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CHARACTERIZATION OF SELECTED PROPERTIES OF COMPOSITES OF WASTE PAPER WITH UNTREATED BAMBOO STEM FIBRE AND RICE HUSK

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Abstract. Composite technology is an excellent approach to utilizing natural fibres and agricultural wastes, which constitute an environmental nuisance. Efforts are being made to characterize the properties of composites produced from different sources of these wastes and fibres to facilitate a choice and selection for different applications. In this study, selected properties of composite samples, produced from waste paper in equal mix-ratio with rice husk and bamboo stem fibres (BSF) separately without chemical pre-treatment using cassava starch as a binder, were characterized. Composites from rice husk are better in terms of their higher compressive strength (71–202 N/mm^2), lower water absorption, at a rate of 1.97–5.19 and 1.09–3.02 %/min, and a lower thickness swelling, at a rate of 0.74–1.23 and 0.52–0.70 %/min at 30 min and 1 h immersion time respectively, while that from the BSF is superior for its lower density 0.321–0.358 g/cm^3 and specific weight 3.15–3.51 kN/m^3. The material composition (percentage fibre volume fraction) appears to have no significant effect on the impact strength 26.0–26.4 kJ/m^2 as well as other selected properties of the composites ($p > 0.05$). However, all the samples have properties that meet the requirement for composites except that the water absorption and thickness swelling are relatively high. The composites have considerably low density, which makes them suitable in light weight applications. Their compressive and impact strength make them appear specifically relevant for the production of construction blocks and industrial helmets respectively. Meanwhile, the properties are liable to modification with a chemical pre-treatment of the fibres.

Keywords: biocomposite properties; waste paper; bamboo stem fibre; rice husk.

1. Introduction

Preferences of one engineering material over the other are fundamentally on account of the desired properties. Not all the materials have excellent properties suitable for all applications. At the same time, no material is entirely unsuitable in any application. Characterization of properties of different materials is a subject of great importance in material choice and selection for production engineers. Composite materials produced from agricultural wastes and natural fibres have special merit, because of their elimination of environmental wastes. They have been said to have advantages, such as availability, light weight, specific strength and good modulus properties [1–3].

Biocomposites have been described as composites that contain at least one natural or plant fibre. They are finding relevance in biomedical applications, such as tissue engineering, orthopaedics etc. [4]. Various other uses of agro-based biocomposites have been highlighted [5, 6], while various researchers have emphasized the use of biomass for their productions [5]. Hence, due to their general nature as wastes, paper, rice husk and bamboo stem fibres may be considered as good sources for production of such composites. Organic products and paper constitute 63 percent of global waste composition in ratio 2.7 : 1 respectively [7]. Waste paper constitutes a bulk of wastes turned out daily from academic institution, office, home and industrial activities. Its potential is being technologically underutilized in Nigeria [8]. Rice and bamboo are natural fibres in plant class, which has been generally categorized into six, namely bast (flax, hemp, jute, kenaf, andramie), leaf (abaca, pineapple and sisal), seed or fruit (coir, cotton, and kapok), straw or stalk (corn, rice, and wheat), grass (bagasse and bamboo), and wood (softwood and hardwood) [9]. Some other authors listed them as seven, categorizing seed and fruit as separate classes [10] while [4] also categorized them as six but listed maize as straw/stalk and included corn under the grass class. The chemical composition of plant fibres includes wax and the major ones being lignocellulose (cellulose, hemicellulose, and lignin). Cellulose is described as the stiffest and strongest part of the fibre; lignin is the phenolic compound, which is resistant to microbial degradation and acts as a binder that links the celluloses to retain or support the plant structure while the wax content is said to influence wettability of the composite matrix as well as interfacial fibre-matrix adhesion. These basic components determine the physical properties of the fibres, physico-mechanical properties of the biocomposites and can be altered or disturbed by physical/chemical treatment [9]. For instance, cellulose makes plant fibres hydrophilic [10] and acid treatment reduces their water absorption and thickness swelling [1].

Bast and Leaf fibres have enjoyed greater attention than others because of their generally large amount of cellulose content. The seed/fruit fibres come next due to the fact that cotton and coir, in this class, have the largest amount of cellulose and lignin among the plant fibres respectively. Deep study of the information provided by [9] revealed that rice has the largest amount of hemicelluloses (33.0 %) and is also made of cellulose content (41.0–57.0 %) higher than that of coir (36.0–43.0 %) and kenaf (31.0–39.0 %) in the seed and bast fibres categories respectively. More so, the wax content of rice and rice husk are the highest in the entire categories of plant fibres. Rice husks from rice processing factories are conspicuously mounting in public places and along roadside across the major cities like Makurdi in Nigeria. They are simply qualified as abundant in world production estimation [2]. This is expected to increase as the current government is diversifying the economy with special support for agriculture, especially local rice farming and processing. The husk is said to be formed from hard materials including silica and lignin and could be used as filler in construction, insulation material, fertilizer, or fuel. Its chemical composition is cellulose (35-–45 %), hemicellulose (19–25 %), lignin (20 %) and wax (14–17 %) [9].

However, Bamboo is one of the most commonly found trees within the local community. It is categorized with Bagasse in ratio 1 : 2.5 under the grass class of plant fibres, which has the largest world production of about 80 percent. Its chemical composition is cellulose (26–43 %), lignin (21–31 %), hemicellulose (30 %) and wax (0 %). Although Bamboo has no wax and has lower values than rice husk in terms of cellulose, it has higher values than it in both the lignin and hemicellulose [9]. However, it is one of the least contributors of natural fibres being used in biocomposites. Bamboo stem fibre is ranked next to wood with world production of 99.1 and 0.56 % in 2004 respectively [6]. Meanwhile, other natural fibres, such as flax and hemp, which are commonly used [11, 12], have comparatively less production of 0.05 and 0.01 in this ranking respectively. This may be due to some disadvantages identified with it including high moisture content and difficulties in extracting fine and straight fibres. The high lignin content is said to have influenced the high brittle nature of bamboo and difficulty to obtain its fibres in an uniform length. Meanwhile, it has advantages, such as low density, low cost, high mechanical strength, stiffness etc [10]. The use of bamboo fibre in reinforced composites materials has been strongly recommended [13].

Composite technology is an excellent approach to utilize natural fibres and agricultural wastes, which constitute an environmental nuisance. The use of these composites as packaging materials, automobile body parts, fibreboards etc., has reduced the volume of the plastic in such products resulting into improved biodegradability as well as reduced costs and disposal threats. It is essential to characterize the properties of composites produced from different materials sources to discern suitable blend or composition for specific applications. Chemical pre-treatment has been recommended for natural fibres used in composites to enhance the removal of hemicelluloses constituents, which are hydrophilic and often responsible for high thickness swelling and water absorptivity of the resulting composites [1]. Meanwhile, binders are important components in composites matrix. Replacement of petroleum dependent binder such as Urea formaldehyde (UF) with natural adhesives like starch and natural rubber is being recommended [8]. According to the same authors, cassava starch possesses good ductility, good bind-ability, self-curing properties and hygroscopic-resistance in their incorporated composite. In this study, selected properties of two classes of plant fibres separately bounded with waste paper using cassava starch to formulate composites without any chemical pre-treatment are characterized to ascertain their natural properties.

Figure 1. Paper pulp in the sun.

2. Materials and methods

2.1. Raw materials and apparatus/equipment

The description of material and locations are presented in Table 1 while the apparatus and equipment used are shown in Table 2.

2.2. Methods of preparation

2.2.1. Waste paper, fibres and cassava starch

The waste paper collected was soaked in water for 3 days. It was later pounded and grounded into fine pulp and placed under the sun for drying as shown in Figure 1. Both the rice husk and small bamboo stem branches collected were sun dried to reduce the moisture content. The Bamboo stem fibres (BSF) shown

S/N	Materials	Locations
1	Rice Husk	New Rice Mill, Wurukum, Makurdi
2	Bamboo Stem fibre	Pila Village, Makurdi Local Government
3	Waste (bond) paper	University of Agriculture, Makurdi (UAM)
4	Cassava starch	North bank market Makurdi
5	Water	Water board, University of Agriculture, Makurdi

Table 1. Raw materials.

S/N	Equipment	Model	Manufacturer
1	Sensitive electronic weighing balance	Scout Pro 6000g	Ahans Scale Corp. Okuas U.S.A.
2	Measuring jug	–	–
3	Wooden mould	locally constructed	–
4	Impact testing machine (IZOD)	6705U/D/T85337	LS102DE England
5	California bearing ratio (CBR) machine	40E/E/E5	ELE Limited U.S.A.

Table 2. Apparatus and equipments.

Figure 2. Bamboo stem Fibe before Grinding.

Figure 3. Wooden mould.

in Figure 2 were grinded using a milling machine and sun dried again. Both were initially sieved using a sieve pan of 1500microns and later with 850microns to ensure finer particle-size. The final residues tapped inside the smaller sieve were used for the composites. The starch binder was prepared by mixing 20g of cassava starch with 100 cm^3 of cold water in a vessel at a room temperature. The solution mixture was well stirred before 400cm3 of hot water was poured into it with continuous stirring to form a lump slurry starch.

2.2.2. Composite samples

A wooden mould of a size $100 \times 50 \times 8$ mm shown in Figure 3 was prepared with polythene as a facing material to prevent a leakage as well as enhancing surface smoothness of the composite sample. With a constant mass (20g) of cassava starch, different weight ratios of the waste paper, rice husk and BSF were measured and mixed manually to achieve the required composite blend as shown in Table 3. Equal volume of water was added to the blend to form mouldable matrix. The blend was transferred into the mould and compressed to take shape. The cast was allowed to set properly, after which it was removed and kept in the sun for days to ensure dryness.

2.3. Properties testing methods

2.3.1. Density and specific weight

The mass (m) of each of the samples was determined using sensitive electronic weighing scale, while the volume (v) is already predetermined from dimension of the mould. Consequently, the density ϱ and specific weight γ of the samples are obtained in the following way:

$$\varrho = \frac{m}{v}, \qquad \gamma = \varrho g, \tag{1}$$

where $g = 9.81\,\mathrm{m/s^2}$.

2.3.2. Compression and impact strength

The impact strength of the composite samples determined in the Mechanical laboratory of Univer-

S/N	Rice husk/waste paper composites				Bamboo stem fibre/waste paper composites			
	Samples	Rice husk (wt%)	Waste paper (wt%)	Binder (wt%)	Samples	BSF (wt%)	Waste paper (wt%)	Binder (wt%)
1	$RH_{10}WP_{70}S_{20}$	10	70	20	$BF_{10}WP_{70}S_{20}$	10	70	20
2	$RH_{20}WP_{60}S_{20}$	20	60	20	$BF_{20}WP_{60}S_{20}$	20	60	20
3	$RH_{30}WP_{50}S_{20}$	30	50	20	$BF_{30}WP_{50}S_{20}$	30	50	20
4	$RH_{40}WP_{40}S_{20}$	40	40	20	$BF_{40}WP_{40}S_{20}$	40	40	20
5	$RH_{50}WP_{30}S_{20}$	50	30	20	$BF_{50}WP_{30}S_{20}$	50	30	20
6	$RH_{60}WP_{20}S_{20}$	60	20	20	$BF_{60}WP_{20}S_{20}$	60	20	20
7	$RH_{70}WP_{10}S_{20}$	70	10	20	$BF_{70}WP_{10}S_{20}$	70	10	20

Table 3. Composition Composite Matrix.

Figure 4. Avery-Denison IT Machine.

Figure 5. CRB CT machine (1500 kN capacity).

sity of Agriculture, Makurdi Nigeria using Avery-Denison impact testing (IT) machine is shown in Figure 4. Compression Test to determine the compressive strength of the samples was carried out in Civil Engineering laboratory, Plateau State Polytechnic Barkinladi, Jos Nigeria in accordance with the specifications of ASTM D-1037 (1978), EN 310 (1993) and EN 319 (1993) using the California Ratio Bearing (CRB) Compression Testing (CT) Machine with 1500 kN capacity shown in Figure 5. Each sample was placed on the machine plate and loaded at 5 bars per second until it was crushed. The compressive strength, T_C was determined as calculated by [14]

$$T_C = \frac{W}{bt}, \tag{2}$$

where W (N) is the failure load and b and t (mm) are the breadth and the thickness of the samples, respectively.

2.3.3. Water absorption and thickness swelling

Two samples of each composite were immersed in water in a flat bottom container and removed after separate intervals of 30 min and 1 h. The mass of the sample before (M_1) and after the immersion (M_2) were recorded. Water absorptive rate was calculated as

$$\frac{M_2 - M_1}{M_1 t} \cdot 100\,\%. \tag{3}$$

The experiment was performed at an average room temperature of 33 °C.

The thickness swelling (TS) tests were performed according to the ASTM D-1037. All samples have the same thickness before immersion (8mm), but the thickness of each one after the immersion (T) was recorded. Thickness swelling rate was calculated as

$$\frac{T - 8\,\text{mm}}{8\,\text{mm} \cdot t} \cdot 100\,\%, \tag{4}$$

where t is the duration of immersion.

S/N	Rice husk/waste paper composites			Bamboo stem fibre/waste paper composites		
	Samples	Density (g/cm^3)	Specific weight (kN/m^3)	Samples	Density (g/cm^3)	Specific weight (kN/m^3)
1	$RH_{10}WP_{70}S_{20}$	0.325	3.19	$BF_{10}WP_{70}S_{20}$	0.321	3.15
2	$RH_{20}WP_{60}S_{20}$	0.375	3.68	$BF_{20}WP_{60}S_{20}$	0.325	3.19
3	$RH_{30}WP_{50}S_{20}$	0.425	4.17	$BF_{30}WP_{50}S_{20}$	0.325	3.19
4	$RH_{40}WP_{40}S_{20}$	0.413	4.05	$BF_{40}WP_{40}S_{20}$	0.343	3.36
5	$RH_{50}WP_{30}S_{20}$	0.475	4.66	$BF_{50}WP_{30}S_{20}$	0.345	3.38
6	$RH_{60}WP_{20}S_{20}$	0.500	4.91	$BF_{60}WP_{20}S_{20}$	0.350	3.43
7	$RH_{70}WP_{10}S_{20}$	0.513	5.03	$BF_{70}WP_{10}S_{20}$	0.358	3.51

Table 4. Density and specific weight of the samples.

S/N	Rice husk/waste paper composites			Bamboo stem fibre/waste paper composites		
	Samples	Compression strength (MPa)	Impact strength (J)	Samples	Compression strength (MPa)	Impact strength (J)
1	$RH_{10}WP_{70}S_{20}$	202	130	$BF_{10}WP_{70}S_{20}$	166	132
2	$RH_{20}WP_{60}S_{20}$	108.5	132	$BF_{20}WP_{60}S_{20}$	95	132
3	$RH_{30}WP_{50}S_{20}$	128	131	$BF_{30}WP_{50}S_{20}$	93	132
4	$RH_{40}WP_{40}S_{20}$	71	132	$BF_{40}WP_{40}S_{20}$	80	131
5	$RH_{50}WP_{30}S_{20}$	79	132	$BF_{50}WP_{30}S_{20}$	77	131
6	$RH_{60}WP_{20}S_{20}$	89.5	132	$BF_{60}WP_{20}S_{20}$	77	131
7	$RH_{70}WP_{10}S_{20}$	72.5	132	$BF_{70}WP_{10}S_{20}$	74	131

Table 5. Compression and impact strengths of samples. The area of the samples is 5000 mm^2.

2.4. Statistical analysis

IBM SPSS Statistical software tool (version 21) was used to examine the relationship and differences among the properties as well as between each of the properties and the percentage fibre volume fraction (PFVF, i.e., 10–70 %) of each of the rice husk and the BSF contained in the samples.

3. Results and discussions

3.1. Density and specific weight

The results on density and specific weight of the samples were presented in Table 4. It shows that the density and specific weight of the samples increase with increased quantity of rice husk and the BSF. Meanwhile, increased quantity of Waste paper in either of both waste materials leads to decrease in these properties implying that it has a much lesser density and specific weight than these materials. It also reveals that rice husk is heavier than the BSF having densities ranging between 0.325–0.513 and 0.321–0.358 g/cm^3 while having specific weight of 3.19–5.03 and 3.15–3.51 kN/m^3, respectively. These values are lower than the light weight blocks 0.356–0.713 g/cm^3, which production is predicted from composites of saw dust, paper and lime [7] and can be well compared to 0.213–0.580 g/cm^3 obtained for fonio (Acha) husk/gum Arabic-resin bounded composites [15]. They are even lower than the lowest density of 0.6 g/cm^3 recorded for natural plant fibres and 0.6–1.1 g/cm^3 specifically for bamboo fibres [9] and for all the natural fibres listed by [11]. They are also lesser than that of a typical cement boards (1.86 g/cm^3) as well as 1.408–1.603 g/cm^3 found with the composites developed for similar application from paper, natural fibres (rice husk and rice), silica, cement, polyvinyl acetate and poly ol [16]. Low density or weight is one of the most important advantages of composites from natural fibres. Consequently, the composites from this study are acceptable and suitable in light weight applications.

3.2. Compression and impact strength

The outcome of compression and Impact test on the samples are present in Table 5. It shows that the composites of rice husk and the BSF have compression strength of 71–202 and 77–166 MPa (i.e., N/mm^2), respectively. The compression strength of the composites is higher than 50–80 MPa observed for two different species of bamboo strips in previous research [10]. They are also higher than 0.057–0.397 N/mm^2 that is the value for the particleboards produced from composites of fonio husk and gum Arabic at the lowest to highest percentage of resin adhesive used as a binder and the minimum (2.5 N/mm^2) compressive strength acceptable for construction blocks [15]. They

Rice husk/waste paper composites						Bamboo stem fibre/waste paper composites					
Samples	**Initial weight** (g)	**Final weight** (g)		**Absorptive rate** (%/min)		**Samples**	**Initial weight** (g)	**Final weight** (g)		**Absorptive rate** (%/min)	
		@30	@60	@30	@60			@30	@60	@30	@60
$RH_{10}WP_{70}S_{20}$	12.6	32.23	35.44	5.19	3.02	$BF_{10}WP_{70}S_{20}$	12.86	44.14	44.87	8.11	4.15
$RH_{20}WP_{60}S_{20}$	15.5	35.64	36.62	4.33	2.27	$BF_{20}WP_{60}S_{20}$	13	41	43.62	7.18	3.93
$RH_{30}WP_{50}S_{20}$	16.5	35.42	37.78	3.82	2.15	$BF_{30}WP_{50}S_{20}$	13.33	39.67	43.56	6.59	3.78
$RH_{40}WP_{40}S_{20}$	16.83	27.1	27.82	2.03	1.09	$BF_{40}WP_{40}S_{20}$	13.67	36.33	39.2	5.53	3.11
$RH_{50}WP_{30}S_{20}$	19.17	31.17	33.19	2.09	1.22	$BF_{50}WP_{30}S_{20}$	13.83	35.17	38.37	5.14	2.96
$RH_{60}WP_{20}S_{20}$	19.67	31.67	33.69	2.03	1.19	$BF_{60}WP_{20}S_{20}$	14	34	38.2	4.76	2.88
$RH_{70}WP_{10}S_{20}$	20.33	32.37	33.92	1.97	1.11	$BF_{70}WP_{10}S_{20}$	14.34	31.66	36.88	4.03	2.62

Table 6. Water absorption of samples. Legend: @30 – at 30 min time; @60 – at 60 min time.

Rice husk/waste paper composites					Bamboo stem fibre/waste paper composites				
Samples	**Final thickness** (mm)		**Thickness swelling rate** (%/min)		**Samples**	**Final thickness** (mm)		**Thickness swelling rate** (%/min)	
	@30	@60	@30	@60		@30	@60	@30	@60
$RH_{10}WP_{70}S_{20}$	10.36	11	0.98	0.63	$BF_{10}WP_{70}S_{20}$	11.98	14.15	1.66	1.28
$RH_{20}WP_{60}S_{20}$	10.96	11.15	1.23	0.66	$BF_{20}WP_{60}S_{20}$	11.95	13.05	1.65	1.05
$RH_{30}WP_{50}S_{20}$	10.37	11.2	0.99	0.67	$BF_{30}WP_{50}S_{20}$	11.38	12.05	1.41	0.84
$RH_{40}WP_{40}S_{20}$	10.52	10.84	1.05	0.59	$BF_{40}WP_{40}S_{20}$	10.49	11.5	1.04	0.73
$RH_{50}WP_{30}S_{20}$	10.1	10.5	0.88	0.52	$BF_{50}WP_{30}S_{20}$	10.18	11.28	0.91	0.68
$RH_{60}WP_{20}S_{20}$	9.82	10.6	0.75	0.54	$BF_{60}WP_{20}S_{20}$	10.13	10.38	0.89	0.5
$RH_{70}WP_{10}S_{20}$	9.77	11.38	0.74	0.7	$BF_{70}WP_{10}S_{20}$	10.01	10.08	0.84	0.43

Table 7. Thickness swelling of samples. The initial thickness was 8 mm. Legend: @30 – after 30 min; @60 – after 60 min.

are also higher than that of a typical cement boards (26.9 N/mm^2) as well as 17.5–22.1 N/mm^2 that was measured for the composites developed for similar application from paper, natural fibres (rice husk and rice), silica, cement, polyvinyl acetate (PVA) and poly ol [16]. On average, it can be well compared to the optimum compressive strength of 90 MPa reported for epoxy resin filled rice husk [17]. Meanwhile, the composition of the composites appears to have no significant effect on the impact strength with composites of rice husk and bamboo stem fibres having impact strength of 26.0–26.4 and 26.2–26.4 kJ/m^2, respectively. This result can be well contrasted with Polycarbonate (20.0–30.0 kJ/m^2) and Acrylonitrile butadiene styrene (10.0–29.0 kJ/m^2) being used for production of industrial helmet shell and coir/epoxy resin composite (21.80–26.43 kJ/m^2) being proposed for similar application [18].

3.3. Water absorptivity and thickness swelling

The result of water absorption and thickness swelling test are presented in Tables 6 and 7.

Table 6 shows that rice husk have a lower affinity for water (i.e lower water absorption capacity) than the BSF. The composites from rice husk have water absorptive rate (WAR) of 1.97–5.19 and 1.09–3.02 %/min while those from the BSF have 4.03–8.11 and 2.62–4.15 %/min at 30 min and 1 h time of immersion, respectively. Table 7 shows that the rice husk is better than the BSF in terms of its resistance to thickness swelling. The composites from rice husk have thickness swelling rate (TSR) of 0.74–1.23 and 0.52–0.70 %/min, while those from the BSF have 0.84–1.66 and 0.43–1.28 %/min at 30 min and 1 h time of immersion, respectively. A contrast may not be appropriate between these values and 81.2 % of the dry weight measured for water absorbed by Bamboo fibre when soaked in water for 144 h (absorptive rate of 0.009 %/min) [10] and for some selected natural fibres [11] due to the extended and unknown length of immersion respectively. However, a comparatively similar outcome may be expected since this result indicates that the water absorption of the composites decreases with prolonged time of the immersion in water. This may be partly due to the presence of

Paired factors	Pearson correlation			Differences		
	N	Correlation	Sig. (2-tailed)	t	df	Sig. (2-tailed)
PFVF & density	14	−0.34	0.234	6.328	13	0
PFVF & specific weight	14	−0.342	0.231	3.124	13	0.008
PFVF & compression strength	14	−0.522	0.055	−8.415	13	0
PFVF & impact strength	14	−0.071	0.81	−108.435	13	0
PFVF & water absorptive rate	28	0.284	0.143	5.284	27	0
PFVF & thickness swelling rate	28	0.005	0.981	8.501	27	0

Table 8. Percentage fibre volume fraction (PFVF) and composite properties.

Properties		Sig. (2-tailed)					
		SW	**CS**	**IS**	**WAR**	**TSR**	**Time**
Density	**D**	0	0.196	0.167	(−)0.000	(−)0.016	NP
Specific weight	**SW**		(−)0.199	0.165	(−)0.000	(−)0.017	NP
Compression strength	**CS**	NS		(−)0.152	0.114	0.213	NP
Impact strength	**IS**	NS	NS		(−)0.648	0.231	NP
Water absorptive rate	**WAR**	HS	NS	NS		0	(−)0.003
Thickness swelling rate	**TSR**	HS	NS	NS	HS		(−)0.001

Table 9. Correlation between composite properties. Legend: NS – not significant, HS – highly significant, NP – not possible.

waste paper, which creates further interfacial space within the matrix of the composites. It may also be partly due to the lack of pre-treatment of the fibres with the aim of characterizing the properties of the composites in natural composition.

Meanwhile, [8] has found that untreated composites of rattan particulate reinforced paper pulp, using starch as a binder, is better than alkali treated samples in water absorption. Chemical treatment has been reported as capable of removing hemicelluloses and lignin content of the plant fibre resulting in a reduction of water absorption and thickness swelling of the biocomposites [1, 19]. This result agrees with this earlier finding as the BSF contains no wax and has higher amount of lignin and hemicelluloses than rice husk. Therefore, it implies that the hydrophilic nature of plant fibres is more due to hemicelluloses than cellulose or that biocomposites are less hydrophilic with increased wax content and reduced hemicelluloses and lignin content of the plant fibres from which they are made. Hemicellulose and lignin have been described as amorphous and hygroscopic thermoplastic substances, which are affected by environmental conditions, such as humidity and temperature [20]. Since rise husk is higher in cellulose content and yet has the lower water absorption and thickness welling, it may be concluded that the relationship between cellulose and these composite properties is inverse as that of the wax. This result is in agreement with the observation that increase in cellulose improves the mechanical properties of the fibres [13] and also suggests that same may be true for wax. Cellulose has been described as the main reinforcing element and it is not affected by alkalis and dilute acids [20]. Logically, this analysis suggests that cellulose and wax are like binding agents while the lignin and hemicelluloses act like pore cavities within the matrix of the fibres. This result agrees with information in Table 5 — that the composites with rice husk has higher compression strength compared to the BSF. The former is expected to have a greater resistance to compression since its matrix is composed of more binding structures than the pore cavities.

3.4. Result of statistical analysis

The outcome of Pearson correlation and t-test are shown in Tables 8 and 9.

Table 8 shows that the percentage volume fraction of the fibres in the composites matrix has no significant effect on the selected properties ($p > 0.05$), but there is a highly significant difference in each of these properties for varying percentage fibre volume fraction (PFVF) in the samples ($p < 0.05$). This implies that these properties are significantly different for each sample, but this difference is not related to their compositions. This result has confirmed that it is not just that the sample composition has no significant effect on the impact strength (as earlier suspected on table 5), but also that the same applies to every other selected property.

Table 9 shows that Compression and Impact strength has no significant relationship neither with each other nor with any of the selected properties ($p > 0.05$). Meanwhile, the density has a highly significant effect on the specific weight, water absorption rate (WAR) and thickness swelling rate (TSR) of the samples ($p < 0.05$). However, its relationship with the WAR and TSR is negative, implying that as the density of the composite samples reduces, both properties increase and vice versa. Specific weight also has a similar relationship with the both properties. The WAR has a highly significant positive relationship with the TSR and vice versa ($p < 0.05$). This suggests that the increase in one implies increase in other. Meanwhile, both the WAR and the TSR have highly significant negative relationships with time such that the higher the duration of immersion, the lesser the both properties (as observed in Tables 6 and 7). This result gives a more logical justification to the remark earlier made that the WAR of 0.43–1.28 %/min, observed in this study for the BSF (Table 6), and the estimated corresponding value of 0.009 %/min, observed by [10] after 1 and 144 h of immersions, respectively may be equivalent and corroborative.

4. Conclusion

Waste paper, rice husk and bamboo stem fibre, which constitute wastes have been used to produce composites and the selected properties of the composites produced have been characterized. Composites from rice husk are better in terms of their higher compressive strength, lower water absorption and thickness swelling while bamboo stem fibre is superior for its lower density and specific weight. Water absorption and thickness swelling of the composites decrease with increase of the immersion time in water for each of the samples. Waste paper has a lower density, specific weight and higher compression strength than both materials such that the higher the quantity of waste papers in the composition the better the compression strength and lower density and specific weight of the composites. The material composition (percentage fibre volume fraction) appears to have no significant effect on the impact strength as well as on all other selected properties of the composites ($p > 0.05$). However, all the samples have properties that meet the requirements for composites, except the fact that the water absorption and thickness swelling are relatively high. The composites have considerably low density, which makes them suitable in light weight applications. Their compressive and impact strength make them appear specifically relevant for production of construction blocks and industrial helmets respectively. The properties are liable to a modification with chemical pre-treatment of the fibres.

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