Properties of Sugar Cane Bagasse to Use in OSB

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Abstract   The composites of natural fibers are products known in several parts of the world, however their utilization is relatively restrict due to the lack of information concerning their properties and structures. Lignocellulosic fibers present high length/thickness relation, which contributes to the biodegradation and continuity of the ecological cycle. Such fibers present low density and enable a lower cost in composites manufacture, playing an important role in the definition of their physical and mechanical properties. The cane bagasse is a residue derived from sugar cane, a commercially important product in Brazil, with a high concentration of fibers, high content of lignin, which is a factor of environmental impact, with future perspectives of use. The present paper aims to evaluate the density of cane bagasse as composites of long particles and their internal adhesion, as well as to verify their temperature until decomposition and suggest their possible future utilization. The requisites of this product in terms of limit values for the properties of OSB are defined by EN-300/2002 standard.

Keywords   Composites, OSB, Sugar Cane Bagasse

1. Introduction

The reutilization of natural organic residues to obtain an applicable product is a very useful practice that generates many advantages in the evaluation of social areas, expanding baselines for economic applications, with a low cost product which is ecological and far less polluting, in order to create a country's sustainable development.

Alternatively to the use of organic waste for use in buildings and other compounds are distinguished OSB (Oriented Strand Board), made up of wooden panels or comparable (long, large and fine particles) agglutinated with a resin and compressed in layers.

Generally, on its external layers the OSB has its flakes arranged longitudinally in relation to the length of the board, while in the intermediate layers they are arranged perpendicularly or randomly distributed, as illustrated in Figure 1.
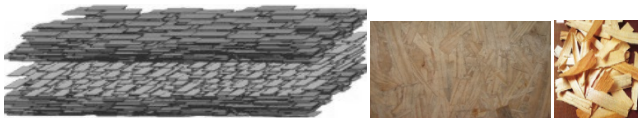
Figure 1.   Directed layers, long particles and OSB panels in the market. Source:[1]

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Because it is a composite material, the choice of factors and levels associated with these in the development of OSB provide for the development and study of a series of surveys.

Zhow[2] asserts that the direction of the particles causes a 40 to 50% increase in MOR and MOE, respectively, parallel to the direction in relation to the particle panels that are distributed randomly.

According to[3], the angle formed in the particle distribution in the layer is highly dependent on the height of the particles falling, with lower heights providing better direction as a consequence of forming a smaller angle.

Also with respect to other works OSB panels can be mentioned, as[4], studied the Poisson's ratio by varying the orientation of the chips, and[5], using a method based on image analysis for the determining the modulus of elasticity (MOE) and rupture (MOR),[6], investigated the influence of pressure levels on the mechanical performance of composite OSB,[7] and evaluated the mechanical properties of panels composed of wavy wires,[8], using the compounds in OSB manufacture of furniture and others.

In the OSB panels the long particles are bonded with the types of resin: phenol-formaldehyde, melamine-urea-formaldehyde and polyurethane, all of which are ligaments resistant to moisture and therefore the panel, which is pressed under medium or high temperature, increases its mechanical resistance and hardness.

According to[9], the São Carlos Chemistry Institute, São Paulo University (USP), bestowed an important national contribution by developing a polyurethane resin that has

many advantages, such as: manipulation in room temperature, water resistance, mechanical resistance, moreover it resulted from a renewable natural source, whose raw material (mamona) can adapt climatically throughout the entire national territory.

AraújO[10] performed a series of tests in order to determine the characteristics of various polyurethane resin compositions based on mamona oil. With regards to the thermal stability of the polyurethanes, by means of thermal analysis that close to 220°C there is only a small mass loss, which evidences thermal stability of the resins up to this temperature.

Claro Neto[11] determined the physical-chemical properties of the polyurethane resin polymer, bi-component, derived from mamona oil. He verified the thermal component of the polymer between two components in his research, verifying that the polymer's decomposition curve has two decomposition stages; the first stage beginning at 300°C and the second one at 400°C.

OSB panels are usually made with wood chips oriented[1]. In order to strengthen, other materials may also be used, among them, bagasse from sugar cane. Brazil is the largest producer of sugar cane worldwide and the residues from this product are generated in equal proportions, moreover reutilization of the components of this vegetal biomass is extremely important environmentally and economically.

According to[12], sugar cane bagasse is composed of fibers, medule, fine particles and soluble materials, with the in natura bagasse chemically composed of 44,5% of lignocellulosic fibers; 50% of moisture; 2,5% of soluble solids in water and 3,0% of ash.

Han and Wu[13] compared the properties of the rind of the sugar cane against pine wood flakes in the manufacture of structural composite and verified a chemical similarity of the more external part of the cane with the wood, however with less homogeneity, lesser thermal stability (TG and DSC) and resistance to traction slightly superior to the wooden slivers for structural effects.

The use of sugarcane bagasse in compounds intended for most of the cement matrix, which may be mentioned the work of[14],[15],[16],[17],[18].

In view of the expounded elucidation regarding the study of developed materials of sugar cane derivates, or to be more precise, of its residue, it is very relevant in environmental, social economic and technological aspects.

The present paper evidences originality, interest and the immense field of application for the sugar cane residue as bagasse, in which the residue is tested without separating the denser fibers, less dense ones and the medulla, aiming at conveying more advantage, aggregated value and economic impact to the product, being investigated the response variables: moisture, density, swelling, internal compliance and modulus of elasticity and rupture strength.

To assess sugar cane bagasse without separating its composition; fibers, medulla and fine particles, randomly verifying its pressing temperature until decomposing,

assessing its properties as long and directed particle composites (OSB) and eventual utilization as sustainable product, corroborating as one of the investment solutions for new products and future technologies.

2. Materials and Methods

The material used in this evaluation was the sugar cane residue, commonly known as "bagasse" originating from the mills located near the city of São Carlos, SP, Brazil. It was evaluated as composite, which is particulate and resin composites. The resin employed was polyurethane based on mammon oil, type bi-component and the reaction time was of 25 minutes. The resin with pre-polymer I201 will be used with 1:2 feature to produce the panels, with one part of pre-polymer based on di-isocyanate and 2 parts of polyol. These resin composites were donated by KEHL Chemical Industry of São Carlos-SP. One of the resins is done by cold curing process, which can be accelerated by increasing the temperature up to 120°C without losing its properties. Because the group of derivatives usually applies this temperature, 90ºC was chosen, thus generating less energy in the fabrication process of panels[1].

2.1. Thermogravimetry (TG) and Differential Thermal Analysis (DTA)

A simultaneous thermal balance TG-DTA, brand NETZSCH, model STA 409 Cell (Figure 2) was employed for this analysis, with a heating rate of 10°C/min. owing to the fact that this heating ratio promotes a better resolution curve standard in nitrogen atmosphere.

Figure 2. NETZSCH Equipment, model STA 409 Cell-Thermogravimetric analysis

2.2. Treatment

Figure 3. Material treated in water and sun dried for preliminary drying

The bagasse is submersed in room temperature water to

remove saccharose and impurities, afterwards it is removed and dried, a shown in Figure 3.

2.3. Drying

The artificial drying process is done in heater for 16 hours at 60ºC temperature, where it is checked for possible anomalies, since above this temperature there is water loss that could cause disequilibrium to its basic structural form. Immediately after treatment and drying it is prepared for particulate obtainment by cutting (Figure 4) it to mean length of 14cm.

Figure 4.   Bagasse after being dried in heater, test equipment, solid percentage and slicing of sugar cane bagasse

2.4. Mixture Particulate Direction and Pressing

The mixing process is relative to the degree of residue compaction and follows the standard guidelines commonly used to industrially manufacture oriented strand board (OSB). Cane bagasse offers a wide range of applications owing to its low density fiber and low cost. In the present paper for the production mixture, a mammon based oil polyurethane resin was employed at a proportion of 1:2, pre-polymer/polyol and cane-bagasse type residue in compaction proportion and intended density, respectively.

Subsequent to the resin application, the long particles were placed in a particle orienter to divide the layers. Such layers are divided in external and internal layers. The external layers imperatively have the same orientation, while the internal ones can be oriented or not, as illustrated in Figure 5.

Figure 5.   Large particle orienter developed in LaMEM-SET and layers of oriented particles of cane bagasse

From preparation time to particle orientation, it takes 12 to 15 minutes, initial reaction time of resin or gel time of mammon based resin. After orientation, the long particles are pre-pressed aiming to uniformly distribute layer compaction and then are subjected to 90°C temperature to be pressed for 10 minutes in a hydraulic type press brand Marconi MA-98/50, Figure 6. This temperature is responsible for acceleration of the resin cure and accountable for thermal standards of the cane bagasse.

Figure 6.   Long particles in Marconi MA-98/50 hydraulic press and definitive panel

After pressing, a panel is formed when each one is positioned vertically and maintained in this position for 30 days. This time is necessary for the panels to stabilize the pressing and ambient temperature, thus complementing the resin cure and correlating the moisture on the sides and center of the board.

The boards were squadded into 400mm×400mm×13mm, subsequently they were cut as samples for tests in agreement with standard EN/300[19].

2.5. Moisture Test

The samples with a minimum weight of 20g must be removed, their form and dimensions are not important. However, they must not possess free particles.

Initially, the samples should be weighed and then placed in a heater at a temperature of (103 ± 2)ºC until they reach a constant mass.

Afterwards, it must cool to room temperature, weighed again and the moisture ratio calculated by Equation 1:

$$H = \frac{m_v - m_s}{m_s} \cdot 100 \qquad (1)$$

H = humidity (%);
ms = dry mass (g);
mv = green or humid mass (g).

2.6. Density Tests

The square samples must be removed and the sides should measure nominally 50 mm and conditioned up to a constant mass to a relative moisture of (65 ± 5) % and a temperature of (20 ± 2) ℃. Constant mass is when the results of the successive weighing, performed with at least 24 h. interval, do not differ more than 0,1% in relation to the sample mass.

The samples should initially be weighed and their t thickness measured at the point they meet diagonally. b1 and b2 should be measured at two points, parallel to the edge of the sample, along the lines that pass through the center of the opposing edges. Density is calculated by Equation 2:

$$\rho = \frac{m}{b_1 \cdot b_2 \cdot t} \cdot 10^6 \qquad (2)$$

m = mass (g);
t = thickness (mm);
b1 and b2 = dimension of edges (mm).

2.7. Test of Swelling in Thickness

To determine the swelling in thickness, after immersion of the panels in distilled water for 24 hours, the square format samples with edges of (50 ± 1) mm must be removed.

The thickness of the samples must be diagonally measured at the intersection before and after it is immersed in clean water with pH 7 ± 1, at a temperature of 20 ± 1 oC and must remain submerged in 25 ± 5 mm of water for 24 hours. The thickness swelling in percentage is calculated by Equation 3:

$$G_t = \frac{t_2 - t_1}{t_1} \cdot 100 \qquad (3)$$

Gt = thickness swelling 24h (%);
t1 = initial thickness (mm);
t2 = final thickness after 24h (mm).

2.8. Internal Adhesion

For internal adhesion (IA) of the panels, the square shaped samples must be removed with edges measuring (50 ± 1) mm.

Metal supports are fastened on both sides of the samples, subsequently they undergo traction in opposite directions so that they sever. Internal Adhesion is calculated by Equation 4:

$$IA = \frac{F_{max}}{a \cdot b} \qquad (4)$$

Where,
IA = Internal adhesion (MPa)
Fmax = Maximum force (N);
a = sample length (mm);
b = sample width (mm);
A (Adhesive area) = a×b.

2.9. Modulus of Elasticity and Modulus of Rupture in Static Bending Tests

To determine modulus of elasticity (Em) and modulus of rupture (Fm) in static bending tests, rectangular shaped samples must to used, with (50 ± 1)mm midth (b). The length (l1) should be 20 times the nominal thickness plus 50mm.

The specimens should be conditioned up to constant weight, under relative moisture of (65 ± 5)% and a temperature of (20 ± 2) oC, considering that constant weight is obtained when the results of two successive weighing, performed with at least 24h of interval, do not differ more than 0,1% in relation to the initial sample weight.

The Modulus of Elasticity in bending strength (Em) is calculated by Equation 5. Each set of samples taken from the same panel gives the mean value to Em:

$$E_m = \frac{l_1^3 \cdot (F_2 - F_1)}{4 \cdot b \cdot t^3 \cdot (a_2 - a_1)} \qquad (5)$$

l1 = distance between the support centers (mm);
b = sample width (mm);
t = sample thickness (mm);
F2 – F1 = force increase, Newton, in the rectilinear section of the force-arrow curve, where F1 should be about 10% and F2 about 40% of the rupture force;
a2 – a1 = increase of corresponding arrow F2 – F1.

The fm value of each sample, given in N/mm2, is calculated by Equation 6. Each set of samples taken from the same panel gives the mean value to fm:

$$f_m = \frac{3 \cdot F_{max} \cdot l_1}{2 \cdot b \cdot t^2} \qquad (6)$$

Fmax = Rupture force (N);
l1 = distance between support centers (mm);
b = sample width (mm);
t = sample thickness (mm).

2.10. Internal Adhesion in Boiling Water

The test in boiling water is employed to verify conformity in order to control adhesion quality obtained through such approved adhesion methods. This standard is applied following the procedures:

Place the samples in boiling water and remove after (120 ± 5) minutes, afterwards remove them and immerse in water (20 ± 5)°C for (60 ± 5) minutes. Place the samples with their sides in vertical position, with at least 15mm from each other, from the sides and the bottom of the recipient.

Remove the samples and dry them with absorbing paper, then place them in a heater for (70 ± 2)°C.

Remove samples, dry them with absorbent paper and place them in heater.

The samples should be placed horizontally in air circulating heater capable of maintaining interior temperature at (70 ± 2)°C during (960 ± 15) minutes.

Afterwards, remove the samples from the heater and allow them to cool to room temperature, bind the boards on the sides of the samples and if the surface is wrinkled or uneven, it can be corrected prior to binding the test boards by polishing with sandpaper.

3. Results

Thermal characteristics

In the analysis of thermal characteristics of the sugar cane bagasse is taken into consideration as well as the polyurethane mammon based resin applied.

For the cane bagasse a thermogravimetric decomposition curve was set up, varying from room temperature up to 300°C, as seen in Figure 7.

Suitable behavior was verified from room temperature up to 60°C, higher than this temperature there is a water loss up to 75°C, after this point the beginning of an ebullition reaction at around 100°C is seen, afterwards water loss of

decomposition near 125°C begins, hence occurring the start of decomposition of the bagasse structure at 200°C and from this temperature the process of total burning of the residue initiates.
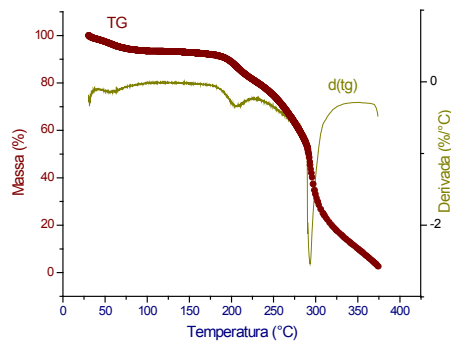
Figure 7. Thermogravimetric decomposition curve of the sugar cane bagasse

Based on this fundamental information we can define the temperature at 90°C for long particle pressing, because it is within the acceptable thermal standard for the bagasse/resin ratio.

Moisture and density ratio

The Table 1 shows the results of the moisture and density ratio of cane bagasse with 10% of polyurethane mammon based resin.

Table 1. Moisture and density ratio of cane bagasse composite

Specimens	Volume	mv	ms	H	ρap	ρap v
	(cm³)	(g)	(g)	(%)	(g/cm³)	(g/cm³)
1	34,1	20,5	19,1	7,3	0,56	0,60
2	34,1	20,7	19,2	7,6	0,56	0,61
3	33,7	20,4	19,1	7,1	0,57	0,61
4	33,4	20,3	18,9	7,2	0,57	0,61
5	33,7	20,4	19,0	7,5	0,56	0,61
6	34,0	20,6	19,1	7,4	0,56	0,60
7	33,3	20,3	18,9	7,6	0,57	0,61
8	33,5	20,4	19,0	7,2	0,57	0,61
9	33,0	20,3	19,0	7,0	0,57	0,61
10	33,7	20,4	19,0	7,4	0,56	0,61
11	34,3	20,8	19,3	7,6	0,56	0,61
12	33,4	20,4	19,1	6,9	0,57	0,61
Average	33,7	20,4	19,0	7,3	0,57	0,61
StDev	0,4	0,1	0,1	0,2	0,00	0,00
V.C.(%)	1,1	0,7	0,6	3,3	0,70	0,57

It can be concluded that apparent density at 12% moisture obtained a value of 0,57 g/cm³ with relative moisture at around 7%, a favorable result for the production of orientated OSB panels.

Swelling in Thickness

The Table 2 shows the results of the swelling in Thickness test by 24 hours.

Table 2. Swelling in Thickness test by 24 hours

Specimens	t₁(mm)	t₂(mm)	G(%)
	t_1(mm)	t_2(mm)	G(%)
1	12,2	14,3	17,2
2	13,0	14,5	11,5
3	13,0	14,4	10,8
4	13,1	14,5	10,7
5	12,2	13,7	12,3
6	12,8	15,0	17,2
7	13,2	14,7	11,4
8	13,0	13,9	6,9
9	12,4	13,9	12,1
10	13,1	14,7	12,2
11	12,6	13,9	10,3
12	12,4	14,1	13,7
Average	12,8	14,3	12,2
StDev	0,4	0,4	2,8
V.C.(%)	2,9	2,8	23,4

The thickness swelling test 24h for OSB shows values from 12 to 25%. Based on such information, in relation to thickness swelling the composite of cane bagasse long particles presented mean value of 12.2%, which is within acceptable standard standards.

Internal Adhesion

The Table 3 shows the results of the internal adhesion tests of cane bagasse with 10% resin.

Table 3. Internal adhesion of cane bagasse with 10% resin

Specimens	F_{max}(N)	A (mm²)	IA(MPa)
1	565	2500	0,23
2	486	2500	0,19
3	534	2500	0,21
4	676	2500	0,27
5	686	2500	0,27
6	451	2500	0,18
7	462	2500	0,18
8	680	2500	0,27
9	678	2500	0,27
10	690	2500	0,28
11	630	2500	0,25
12	575	2500	0,23
Average	593	2500	0,24
StDev	93	0	0,04
V.C.(%)	16	0	15,63

Internal adhesion is influenced by the particles/resin relation and its mixing process. However, this test obtained a mean internal adhesion value of 0,24MPa, Table 5. The value obtained for internal adhesion in OSB by EN300[19] is equal to or higher than 0,28MPa. On the other hand, this result is attributed to the fact that mixing is manual and takes into consideration losses due to industrial processes. Thus,

we suggest this as an acceptable assessment for future studies.

Internal adhesion in boiling water (Cyclic test)

The Table 4 shows the results of the internal adhesion after boiling water test.

Table 4.   Internal adhesion after boiling water test

Specimens	F_{max}(N)	A (mm²)	IA(MPa)
1	350	2500	0,14
2	289	2500	0,12
3	410	2500	0,16
4	370	2500	0,15
5	361	2500	0,14
6	382	2500	0,15
7	371	2500	0,15
8	528	2500	0,21
9	317	2500	0,13
10	644	2500	0,26
11	437	2500	0,17
12	339	2500	0,14
Average	400	2500	0,16
StDev	98	0	0,04
V.C. (%)	25	0	24,60

Internal adhesion for boiling water test in thickness between 10 and 18mm varies from 0,13 to 0,14 MPa. In this paper an internal adhesion value in boiling water of 0,16 MPa was observed, in a bagasse/resin composition with 10% mammon based resin at pressing temperature of 90°C. Thus, concluding that this bagasse/resin relation obtained superior standard values.

Modulus of Elasticity and Modulus of Rupture

The Table 5 shows the results of the modulus of elasticity in bending tests for condition: longitudinal fibers with 10% of pressed resin at temperature of 90°C.

Table 5.   Results of bending tests: longitudinal fibers with 10% of pressed resin at temperature of 90°C

Specimens	l (mm)	F_{max}(N)	F_1	F_2	a_1	a_2	F_m(MPa)	E_m(MPa)
1	260	730	73,0	292,0	0,70	2,32	35	5675
2	260	870	87,0	348,0	0,58	2,53	41	5609
3	260	908	90,8	363,2	0,70	2,54	41	5731
4	260	855	85,5	342,0	0,62	2,31	38	5796
5	260	634	63,4	253,6	0,56	2,02	29	5100
6	260	785	78,5	314,0	1,04	2,89	37	5349
7	260	860	86,0	344,0	1,25	3,14	39	5336
8	260	638	63,8	255,2	0,63	2,20	29	4873
9	260	737	73,7	294,8	0,78	2,52	33	4872
10	260	741	74,1	296,4	0,69	2,31	35	5642
11	260	685	68,5	274,0	0,67	2,31	31	4898
12	260	715	71,5	286,0	0,72	2,56	35	5004
Average	260	780	78,0	311,9	0,76	2,50	36	5371
StDev	0	101	10,1	40,6	0,23	0,34	5	359
V.C.(%)	0	13	13,0	13,0	30,56	13,81	13	7

In agreement with standard EN-300[19], modulus of rupture in longitudinal bending, in thickness between 10 and 18mm requires values from 18 to 28 MPa and modulus of elasticity from 2500 to 4800 MPa. In the work, to panels with 10% mammon based resin, 90°C pressing temperature, f_m=36 MPa and E_m=5371MPa were obtained. Requirements of EN-300[19] were reached.

The Table 6 shows the results of the modulus of elasticity in bending tests for condition: transversal to fibers with 10% of pressed resin at temperature of 90°C.

Table 6.   Results of bending tests: Transversal fibers with 10% of pressed resin at temperature of 90°C

Specimens	l_1(mm)	F_1	F_2	a_1	a_2	F_m(MPa)	E_m(MPa)
1	260	27,0	108,0	2,0	6,0	13	826
2	260	25,9	103,6	1,4	5,0	12	815
3	260	26,8	107,2	1,3	4,5	13	1066
4	260	25,5	102,0	1,4	5,1	12	807
5	260	31,6	126,4	1,8	6,7	14	746
6	260	39,2	156,8	1,9	7,2	18	872
7	260	33,5	134,0	1,6	5,9	15	903
8	260	28,1	112,4	1,5	5,8	13	793
9	260	29,2	116,8	1,5	5,9	14	821
10	260	27,1	108,4	1,4	5,8	13	755
11	260	29,7	118,8	1,5	5,9	14	841
12	260	32,1	128,4	1,8	6,6	15	779
Average	260	29,6	118,6	1,6	5,9	14	835
StDev	0	3,9	15,8	0,2	0,7	2	85
V.C.	0	13,3	13,3	13,7	12,6	12	10

In transversal direction, to panels with 10 to 13mm thickness, EN-300 requires f_m between 9 to 15 MPa and E_m between 1200 and 1900 MPa. In this work, to the studied panels, f_m= 14 MPa and E_m= 835 MPa were obtained.

The low value of the modulus of elasticity is probably attributed to the process of mixture, the pressure and temperature. In the next studies these variables will be more carefully controlled in order to confirm the cited hypothesis.

4. Conclusions

Sugar cane bagasse possesses a broad thermal baseline in its use of resins and other applications, which ranges from room temperature up to 150°C, with decomposition beginning at 200°C. Results indicate to application of cane bagasse with long particles, evidencing high, medium and low density.

The values of modulus of rupture and modulus of elasticity in longitudinal direction reached the method requeriments. In transversal direction, only the modulus of rupture reached the method requeriments. Modulus of elasticity values can be incresed by a more care control of mixing process and pressing temperatures.

Internal adhesion of the particulate with 10% of polyurethane mammon based resin is considered satisfactory,

notwithstanding the mix process was manual.

Since Brazil is the biggest worldwide producer of sugar cane residue, it is considerably favorable for this type of particulate with this kind of raw material and technique.

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