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(Research Article)

Properties of elephant grass made particleboards: Influence of a hardener

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Abstract

The objective of the study was to assess the performance of one of the most abundant raw materials on Earth – the Elephant grass, for the production of particleboard bonded using cassava starch blended with Aluminium sulphate ($Al_2(SO_4)_3$) as hardener. The physical, mechanical and decay properties of the manufactured particleboards were analyzed and compared with EN 312-2 (2005) and ANSI A208.1 (1999) standards for particleboards. The characterization also included thermogravimetric analysis and scanning electron micrographs. The results showed that the interaction of the Aluminium sulphate ($Al_2(SO_4)_3$) hardener and the adhesives in the particleboard significantly affected the physical, mechanical, thermogravimetric and the decay properties of the manufactured particleboards. The particleboards with only Cassava starch as adhesive recorded 11.14% and 24.84% for 24-hour water absorption and thickness swelling respectively. However, with the blending of the adhesive with $Al_2(SO_4)_3$, Cassava starch recorded 20.51% better for 24-hour WA and 35.62% better for 24-hour TS. Urea formaldehyde as an adhesive blended with the hardener also recorded better performance in the 24-hour dimensional stability property assessment. Similar trends of enhanced property performance were observed for the intended properties tested when $Al_2(SO_4)_3$ is added to each adhesive. Static bending, hardness, internal bond strength, dimensional stability, thermogravimetric and decay resistance properties of the test particleboard improved with the addition of $Al_2(SO_4)_3$.

Keywords: Aluminium sulphate; Cassava starch; Particleboard; Mechanical properties; Physical properties

1. Introduction

Rapid infrastructural development in the developed and the developing economies is significantly complemented by particleboards in the areas of formwork, flooring, ceiling, wall cladding, cabinetry, shelfing, general furniture and other fitments. However, with rising forest depletion, biodiversity loses and landscape deterioration, with its consequential impact on global warming and climate change as a result of indiscriminate felling of timber, wood which is the main lignocellulosic raw material for the manufacturing of particleboards will be unsustainable. Globally the production and consumption of sawn wood is on the rise and could amount to an increase by approximately 39% by 2030, reaching US$ 98 trillion. (Eurostat, 2023; FAO, 2009).

The demand for wood by the forest industry in recent times has outstripped the production capacity of the forest. Over 1.2 million m^3 of logs is harvested from natural forests annually (FC-TIDD Annual Report 2021), thus signaling the over-burden and over-exploitation of forest resources for industrial purposes.

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This situation has therefore caused a paradigm shift from wood to a league of research in alternative source of lignocellulosic annual and biannual plant origin. These are not only proving to be excellent resources for the fibre industry, but also make new promising raw materials for very essential and different composite or fibreboard - particleboard. Alternative raw materials such as agricultural residues and fast-growing species can play an important role in the particleboard industry in the future (Melo *et al.* 2014, 2015; Nemli *et al.* 2009; Papadopoulos *et al.* 2004). Hence numerous studies have shown that agricultural residues are suitable materials for the manufacturing of particleboards, and produces particleboards with adequate properties for construction, furniture and other fitments. Several works have been done using agriculture residue in particleboard manufacturing including; Bekalo & Reinhardt, (2010); Hua *et al.,* (2022); Kwon *et al.,* (2014); Melo *et al.,* (2014); Owodunni *et al.,* (2020); Pantawee et al., (2017); Scatolino *et al.,* (2013).

Elephant grass (*Pennisetum purpureum*) is a potential substitute lignocellulose biomass that possesses high rates of growth, with its high possibility to satisfy cellulose needs, due to its high productivity and availability (Basso *et al.,* 2014; Menegol *et al.,* 2016; Ohimain *et al.,* 2014; Scholl *et al.,* 2015). Elephant grass has a burst strength of above 5.85 kPm^2/g and average fibre length of 1.32 mm with a high fibre mechanical property (Madakadze *et al.,* 2010; Zhang *et al.,* 2015; Zhang *et al.,* 2020). These properties make Elephant grass suitable for utilization in manufacturing particleboards industry.

Another area of concern that this study seeks to address was the use of synthetic resins for the production of particleboard. Since most of applications are interior, particleboard is usually bonded with urea-formaldehyde (Uf) adhesive (Bekhta *et al.,* 2021; Mahrdt *et al.,* 2016). However, Uf adhesive can release low concentrations of formaldehyde gas from bonded wood - based products. When the products are new, high indoor temperatures or humidity can cause increase release of formaldehyde. In the European Union, formaldehyde is considered as a high priority pollutant, whereas International Agency for Research on Cancer classifies formaldehyde as carcinogenic to humans (IARC 2012). The growth and continued success of the wood composite industry will be of benefit if wood adhesives are derived from renewable materials such as cassava starch. The application of aluminium sulphate allows reduction in the content of free formaldehyde in adhesive compositions in comparison with ammonium chloride (Bekhta *et al.,* 2016). Therefore, this study was designed to characterize particleboards manufactured from Elephant grass applying cassava starch as an adhesive blended with aluminium sulphate ($Al_2(SO_4)_3$) as hardener. The study achieved the following objective: improvement in the mechanical and physical properties performance of cassava starch adhesive as aluminium sulphate ($Al_2(SO_4)_3$) hardener was added to it, and the enhancement of decay resistance properties of the manufactured particleboards bonded using cassava starch with aluminium sulphate ($Al_2(SO_4)_3$) hardener.

2. Material and methods

2.1. The Elephant grass (*Pennisetum purpureum*)

The elephant grass for the study was extracted from Daboase (GPS: 5.098403, -1.649607), a semi-deciduous forest zone in the Western Region, Ghana. The stalks were cut from two patches within the zone and leaves slashed off before carting to the factory. The materials were first washed with water to reduce accumulated silt and dried in the open air before starting the manufacturing processes.

2.1.1. Particle preparation

The preparation of flakes of elephant grass started with the hogging processes (Figure 1) where dried elephant grass stalks were loaded onto a conveyor belt that drove the materials to a Kloeckner hogger which is powered by a 350 hp electric motor and a throughput of approximately 11 metric tons of wet chips per hour. The stalks were then crushed into chips mostly measuring 10 mm × 10 mm × 50 mm. Subsequently, Pallmann flaking machine refined the hogged chips into much smaller particles measuring approximately 5mm × 2mm × 1mm and finer. These smaller particles were then conveyed from the flakers by means of a pneumatic system into a wet material storage silo prior to drying.

Figure 1 Elephant grass stalks being loaded unto hogger

2.2. Classification of particles

It is desirable to classify the particles before they proceed to further operations. Very small particles increase furnishes surface area and thus increase resin requirements while oversized particles also adversely affect the quality of final product because of internal flaws in the particles. While some classification is done using air streams, screen classification methods are the most common and the type used for this project. From the dryer exit, the mixture of flakes and fine materials (now dried at 3% moisture content) were conveyed to the next station for size classification, using the Allgaier Screen. This machine separates the incoming flow into three categories of sizes and the system works to generate the following classifications:

- Oversized – materials which are too large for normal production and need to be recycled.
- Core – materials which consist of a flake mixture with an approximate average dimension of 20 mm × 4 mm × 1 mm. This is the ideal size for the core of the board.
- Surface – This material is much finer and it consists of very small flakes not larger than 6 mm × 2 mm × 1 mm and actually goes down in size to 'dust'. It is utilized for the top and bottom layer (surfaces) of the particleboard to provide a smooth finish.

The flake analysis of materials at 3% moisture content was carried out using 100 gm of each sample material.

2.2.1. Adhesives

Commercial urea formaldehyde (Uf) adhesive with the following properties; viscosity = 2.24 p, specific gravity = 1.27, solid content = 65.3 and 0.32% free formaldehyde, was purchased from Ecc. 3 Multi Ventures, Takoradi and, Cassava starch (Cs) purchased from the local market, was used to produce the particleboard. The amount of any of these adhesives used was 15 weight parts per 100 weight parts of particles dry mass.

2.2.2. Hardener

Aluminium sulphate ($Al_2(SO_4)_3$) was used as the hardener. It is an affordable and relatively inexpensive additive. The $Al_2(SO_4)_3$ purchased from Allemar Aluminium Systems plot 4 Kumasi-Mampong Road in Ghana was used as the hardener.

2.2.3. Preparation of Uf-Hardener and Cs-Hardener Adhesives

The $Al_2(SO_4)_3$ was added to each adhesive separately to form aqueous solutions. The amount used was 2.0 weight parts per 100 weight parts of Cs and Uf adhesives. Each of the formulated adhesive was immediately mixed with the particles to form a batch.

2.2.4. Mat forming

After the particles have been prepared, they were laid into an even and consistent mat to be pressed into a panel. This can be accomplished in a batch mode or by continuous formation (the type used for this project). The batch system employs a caul or tray on which a deckle frame is placed.

Mat formation is induced both by the back-and-forth movement of the tray or the back-and-forth movement of the hopper feeder which was used for the project. After formation, the mat is pre-pressed (cold press) prior to hot-pressing. This was done to reduces the mat height and consolidate the mat before hot-pressing as shown in Figure 2a. Three-layer boards were produced in this system, using three forming stations. For three-layer boards, the two outer layers consist of particles differing in geometry from those of the core. 15% adhesive content was used for the outer layers, whereas 8% adhesive content was used for the core. A continuous mat forming systems was employed, during which blended particles were distributed in three layers on a moving belt with a pressing temperature of 180 °C and a pressure of 3.5 MPa.

Figure 2 Cold pressed mat formed from blended particles

Figure 3 Pressed panel being edge-trimmed

After pressing, the boards were trimmed to bring it to the desired length and width, and to square the edges Figure 3. Six replicates Defect-free clear specimens were prepared and conditioned for 4 weeks, according to standard for all the tests.

2.2.5. Dimensional stability

Thickness swelling and water absorption test were conducted using ASTM D-1037-06 (1999). Specimens of dimensions of 20 mm x 50 mm 50 mm were soaked in clean water at room temperature for 2 and 24 hours respectively for the test (Figure 4). Difference in dimension and weight were determined using digital veneer caliper and weighing scale.

Figure 4 Soaked specimens for dimensional stability test

2.2.6. Static bending

ASTM D-1037-06 (1999) was used to determine the moduli of elasticity and rupture, using UTM model Inspekt 50-1 with a load cell of 50 kN at a loading rate of 4 mm/min. Specimens of dimensions 20 mm x 50 mm x 250 mm were used.

2.2.7. Internal bond

The procedures in ASTM D-1037-06 (1999) and ASTM D-7519-11 (2011) were used to determine internal bond using UTM model Inspekt 50-1.

2.2.8. Hardness

Janka ball test was used to determine the hardness using UTM model 4482 operating with a load cell capacity of 100kN following the procedure in ASTM D-1037-06 (1999) with specimen of dimension 20 mm x 75 mmx 150 mm.

2.2.9. Scanning Electron Micrograph (SEM)

The specimens were coated with a thin film of gold and mounted on aluminium stub using carbon tape and then analysed with Phenom ProX desktop scanning electron microscope (SEM) with Energy Dispersive Spectrometer (EDS) at 15kV with a magnification range of 1300x to 1500x.

2.2.10. Thermogravimetric Analysis

Thermal analysis of the manufactured particleboard specimen was done using SDT Q600 V20.9 Build 20, model SDT Q600, at a heating temperature range of 30 – 600 °C. manufactured particleboard specimens were mashed into particles of sizes 0.65 – 2.6 mm with an initial mass of 20 gm were used. Graphs were used to represent the collected data.

2.2.11. Assessment of the Durability Property

Accelerated laboratory (A soil-block) test, method in accordance with ASTM D 2017 (2005), was used to measure the decay resistance. Specimen sizes of 14 mm by 14 mm by 14 mm were prepared from the manufactured particleboards for the decay resistance test. Six replicate specimens were dried to constant weight at 103 °C ± 2°C and steam-sterilized in an autoclave at a temperature of 121 °C with a pressure of 15 psi for 20 minutes. The sterilized specimens were exposed to actively growing mycelium discs of *Coriolopsis polyzona* of 10 mm diameter and were placed in an incubator at a temperature of 25 °C and a relative humidity of 70% for 12 weeks. The surface fungi mycelia were gently removed, the specimens were dried at 60 °C, and mass losses were determined as a percentage of total specimen mass based on initial mass of the specimens before decay tests. The percentage mass loss in the test specimens provided the assessment of decay resistance of the manufactured particleboard.

3. Results and discussion

3.1. Scanning Electron Micrograph Analysis

The micrograph illustrations of particleboards manufactured from Elephant grass (Eg) bonded with cassava starch (Cs) and urea formaldehyde (Uf) treated with Aluminium sulphate ($Al_2(SO_4)_3$) hardener (H) is shown in Figures 5a-d. The microstructural studies of the particleboards reveal a uniform distribution of agro-residue particleboards with Cs and Uf adhesives. The distribution of particles was influenced by the compounding of the particles and the adhesives which resulted in good interfacial bonding Idris *et al.,* (2011). The microstructure reveals that there were small discontinuities and a reasonably uniform distribution of particles and the adhesive in the Cs bonded particleboard. These micro gaps are caused by shrinkage of the particles during drying of the particleboard, as the particles absorb water during mixing which leads to slight expansion (Danso, 2017). This could lead to a reduction in strength, which attributed to the bridging effect of the particles-adhesive in the matrix which allows transfer of stresses. Thus, increased cracks and micro gap limits the holding characteristics between the particles and the adhesive (Aymerich *et al.,* 2016; Deplace *et al.,* 2009). Whereas in the case of Uf bonded, the surface of the particleboard was smooth, indicating that the compatibility between particles and resin was good. It can be seen that the agro-residue particles were not detached from the resin surface as compared to Cs bond. Similar observation was made by Idris *et al.,* (2011). Figures 5c and 5d indicate the micrographs of the manufactured particleboards with the two respective adhesives when treated with Aluminium sulphate ($Al_2(SO_4)_3$) hardener (H). There was a complete absence of gap in the particleboard manufactured with Uf+H, and Cs+H there was an improvement in adhesive-particle interaction, thus closing the gaps in the case of Cs bonded panels. Hence recording an improved static bending property figures above the compared standards (Figures 9 and 10).

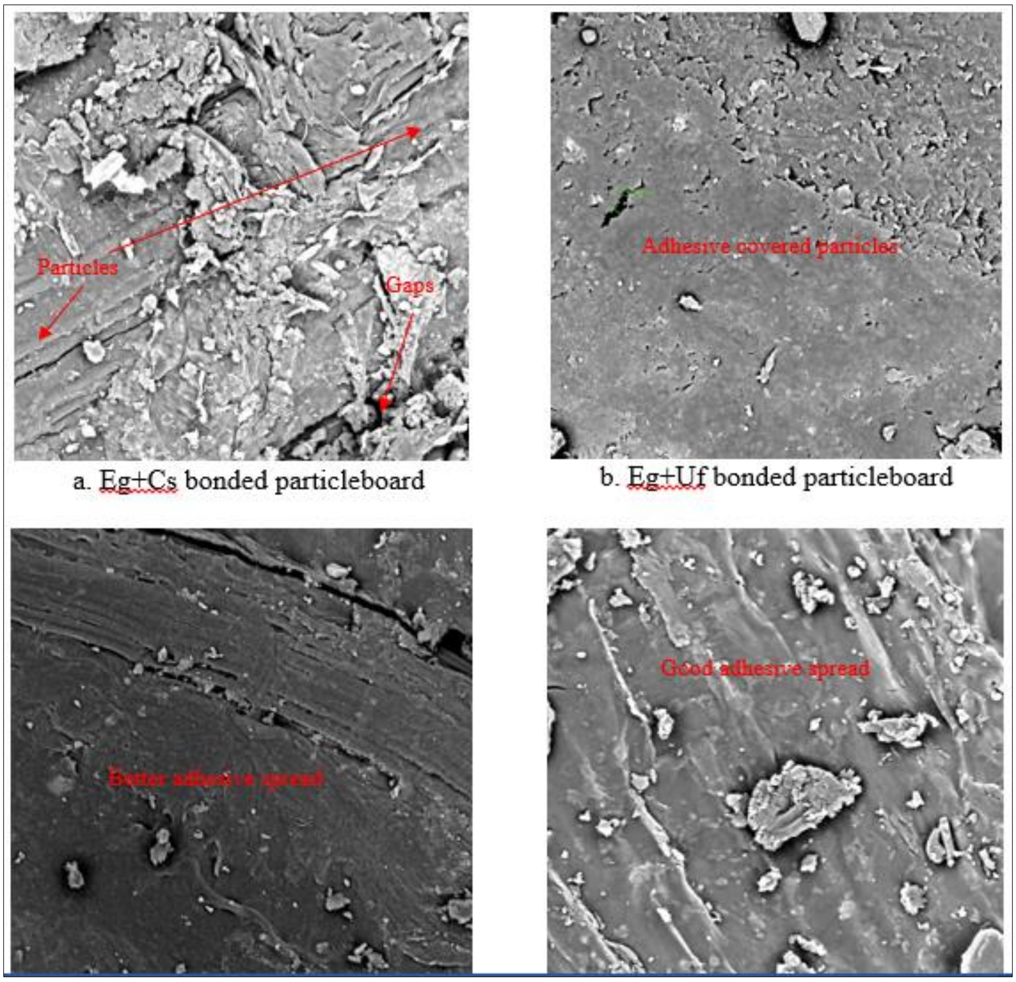
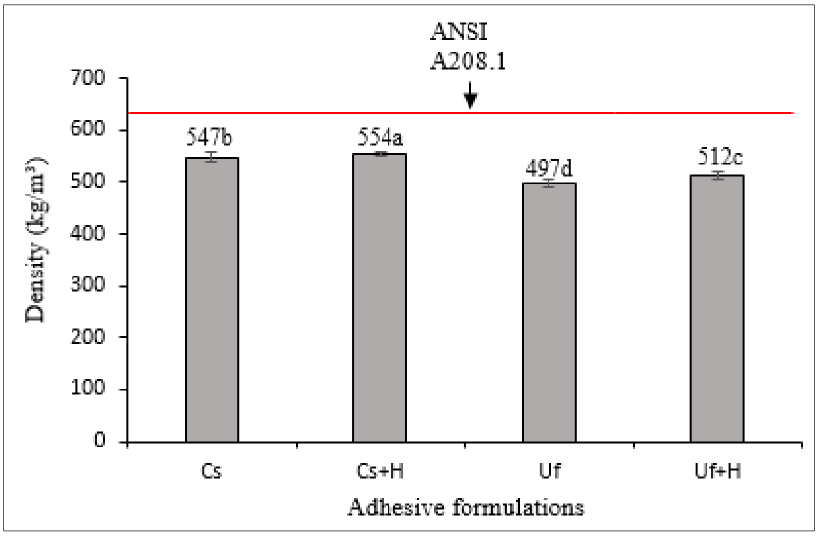


Figure 5 SEM images of Cassava starch (Cs) and Urea formaldehyde (Uf) blended particleboards manufactured from Elephant grace (Eg), with a magnification range of 1300x to 1500x. at 15kV

Bekhta *et al.* (2016) submitted the distinguishing features of the obtained adhesive blended with $Al_2(SO_4)_3$ are that curing time is reduced, viscosity is increased, solid content is slightly raised and strength properties enhanced with increasing amount of aluminum sulphate. These features contributed to the agglomeration of the adhesive, enhanced particle-adhesive interaction and thus improved properties as exhibited by the particleboard with hardener blended Cs and Uf adhesives, hence fewer void spaces improving the dimensional stability. Similar result was obtained by Adediran *et al.,* (2019).

Physical properties of the manufactured particleboard – Density

The density of the particleboards manufactured with Elephant grass (Eg) blended Cassava starch (Cs) and Urea formaldehyde (Uf) with Aluminium sulphate ($Al_2(SO_4)_3$) as the hardener is presented in Figure 6. The density ranged between 497 kg/m^3 and 554 kg/m^3. ANSI A208.1 (1999) classifies this range of density values (< 640 kg/m^3) as low-density particleboards, suitable for construction and other fitments. From Figure 6, it was observed that the particleboards densities increased as ($Al_2(SO_4)_3$) hardener was added. Tukey multiple range test at ($p \leq 0.05$), showed a significant difference between the density values of particleboards manufactured with only Cs and Uf adhesives and those with the adhesives blended with ($Al_2(SO_4)_3$) hardener. This confirms Bekhta *et al.* (2016) submission that the addition of ($Al_2(SO_4)_3$) hardener enhances particle-adhesive interaction and thus improving properties of the manufactured particleboards. Similar result was obtained by Galeazzi, (2017).

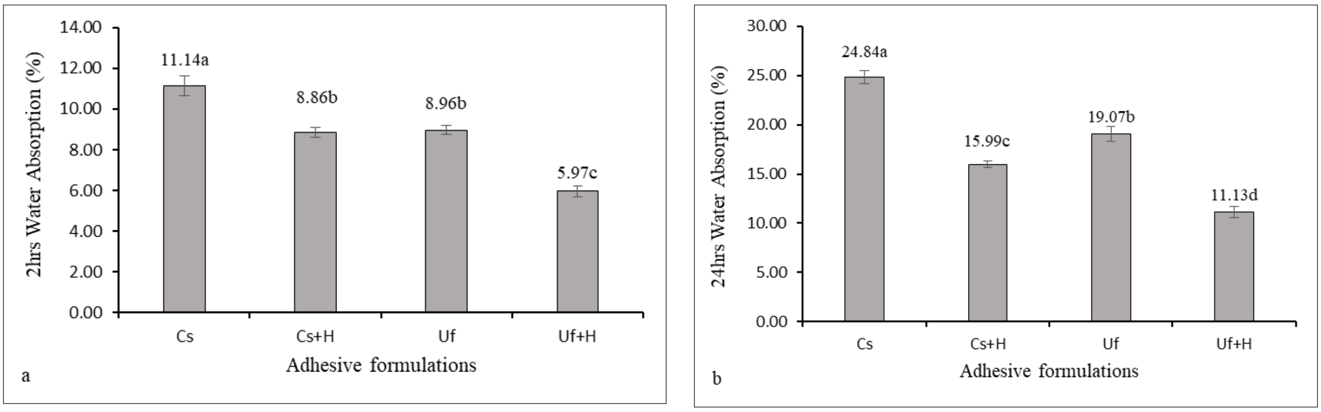


The data is expressed as the average of six specimens. Means followed by the same letter in a column are not significantly different at ($p \leq 0.05$) according to Tukey multiple range test.

Figure 6 Density Properties of the manufactured particleboards produced using varied adhesive formulation with hardener. Cs = Cassava starch, H = Hardener and Uf = Urea-formaldehyde

3.2. Physical properties of the manufactured particleboard – Water Absorption (WA)

The manufactured particleboards recorded 2-hr Water absorption (WA) values ranging from 5.97% for Uf+H to 11.14% for Cs, with adhesives composition blended with H recording least values for both mixes. Whereas 24-hr WA values ranged from 11.13% for Uf+H to 24.84% for Cs. In the 2-hr WA, the effect of H cannot be considered significant for Cs+H and Uf adhesives (Figure 7a and b). This indicate that Cs+H bonded particleboard can perform as Uf could in 2-hr WA. However, there were a positive significant difference between 2-hr WA values recorded by Cs and Uf+H, and Uf and Uf+H. The 24-hr WA recorded the expected trend with a significant reduction in WA values for the H blended adhesives. As Cs recorded 24.84%, Cs+H recorded 15.99% indicating about 35.63% reduction in water absorption as a result of the addition of H. Uf also recorded 19.07% as Uf+H recorded 11.13%, implying a reduction of 41.64% WA when H was added. Thus, the addition of ($Al_2(SO_4)_3$) to the adhesives significantly reduces the amount of water absorbed by the manufactured particleboards. Similar result was obtained by Abed *et al.,* (2021); Chen *et al.,* (2021); Melo (2019).



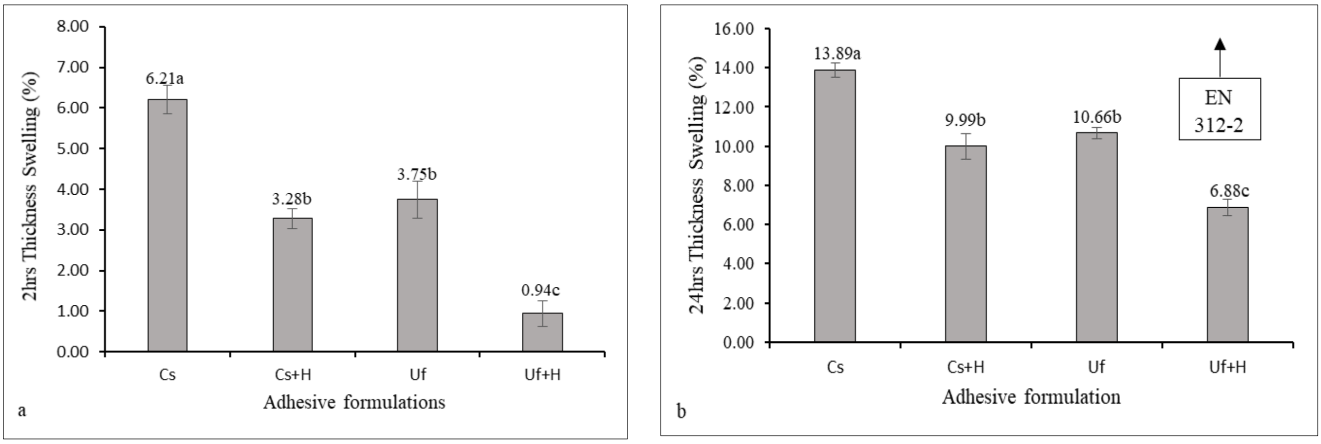
The data is expressed as the average of six specimens. Means followed by the same letter in a column are not significantly different at ($p \leq 0.05$) according to Tukey multiple range test.

Figure 7 Water Absorption Properties of the manufactured particleboards produced using varied adhesive formulation with hardener. Cs = Cassava starch, H = Hardener and Uf = Urea-formaldehyde

3.3. Physical properties of the manufactured particleboard – Thickness Swelling (TS)

The effect of aluminium sulphate ($Al_2(SO_4)_3$) hardener blended adhesives on the 2- and 24-hr thickness swelling (TS) properties of the manufactured particleboards are shown in Figures 8a and b. For the untreated adhesives, cassava starch (Cs) recorded 6.21% and 13.89% for the 2- and 24-hr respectively. Whereas the urea formaldehyde (Uf) recorded

3.75 and 10.66% for the same duration of immersion. Hence, untreated Uf exhibiting superior TS characteristics compared to untreated Cs. However, Tukey multiple range test at $p \leq 0.05$, showed no significant difference between the TS values recorded for Cs adhesive treated with $Al_2(SO_4)_3$ hardener and untreated Uf for the 2- and 24-hr duration of immersion Figures 8a and b. Thus, indicating a significant improvement in the performance of Cs adhesive treated with $Al_2(SO_4)_3$ hardener in TS, which agrees with Akyüz *et al.*, (2010); Bekhta *et al.,* (2016); Chen *et al.,* (2021); Jathungeye, (2007) and Melo (2019).



The data is expressed as the average of six specimens. Means followed by the same letter in a column are not significantly different at ($p \leq 0.05$) according to Tukey multiple range test.

Figure 8 Thickness Swelling and Water Absorption Properties of the manufactured particleboards produced using varied adhesive formulation with hardener. Cs = Cassava starch, H = Hardener and Uf = Urea-formaldehyde

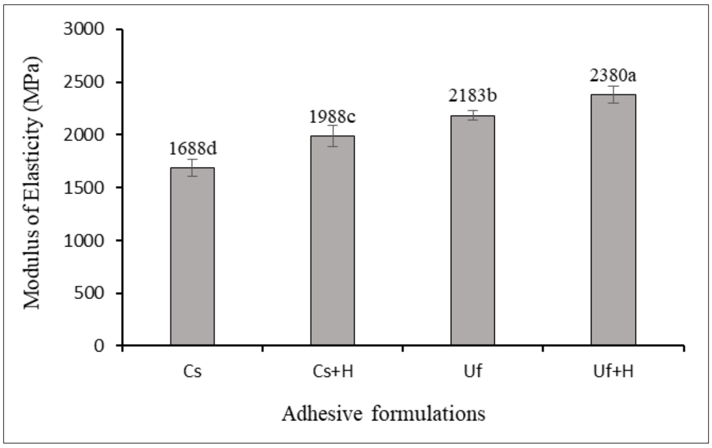
According to ANSI A208.1 (1999) the maximum TS tolerable after 24-hr water immersion expected of low-density particleboards for commercialization is 35%. Also, EN 312-2 (2005) standards indicate 8% and 15% as maximum TS for 2- and 24-hr water immersion respectively. The TS values obtained for all the manufactured particleboards were below the maximum limit given by both standards as shown in Figures 8a and b. It could therefore be inferred that the obtained physical properties of the manufactured particleboards convincingly indicate superior bonding ability of the adhesives formulated with the $Al_2(SO_4)_3$ hardener, as confirmed by the study of Altinkok et al., (2007); Bekhta *et al.,* (2016) and Jathungeye, (2007).

3.4. Mechanical Properties of the Manufactured Particleboard

3.4.1. Moduli of Elasticity and Rupture

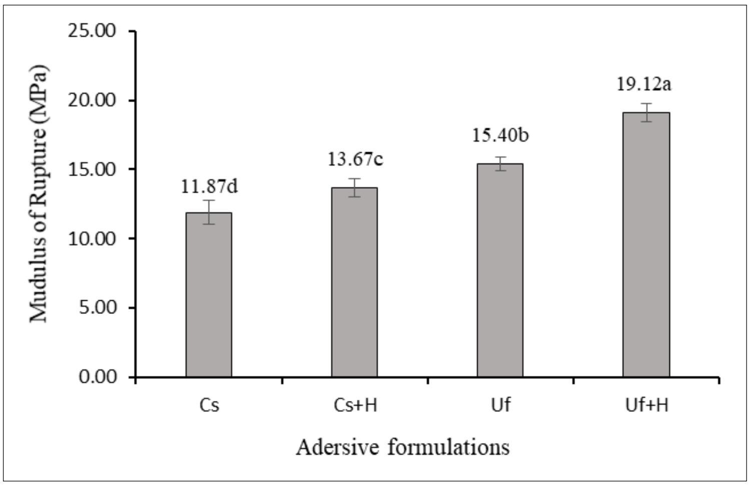
The values obtained for the moduli of elasticity (MoE) and rupture (MoR) are illustrated in Figure 9 and 10. Although, the urea formaldehyde bonded particleboard with hardener recorded the highest MoE and MoR values (2380 and 19.12 MPa) respectively, all the manufactured particleboards recorded MoE and MoR values which were higher than the minimum values as state by the ANSI A208.1 (1999) as 1550 and 10 MPa, and EN 312-2 (2005) as 1600 and 11.5 MPa respectively, for particleboards for general purposes and interior fitment. This significant increased (comparative to the referred standards) in the static bending values of the manufactured particleboards could be attributed to the low density, mechanical interconnectivity of the particles, better particle-adhesive interaction and high aspect ratio of Elephant grass particles which causes more compactness at the surface. This in turn leads to better adhesion during hot pressing. Similar results were also stated by Azizi et al., (2011); Dahmardeh Ghalehno et al., (2011); Khanjanzadeh et al., (2012); Kord et al., (2016); Mitchual et al., (2020); Papadopoulos et al., (2004); Tabarsa et al., (2011) who also manufactured particleboards with plant residues.

Additionally, in both static bending properties tests, the addition of aluminum sulphate ($Al_2(SO_4)_3$) hardener, significantly increases the performance of the manufactured particleboards (Figure 9 and 10). This could be as a result of the higher viscosity (Aizat *et al.,* 2019) of the hardener and its ability to enhance compaction and increase particle-adhesive adhesion thus enhancing strength properties of the manufactured board. The hardener again forms chemical-metallic bond with the elephant grass particles which contain high potassium (41.86 %) Adeniyi et al., (2019) during hot pressing and exhibit malleability property which in turn improve the load bearing ability of the manufactured particleboard. Similar results were also stated for particleboards manufactured with $Al_2(SO_4)_3$ as a hardener by Aizat *et al.,* (2019); Atar *et al.,* (2014); Marzuki *et al.,* (2011); Uğur *et al.,* (2019). Bekhta *et al.,* (2016) emphasized that the addition of aluminium sulphate hardener to the adhesives significantly improved the strength properties of the manufactured particleboard.



The data is expressed as the average of six specimens. Means followed by the same letter in a column are not significantly different at ($p \leq 0.05$) according to Tukey multiple range test.

Figure 9 Modulus of Elasticity properties of the manufactured particleboards produced using varied adhesive formulation with hardener. Cs = Cassava starch, H = Hardener and Uf = Urea-formaldehyde

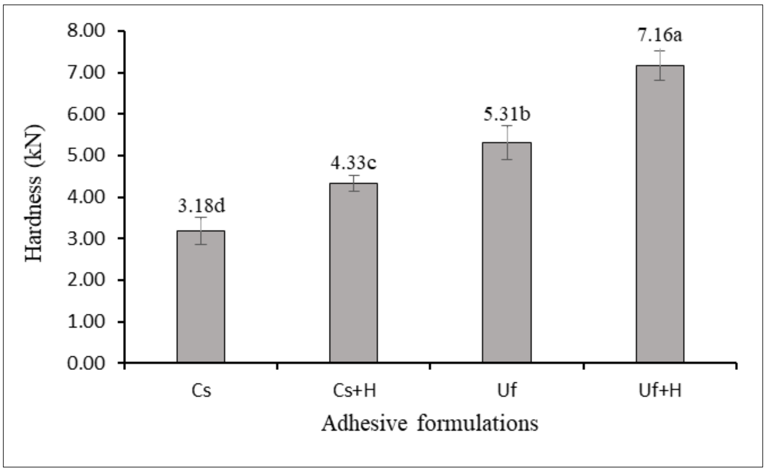


The data is expressed as the average of six specimens. Means followed by the same letter in a column are not significantly different at ($p \leq 0.05$) according to Tukey multiple range test.

Figure 10 Modulus and Rupture Properties of the manufactured particleboards produced using varied adhesive formulation with hardener. Cs = Cassava starch, H = Hardener and Uf = Urea-formaldehyde

3.4.2. Hardness

The results obtained from the hardness test is illustrated in Figure 11. The average hardness values recorded for the manufactured particleboards were between 3.18 and 7. 16 kN. The particleboard blended with urea formaldehyde and hardener (Uf+H) recorded the highest hardness values, whereas that manufactured with cassava starch (Cs) recorded the least value which was above the minimum requirement for furniture and fitments by the standard compared, 2.8 kN (ANSI A208.1, 1999). The results indicate that there was a significant improvement in the hardness property of the manufactured particleboard with the addition of the hardener. This implies that there was a good compaction and compression as $Al_2(SO_4)_3$ was blended with the adhesive. Increased in viscosity of the adhesive as was observed by Bekhta *et al.,* (2016) contributed to the improvement in the hardness of the manufactured particleboards.



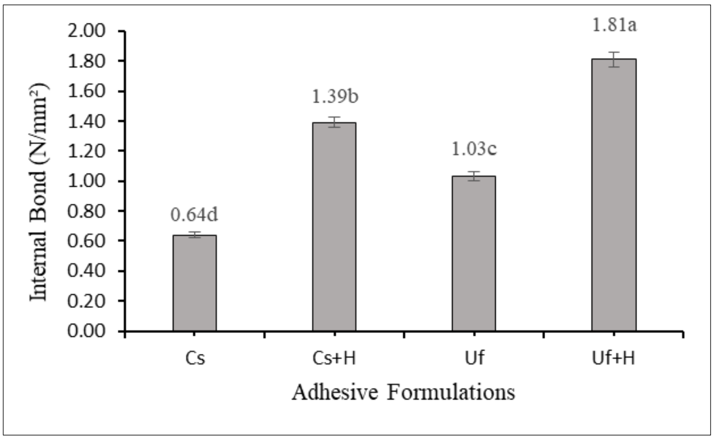
The data is expressed as the average of six specimens. Means followed by the same letter in a column are not significantly different at ($p \leq 0.05$) according to Tukey multiple range test.

Figure 11 Hardness properties of the manufactured particleboards produced using varied adhesive formulation with hardener. Cs = Cassava starch, H = Hardener and Uf = Urea-formaldehyde

3.4.3. Internal Bond Strength

The average values of internal Bond strength (IBS) of the manufactured particleboard blended with cassava starch (Cs) and urea formaldehyde (Uf) with aluminium sulphate as a hardener (H) are provided in Figure 12. As can be seen, the highest IBS value (1.81 N/mm^2) was recorded for Elephant grass bonded with Uf+H particleboard. Whereas Elephant grass bonded with Cs recorded the least value (0.68 N/mm^2). All particleboard specimens showed statistically significant difference in IBS values. The enhanced internal bond strength can be as a result of the adhesive and hardener formulation and the particles geometry which caused adequate adhesive-particles interaction and high mechanical interlocking between particles. The results are confirmed by the studies conducted by Akyüz *et al.,* (2010); Atar *et al.,* (2014); Brantseva *et al.,* (2018); Kord *et al.,* (2016); Liu *et al.,* (2022); Scheikl *et al.,* (2003); Yang *et al.,* (2021).

The minimum IBS property requirement for particleboards to be used for furniture and other fitments by ANSI A208.1 (1999) is 0.5 N/mm^2 and that of EN 312-2 (2005) is 0.40 N/mm^2. Hence the IBS of manufactured particleboards exceeded the standard rate and can be used for construction.



The data is expressed as the average of six specimens. Means followed by the same letter in a column are not significantly different at ($p \leq 0.05$) according to Tukey multiple range test.

Figure 12 Internal Bond properties of the manufactured particleboards produced using varied adhesive formulation with hardener. Cs = Cassava starch, H = Hardener and Uf = Urea-formaldehyde

From results of all the mechanical properties tested it could be inferred that addition of aluminum sulphate ($Al_2(SO_4)_3$) hardener indicated a significant improvement in the MoE, MoR, Hardness and Internal bonding strength of the manufactured particleboards. Similarly, the results of studies by Altinkok *et al.* (2007), Bekhta *et al.* (2016), Pantawee *et al.* (2017), Vimmrova *et al.,* (2011) indicated that the treatment of composite materials with aluminium sulphate hardener increases the compressive strength.

3.4.4. Thermogravimetric Analysis

The thermal properties of the particleboard manufactured from Elephant grass blended with cassava starch (Eg+Cs) and Elephant grass blended with Urea formaldehyde (Eg+Uf) is characterized in Figures 13 and 14. The peak temperature recorded by Eg+Cs and Eg+Uf was 356.43°C, which according to Sebio-Puñal *et al.* (2012), could be interpreted as the result of overlapping degradation of some by-product of lignin, which had early termination at a temperature of 393.75°C and 394.62°C for both Eg+Cs and Eg+Uf at a rate of 15.22% min^{-1} and 13.29% min^{-1} respectively. Indicating that adhesive type had no significant effect on thermal degradation of the manufacture particleboard. However, slower rate of degradation indicates better particle-adhesive interaction in the bond of Eg+Uf, which could result in partial decomposition as was observed by Fu *et al.,* (2008); Richards and Zheng (1991).

We observed the occurrence of a shoulder as was observed by Tomeleri *et al.,* (2021) during the burning phase at 250 °C for Eg+Cs and at 275 °C for Eg+Uf particleboards. According to Sebio-Puñal *et al.* (2012), this peak refers to the transition from the degradation of hemicellulose to cellulose, partially superimposed with lignin.

The weight loss observed from the TGA curves between 50 and 150 °C was 8.73 and 9.55% for Eg+Cs and Eg+Uf specimens respectively. Whereas between 200 and 425 °C heating temperature, Eg+Cs recorded 58.03% weight loss and Eg+Uf 57.40%.

The effect of adhesive formulation on the particleboard thermal degradation process was observed with Eg+Cs recording a weight change of 84.84% and Eg+Uf 82.98%, confirming accumulated residue of 15.04%, for the Eg+Cs specimen and 16.53% for Eg+Uf specimen at the heating temperature of 600°C. Therefore, the adhesive contributes to the decrease in the rate of degradation, and to a greater generation of flammable waste, resulting in less efficient burning (Tomeleri *et al.,* 2021).

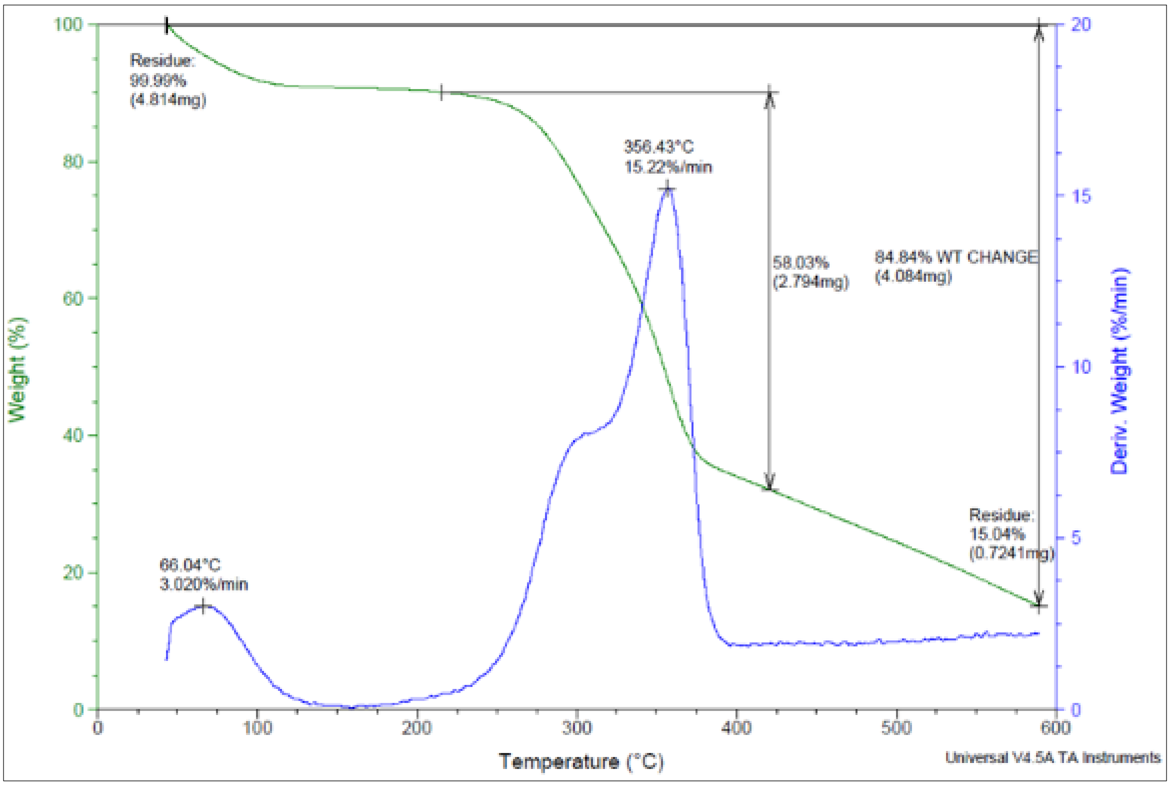


Figure 13 TGA-DSC curves of Elephant grass (Eg) particleboard manufactured with cassava starch Cs) adhesive (30-600 °C heating temperature)

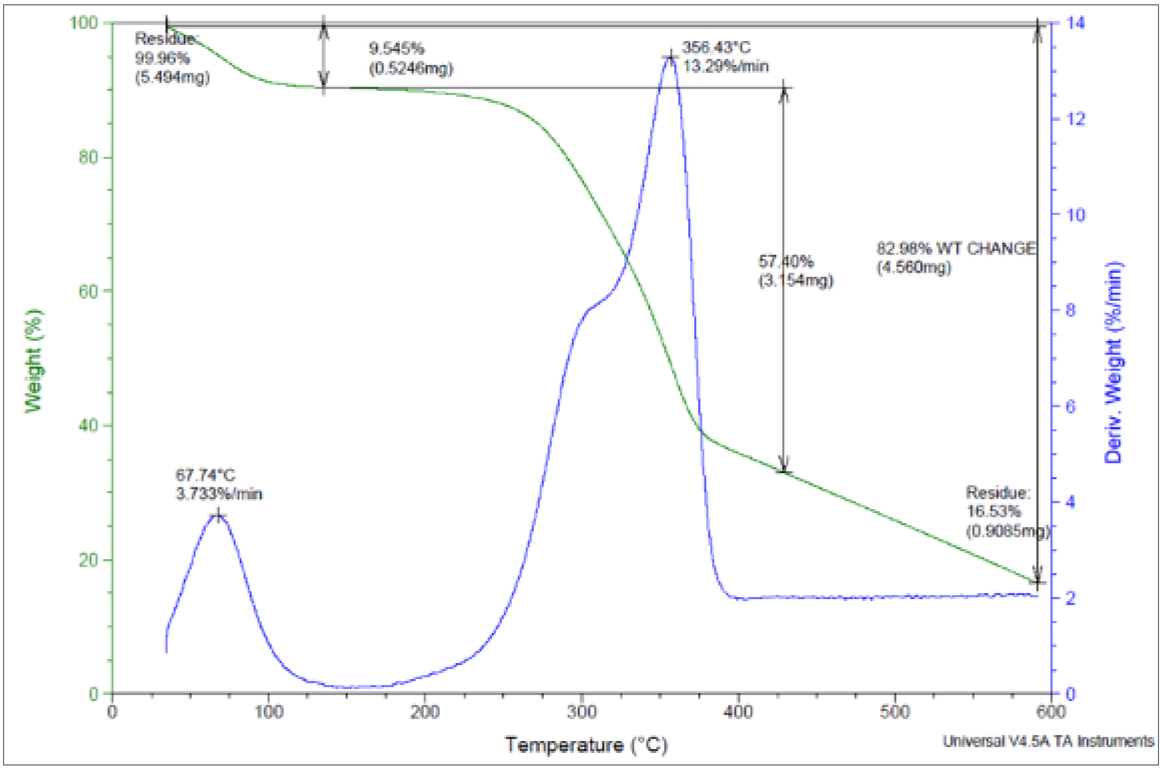
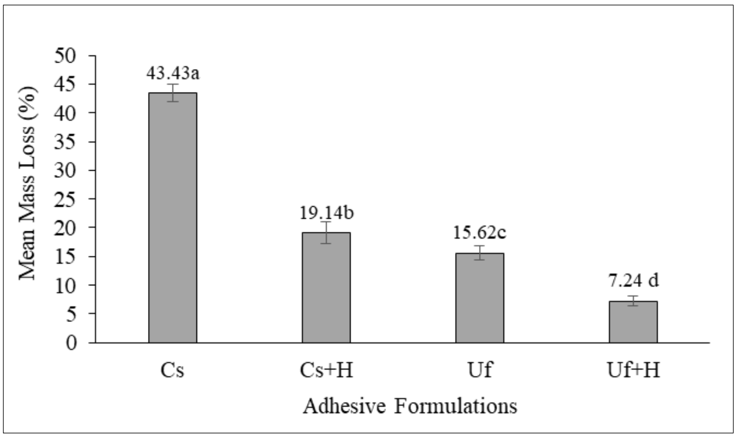


Figure 14 TGA-DSC curves of Elephant grass (Eg) Particleboard manufactured with urea formaldehyde (Uf) adhesive (30-600°C heating temperature)

3.4.5. Decay Resistance of the Manufactures Particleboard

Coriolopsis polyzona used in the study caused mass losses of around 43% in Cs based particleboard specimens (Figure 15). Cassava starch in the manufactured particleboard was an impetus in obtaining high mass loss in the specimens exposed to the activities of the decay fungi. Particleboard manufactured with Cs only is moderately resistant against fungi deterioration. Cassava starch adhesive formulated with aluminium sulphate ($Al_2(SO_4)_3$) at 2% concentration level, resulted in a significant decrease in mass loss. This trend was also observed in Uf adhesive formulated with the same amount of $Al_2(SO_4)_3$ (Figure 15). This suggest that the hardener used provided protection against the decaying activities of *C. polyzona*. Ammonium sulphate hardener and Uf adhesive provide protection against fungi degradation which confirms the works of Antwi-Boasiako & Appiah (2017); Bekhta *et al.* (2016); Kose *et al.,* (2011).



The data is expressed as the average of six samples. Means followed by the same letter in a column are not significantly different at ($p \leq 0.05$) according to Tukey multiple range test.

Figure 15 Decay test of the manufactured particleboards produced using adhesives combination with hardener. Cs = Cassava starch; Cs+H = Cassava starch + Hardener; Uf = Urea formaldehyde; Uf+H = Urea formaldehyde + Hardener

Additionally, Elephant grass has a high content of carbon, extractives and inorganic compounds which are difficult to digest by the fungi Dai *et al.,* (2019); Kogbara *et al.,* 2016; Mensah *et al.,* (2020). The result further indicates that for the same raw material, particleboards produced using Uf had mass loss far lower than their corresponding ones produced from Cs. This could be attributed to the toxic preservative-chemicals found in Uf meant to extend the service-life of particleboards manufactured with it (Antwi-Boasiako & Appiah 2017; Iswanto *et al.,* 2018).

4. Conclusion

Based on the experimental research findings, the following conclusion could be deduced:

- Firstly, the treatment of cassava starch and urea formaldehyde adhesives with $Al_2(SO_4)_3$ helps to enhance the dimensional stability and the static bending properties of the particleboards manufactured with it.
- Secondly, the TGA result revealed that the mass loss of the cassava starch bonded adhesive specimen between 30 and 600°C heating temperature was 18.42% less than the Uf particleboard specimen, implying that the cassava starch specimens have better thermal resistance than the urea formaldehyde specimen.
- Thirdly, the treatment of cassava starch and urea formaldehyde adhesives with aluminium sulphate ($Al_2(SO_4)_3$) at 2% concentration level, resulted in a significant reduction of mass loss in the manufactured particleboards.
- Finally, cassava starch adhesive exhibited improved properties when treated with aluminium sulphate ($Al_2(SO_4)_3$) at 2% concentration level, making it an alternative adhesive for industrial utilization in the composite industry. The addition of aluminium sulphate ($Al_2(SO_4)_3$) hardener that improves properties of the manufactured particleboard using cassava starch as an adhesive should be encouraged.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest regarding the publication of this paper.

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