, lignin, and traces of mineral components (ash). Not only the percentages of these components vary from species to species or part to part in the same wood species but also plant age, geographic location, climate and soil condition are factors which have some effect on wood composition.

2 MATERIAL AND METHOD

2.1 SAMPLES COLLECTION AND PREPARATION

This research has been carried out at Nag-Hamady Fiberboard Company (**NFB**) laboratories and research pilot plan. The tested raw materials were based on Sesbania Sesban plant (Sesbania aegyptiaca) (**SES**), Banana pseudo stems (**BPS**), grain Sorghum stalks (**GSS**) and sugarcane bagasse (**SCB**) the conventional raw material of wood based panel in Egypt, **SCB** were collected from bagasse depither located at **NFB**. All of these materials were collected from local areas in Qena governorate, South of Egypt. They were washed with tap water to remove all suspended particles, followed by open air-dried for three days. In order to prepare the samples for physical or chemical analysis: each type of them was cut into small strips, and then cut into small chips, to be placed in a laboratory electrical mill for grinding. The resulted materials were placed in a shaker with 500-µm & 250-µm sieves to pass through the 500-µm sieve and are collected on the 250-µm sieve, i.e. near to 40 mesh screen; finally, the sieved materials were placed and labeled with appropriate code for analysis.

2.2 METHODS

Moisture & ash Content were determined in accordance with **ASTM, D4442-92 [6]** and **(D 1102-84) [7]** respectively. Extractives was Determined in two-step extraction process to remove water soluble and benzene-ethanol soluble materials according **(NREL, 2008) [8]** but it was founded that it was more useful to use mixture of benzene-ethanol 1:1 (V/V) instead of ethanol alone, as it was reported in (**T 204 cm-97**) **[9]**. Hot alkali solution extracts (NaOH 1% solubility), cold water solubility & acid-insoluble lignin (Klason lignin) were done according **TAPPI, (T 212 om-02) [10], (T 207 cm-08) [11] &** (**T 222 om-11) [12]** respectively**.** Holocellulose content & α-Cellulose content were determined according method that descried by **(Han, J. S. and Rowell, J. S. 1997) [13]**. pentosan was determined according the procedure was describe by **(Jayme, G. and Sarten, P. 1940) [14]. α-**cellulose degree of polymerization (DP) was determined in Cadoxen soln; The method & Cadoxenn prepation was done according to the procedure described by **Dupont, A-L (2003**) **[15]**. The pH of fibers was measured by a previous calibrated JENWAY 3505 pH meter with a glass electrode in accordance with **TAPPI (T 509 om-83) [16]**. Density of fibers was determined based on the oven dry weight according **TAPPI (T 258 om-02) [17].** Observation with SEM was done by using (JEOL, Japan) Instrument, JEOL - JSM-5500 LV scanning electron microscope. The sample introduce to SEM observation as it is with no preparation and it also introduced as pretreated sample by **(Franklin 1945)** method **[18]**. Bending strength or modulus of rupture (MOR), modulus of elasticity in bending test (MOE), internal bond (IB) and swelling in thickness test were performed according to **ASTM (D1037- 06a) [19].**

2.3 TECHNOLOGICAL PROCEDURES AND MANUFACTURING PROCESS

The selected woody materials were air dried in sun light for 48 hours, and then cut to 25 x 25 x 5 mm chips that suitable size for grinding in hammer mill. For particles classification a shaker with series of seven screens (12 mm, 8 mm, 3.15 mm, 2 mm, 1 mm, 0.5 mm and 0.4 mm respectively) was used, particles which were collected on 12 mm, 8 mm and 3.15 mm screens were re-grinded. The particles that were remained on 2 mm and 1 mm sieves were used in core layer while particles on 0.5 and 0.4 mm sieves were used for surface layer. The particles were then dried to a target 3% MC. Constant weight of both core and surface particles were weighted to get target density. The table 1 is showing all manufacturing parameters. Nine panels were manufactured from each type of woody material (**SES**, **BPS**, **GSS**, and **SCB**); these nine panels were classified into three groups (A, B and C), the only difference between them that the adhesive content %, in the surface layer

& core layer, which was 8 % in the surface layer & 6 % in core for group A, but the adhesive content % of group B was 10 % & 7 % respectively, finally it was 11 % & 8 % in group C respectively. After the particleboards were glued, they were pressed at specific pressure 35 kg/cm^2 by using laboratory press of NBF research plant. Lastly the manufactured panels were air-conditioned, they were cut into specimens according to the requirements of each test, and then the physical and mechanical properties were determined.

Table 1: Particleboards manufacturing parameters

GR	SL	CL	BW	BD	BT	SLR	CLR	Wax	Hard.	PT	PC
	%	%	Kg	Kg/m^3	mm	%	%	%	%	°C	Sec
A	30	70	1.3057	680	12	8	6	0.5	1	177	144
B	30	70	1.3057	680	12	10	7	0.5	1	177	144
C	30	70	1.3057	680	12	11	8	0.5	1	177	144

GR = group, SL = surface layer particles, CL = core layer particles, BW = board weight, BD = board density, BT = board thickness, SLR = surface layer resin, CLR = core layer resin, Hard = hardener, PC = press cycle and PT = press temperature.

3 RESULTS AND DISCUSSION

Both of the chemical and physical characteristics of the chosen fibers were compared with those characteristics of **SCB**. The same thing was done for the produced panels; their physical and mechanical properties were compared with that panels produced from **SCB** fiber.

3.1 THE CHEMICAL CHARACTERISTICS OF THE TESTED MATERIALS

The chemical characteristics of **SES**, **BPS**, **GSS** and **SCB** fibers are listed in the table 2, percentages of the holocellulose content are ranged from (75.44%) to (57.53%), percentages of alpha cellulose content from (42.72%) to (35.22%), percentages of hemicellulose content from (32.72%) to (22.31%), percentages of lignin content from (18.22%) to (12.41%), percentages of pentosan content from (29.22%) to (14.92%), percentages of water extractives from (14.61%) to (3.97%), percentages of solvent extractives from (4.75%) to (1.45%), percentages of total Extractives from (19.36%) to (5.79%), the solubility of the fibers in hot alkali (1% NaOH solubility %) from (44.9%) to (22.81%), and lastly percentages of ash content from (14.41%) to (1.65%).

Table 2: The chemical characteristics of the tested fibers

Test/Material	SES	BPS	GSS	SCB
Holocellulose %	75.44	57.53	69.76	74.14
α-Cellulose %	42.72	35.22	40.67	42.58
Hemicellulose %	32.72	22.31	29.09	31.56
Lignin %	16.13	12.41	16.38	18.22
Pentosan %	15.7	14.92	26.13	29.22
Water extractives %	7.62	14.61	10.07	3.97
Solvent extractives %	1.45	4.75	1.73	1.82
Total extractives %	9.07	19.36	11.8	5.79
NaOH solubility %	28.71	22.81	44.9	34.5
Ash %	1.65	14.41	2.58	2.85

N.B. *Hemicellulose content % & total extractives can be calculated as follow:*
Hemicellulose % = (holocellulose %) – (α-cellulose %) and the total extractives % = Water extractives % + Solvent extractives %

According the data in table 2, the chart in figure 1 expresses the percentages of the main components of lignocellulosic material (α-cellulose, hemicellulose, pentosan and lignin), while holocellulose content can be arranged from the high to the low value as **SES, SCB**, **GSS** and **BPS** respectively, alpha cellulose content can be arranged from the high to the low value as **SES, SCB**, **GSS** and **BPS** respectively, pentosan content can be arranged from the high to the low value as **SCB**, **GSS**, **SES** and

BPS respectively and lignin content can be arranged from the high to the low value as **SCB**, **GSS**, **SES** and **BPS** respectively. The figure 2 shows the percentages of the fiber extractives including the water extractives, solvent extractives and the total extractives. The percentages of solvent extractives can be arranged from the high to the low value as **BPS**, **SCB**, **GSS** and **SES** respectively, but the percentages of total extractives & water extractives as **BPS**, **GSS**, **SES** and **SCB** respectively.

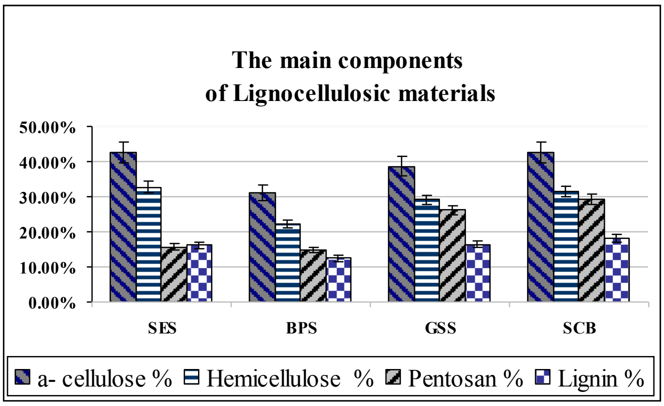

Figure 1: Percentages the main components of the fibers

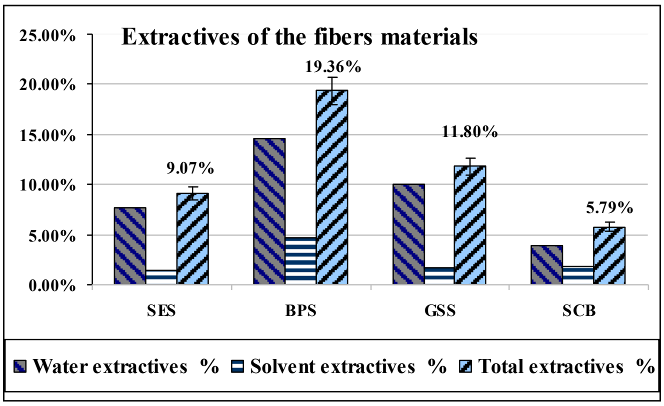

Figure 2: The percentage of the fibers extractives

3.2 THE PHYSICAL CHARACTERISTICS OF THE TESTED MATERIALS

The physical characteristics of **SES**, **BAP**, **SOS** and **SCB** fibers are listed in table 3 & table 4. The results in table 3 present percentages of cold water solubility which are ranged from (14.18%) to (3.4%), pH values from (7.35) to (5.95), densities values (Kg/m^3) from (361.5) to (160) and degree of polymerization (DP) values from (1317.52) to (1099). The table 4 reports the fibers lengths (µm) which are ranged from (1925) to (1533), the fibers width (µm) from (31.38) to (14.4), the fibers lumen width (µm) from (14.7) to (8.73) and the fibers cell wall (µm) from (5.25) to (2.58).

Table 3: the physical characteristics of the tested fibers

Test/Material	SES	BPS	GSS	SCB
Cold water solubility %	7.16	14.18	9.59	3.4
pH	6.38	5.99	5.95	7.35
Density (Kg/m^3)	187.5	361.5	209.9	160
Degree of polymerization	1317.52	1014.3	1172.85	1099

Table 4: the fiber measurements

Test/Material	SES	BPS	GSS	SCB
Fiber length (µm)	1742	1925	1533	1564
Fiber width (µm)	19.18	31.38	14.4	18.17
Lumen width (µm)	8.73	14.7	9.64	10.21
Cell wall thickness (µm)	5.25	2.58	3.03	2.89

3.3 SEM OBSERVATION OF THE TEASED FIBERS

By using JEOL - JSM-5500 LV scanning electronic microscope, the following SEM microphotographs were taken to explain the surface features of teased fibers. The sample was scanned without any chemical treating and also it was pretreated with sodium hydroxide 1%, the best result is obtained when the sample was pretreated with sodium hydroxide 1% before observation.

The surface features of Sesbania sesban (**SES**) fibers were displayed in figure 3; SES-A (350 X) explains a cross section of wood vessel element; SES-B (550 X) explains a magnified view of some wood ray cells. The surface features of Banana pseudo stems (**BPS**) fibers were displayed in figure 4; BPS-A (500 X) explains a cross section of a wood fibril & the wood cells; BPS-B (3,500 X) explains a view of magnified cross-section of wood fiber contains the wood ray cells. The surface features of grain Sorghum stalks (**GSS**) fibers are displayed in figure 5; GSS-A (850 X) is showing a cross section of one fibril which is formed from bundles of micro fibrils; GSS-3 (700 X) explains a longitudinal section of wood vessel element; GSS-B (2,300 X) explains a part of wood ray cells.

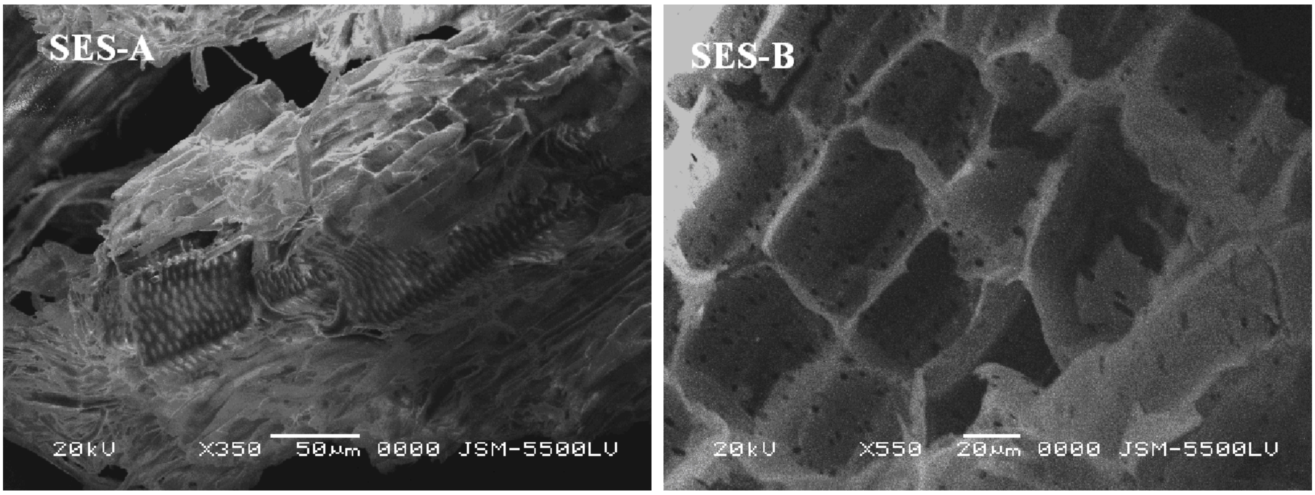

Figure 3: SEM of microphotograph of Sesbania Sesban fibers

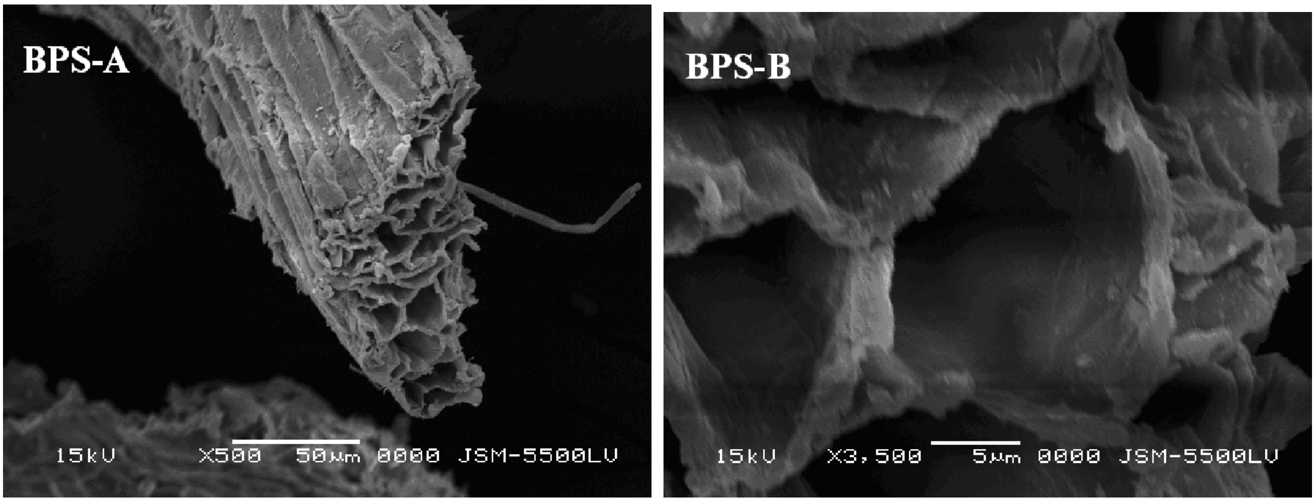

Figure 4: SEM of microphotograph of Banana pseudo stems fiber fibers

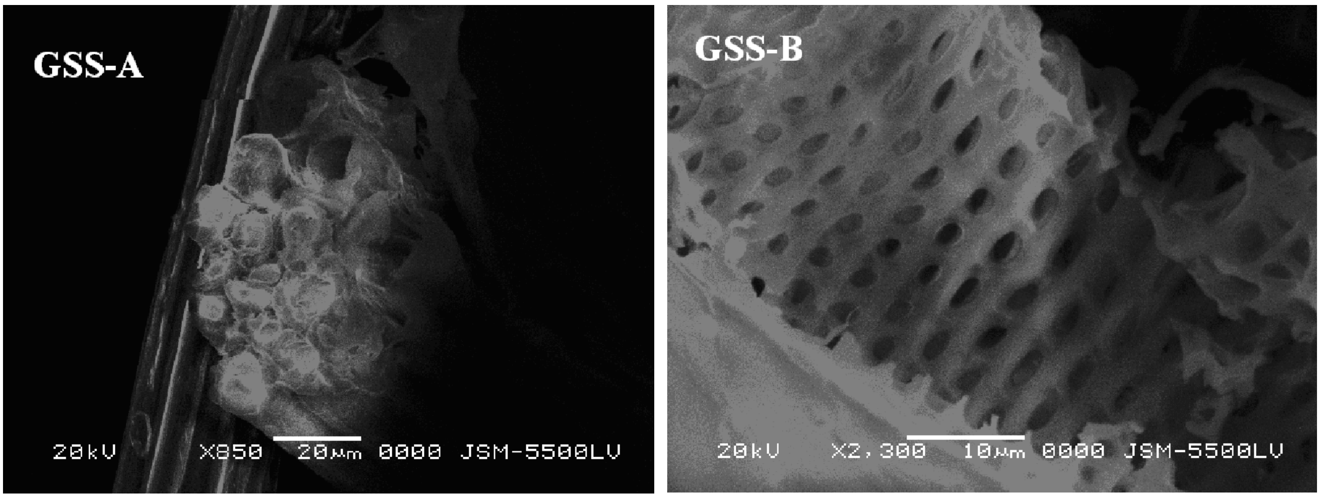

Figure 5: SEM of microphotograph of grain Sorghum stalks fibers

3.4 THE PHYSICAL & MECHANICAL PROPERTIES OF THE MANUFACTURED PANELS

The physical & mechanical properties of the manufactured panels are listed in table 5; they include panels densities, modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB) and thickness swelling after 24 h. The Standard at the end of the table 4 is referred to European Standard type P4 (**EN 312-2010**) **[20]**.

Basing on the data in table 5, the mechanical properties of the manufactured panels are shown in figures 6, 7, 8 and 9. The figure 6 shows the modulus of rupture (MOR) values of the manufactured particleboard; the panels manufactured from **SES** fibers have the superior values followed by the panels manufactured from **GSS** and **SCB** fibers which they have very closed values, lastly the particleboard panels manufactured from **BPS** fibers which they have the lowest values. The same thing for MOE & IB values which they are shown in figure 7 & 8 respectively. The mechanical properties values of group C is the highest values in the three groups and the mechanical properties values of group B is higher than them in the group A; this means that the resin content has a positive effect on the mechanical properties of the manufactured panels. The figure 9 shows the percentage of the swelling properties of the panels thickness after 24 h. (Ws -24 h), it is an undesired property, i.e. panels have low value of (Ws %) is more preferable than those have higher values. The panels manufactured from **SES** fibers have the minimal values followed by the panels manufactured from **GSS** and **SCB** fibers which they have very closed values, lastly panels manufactured from **BPS** fibers which have the maximum values.

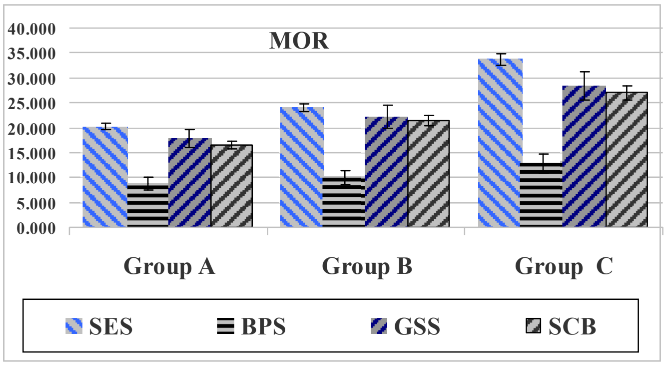

Figure 6: The modulus of elasticity (MOR) values of the panels

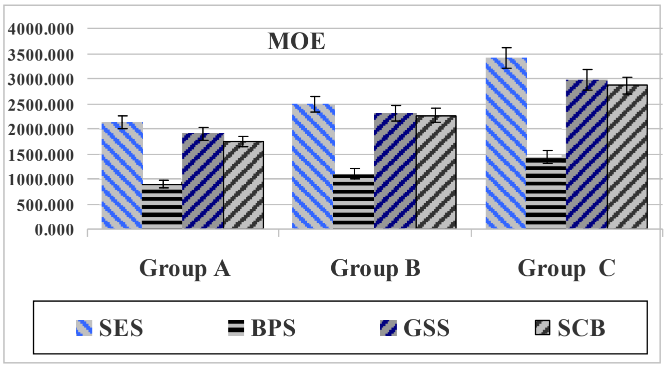

Figure 7: The modulus of rupture (MOE) values of the panels

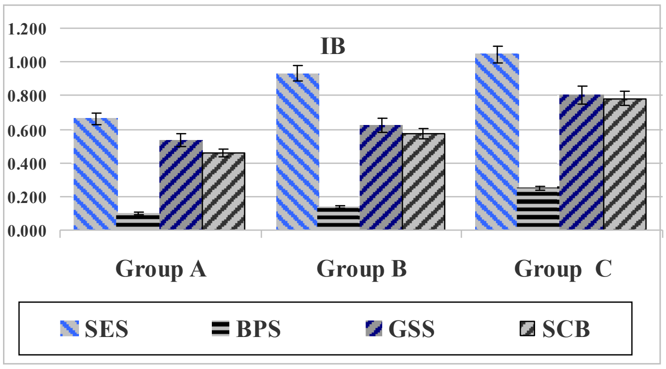

Figure 8: The internal bond strength (IB) values of the panels

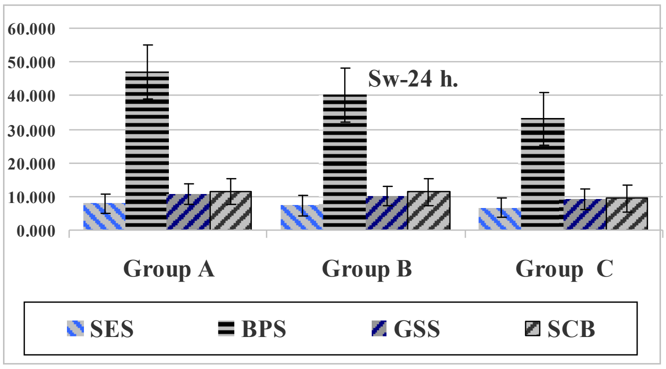

Figure 9: Thickness swelling after 24 h (Sw-24%) of the panels

Table 5: The mechanical & physical properties of tested panels

Sample	Resin		Density	MOR	MOE	IB	Sw.24h
Unit	%	%	Kg/m^3	N/mm^2	N/mm^2	N/mm^2	%
SES	**S.L**	**C.L**					
group A	8	6	619.0	20.167	2117.33	0.66	7.84
group B	10	7	641.0	24.010	2490.67	0.93	7.25
group C	11	8.	655.0	33.723	3408.00	1.04	6.65
BPS	**S.L**	**C.L**					
group A	8	6	663.5	8.770	892.333	0.098	46.93
group B	10	7	665.2	10.000	1108.50	0.10	40.10
group C	11	8.	678.3	12.813	1431.00	0.25	33.06
GSS	**S.L**	**C.L**					
group A	8	6	655.8	17.783	1893.00	0.538	10.81
group B	10	7	664.0	22.180	2308.25	0.62	10.10
group C	11	8.	669.0	28.315	2972.50	0.80	9.18
SCB	**S.L**	**C.L**					
group A	8	6	619.3	16.450	1738.33	0.46	11.47
group B	10	7	625.0	21.340	2256.33	0.57	11.41
group C	11	8.	629.0	27.000	2865.00	0.78	9.43
Standard	**-**	**-**	**-**	**16**	**2300**	**0.4**	**16**

S.L= surface layer, C.L= core layer, MOR = modulus of rupture, MOE = modulus of elasticity, IB = internal bond strength, Sw.24% = thickness swelling after 24 h ***N.B:*** *the average boards thickness =12 mm.*
Standard *= EN 314 (standard Type P4, with board thickness 6 - 13 mm).*

3.5 EFFECT OF THE COMPOSITE PROPERTIES ON THE PHYSICAL & MECHANICAL PROPERTIES OF THE MANUFACTURED PANELS

Choosing the suitable lignocellulosic raw material is one of the important challenges in The MDF technology. the composite material should be fulfilled the minimum technology requirements, i.e. it should have an acceptable level of cellulose, lignin and hemicellulose where lack of anyone of these main three Components leads to undesirable boards properties **(Maloney T. M**. **1989) [21]** & (**Youngquist , J. A.** ***et al.*** **1969**) **[22]**.

Because of the performance of the produced fiberboards depend on the properties of its composite, study of the composite physicochemical properties as well as the geometric properties of its particles add to bonding strength between its particles are the key of success for expecting the properties of the produced panels. In the following lines, the effect of each property will be discussed alone to report its positive or negative effect, but the final evaluation of the selected fibers is based on the evaluation of the total properties of the produced panels.

3.5.1 EFFECT OF HOLOCELLULOSE CONTENT

Holocellulose can be defined as the total polysaccharide fraction of the wood fibers or the lignocellulosic composite, it is made up of cellulose (α-cellulose portion) and all of the hemicelluloses, it can be determined by removing the extractives and the lignin content from the wood material fibers or lignocellulosic composite. The cellulose portion is a large and well-organized polysaccharides polymer; it is located in the primary cell wall, while hemicelluloses are branched polysaccharides polymer that are less rigid than cellulose, it is made up of two monomers (pentose & hexose) and able to wrap around the cellulose **(Resasco, Daniel E. 2011) [23]**.

One can guess that good mechanical properties of the manufactured panels is related to high holocelluloses content of their composite, but the previous statement is not always right where there are many other factors can affect the mechanical properties of the manufactured panels.

From the chemical properties data in table 2 and according to the fibers holocellulose content only, one can guess that Sesbania sesban fibers (76.44%), Sugarcane bagasse fibers (74.14%) and grain Sorghum stalks fibers (67.76%) have good suitability for manufacturing than Banana pseudo stem fibers (53.53%), i.e. they can be ordered from high to low value as **SES**, **SCB**, **GSS** and **BPS**; but table 5 indicates that the mechanical properties of the manufactured panels is arranged from high to low value as the flowing order **SES**, **GSS**, **SCB** and **BPS**. The difference between the two orders is referred to the differences of hemicellulose content in these fibers, where hemicellulose is less rigid than α-cellulose, i.e. high content of it decrease the mechanical strength properties of the manufactured panels and the data in table 2 indicates that hemicellulose content of **SCB** (31.56%) is higher than **GSS** (29.09%). All these results are in accordance with **(Sari, B. *et al.* 2012) [24]**, where he reported that while high content of cellulose or α-cellulose caused superior mechanical properties of the wood based panels, high hemicelluloses content decreased the mechanical properties and increased the thickness swelling.

3.5.2 EFFECT OF A-CELLULOSE CONTENT

According to the fibers α-cellulose content in table 2 only, one can guess the mechanical properties of manufactured panels are ranged from high to low value as **SES** (42.72%), **SCB** (42.58%), **GSS** (38.67%) and **BPS** (31.22%) respectively, but the mechanical properties of the manufactured panels in table 5 is ranged from high to low values as the flowing order **SES** , **GSS**, **SCB** and **BPS**, As in **3.5.1** (Effect of holocellulose content) the difference between the two orders is referred to the differences of hemicellulose content in these fibers, similar results is noted by **(Harmsen, P. F. H. *et al.* 2010) [25]** he reported that cellulose is the major component of cell wall that provides plants the required mechanical strength and chemical stability also **(Mohan, Dinesh *et al.* 2006) [26]** reported that wood strength is related to the presence of cellulose in the plant fibers.

3.5.3 EFFECT OF HEMICELLULOSE CONTENT

Depending on the hemicellulose & α-cellulose content of the fibers in table 2, one can decide that both of **SES**, **SCB** and **GSS** have good manufacturing profiles but **BPS** fibers have not, where the first group (**SES**, **SCB** and **GSS**) have high content of α-cellulose & suitable content of hemicellulose, but **BPS** has mild α-cellulose content add to low hemicellulose content, lastly the data in table 5 shows that both of **SES**, **SCB** and **GSS** have good mechanical properties than **BPS** does, where one disadvantage of hemicellulose that it is less rigid and has low molecular weight than α-cellulose, i.e. if the composite has high content of hemicellulose and low content of α-cellulose, the manufactured panels will not have good mechanical properties.

Another of hemicellulose disadvantages that it is rich in hydroxyl groups, where hemicellulose is the most sensitive component to hydrolysis **(Halvarsson *et al.* 2010) [4],** basing on data in table 5 we can observed that high content of it lead to decrease the water resistance properties of the manufactured panels, where SW-24% can be arranged from low to high value as **SES**, **GSS**, **SCB** and **BPS**.

High content of hemicellulose is not preferable in the composite materials but presence of hemicellulose in suitable amount plays an important role in the lignocellulosic materials; it acts as interfacial coupling agents between the highly polar surface of the cellulose and the less polar lignin matrix **(Li, Yongfeng 2011) [27],** thus **SES**, **SCB** and **GSS** have good IB than **BPS**.

3.5.4 EFFECT OF LIGNIN CONTENT

Not only lignin is the main binder for the cellulosic fibrous components, but also it is providing a shield against the bacterial or fungal destruction of the cellulosic fibers **((Mohan, Dinesh *et al.* 2006) [26]**. Presence of a sufficient content of lignin in the lignocellulosic fiber can serve as a binder material, under heat and pressure the lignin will flow and act as a thermosetting adhesive, enhancing the naturally occurring hydrogen bonds **(English, Brent *et al.* 1997) [27]**. Lignin is a complex phenolic polymer with medium molecular weight, it provides stiffness properties to the cell wall and also it serves as a binder material to bond the individual cells together in the middle lamella region **(Li, Yongfeng 2011)[28]**.

Basing on the fibers lignin content in table 2, we can introduce another explanation for why does BPS has less mechanical properties than SCB & GSS. The stiffness properties and self bonding between than SES & GSS fibers are higher than BPS due to they have higher lignin content than BPS.

3.5.5 EFFECT OF EXTRACTIVES CONTENT

Basing on total extractives % and hot water extractives % data which is listed on table 2, one can noted that abundance of total extractives has a negative effect on mechanical properties of the manufacturing panels, where **SES**, **GSS** and **SCB** have superior mechanical properties than **BPS**. Also presence of high contents of 1 % NaOH extractives in composite decreases the mechanical properties of the manufacturing panels.

In the same time presence of extractives like wax and liphophilic extractives increase the waterproof of manufactured particleboards i.e. they improvement the resistance to water and humidity. One can introduce an explanation for why does

GSS has some better welling properties than **SCB**, low values of water absorption & thickness swelling of panels which manufactured from **GSS** is better than those from **SCB** due to **GSS** fibers have higher total extractives % and hot water extractives % than **BPS** fibers do and this is in accordance with **(Sari, B. *et al.* 2012) [24]**.

3.5.6 Effect of UF content

The data in table 3.5 improves that with increasing of adhesive content (from group A to group C); high values of MOR, MOE, and IB were obtained but low values of water absorption & thickness swelling and this is accordance with many recharges. These results is accordance with many researchers, where **(Ye, X. Philip *et al.* 2007) [2]** reported that boards properties improved with increasing adhesive levels. Both of **(Saad *et al.* 2012) [29] & (Labosky *et al.* 1993) [30]** reported that with increasing of resin content, high values of MOR, MOE and IB but low values of water absorption & thickness swelling. These decreasing in water absorption with increasing of resin content, may be due to effect of hydrogen bonds between the resin and hydroxyl group of the fiber which leading to reduce the hygroscopicity of the boards **(Nayeri, M. Dehghan *et al.* 2014) [31],** hygroscopy is defined as the ability of the substance to attract and hold water molecules from the surrounding environment by adsorption or absorption leading to changes in physical properties of the absorbed and or adsorbed substance.

3.6 The Final Evaluation Of The Selected Fibers

3.6.1 Sesbania sesban, and grain Sorghum stalks fibers

Both of **SES** and **GSS** are lignocellulosic materials that contain high content of holocellulose equal to (75.44%) & (67.76%) respectively and high content of α-cellulose equal to (42.72%) & (38.67%) respectively, similar to those found in **SCB**, these high contents of holocellulose & α-cellulose act as fiber-reinforced materials in the composite and that interprets the suitable mechanical properties of the panels which are made from their composite.

Both of **SES** and **GSS** fibers have suitable lignin content equal to (16.13%) & (16.38%) respectively; this lignin content just makes them rigid material with higher strength suitable for particleboards manufacturing add to that lignin has a binder properties which facilitates the particles binding.

Both of **SES** and **GSS** fibers have a suitable hemicellulose equal to (32.72%) & (29.09%) respectively and pentosan content equal to (15.7%) & (26.13%) respectively, which explain the good bending strength & flexibility properties of the panels without undesirable proprieties.

Finally panels which is made from **SES** and **GSS** composites have good mechanical proprieties, these high values of MOR, MOE, IB and high water resistance properties are exceeded the requirements of European Standard **(EN 312-2010) [20]**.

3.6.2 Banana pseudo stem fibers

BPS fiber is lignocellulosic materials that contain mild content of holocellulose (53.56%), add to it has a mild content of α-cellulose (31.25%), these low contents of holocellulose & α-cellulose decrease the strength & the mechanical properties of the panels which are made from this composite.

Although **BPS** doesn't comply with the requirements of European Standard **(EN 312-2010) [20]**, they can be used as co-material in the composite to form the core layer of the particleboards or they are used for interior purposes.

3.7 Conclusions

In the end and based on the results of this study, it can be concluded that Egyptian lignocellulosic materials which they are residues accumulate in suitable amounts all over Egypt can be a potential materials for particleboards manufacturing. Using both of Sesbania sesban fibers and grain Sorghum stalks fibers for particleboards manufacturing are good solution to face the raw materials shortage in wood based panels industry. The mechanical evaluations of panels that adjusted to 12 mm of the thickness and glued with urea formaldehyde resin indicate that these particleboards are complied with the requirements of European Standard type P4 **(EN 312-2010) [20]**; where the results indicated that all the manufactured panels have good physical & mechanical profiles. Finley using these renewable lignocellulosic raw materials for particleboards manufacturing not only it contributes to reduce the shortage of raw materials but also it solves the environmental problems which are resulted from burning these residues.

Banana pseudo stem is lignocellulosic material that contains mild content of holocellulose & α-cellulose, these low contents decrease the mechanical strength properties of the panels which are made from its composite. Although Banana pseudo stem fibers don't comply with the requirements of European Standard, they can be used as co-material in the composite to form the core layer of the particleboards or they are used for interior purposes.

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