

Production and Characterization of Reed and Wood Particles/Phenol Formaldehyde Resin Composite Board

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Abstract The present research focuses on the production of a single-layer composite board made from a mixture of reed and pine wood particles as well as unsaturated phenol formaldehyde resin. Reed culms used had an average length of 4.2m, stalk base diameter of 7.1cm and had the capacity to produce 250g particles when ground; the particles used had an average length and width ranging from 8 to 12mm and 1 to 3mm respectively. The particles were boiled in 4.2% sodium hydroxide (NaOH) for an hour so as to improve their wettability with the resin during the fabrication process. Systematic experiments were designed; these led to determination of significant process parameters and material variables that predominantly influence the characteristics of the composite board. The independent variable factor was the mixing ratio of reed and wood particles. Other parameters such as resin content, pressing cycle time, hardener content and press pressure; were maintained constant. The physical and mechanical properties of composite boards including flexural strength, compression strength, tensile strength and water absorption were determined according to ASTM standards. One-way Multi-variance analysis (MANOVA) was conducted using SPSS programming (version 16) to assess whether the mixing ratios of reed and wood particles had an influence on the mechanical properties of experimental boards. Findings revealed that particle mixing ratio exerted a significant effect on the mechanical and physical properties of boards. On the other hand, particle volume fraction (V_p) was shown to have a crucial influence on the performance of composite boards.

Keywords Composites, Volume fraction, Reed particles, Wood particles, Phenolic resins

1. Introduction

Polymeric materials reinforced with synthetic fibers such as glass, carbon and aramid provide advantages of high stiffness and strength to weight ratio as compared to conventional construction materials, that is; wood, concrete and steel. Despite these advantages, the widespread use of synthetic fiber-reinforced polymer composite has a tendency to decline because of high initial costs, their use in non-efficient structural forms and most importantly their adverse environmental impact [1]. Researchers have thus pursued natural, high performance engineering materials because they are renewable, environmentally sound and pose no health hazard. The increasing interest in using natural fibers as reinforcements in polymers has posed some controversies and wood fiber is a good example. With the rapid increase in usage of wood in energy generation and development of wood-based composites, more and more wood processing enterprises are facing raw material shortages due to global decline in forest resources. An alternative that can reduce wasteful deforestation is the use

of waste wood particles instead of virgin woods since this waste represents 50.7% of all log production [2]. Current research trends therefore lay more emphasis on non-wood and ligno-cellulosic biomass for use in composite manufacture [3, 4]. These agricultural lignocellulosic plants can be easily crushed to chips or particles, which are similar to wood particles, and may be used in combination or as substitute for wood-based raw materials.

Literature contains several studies on the manufacture of composite boards using particles or fibers from different lignocellulosic sources and synthetic binders or adhesives to bond the particles, often by applying heat. Kalaycioglu and Nemli [5] investigated on the parameters affecting the properties of kenaf fiber and from their study it was found that press temperature, time, density and shelling ratio affects the physical and mechanical properties of particleboards. Literature also indicates that among other cellulosic fibers, reed plant has been reviewed for use in particleboards because of its fast growth properties, high cellulose and lignin content as well as high fiber length properties [6-8]. In 2005, Behzad Kord and others [9] carried a study which concluded that reed stem was suitable for use in the manufacture of particleboards. In another study [10], Dahmardeh Ghalehno investigated on mechanical properties of a composite material which was prepared from unsaturated polyester resin UPE with two

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types of fillers (reed and some commercial species). The results obtained showed that composite materials of reed fillers had good mechanical properties.

A comparative study between properties of particleboards produced from saw dust with phenol formaldehyde (PF) and urea formaldehyde (UF) resin revealed that particleboards produced with PF had better properties compared to that of UF [11]. The study further showed that processing temperature, particle size and geometry, compaction pressure, type of resin and/ or adhesive and their mixing time are the most significant properties to be considered during composite development. This research therefore focused on the production and characterisation of a composite board produced from two types of reinforcements (that is; reed and wood particles) and phenol formaldehyde resin.

2. Methodology

2.1. Preparation of Raw Materials

Reed stalks or culms were harvested, baled and then left to dry under direct sunlight for 31 days. The stalks were manually cut to 30cm length and then chopped to small particles using a hammermill. To obtain a homogenous particle size, the reed particles were passed through a sieve and the average size of reed particles was maintained at 12mm length and 2.5mm width. Wood particles from pine wood were picked and screened for removal of contaminants as well as to come up with uniform particle size. The average size of the particles was 12.5mm length and 2.7mm width.

2.1.1. Surface Modification of Particles

Different constituents of plant materials (reed and wood plants) such as lignin, silica, ash and other metal elements were eliminated through a surface modification or pre-treatment process [12, 13]. Two samples from both reed and wood particles were prepared, that is; one sample was treated with a surface modifier whilst the other sample was left untreated. In this method, 10g of material was treated with 4.2% of hot NaOH [12] solution for an hour with temperature maintained at 80°C. The particles were then washed twice with distilled water containing 1ml of acetic acid to neutralize excess sodium hydroxide, and the extract evaporated to dryness. The residues water absorption characteristics were determined gravimetrically.

2.1.2. Moisture Regain of Particles

Moisture regain of both reed and wood particles was determined through water absorption (WA) test based on ASTM D570 [14]. Both particles, that is; surface modified and unmodified reed and wood particles were immersed in distilled water for 24 hours. Reed and wood particles used in this study had water absorption of 23.1% and 36.0% which was further increased by 5.5% and 3.3% respectively after surface modification.

2.2. Synthesis of Phenol Formaldehyde (PF) Resin

Phenol was mixed with formalin (37% solid content) in the ratio of 2:1.3 based on results from trial and error method. A full factorial method was designed to vary the concentration of phenol formaldehyde and hydrochloric acid (HCl). Using this experimental design, six (6) independent tests were carried out, each with varying concentration of hydrochloric acid (hardener) to determine the effect of varying the concentration of HCl on the resin curing time. 12% HCl was chosen as the optimum concentration considering that it offered ideal time for particles and resin to mix homogeneously before resin curing. Thus 12% HCl was added to the mixture slowly with stirring till polymerization point was reached. At this point, 20% excess formalin was added. Stirring was done continuously as the plastic was forming and becoming a pink precipitate. The density of the resin after curing was found to be 1.1g/cm³ which conforms to the standard densities of phenol based resins [11, 15, 16].

2.3. Composite Board Fabrication

The percentage of reed (R) and wood (W) particles used during the composite fabrication was varied according to the ratios in Table 1.

Table 1. Mixing Parameters for Composite Development

Vp (%)								R:W
0		10		25		40		
R	W	R	W	R	W	R	W	Ratio
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
		10	0.0	25.0	0.0	40.0	0.0	1:0
		7.5	2.5	18.8	6.2	30.0	10.0	3:1
		5.0	5.0	12.5	12.5	20.0	20.0	1:1
		2.5	7.5	6.2	18.8	10.0	30.0	1:3
		0.0	10.0	0.0	25.0	0.0	40.0	0:1

The composite Vp (which is a mixture of reed and wood particles) was varied in relation to the volume of PF resin. At each Vp, the mixture ratio of reed and wood particles was chosen at five levels (that is; 1:0, 3:1, 1:1, 1:3 and 0:1). An unreinforced composite (0% Vp) was also developed and used as the control of the experiment. Based on these variables, 16 board formulations were developed. The particle-boards dimensions were maintained at 240mm length and 210mm width. Pre-pressing was performed under ambient conditions. A target density ranging between 0.40g/cm³ and 0.85g/cm³ was maintained so as to allow comparisons to be made with other standard medium density particleboards.

Figure 1 shows the design of the mould used in composite board development. The mould consists of a rectangular frame, a base plate and similar plate for mould top. The mould was made from aluminium metal.

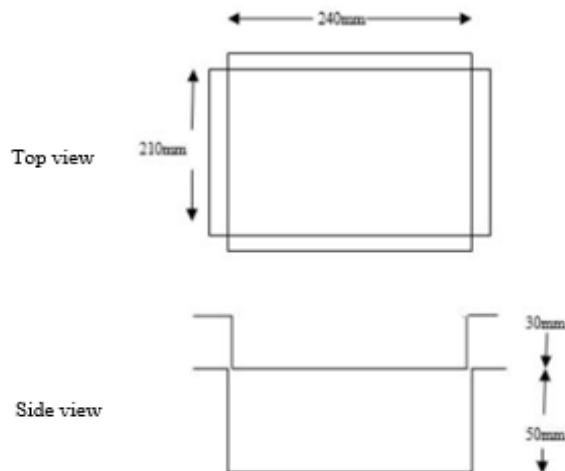


Figure 1. 2-D sketch of the mould

Hand laying and compression moulding methods were used to fabricate the composite board [17, 18]. The internal surface of the mould was coated with polyvinyl alcohol (PVA) followed by a release film. The dried wood and reed particles were randomly hand laid onto the mould according to the ratios shown in Table 1. Phenol formaldehyde mixture (as soon as the precipitate started to increase its viscosity) was then poured evenly onto the particles on the mould. The mould was then closed and pressed into panel mat using a force of 32kg/m². The mixture was left to cure under ambient conditions for 30minutes so as to allow more consolidation through pressing pressure. The composite boards were then conditioned under ambient conditions for 24hours before testing.

2.4. Composite Board Density

Developed composite board had a thickness of 5mm, 8mm and 10mm, and a density ranging between 0.66g/cm³ and 0.85g/cm³. This density and thickness met the density requirements for medium density particleboards [19]. Board density was shown to increase directly proportional to particle volume fraction. In the absence of wood particles, reed gave a lower density as compared to when mixed with wood. This low densification of reed is a benefit in the properties of the overall composite as it allows addition of more particles per given board and this enables effective distribution of stress within the internal structure of the composite.

2.5. Characterisation of Composite Boards

For each of the following tests, three (3) test specimens were prepared according to sample dimensions recommended by ASTM standards.

2.5.1. Flexural Strength (FS)

Test specimen from the developed composites were taken and tested for their flexural strength properties according to ASTM D790 [20]. The test sample dimensions were 150mm x 25mm. The test specimen was suspended on a flexure

(three-point bending) machine as a simple beam supported at two points and loaded at its midpoint. This allowed the stress in the outer surface of the specimen to occur at the midpoint. The test speed was maintained at 0.10kN/min. The maximum flexural stress sustained by the test specimen during the bending was calculated electronically based on the equation:

$$\delta f = 3PL/2bd^2 \quad (1)$$

P is the load (force) at fracture point

L is the length of support span

b is width

d is thickness

δ is the stress in the outer particles and at midpoint (Mpa)

2.5.2. Compression Strength (CS)

Compression testing was conducted on composites test samples according to ASTM D695 [21] so as to determine the change in composite length as a function of the load on the test specimen. Before mounting the specimen onto the compressometer, the initial length of the specimen was first recorded. The specimen was then mounted in between the plunger and the hardened ground of the test equipment. As the plunger was moved towards the specimen, it forced the specimen to contract. The maximum compressional strength carried by the specimen before rupture (also known as the breaking load) was determined.

$$\delta c(Mpa) = \frac{\text{Breaking Load}(kN)}{\text{Conversion Factor}(kN/min)} \quad (2)$$

where: cross-sectional area (A) of the specimen is equivalent to the conversion factor;

δc = Compressive Strength; and

$$A = \text{length}(l) \times \text{width}(w) \quad (3)$$

The test speed was maintained at 45kN/min, ensuring that the specimen was in-line with the plunger during the compression testing process.

2.5.3. Tensile Strength (TS)

The tensile strength of experimental boards was determined using the principle of constant rate of elongation (CRE). Testing was done according to ASTM D638 using Testometric tensile testing instrument [22]. A load of 2500kg was used to elongate the specimen at a speed of 200mm/min till rupture point. Tensile strength of the board was calculated according to equation 4.

$$\delta t(\text{tensile strength}) = \frac{Wt(\text{failure tensile load})}{b \times t (\text{breadth} \times \text{thickness})} \quad (4)$$

2.5.4. Water Absorption (WA)

Water absorption test was employed according to ASTM D570 [14] to determine the relative rate of absorption of water by composite board. The specimen was dried in an oven to a moisture content (Mc) of 0% prior to testing. The conditioned specimen was submerged in distilled water for 24hours. After 24 hours the sample was removed from water and excess water from the sample removed prior to weighing.

Percentage (%) Moisture regain (Mr) was calculated using the equation:

$$\% Mr = \frac{\text{mass of absorbed water in the specimen (g)}}{\text{mass of dry specimen (g)}} \times 100 \quad (5)$$

The test results obtained were used as a guideline to determine the proper proportions of resin and particles to be used in production of the particleboard of the same, depending on the required end use properties of the composite board.

2.6. Statistical Analysis

MANOVA was conducted using SPSS programming to assess whether the mixing ratios of reed and wood particles had an influence on the mechanical and physical properties of experimental boards in terms of flexural strength, compression strength, tensile strength and water absorption. Differences between each board type were also analyzed. A sample size of 3 was used for each property being analyzed; and this was done at 16 levels of reed and wood mixing ratios.

3. Results and Discussion

3.1. Mechanical and Physical Properties

The density of the developed composite ranged from 0.66g/cm³ to 0.85g/cm³, whereas the thickness ranged from 5 to 10mm. According to Australian standards [23], the developed composite is categorized under thin composites based on board thickness. To assess the statistical difference in mechanical and physical properties of thin composites, multivariate test and tests of between-subjects effects was carried out. The results obtained from the tests are shown in Table 2.

Table 2. Statistical Analysis Results

Property	F-value	P-value
Flexural Strength (Mpa)	222.666	.000
Compression Strength (Mpa)	42.15	.000
Tensile Strength (Mpa)	176.153	.000
Water Absorption (%)	169.736	.000
Wilks' Lambda	107.811	.000

The multivariate test using Wilks' Lambda produced an F value of 107.81 and a p-value of .000, which meant that $p < .0005$. Therefore, it was concluded that there was a statistical difference in mechanical and physical properties of composite boards based on reed and wood particle mixture.

3.1.1. Flexural Strength

The flexural strength (FS) obtained from this study ranged from 20 to 190Mpa. Composites made from 3:1 reed to wood particle mixing ratio gave the highest values at each percentage particle volume fraction. However, only 3:1 reed to wood ratio at 40%Vp gave the highest FS value of

190Mpa. Based on Australian standards [23], 43.5MPa and 44MPa are the minimum FS requirements for general uses and furniture manufacture respectively. Based on results shown in Figure 2 it was observed that 0% and 10% particleboards did not meet the standard requirements whereas boards with 25% and 40% Vp met and exceeded the standard requirements [23].

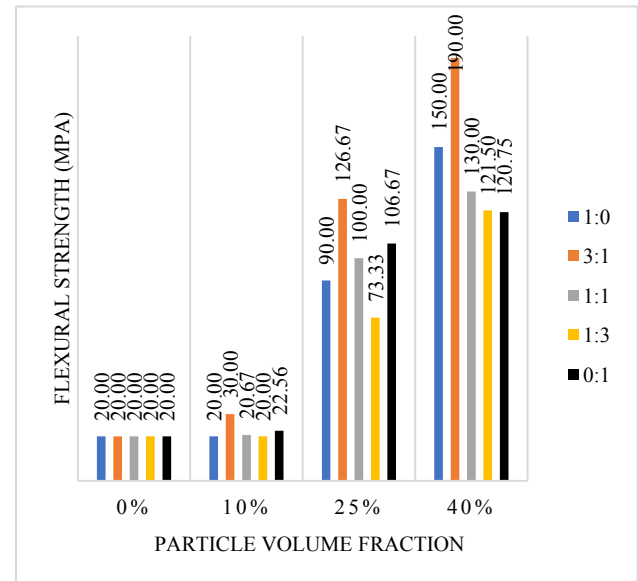


Figure 2. Flexural strength at different particle volume fraction

MANOVA analysis showed that FS was significantly ($F = 222.67$, $p < .0005$) affected by the particle mixing ratio and this was shown by an increase in FS as Vp increased from 0 to 40%. At each level of Vp, composites consisting of high ratio of reed particles as compared to wood showed high FS properties. This was because of low density of reed particles [8, 24] which subsequently results in addition of more particles during fabrication in-order to meet the standard density requirements. Because of the increased number of particles, when a stress is applied to the board it is evenly distributed from the resin/ matrix to the reinforcement hence giving high resistance to the force applied.

3.1.2. Compression Strength

Compression strength (CS) is the ultimate stress that a specimen with a given area can withstand before fracture. The composite particle-volume has a high influence to this property as evident by a 1:1 board with a particle volume of 25% giving high compressional strength of 3.76Mpa whereas the control board (0% Vp) gave a value of 0.87Mpa. In 2011 Garcia-Ortuno and others [25] reported that board density which is directly proportional to particle volume was the most important factor affecting all physical and mechanical properties of composites. The results obtained from Behzard Kord and others in 2016 [26] also showed that an increase in particle volume improved the compressional strength properties. The univariate test of between-subjects effects as seen in Table 2 showed that the mixing ratio of reed and wood had a statistically significant

effect on compressive strength ($F = 42.15$, $p < .0005$).

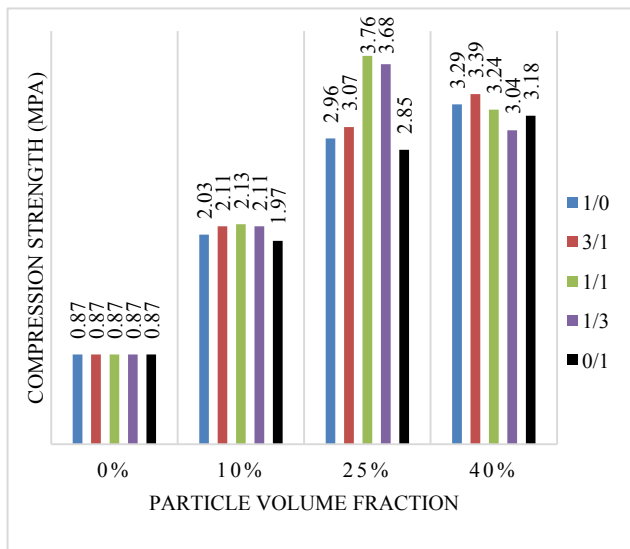


Figure 3. Compression strength at different particle volume fraction

According to Figure 3, the compression force in composites was shown to increase with an increase in particle volume fraction and thus increasing the contact between individual particles. However, the increase in compression force occurred up to a critical level and beyond this level it started to decrease. This is based on the observation that at 25% particle volume, particles effectively act together to distribute the load equally along the plane of the stress applied, but above this volume phenol formaldehyde resin becomes insufficient to completely encapsulate all the individual particles.

Based on standards for general purpose boards, the minimum requirements for CS is 10Mpa. However, all board types failed to meet this standard value as shown by the highest value being only 3.8Mpa. According to Azizi [3] low matrix-reinforcement adhesion causes inadequate compaction pressure during composite development as attributed to hand laying method [17]. Low matrix-adhesion thus results in an increase in slippage when a stress is applied, thus propagating the cracks among the reinforcement leading to fracture at low stress levels.

3.1.3. Tensile Strength

An unreinforced board exhibits a brittle fracture and thus fractures at low stress levels [27, 28]. This was evident by a tensile fracture of 0.01Mpa for the control board with 0% particle volume fraction. However, the tensile strength (TS) value increased steeply as more particles were added onto the brittle matrix. Tensile strength was shown to increase with an increase in particle volume fraction up to a threshold of 1.75Mpa after which it decreased gradually. This decrease in tensile strength at high particle volume conforms with the rule of mixtures which states that each particle should be surrounded by matrix to make a homogenous mixture of resin-rich areas and particle-rich

areas [3, 11, 29]. However, at 40% particle volume this rule is violated leading to low tensile strength.

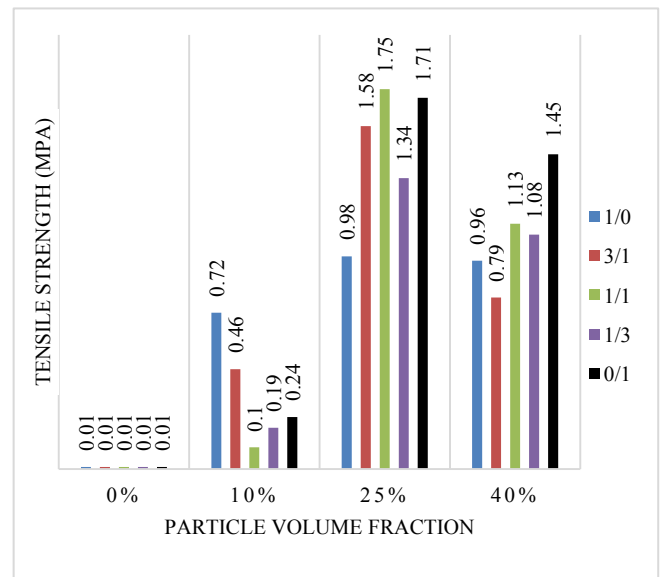


Figure 4. Tensile strength at different particle volume fraction

Almost all board types made of 25 and 40% particle volume fraction met and exceeded the minimum tensile strength standards (1.15Mpa) for medium density boards [23] and only boards made using 25%Vp, 1:0 reed to wood ratio and 40%Vp, 1:0 and 3:0 ratio failed to meet these standards. From the statistical test of between-subjects effects in Table 2, it was shown that the particle mixture had a statistically significant effect on tensile strength ($F = 176.15$, $p < .0005$). This was evident in major variations being observed in the bars of Figure 4. These variations are not only caused by different particle mixture, but also by defects like poor particle dispersion, voids and poor particle-matrix adhesion which occurs during composite fabrication.

As stated by Paul Mamza et al [11], hand laying method results in poor particle dispersion as it causes less consistent control of reinforcement and resin content. The other cause of variation is the different maturity levels of reed plant which affect the strength properties of reed particles [8]. Reed plant is made of three sections (that is; top, middle and bottom sections) and mechanical strength properties have shown to increase from bottom to top due to an increase in the number of vascular bundles from bottom to top [30].

3.1.4. Water Absorption

Water absorption (WA) in particleboards is determined by the nature of particles used. By nature, cellulose-based particles are hydrophilic and surface modification through treatment with sodium hydroxide further increases water absorption properties [12]. The univariate test of between-subjects effects showed that the particle mixing ratio of reed and wood had a statistically significant effect on water absorption ($F = 169.74$, $p < .0005$).

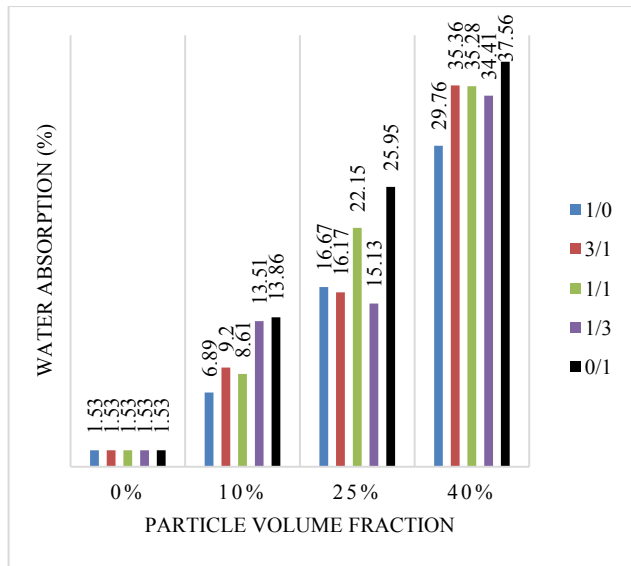


Figure 5. Water absorption of developed composites

The water absorption values for all reinforced board types ranged from 7 to 38% after they were immersed in water for 24 hours. Board types with 10%Vp failed to meet the minimum FAO water absorption standard range of 20 to 75% WA [23]. MANOVA results showed that WA after 24-hour test was significantly ($p < 0.01$) affected by the type of composite board. The results presented in Figure 5 showed that boards made with 10% Vp had significantly lower WA values compared to the rest of the boards. It was also observed that particle mixing ratio had an effect on the amount of water absorbed as observed on 1:0 reed to wood ratios which gave lower water absorption properties.

Board types with a high ratio of reed particles as compared to wood showed low levels of water absorption. This is because wood particles have high amount of pith which consists of parenchyma cells. The parenchyma tissue contains hydroxyl groups which enables the panels to bond with water molecules on their surface through hydrogen bonding [31].

4. Conclusions

Samples made from a combination of 3:1 and 1:1 reed to wood particle volume showed higher mechanical properties than the AS/NZS1170 standards for medium density particleboards. However, the use of reed particles in composite boards showed high performance on mechanical properties in this study as the reed particle volume fraction increased from 0% to 40%. The reason for this improvement can be related to the low density of reed particles which causes more densification. This in turn causes better adhesion during hot pressing and more particles to act together thereby distributing the load exerted on them leading to improved mechanical properties.

Based on mechanical property results of this study, it can be concluded that reed stem has potential as a raw material

for composite board manufacturing, not only for those made exclusively with reed particles, but also through the combination with wood particles. The use of reed in composites is a feasible solution for the particleboard industry because it is economically, ecologically and socially viable and enables management of the reed grass (invasive plant) and, empowers small scale entrepreneurs. Furthermore, environmental excellency is achieved through acting as a carbon sink as well as a soil reinforcer to reduce soil erosion. Composite boards developed from this study can be used as general-purpose boards, that is; as construction material in furniture, wall and ceiling panelling, floor underlayment et cetera.

5. Recommendations

There is need for future research which concentrates on reducing or eliminating usage of phenol formaldehyde resins due to their toxicity on the environment. This can be done through some improvements on greener resins so that they can offer properties which tally with those of synthetic resins. There is also a need for more analysis on the different properties of reed or wood composites by modern equipment in most of the areas covered in this review.

REFERENCES

- [1] Rai A, Jha C: Natural fibre composites and its potential as building materials. *Express Textile* 2004, 25: 116-220.
- [2] Food F: Agriculture Organization of the United Nations. (2007). National report Belize. *FAO Corporate Document Repository*.
- [3] Azizi K, Tabarsa T, Ashori A: Performance characterizations of particleboards made with wheat straw and waste veneer splinters. *Composites Part B: Engineering* 2011, 42(7): 2085-2089.
- [4] Khanjanzadeh H, Bahmani AA, Rafighi A, Tabarsa T: Utilization of bio-waste cotton (*Gossypium hirsutum* L.) stalks and underutilized paulownia (*Paulownia fortunei*) in wood-based composite particleboard. *African Journal of Biotechnology* 2012, 11(31): 8045-8050.
- [5] Kalaycioglu H, Nemli G: Producing composite particleboard from kenaf (*Hibiscus cannabinus* L.) stalks. *Industrial crops and products* 2006, 24(2): 177-180.
- [6] Finell M: The use of reed canary grass as a short fibre raw material for the pulp and paper industry. PhD Thesis. Swedish University of Agricultural Sciences, Unit of Biomass Technology and Chemistry, Umea; 2003.
- [7] Mathur V: Composite materials from local resources. *Construction and Building Materials* 2006, 20(7): 470-477.
- [8] Pahkala K, Pihala M: Different plant parts as raw material for fuel and pulp production. *Industrial Crops and Products* 2000, 11(2): 119-128.

- [9] Kord B, Roohani M, Kord B: Characterization and utilization of reed stem as a lignocellulosic resource for particleboard production. *Maderas Ciencia y tecnología* 2015, 17(3): 517-524.
- [10] Dahmardeh Ghalehno M, Madhoushi M, Tabarsa T, Nazerian M: The manufacture of particleboards using mixture of reed (surface layer) and commercial species (middle layer). *European Journal of Wood and Wood Products* 2011, 69(3): 341-344.
- [11] Mamza PA, Ezech EC, Gimba E, Arthur DE: Comparative study of phenol formaldehyde and urea formaldehyde particleboards from wood waste for sustainable environment. *International Journal of Scientific & Technology Research* 2014, 3(9): 53-61.
- [12] Bekhta P, Korkut S, Hiziroglu S: Effect of pretreatment of raw material on properties of particleboard panels made from wheat straw. *BioResources* 2013, 8(3):4766-4774.
- [13] Owen M: The effects of alkali treatment on the mechanical properties of jute fabric reinforced epoxy composites. *International Journal of fiber and textile research* 2014, 4(2): 32-40.
- [14] ASTM D570-98. *Standard Test Method for Water Absorption of Plastics* 2010 ASTM International.
- [15] Leite J, Pires A, Souza S, Souza A: Characterisation of a phenolic resin and sugar cane pulp composite. *Brazilian Journal of Chemical Engineering* 2004, 21(2): 253-260.
- [16] Jin Y, Cheng X, Zheng Z: Preparation and characterization of phenol-formaldehyde adhesives modified with enzymatic hydrolysis lignin. *Bioresource Technology* 2010, 101(6): 2046-2048.
- [17] Zin M, Razzi M, Othman S, Liew K, Abdan K, Mazlan N: A review on the fabrication method of bio-sourced hybrid composites for aerospace and automotive applications. In: *IOP Conference Series: Materials Science and Engineering: 2016*. IOP Publishing: 012041.
- [18] Agarwal BD, Broutman LJ, Chandrashekhara K: Analysis and performance of fiber composites: John Wiley & Sons; 2017.
- [19] Composite Panel Association. *ANSI A2082-2016 Medium Density Fiberboard (MDF)* 2016, <http://www.compositepanel.org/education-resources/Store/Standards/ansi>.
- [20] Retrieved from flexure Test: <http://www.Instron.com/en-us/ourcompany/library/test-types/flexure-test>.
- [21] Retrieved from compression tests: <http://www.Instron.com/en-us/ourcompany/library/test-types/compression-test>.
- [22] Retrieved from tensile tests: <http://www.Instron.com/en-us/ourcompany/library/test-types/tension-test>.
- [23] Standards A: Facts about particleboard and MDF EWPA. *Australian Wood Panels Association Incorporated* 2008: <http://www.ewp.asn.au>.
- [24] Wang X, Deng Y, Wang S, Liao C, Meng Y, Pham T: Nanoscale characterization of reed stalk fiber cell walls. *BioResources* 2013, 8(2): 1986-1996.
- [25] Ortuño TG, Rodríguez JA, García MTF, García MF-V, García CEF: Evaluation of the physical and mechanical properties of particleboard made from giant reed (*Arundo donax* L.). *BioResources* 2011, 6(1):477-486.
- [26] Kord B, Zare H, Hosseinzadeh A: Evaluation of the mechanical and physical properties of particleboard manufactured from Canola (*Brassica napus*) straws. *Maderas Ciencia y tecnología* 2016, 18(1):09-18.
- [27] JIANG H-y: Thermal modifying methods and progress of phenol-formaldehyde resin. *Journal of Materials Engineering* 2011, 1(10): 91-96.
- [28] Mirski R, Dziurka D, Łęcka J: Properties of phenol-formaldehyde resin modified with organic acid esters. *Journal of applied polymer science* 2008, 107(5): 3358-3366.
- [29] Yasina M, Bhuttob AW, Bazmia AA, Karimb S: Efficient utilization of rice-wheat straw to produce value-added composite products. *International Journal of Chemical and Environmental engineering* 2010, 1(2).
- [30] Li X: Physical, chemical, and mechanical properties of bamboo and its utilization potential for fiberboard manufacturing. 2004.
- [31] Gardner DJ, Han Y, Wang L: Wood-Plastic Composite Technology. *Current Forestry Reports* 2015, 1(3): 139-150.