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Characterizations of GT Composite Boards from the Mixture of Two Grass Family as an Alternative to Timber Species: *Gigantochloa Scortechinii* and *Themeda Arguens* (L.) Hack

Razak Wahab[1,2]*, Rashidah Kamarulzaman[1,2], Mohamad Saiful Sulaiman[1,2], Hashim W. Samsi[3], Sofiyah Mohd Razali[1,2], Taharah Edin[1,2], Nasihah Mokhtar[1,2], Ros Syazmini Mohd Ghani[1,4] and Ellisha Iling[1,2]

[1]Centre of Excellence for Wood Engineered Product (CeWEP), UTS, 96000 Sibu, Sarawak, Malaysia

[2]University of Technology Sarawak (UTS), Sibu 96000, Sarawak, Malaysia

[3]Forest Research Institute Malaysia (FRIM), 52109 Kuala Lumpur, Malaysia

[4]University of Tasmania, Launceston, TAS 7250, Australia

* Correspondence Author

Abstract: The characterizations of composite boards made from two grass family of *Gigantochloa scortechinii* and *Themeda arguens* were investigated. The two species were harvested at their respective matured ages. They were segregated, cut and chipped into smaller pieces, and mixed at five different ratios. They were later mixed thoroughly and bonded together using 12 % and 14 % Urea-formaldehyde (UF) and hot pressed into composite boards. Hardener and wax were added at 1% and 3% weights, respectively, during the mixing process. The boards were tested for physical and mechanical characterizations. European standards procedures were followed in the board's preparation and testing. The findings suggest that the ratios and resin contents have great influence on the board characterizations. The GT composite boards produced from 100% *G. scortechinii*, and boards at ratio 30:70 (*G. scortechini* and *T. arguens*) gives the best characterization in terms of the physical, mechanical, and thermal values.

Keywords: bio-composite boards, *Gigantochloa Scortechinii*, *Themeda Arguens*, physical properties, mechanical properties, thermal properties

INTRODUCTION

Demand for timber for human development has resulted in the exploitation of virgin forests and the clearing of forest areas, particularly in the tropical region. Increased awareness, particularly of the importance of recycling traditional materials, unprecedented forest product depletion, and climate change have resulted in the global search to come up with an eco-friendly composite from non-wood resources [1]. The wood composite industry has used forest plantation and mill residues as raw materials in recent decades. Strict harvest regulations and environmental policy pressure have resulted in a decrease in the supply of high-quality timber and an increase in costs. As one of the most abundant non-wood, bamboo has a good potential as a composite residue [2]. The situation was supported by bamboo is a fast-growing species and can be matured within 3 - 4 years after cultivation [3]; [4]. Bamboo was a cheap material and have a good natural strength in terms of physical and mechanical properties [5]; [6]. However, it was influenced by their species, ages, position along with the culm, diameter, thickness, density, and moisture content [7]. Research and the development which includes all aspects of propagation, processing, properties, and utilization of wild and cultivated bamboo has intensified recently [8]. Currently, most of the bamboos are used for making traditional products such as handicrafts, basketry, and high-value-added products [9]. The non-wood and agricultural materials have been considered as the best alternative raw materials for structural bio-composite materials [10], [11]. Composites made from these resources are lighter, less expensive, and biodegradable, thus making them eco-friendly [12]. These materials are easily obtained from non-wood resources and agricultural residues. This paper highlighted the characterizations of the GT composite boards from *G. scortechinii* and *T. arguens* made at different ratios. The study's objectives focused on the boards' physical, mechanical, and thermal properties. The thermogravimetric analysis was used in the boards' thermal analysis.

MATERIALS AND METHODS

The *G. schortechinii* and the Christmas grass *T. arguense* (L.) Hack were both used in this study. The composite board was made from 3 to 4-year-old *Gigantochloa scortechinii* and matured wild grass. The materials from these two-grass family were harvested at their respective matured ages, cut, chipped into smaller pieces, and bonded with Urea Formaldehyde. The composites were produced by varying the composition ratio of the two materials.

Material Preparation

T. arguense and *G. scortechinii* were collected from the FRIM Research Station in Batu Melintang, Jeli, Kelantan. The harvested bamboo culms were processed immediately upon arrival at the UMK wood workshop. The bamboo was cut into a one-metre length. The inner and outer skins were manually segregated by peeling with machetes. The Christmas grass stems were separated from the leaves and cut to a one-meter length for easy handling. The materials are then air-dried for several days to increase their resistance to fungi and insect attacks. They were then transported to FRIM, Kepong, for the subsequent process of manufacturing composite boards. The resin was supplied by a local company name Dynea Malaysia Sdn. located in Seremban, Negeri Sembilan.

Composite Board Process

A chipper drum machine was used to chip both species of bamboos. The samples were inserted into the knife ring flakes after forming a chip. The bamboo flakes were filtered through sieves of 4.00mm, 0.8mm, 0.5mm, and 0.5mm to 0.8mm. After filtering, the samples were dried in an oven set at 105± 5 ºC for 2 to 3 days. Samples with a diameter above 4.0 mm were flaked with knife ring flakes and filtered to the required size. Following the drying process, the two species were weighed and mixed in a mixer machine with urea-formaldehyde, wax, and hardener in the calculated ratio. The mixing material is molded and compressed using a cold-press machine. The compressing process lasted several minutes at a strain of 20kg/m3. To produce GT composite boards, the halfway boards were placed in a hot press machine at 176 °C with pressures of 120, 90, and 70 MPa and timings of 3 minutes, 2 minutes, and 1 minute, respectively. Physical and thermal characterization were tested using standard laboratory equipment, and an Instron Universal Testing Machine was used on the mechanical characterizations. All mechanical testing was conducted at the FRIM, Kepong, using the methods of Rasat *et al.*, [11] and Wahab *et al.*, [13].

Physical test

Basic Density

The basic density values for the boards were calculated in accordance to EN 323: 1993 [14]. The green volume was obtained using the water displacement method. The oven-dried weight was obtained by placing the boards samples in an oven set at 105±2 °C for 48 hours periods.

Thickness swelling

The thickness swelling was obtained following the European Standard EN 317: 1993 [15]. The test boards were cut into sizes of 50±1 mm in length and conditioned in a conditional chamber set at the relative humidity of 65±5 % and 20±2 °C in temperature to achieve a final moisture content of 12 %. The test samples were immersed in clean, still water having pH of 7±1, and a temperature of (20±1) °C. This temperature remained constant throughout the testing period. Throughout the test, the upper edges of the pieces were covered by 25±5 mm of water. After each test, the water changed.

Water Absorption

Water absorption was measured by the weight increase of the test piece after complete immersion in water. This test is carried out to collect data on how much water is absorbed by the composite boards produced. For thickness swelling data, the weight of each test piece was measured immediately before the thickness of each test piece. This test was conducted concurrently with the water absorption test.

Mechanical Test

Modulus of elasticity (MOE) and Modulus of Rupture (MOR)

The modulus of elasticity in bending was determined by applying a load to the centre of two test samples. Because the test method includes shear and bending, the modulus of elasticity is calculated using the slope of the linear region of the load-deflection curve; the value calculated is the apparent modulus, not the proper modulus. The bending strength of a test piece is calculated by dividing the bending moment M at the maximum load F max by the time it takes to complete its entire cross-section. MOE and MOR were tested concerning the European Norm (EN 310 [16]).

Internal Bonding

The trial begins when the glue has had enough time to cure so no rupture occurs in the glue line and the test pieces have regained an equal distribution of moisture. In my experience, using hot-melt or epoxy glues for 24 hours and other adhesives for nearly 72 hours is sufficient. The glued assembly was kept under controlled conditions of (65±5) % relative humidity and (20±2) °C. The test pieces were tested within one hour of being removed from the conditioning environment. Conditioning does not apply to test parts or glued assemblies that have been subjected to a cyclic test in humid conditions or an immersion-in-water test and are being tested in the wet stage.

Screw Withdrawal

The force needed to remove a wood screw from a test specimen is measured. Screw withdrawal tests were performed following British Standard [17]. The test pieces were square with (50±1) mm side lengths. An about 1.5 mm diameter hole was drilled to a depth of 6 mm in the centre of one of the test samples' faces and two adjacent edges. A screw was inserted to a depth of 13 mm into each hole, ensuring that it was upright.

Thermogravimetric Analysis (TGA) Test

Thermal decomposition is determined by measuring weight loss as temperature rises in a controlled environment. TGA testing was performed with TA Instruments DSC SDT Q600 V20.9 Build 20 - Thermogravimetric Analyzer (TGA) and Differential Scanning Calorimeter (DSC). Wahab *et al*. [18] technique outlines were used. Small sample pieces were taken from the boards. A Wiley mill was used to grind the pieces. Approximately 20-30 mg of ground samples were securely placed in the ceramic pan using a small metal spoon to avoid contamination. The sample was heated from 250°C to 5000°C using a nitrogen gas flow rate of 100 ml/min. The heating rate was set to 100 degrees Celsius per minute. The samples were decomposed using the TA Instruments Q600 software. The acquisition of continuous records of percentage weight loss at specific temperatures and times. The result is displayed in the form of a graft from the TA Instrument computer.

RESULT AND DISCUSSION

Physical characterizations of GT composite boards

This study looked into the physical characterizations of the GT composite boards made from *G. scortechinii* (bamboo) and *T. arguens* (L.) Hack (Christmas grass). The characterization studies and analyzed were the basic density, thickness swelling, and water absorption. Table 1 displays the results of the study.

Basic density

The basic density of GT composite boards ranged from 0.603 to 0.689 g/cm^3. Boards from 100% bamboo possess the highest basic density at 0.689 g/cm^3 for 14% resin content and 0.664 g/cm^3 for 12% resin content. They were followed by boards at 30:70 ratios having 0.638 g/cm^3 and 0.609 g/cm^3, GT composite boards made at 100:0 ratios having 0.633 g/cm^3 and 0.603 g/cm^3, and boards at 50:50 ratios possessing 0.609 g/cm^3 and 0.577 g/cm^3 for both 14% and 12% resin contents respectively. The GT boards with 70:30 resin contents have the lowest values of 0.564 g/cm^3 and 0.522 g/cm^3 for 14% and 12% resin contents, respectively. Boards at all ratios with 14% resin content boards show higher values than 12% resin content. The basic density increases as the resin content increases. Basic density is significant because it influences all aspects of the quality and quantity of test samples [19], [20]. Moisture content has a significant impact on wood density. Because of its influence, the oven-dry density of test samples is used to compare results with its uniqueness of determination. This value represents the amount of wood mass in a volume of wood with a specific moisture content [21]. Basic density is important in estimating the variability of a wood product's strength [22], [23].

Thickness Swelling

Thickness swelling of boards made from 100% *T. arguens* at 100:0 ratios show lowest values which are 18.8% and 15.8% for both resin contents respectively. Boards at 70:30 ratios possess thickness swelling of 19.6% and 16.9%, boards at 50:50 ratios possess 21.6% and 17.9%, and boards at 0:100 ratios 22.9% and 18.7% respectively (for both 12% and 14% resin contents). The boards at 30:70 ratios show the highest values of thickness swelling which were 26.4% and 21.2% for both 12% and 14% resin contents respectively. For resin contents, all ratios of boards made of 14% resin content show lower values compared to board produced with 12% resin contents. The thickness swelling decreased with the increase of the resin contents. Boards made from *T. arguens* at 100:0 ratios showed a value of 15.8% at 14% resin contents is the only boards that met the minimum requirement of thickness swelling set by EN Standard 317 [15]. The thickness swelling was measured by calculating the difference between sample thicknesses before and after 24 hours soaking in the water. Thickness and swelling of the board are proportional to water absorption. When the water absorption is high, the thickness and swelling will also be high due to the swelling of the fibre inside the board manufactured. When the boards are exposed to moisture, the hydrophilic in both thew *G. scortechinii* and *T. arguens* swells resulting in increases in thickness swelling.

Water Absorption

Water absorption of GT composite boards made from 100% *T. arguens* show the lowest values which were 72.5% and 65.0% for both resin contents at 12% and 14% respectively. These follow closely by boards of 70:30 ratios at 75.4% and 67.6%, boards at 50:50 ratios 77.8% and 69.9%, and finally boards at 0:100 ratios 78.8% and 73.9% for both 12% and 14% resin contents respectively. Boards at 30:70 ratios show the highest values which were 83.9% and 75.3% for both 12% and 14% resin contents respectively. For resin contents, all ratios of composite board made of 14% resin content show lower values than composite board made of 12% resin contents. The result shows that the water absorption decreased with the increase of resin content. This occurred because of the chemical components in the resin that is capable of cross-linking with the hydroxyl group of *T. arguens* and *G. scortechinii* fibres.

Table 1: Basic density, thickness swelling and water absorption of GT composite boards

Ratios (Grass: bamboo)	Basic density		Thickness swelling (%)		Water absorption	
	12% Resin	14% Resin	12% Resin	14% Resin	12% Resin	14% Resin
100:0	0.603	0.633	18.8	15.8	72.5	65.0
70:30	0.522	0.564	19.6	16.9	75.4	67.6
50:50	0.577	0.609	21.6	17.9	77.8	69.9
30:70	0.609	0.638	26.4	21.2	83.9	75.3
0:100	0.664	0.689	22.9	18.7	78.8	73.9

Water absorption in the GT composite boards is of serious concern for both indoor and outdoor applications. Composite boards at a ratio of 30:70 absorb more water than the boards from 100% *T. arguens*. The increase in water absorption in the composite ratio of 30:70 indicates rapid moisture penetration into the boards. The trends are associated with water permeability and capillary action, become active when water penetrates the void's spaces caused by swelling in the cells [24]. The occurrences of the water absorption cause changes in the shape, debonding, or loss of strength in composite boards frequently exposed to moisture [25]. In certain boards, the water absorption characteristics are depended on the fiber content, fiber orientation, temperature, exposed surface area, fiber permeability, void content, and hydrophilicity of the individual components. [26]. The cells present in the composite boards behave like a sponge and absorb moisture spontaneously [27]. The larger cells size particularly in the parenchyma cells will normally abort more water. The increase in the water absorption by the cells present in the boards should be considered when evaluating the suitability of the boards for various applications [28].

Mechanical characterizations of GT composite boards

Table 2 shows the mechanical characterizations of GT composite boards. The mechanical characterizations are the characteristics of the material to response whenever externally forces are applied [29], [30]. Mechanical characterizations reflect to the strength and the resistance to deform the material. The most common mechanical characterizations are the modulus of elasticity (MOE) and modulus of rupture (MOR). The MOE measures the stiffness or rigidity of material and the MOR measures the resistance to breakage.

Modulus of Elasticity (MOE)

The GT composite boards made from 100% bamboo showed the highest MOE at 2873.5 N/mm^2 and 2857.4 N/mm^2 for both resin contents at 14% and 12% respectively. The boards at 30:70 ratios (*T. arguens* and *G. scortechinii*) followed at 2803.3 N/mm^2 and 2777.0 N/mm^2, boards at 100:0 ratios were 2783.4 N/mm^2 and 2738.0 N/mm^2, and boards at 50:50 ratios were 2726.7 N/mm^2 and 2691.5 N/mm^2 for both resin contents respectively. The GT composite boards at ratio 70:30 ratios (*T. arguens* and *G. scortechinii*) has the lowest MOE at 2630.9 N/mm^2 for 14% and 2596.4 N/mm^2 for 12% resin contents.

The GT boards for all ratios of boards with 14% resin content show higher MOE than the boards of 12% resin. This shows that the MOE increases with the increases in the resin content. This indicates that the addition of resin to the board has increased the MOE or made the board more brittle [31]. Both GT boards met the minimum required standard set by the EN Standard 312-3, and shows higher strength than the rubber-wood [11]. The modulus of elasticity is a measure of the elasticity of a material whose resistance to deformation under load. MOE is purely a material property, and stiffness depends on both the material and the size of the beam. Large and small beams of similar material would have similar MOE's but different stiffness. MOE is calculated from the stress-strain curve as the change in stress causes a corresponding change in strain.

Modulus of Rupture (MOR)

The GT composite boards of 100% bamboo show high MOR at 17.5 N/mm^2 for 14% resin contents and 16.9 N/mm^2 for 12% resin contents. The boards at 30:70 ratios followed closely at 16.9 N/mm^2 and 16.3 N/mm^2, boards of 100% grass were 16.5 N/mm^2 and 16.3 N/mm^2, and boards at 50:50 ratios were 15.7 N/mm^2 and 15.6 N/mm^2 for both resin at 14% and 12% respectively. Boards at 70:30 ratios show the lowest values which are 14.8 N/mm^{2}and 13.9 N/mm^2 for both 14% and 12% resin contents respectively. For resin contents, all ratios of boards made of 14% resin content show higher values than boards made of 12% resin contents. The finding indicates that the MOR increases with the increases in resin content. Boards at all ratios manufactured from both 12% and 14% resin contents meet the minimum standards set by EN Standard 310 [16]. However, the MOR was slightly lower than MOR of the rubber-wood (22.8 N/mm^2). The amount of adhesive present in the boards as expected plays a major role in increasing the MOR of GT composite boards. The adhesive enables the transferring and distribution of stresses effectively. This increases the strength and stiffness of the boards. Urea-formaldehyde with higher solids content was able to penetrate and the cell walls of the compressed composite boards [32]. Thus, the urea-formaldehyde resin increases the MOR strength of composite boards.

Internal Bonding (IB) of GT composite boards

The IB tests were conducted to determine the strength of the interfacial bonds between the fibers in the board. The GT composite boards made from 100% bamboo show high IB at 0.688 N/mm^2 and 0.623 N/mm^2 for both resin contents at 14% and 12% respectively. The boards made at 30:70 ratios (*T. arguens* and *G. scortechinii*) followed with values 0.534 N/mm^2 and 0.501 N/mm^2, the boards of 100% grass were 0.526 N/mm^2 and 0.474 N/mm^2, and boards at 50:50 ratios which are 0.478 N/mm^2 and 0.437 N/mm^2 for both resin contents at 14% and 12% respectively. Boards at 70:30 ratios show low values in internal bonding with 0.434 N/mm^{2}and 0.391 N/mm^2 for both resin contents at 14% and 12% respectively. All boards at all ratios with 14% resin content show higher values than boards made of 12% resin. The internal bonding increased with the increase of resin content. Boards at all ratios with 12% and 14% resin contents met the minimum requirement of internal bonding for general according to EN Standard 310 [16] except the GT composite boards at 70:30 ratios which were 0.391 N/mm^2 at 12% resin contents. However, the boards made from both 12% and 14% resin contents possess a slightly lower IB of the rubber-wood (1.300 N/mm^2). The high amount of resin present in the GT composite boards produced a stronger interface bond between the cells in the board thus extending the ability of the board to withstand the traction created. The lower IB occurrence was expected as the surface chemical properties of fibrillar in extractives and lignin influence the absorption, adhesion and strength properties and finally interrupt the bonding characterizations of the boards [33]. Weak IB occurs in the boards especially when they were cut into small sizes until they are no longer able to be split further anymore and maintain a tubular shape [34]. Most of the failures in the IB characterizations occurred in areas where the *T. arguens* were located.

Table 2: Modulus of elasticity, modulus of rupture & internal bonding of GT composite boards

Ratios (Grass: bamboo)	Modulus of Elasticity (MOE) (N/mm^2)		Modulus of Rupture (MOR) (N/mm^2)		Internal bonding (N/mm^2)	
	Resin Content		Resin Content		Resin Content	
	12%	14%	12%	14%	12%	14%
100:0	0.603	0.633	18.8	15.8	0.474	0.526
70:30	0.522	0.564	19.6	16.9	0.391	0.434
50:50	0.577	0.609	21.6	17.9	0.437	0.478
30:70	0.609	0.638	26.4	21.2	0.501	0.534
0:100	0.664	0.689	22.9	18.7	0.623	0.688

Screw withdrawal tests GT composite boards

A screw was inserted into each of the holes at the centre of one face and two adjacent edges of the test specimen to a depth of 13 mm. The purpose of the screw withdrawal test is to evaluate the holding strength of the board screws. The higher particle loading strengthens the board as well as increases its density which helps the board hold the screws better. Screw withdrawal resistance-associated highly with the board density and the geometry of the particles [35]. The screw withdrawal tests results for both edge Screw withdrawal (tangential direction), edge screw withdrawal (radial direction) and face screw withdrawal are presented in Table 3.

Edge Screw Withdrawal (Tangential direction)

The edge screw withdrawal (tangential direction) (N/mm^2) of boards made from 100% bamboo at 0:100 ratios show the highest values which were 609.8 N/mm^2 for 14% resin and 570.7 N/mm^2 for 12% resin contents. Follow by, boards made of 100% *T. arguens* at a ratio of 100: 0 which is 518.4 N/mm^2 and 460.6 N/mm^2, boards at a ratio of 70:30 which is 486.2 N/mm^2 and 417.9 N/mm^2, and boards at 50:50 ratios of 406.4 N/mm^2 and 358.0 N/mm^2 for both 14% and 12% resin content, respectively. As presented in Table 3, boards with 30:70 ratios show the lowest values with 376.5 N/mm^2 and 345.6 N/mm^2 for both 14% and 12% resin contents respectively. For resin contents, all ratios of boards made of 14% resin content show higher values than boards made of 12% resin contents. It is apparent from the table that the edge screw withdrawal at the tangential direction increases with the increase of resin content. GT boards made at a ratio of 50:50 have values of 358.0 N/mm^2 and boards at a ratio of 30:70 345.6 N/mm^2 both at 12% resin content do not meet the minimum requirements of edge screw production (360.0 N/mm^2) for general using board types according to BS Standard, BS 5669 [17], while others exceed the minimum requirements.

Edge Screw Withdrawal (Radial direction)

Edge screw withdrawal (radial direction) (N/mm^2) of boards made from 100% *G. scortechinii* at 0:100 ratios show the highest values which are 628.6 N/mm^2 and 561.8 N/mm^2 for both 14% and 12% resin contents respectively. The boards contain of 100% grass have values at 551.1 N/mm^2 and 471.9 N/mm^2, while the boards with 70:30 ratios have 532.8 N/mm^{2}and 449.6 N/mm^2, and boards made at 30:70 ratios which values were 403.0 N/mm^2 and 366.0 N/mm^2 for both 14% and 12% resin contents respectively. Boards made at 50:50 ratios the how lowest values which were 384.6 N/mm^2 and 337.2 N/mm^2 for both 14% and 12% resin contents respectively. For resin content, all ratios of composite board made of 14% resin content showed higher values than boards made of 12% resin content. The findings find that the edge screw withdrawal at the radial direction increases with the increase of resin content. All boards with a resin content of 14% and 12% excluding boards made at a ratio of 50:50 of 337.2 N/mm^2 at a resin content of 12% exceed the minimum requirement to produce edge screws (360.0 N/mm^2) for general use of board types according to BS Standard, BS 5669 [17].

Face Screw Withdrawal

Face screw withdrawal (N/mm^2) of composite board made from 100% bamboo at 0:100 ratios show the highest values which are 683.9 N/mm^2 and 596.0 N/mm^2 for both 14% and 12% resin contents respectively. Boards made from 100% *T. arguens* have values of 643.4 N/mm^2 and 582.8 N/mm^2, GT boards at 70:30 ratios 589.2 N/mm^{2}and 510.5 N/mm^2, and composite board made from *T. arguens* and *G. scortechinii* at 30:70 ratios which are 531.2 N/mm^2 and 462.3 N/mm^2 for both 14% and 12% resin contents respectively. Boards made from *T. arguens* and *G. scortechinii* at 50:50 ratios show the lowest values which are 499.9 N/mm^2 and 442.0 N/mm^2 for both 14% and 12% resin contents respectively. For resin contents, all ratios of boards made of 14% resin content show higher values than boards made of 12% resin contents. The result indicates that the face screw withdrawal increased with the increase of resin content.

Table 3: Edge and face screw withdrawal tests of GT composite boards

Ratios (Grass: bamboo)	Edge screw withdrawal (tangential direction)		Edge screw withdrawal (radial direction)		Face Screw withdrawal	
	Resin Content		Resin Content		Resin Content	
	12%	14%	12%	14%	12%	14%
100:0	460.6	518.4	471.9	551.1	582.8	643.4
70:30	417.9	486.2	449.6	532.8	510.5	589.2
50:50	358.0	406.4	337.2	384.6	442.0	499.9
30:70	345.6	376.5	366.0	403.0	462.3	531.2
0:100	570.7	609.8	561.8	628.6	596.0	683.9

Analysis of Variance (ANOVA) of GT composite boards

The ANOVA in Table 4 showed the differences in the physical and mechanical properties of the GT composite boards at varying ratios between the *G. scortechinii* and *T. arguens*. The physical properties showed significant differences with ratios where basic density and thickness swelling shows high significant differences at 99% probability and water absorption at 95% probability. The MOE in the mechanical properties shows the significant differences at 95% probability, MOR, and internal bonding have the highly significant differences at 99% probability. However, no significant differences were observed in the screw withdrawal tests. It indicated that the differences in the ratios varying have an impact on the result of physical and mechanical properties of the GT composite boards. A mixed significant difference was noted in the application of the resin at a different level. In the physical properties, the thickness swelling, and water absorption show significant differences at 95% probability, while no significant was observed in the basic density. No significant differences were observed in the MOE, MOR, and internal bonding. The screw withdrawal tests indicated some significant differences at 95% probability. No effect was noted on the basic density, MOE, MOR, and internal bonding but they give some influence on thickness swelling, water absorption, and screw withdrawal tests.

The correlation between physical and mechanical properties of the GT composite board made from grass *T. arguens* and bamboo *G. scortechinii* are shown in Table 5. The physical properties show a positive correlation with different ratios. Negative correlations were observed between resin contents with both thickness swelling and water absorption. These negative correlations are supported by significant differences in the analysis of variance (ANOVA) displayed in Table 4. It can be suggested that resin contents had the inverse effect on thickness swelling and water absorptions. Basic density shows a positive correlation with different resin contents.

For the mechanical properties of boards made from *T. arguens* and *G. scortechinii*, there was a correlation between different ratios and different resin content. All mechanical properties show a positive correlation with different ratios except screw withdrawal. Negative correlations occur between different ratios with screw withdrawal which are SWA, SWB, and SWC respectively. All mechanical properties show a positive correlation with different resin contents.

Table 4: ANOVA on physical and mechanical properties of GT composite boards

Source of Variance	Dependent values	df	Sum of square	Mean square	Pr (F)
Ratio	BD	1	0.051	0.051	0.0000^{**}
	TS	1	158.875	158.875	0.0000^{**}
	WA	1	142.662	142.662	0.0141^{*}
	MOE	1	178834.000	178834.300	0.0271^{*}
	MOR	1	18.615	18.615	0.0091^{**}
	IB	1	0.207	0.207	0.0001^{**}
	SWA	1	235.100	235.060	0.8707^{ns}
	SWB	1	3113.000	3113.050	0.5790^{ns}
	SWC	1	625.600	625.630	0.7811^{ns}
Resin Content	BD	1	0.010	0.010	0.0621^{ns}
	TS	1	174.268	174.268	0.0000^{**}
	WA	1	527.589	527.589	0.0000^{**}
	MOE	1	14910.000	14909.800	0.5149^{ns}
	MOR	1	3.388	3.388	0.2540^{ns}
	IB	1	0.033	0.033	0.0972^{ns}
	SWA	1	92327.800	92327.810	0.0020^{**}
	SWB	1	77918.500	77918.480	0.0072^{**}
	SWC	1	68945.800	68945.820	0.0049^{**}

Note: Total number of samples for each testing = 60, **= significant at p≤ 0.01, *= significant at p≤ 0.05,

ns= not significant, BD=Basic density, TS=Thickness and swelling, WA= Water absorption,

MOE= Modulus of elasticity, MOR= Modulus of rupture, IB= Internal bonding, SWA= Edge screw withdrawal (tangential direction), SWB= Edge screw withdrawal (radial direction), SWC= Face screw withdrawal.

Table 5: Correlation Coefficient on Physical & Mechanical Properties of GT composite boards

	RC	RTO	BD	TS	WA	MOE	MOR	IB	SWA	SWB	SWC
RC	-	0.0000**	0.2138^{ns}	-0.4995**	-0.5194**	0.0831^{ns}	0.1424^{ns}	0.1923^{ns}	0.3940^{ns}	0.3475^{ns}	0.3640^{ns}
RTO		-	0.4889^{ns}	0.4770^{ns}	0.2701^{ns}	0.2878^{ns}	0.3338^{ns}	0.4846^{ns}	-0.0199**	-0.0695**	-0.0347**
BD			-	0.1218^{ns}	-0.0109**	0.3163^{ns}	0.5421^{ns}	0.5355^{ns}	0.2701^{ns}	0.3106^{ns}	0.2825^{ns}
TS				-	0.6691^{ns}	0.1028^{ns}	0.0969^{ns}	-0.0288**	-0.4870**	-0.5690**	-0.4870**
WA					-	0.1509^{ns}	0.0767^{ns}	-0.0399**	-0.5524**	-0.5716**	-0.6033**
MOE						-	0.5902^{ns}	0.4418^{ns}	0.2250^{ns}	0.1230^{ns}	0.0911^{ns}
MOR							-	0.5659^{ns}	0.3196^{ns}	0.1979^{ns}	0.1484^{ns}
IB								-	0.2997^{ns}	0.2984^{ns}	0.2913^{ns}
SWA									-	0.7930^{ns}	0.7500^{ns}
SWB										-	0.7438^{ns}
SWC											-

Note : Total number of samples for each testing = 60, **= significant at $p \leq 0.01$,WA= Water Absorption,

*= significant at $p \leq 0.05$, MOE= Modulus of Elasticity, ns= not significant, MOR= Modulus of Rupture,

RC= Resin Content, IB= Internal bonding, RTO= ratio, SWA= Edge screw withdrawal (tangential direction), BD = Basic Density, SWB= Edge screw withdrawal (radial direction), TS= Thickness and Swelling,

SWC= Face screw withdrawal.

Thermogravimetric Analysis (TGA)

Table 6 shows percentage weight loss with a temperature of GT composite boards, and UF resin sample. Figure 1 shows a TGA graph of composite board made from *T. arguens* and *G. scortechinii*. The decomposition of the GT composite boards began at 100ºC (first peak). The decomposition continued to the second peak at 210ºC and was completed at the third peak (402ºC). The degradation of UF resin was initiated at 100ºC (first peak), continues at 168ºC (second peak), and completed at the third peak (389ºC). Both boards and UF resin lost most of their weight at the third peak which is 66.18% and 58.48% respectively. The final decomposition of boards is higher than the UF resin which indicates that the presence of cellulose fibre from composite board had a significant effect on the thermal stability of the composites. The weight loss began to occur at a temperature of 210°C.

Table 6: Weight loss in TGA with a temperature of GT composite boards and UF resin.

		1st peak	2nd peak	3rd peak
GT Composite board from grass and bamboo	Temperature	99.93ºC	210.08ºC	401.91ºC
	Weight loss	8.182 %	10.63 %	66.18 %
UF Resins	Temperature	99.93 ºC	168.45 ºC	389.26 ºC
	Weight loss	8.433 %	9.389 %	58.48 %

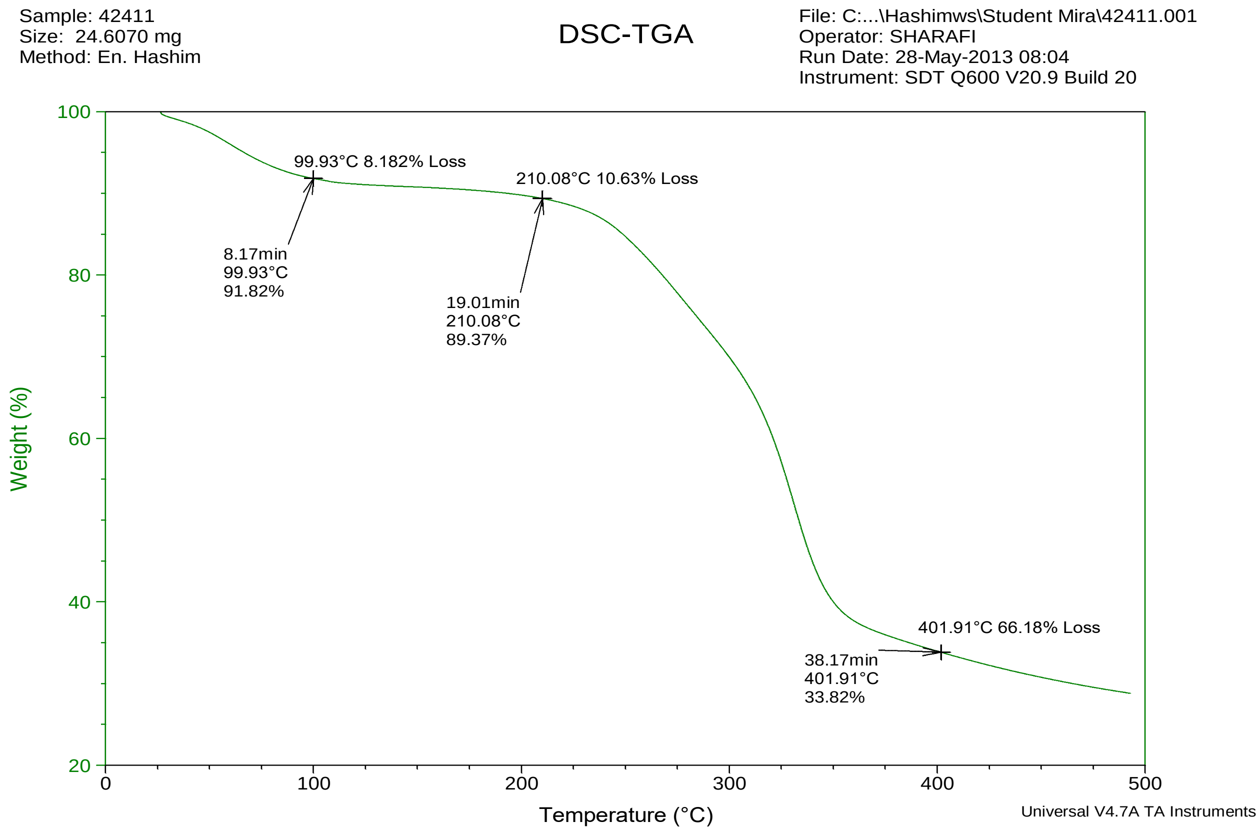

Figure 1: TGA graph of GT composite boards

The value of degradation points for the boards took place at 89.37%. This is probably due to dehydration of the samples and degradation of hemicelluloses [36]. The first stage of mass loss was due to the evaporation of water and depolymerization of molecules' structure from the samples [37], [38]. The process continued by cleaves of linkage that occurred in the composite and UF resin. Kim *et al.* [39] reported the lignocellulosic material decomposed thermos-chemically between 150°C and 500°C, which hemicelluloses mainly between 150°C and 350°C, cellulose between 275°C and 350°C, and lignin between 250°C and 500°C. Thermal degradation of polymer blocks of biomass occurred at the second peak. Hemicellulose and lignin degraded earlier [40], [41]. This might be due to their molecular structure which is less rigid (amorphous than cellulose) compared to cellulose. Finally, upon the introduction of oxygen at the third peak, combustion occurred, and the final weight loss infers the amount of carbon in the composites. The carbon contents of the composites and UF resin are 66.18% and 58.48% respectively. Changes in mass usually occur during sublimation evaporation, decomposition, chemical reaction, and magnetic or electrical transformation of the material, which is directly related to thermal stability [42].

CONCLUSION

The GT composite boards with 12% and 14% resin contents made from 100% bamboo and 75% *G. scortechinii* ratios show the highest values in the basic density. However, boards with 14% resin content possess a higher basic density than the boards with 12% resin. Boards made at a ratio of 30:70 (*G. scortechinii* to *T. arguens*) possesses the highest values for both 12% and 14% resin contents respectively. The GT boards at all ratios with 12% resin content show higher basic density values compared to boards made of 12% resin contents. The GT boards made from 100% bamboo shows high values in MOE for both 12% and 14% resin contents. Boards with 14% resin content possessed higher values in the MOE than boards made of 12% resin contents. The MOR and IB of the GT boards made from 100% bamboo show high values for both resin contents respectively. In the edge screw withdrawal tests for both the tangential and radial directions, the GT boards made from 100% bamboo show an excellent value for both the 12% and 14% resin contents. The face screw withdrawal tests of the GT boards made from 100% bamboo show significant value for both 12% and 14% resin contents. The GT boards of all ratios with 14% resin content show higher values than boards made of 12% resin content in all the mechanical tests. The decomposition of the GT boards began at 100ºC in the first peak. The decomposition continued to the second peak at 210ºC and was completed at the third peak occurred at 402ºC. The high temperature at the final decomposition of the GT boards indicates the presence of cellulose fibre in the boards which effected on the thermal stability of the manufacture boards.

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