# Effects of Cassava Starch and Natural Rubber as Binders on the Flexural and Water Absorption Properties of Recycled Paper Pulp Based Composites

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## Abstract

Responsiveness was given to the effects of cassava starch and natural rubber as binders on the flexural strength and the water absorptivity properties of the developed rattan particulate reinforced paper pulp based composites. Paper pulp was produced by chopping waste papers into smaller pieces and soaked in boiled water after which it was stirred thoroughly to form paper pulp. Rattan particulate was produced by hammering, chopping, pounding and milling of rattan canes followed by sieving into a particle size of 437 μ. Varying mass of paper from 300-400 g and particulate rattan in treated and untreated form of 2-8 g were mixed and bonded with natural rubber and cassava starch, respectively for the various samples developed. The mixtures were thoroughly mixed to produce homogenous pastes and poured into 150 x 50 x 30 mm detachable mould and compacted for 5 minutes using a laboratory compaction machine maintained at 20 KN. The developed composites were allowed to cure at room temperature for 27 days after which flexural and water absorptivity tests were carried out on the samples. It was noticed that the composite samples ST4 and S5 containing cassava starch happen to be the best in terms of flexural strength while NR2 gave the best water- repellent outcome.

**Keywords:** rattan; particulate; waste paper; paper pulp; cassava starch; natural rubber; composite; flexural strength



## 1. Introduction

The particle board industry fully depends on the use of formaldehyde-based resin such as urea formaldehyde (UF), due to its low cost and excellent properties of its panel binders [1]. However, the benefits in term of cost saving is time dependent owing to the continual rise of petroleum prices [2] and, hence, the production of UF which uses petroleum as the raw material will increase the cost of producing this resin [3-4]. One alternative that could be used to replace or minimize the use of UF in the manufacturing of particle boards is the use of natural adhesive such as starch and natural rubber [5-6].

Starch binders which are majorly produce from cassava in Nigeria, possess good ductility, good bind-ability, self-curing properties and hygroscopicity-resistance in their incorporated composites. Starch can be modified by physical or chemical methods to improve its structure and binding property as applicable to foundry as a main binder. Development of α-starch based composite binders by [7] in earlier stage can be regarded as a main starch binder for foundry. The thermoplastic properties of starch have been extensively studied [8] while many technologies have been used to process starch, the easiest

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way of obtaining a film is by casting from a solution. To obtain useful materials from starch, the native properties must be enhanced because of starch's high water sensitivity. The influence of water content and of external plasticizers like glycerol and sorbitol has been investigated to decrease the brittleness of these materials [9].

Natural rubber (NR) primarily comprises polyisoprene and is harvested from the milky white latex of a number of species of plants which flourish in the tropics, above all from the Spurge family. The rubber tree (Hevea brasiliensis) has achieved considerable commercial importance. The tree is native to the Amazon region and is now cultivated in all tropical regions of South America, Africa and Asia. Rubber has such remarkable and desirable properties that encourages it used many engineering applications seal in addition to the manufacturing of bulk products like tyres, tubes, belts, hoses among others. It is the most highly deformable material exhibiting complete recovery and it is virtually incompressible with a bulk modulus some thousand times greater than its shear or young modulus. The significance of plant proteins as binders in cellulosic paper composites are to ; increase the kaolin retention in the paper composites, increase the paper strength properties, enhance the opacity of the cellulosic paper and aid higher paper strength than protein free paper composites. Natural rubbers are favourable than synthetic adhesive because they are biodegradable and do not pose any health challenges to the environment during paper recycling.

Waste papers have been observed to be available in homes, schools and offices where papers are highly used. In Nigeria as well as many developing countries, waste papers are usually burnt or discarded indiscriminately. This implies that, the potentials in these waste materials are presently under-utilized. Globally, recycling of waste materials is an interesting issue to the scientists and engineers and this was one of the reasons for using them as a major source of material for the development of low cost building materials in this research. Also, cassava starch and natural rubber latex have been noticed to possess good properties that will enhance the engineering properties of composites. Therefore, the goal of this research is to characterize the effect of cassava starch and natural rubber as binders on the flexural and water repellent properties of rattan particulate reinforced paper pulp based composites.

The selected raw materials are of natural source in which both the reinforcement and the binders are of natural origin. These natural materials have high strength to weight ratio are easy to process, biodegradable, environmental friendly and are of low cost. They have a much lower undesirable impact on the environment since they are made from renewable resources.

## 2. Material and Method

Materials for this research work includes; waste newsprint papers, rubber latex, cassava starch, rattan canes, water, ammonia solution and potassium hydroxide (KOH) solution.

### *2.1. Production of Paper Pulp*

Thermo-mechanical pulping (TMP) was carried out on the waste white papers in order to turn them to paper pulp. The quality of mechanical pulp has improved steadily over the last few decades. Shortly after the introduction of thermo-mechanical pulp (TMP) it became the preferred furnish for newsprint and in recent years has become a substantial component of super-calendared and lightweight coated grades. With further improvement in fibre and pulp quality, by optimizing refiner operation and fractionation strategies, TMP could conceivably become the sole pulp in many high quality mechanical printing grades.

The three independent properties which must be optimized simultaneously for lightweight mechanical printing papers includes: scattering coefficient which is required for opacity, fibre length for strength, and density for printability. For a given wood species, there is a single relationship between scattering coefficient and fibre length, from ground wood to refiner pulps to Kraft. Greater development of long fibres with less cutting, as measured by density, can be achieved by lowering the refining intensity or increasing either the chemical treatment or temperature.

In this research, the waste papers were chopped into smaller piece using paper cutter and then soaked in boiled water for 3 days in a plastic bucket to form pulp after thorough stirring. The pulp was sieved and sun dried for 5 days as shown in Figure 1. Various weight of the dried pulp was weighed using electronic weighing balance into some plastic bowls in the following proportions: 400, 380, 360, 340, 320, 300 g. Having measured the paper pulp, each of them was soaked with 1200cm3 of water for 15 minutes to wet the texture of the pulp .The wet pulp was pulverised to a slurry form using a milling machine. These proportions were used for the development of the composites.

Fig. 1 Wet (left) and dry samples (right) of paper pulp

*2.2. Production of Rattan particulates*

The rattan canes were hammered into sheet by using a metallic hammer and die. The sheets were later chopped into smaller particles and were reduced to shredded form by the used of mortar and pestle.

*2.3. Chemical Treatment*

The shredded rattan fibres were divided into two halves from which part was treated with potassium hydroxide (KOH) solution to increase the adhesive nature of the fibres as well as remove unwanted constituents from the rattan fibres. Chemical treatment was also carried out to preserve and reduce the rate of contamination of the particles when it is incorporated in to the matrix. The rattan fibres were treated with 1 M solution of potassium hydroxide and this was done by soaking the fibres in the KOH solution and then transferred into a water bath where it is left for 4 hours at a temperature of 50 0C. After this process is carried out, the fibres were removed from the water bath and later washed with tap and distilled water to obtain pH of 7 and sun dried for 7 days.

The sun dried shredded rattan from treated and untreated fibers were pulverised for further size reduction using a milling machine. The milled particles were made to undergo sieve analysis to separate the particles into various particle sizes from which particle size of 437 µm was selected and used.

*2.4. Sourcing of Rubber Latex*

Five litres (5) of rubber latex was sourced from the Federal College of Agriculture (FECA) Akure, Ondo State, Nigeria and it was treated with ammonia solution for preservation.

*2.5. Production of Starch Slurry*

The starch slurry was prepared by mixing 4 kg of cassava starch with 300 cm3 of water at room temperature in a vessel. The mixture form a solution which was also mixed with boiled water and stirred properly to produce lumps free starch slurry. The starch slurry was allowed to cool in air for 15 minutes before and then transferred into a 5 litre jerry can for preservation.

*2.6. Mixing and Compaction of the Composite Components*

The wet slurry of milled paper pulp were mixed with the pulverised rattan particles and these was done at some predetermine ratio of the components with the rubber latex and cassava starch as binders for various samples of the composites, respectively. The mass of the rubber latex and the cassava starch was measured by relating its density to the fixed mass of the desired binder in order to obtain the required volume of the binder needed. The densities of the starch and rubber latex were 1.5 g/cm3 and 0.96 g/cm3 respectively.

The blend as shown in Tables 1 and 2 was thoroughly mixed and then poured to fill up the 150 x 50 x 30 mm mould and compacted under pressure maintained at 20 KN for 5 minutes using a laboratory compacting machine. Before casting, the top of the compacting mould was covered with cellophane to enhance easy removal of the composite from the mould and prevent delamination. Having done this process, the mould was disassembled and the cast composite was removed and then transferred to a wooden board were it was allowed to cure in air in the laboratory for 27 days as shown in Figure 3. The composites were prepared for flexural and water absorptivity tests.

Fig. 2 Samples prepared for flexural test

*2.7. Variation of Components*

In the production of this paper pulp based composites, the following parameters were varied.

- Rattan particulate mass was varied from 2-8 g.
- The paper pulp mass was varied from 300-400 g.
- The rubber latex mass varied from 0-100 g.
- The starch slurry mass varied from 0-100 g.

The variation of the components of the composites in % mass is as shown in Tables 1 and 2.

Table 1 Variation of components with paper pulp and natural rubber.

| Designation of samples | | Paper pulp : Rubber latex/Starch (g) |
|---|---|---|
| A | | 400 : - |
| $NR_1$ | $S_1$ | 380 : 20 |
| $NR_2$ | $S_2$ | 360 : 40 |
| $NR_3$ | $S_3$ | 340 : 60 |
| $NR_4$ | $S_4$ | 320 : 80 |
| $NR_5$ | $S_5$ | 300 : 100 |

Where; A - Paper pulp; NR - Paper pulp +Natural rubber; S - Paper pulp + Starch

Table 2 Variation of components with paper pulp, natural rubber, cassava starch and rattan particulate fibres (Treated and Untreated)

| Designation of samples | | | | Paper pulp : Rubber latex/Starch: Rattan Particulate (g) |
|---|---|---|---|---|
| Treated | | Untreated | | |
| A | | | | 400 : - : - |
| $NRT_1$ | $ST_1$ | $NRU_1$ | $SU_1$ | 300 : 98 : 2 |
| $NRT_2$ | $ST_2$ | $NRU_2$ | $SU_2$ | 300 : 96 : 4 |
| $NRT_3$ | $ST_3$ | $NRU_3$ | $SU_3$ | 300 : 94 : 6 |
| $NRT_4$ | $ST_4$ | $NRU_4$ | $SU_4$ | 300 : 92 : 8 |

Where; T – Treated; U - Untreated

### *2.8. Properties Test*

The dried sample was made to undergo both flexural and water absorption tests.

#### *2.8.1. Flexural Test*

The flexural test was carried out using Instron Universal Tensile Testing Machine that works on a three point flexural technique. The test speed was 50.00 mm/min over a span of 100.00 mm.

#### *2.8.2. Water Absorptivity Test*

The developed composite material is likely to come in contact with water if it used for producing ceiling sheet or partitioning boards, so it is necessary to carry out water absorptivity test to determine the extent to which the formed composites can absorbed water in case of roof leakage or otherwise.

In determining the water absorption property of the composite samples, each of the composite were weighed in air and then immersed in 700 $cm^3$. This test was done for 7 hours for the various samples of the composites. The composites were weighed in air when dried with the aid of an electronic weighing balance and then soaked into water. The weight after 7 hours was taken once they were removed and cleansed. The percentage weight gained was used to determine the water absorptivity.

## 3. Results and Discussion

### *3.1. Flexural Test*

The major mechanical test carried out on the developed composites is the flexural test. This was done because the material in service will be exposed to bending load or stress in most cases when suspended in the house as a ceiling sheet. The results were as shown and discussed below.

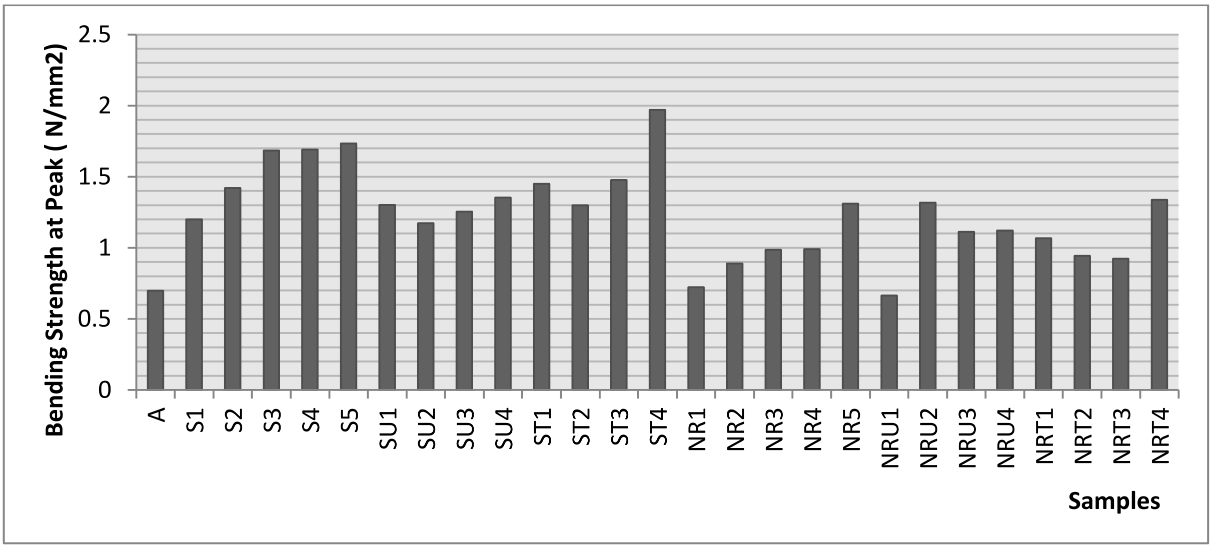


Fig. 3 Variation of bending strength at peak with samples

Figure 3 shows the bending strength at peak results for the samples. From the results, it was observed that the strength tends to increases as the binders content increases except for the rattan particulate reinforced natural rubber bonded samples where the strength tends to decrease as the binder content increases. The results showed that starch bonded samples gave the overall best performance in this respect. However, sample ST4 with composition (300: 92: 8) g has the highest bending strength at peak with a value of 1.97 N/mm2. This was followed by sample S5 with composition (300: 100) g and value 1.73N/mm2. Sample A which has paper pulp alone was with a value of 0.70 N/mm2. With these results, it is obvious that composites developed from starch possess better bending strength at peak than those composites from natural rubber and paper pulp alone (sample A). The composite with ST4 compositions gave about 181 % enhancement compared to A.

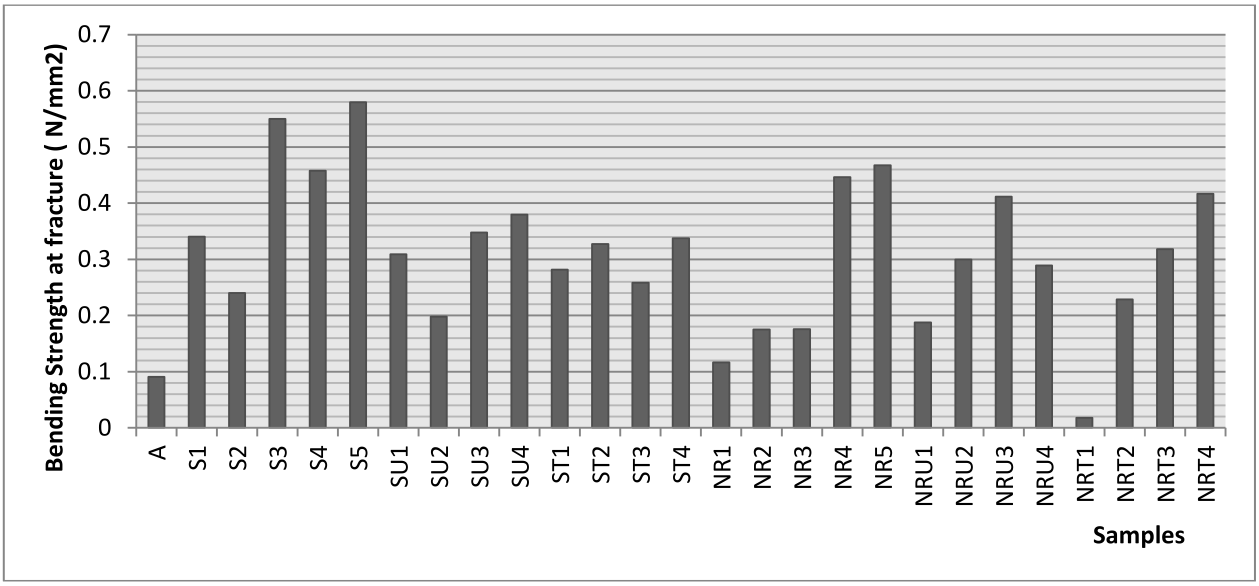


Fig. 4 Variation of bending strength at fracture with the samples

Figure 4 shows the bending strength at fracture results for the composite samples. From the results, it was observed that sample S5 with composition (300:100) g has a value of 0.58 N/mm2 followed by sample S3 with composition (340 : 60 ) g which has a bending strength at fracture of 0.55 N/mm2. Sample A which has paper pulp alone was with a value of 0.09 N/mm2. The delay in fracture was observed in these (S5 and S3) samples compared to the rattan particulate fibre reinforced samples as well as the 100 % paper pulp sample because they are more ductile than others due to the presence of more starch slurry that serves as binder. The results show that fracture strength for starch bonded samples tends to increase as the starch content increases and the rate of increase of fracture strength is higher in the composites containing starch than that of natural rubber.

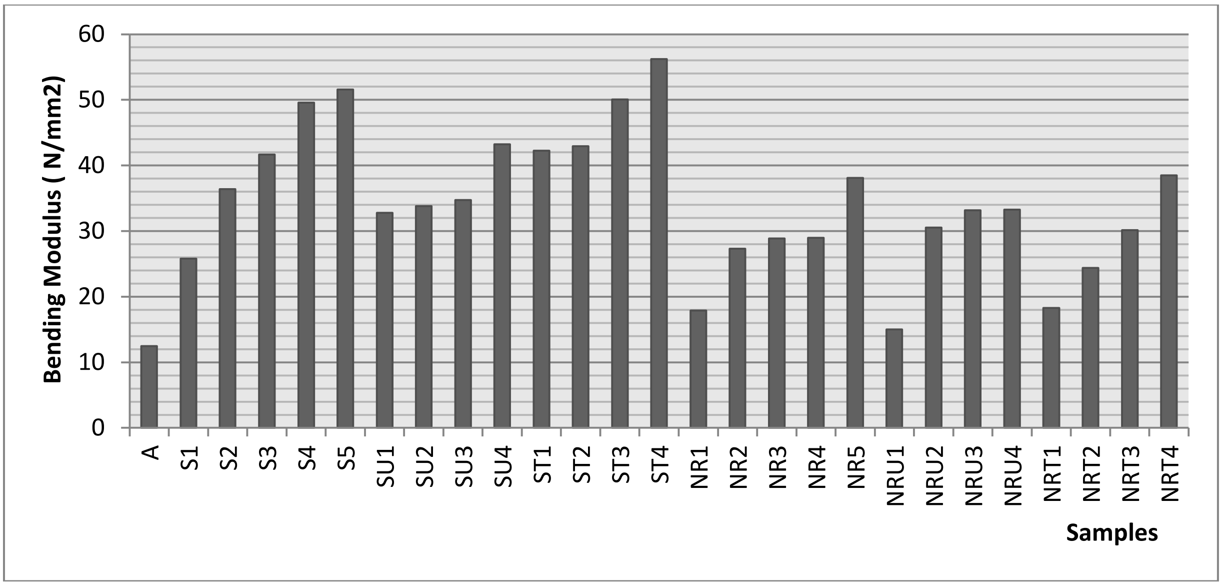


Fig. 5 Variation bending modulus of the composite samples

Figure 5 shows the bending modulus results for the composite samples. Similar trend was observed for all the various collections of samples where it was noticed that the modulus increases as the binders content increases. Again, better results were seen in starch bonded samples than natural rubber bonded samples. Collection of samples from treated rattan particulate reinforced starch composites gave the best results. These showed that the addition of particulate rattan fibre has resulted in the enhancement of the materials stiffness. Also, by obtaining the best upshots from treated rattan fibre indicate that, the treatment as actually cause surface roughening and thus enhanced the bonding strength at the interface with other constituents of the composites. Accordingly, sample ST4 with composition (300:92:8) g has the highest bending modulus with a value of 56.21 $N/mm^2$. This was followed by sample S5 with composition (300:100) g and value 51.58 $N/mm^2$. This further confirmed that, starch slurry impart better strength on the rattan particulate reinforced paper pulp based composite than natural rubber. Compared to these two samples, sample A which has paper pulp alone has the least bending modulus of 12.45 N/mm2. This implies that the addition of the binder and the reinforcement has enhanced the bending modulus of the developed composite by 351 %. Since it is possible to compact paper pulp alone for engineering applications, however, the addition of treated rattan particulate fibre and starch slurry to paper pulp is the best for the development of good and strong paper board ceiling sheet for structural applications.

Considering the bending test results, it can be identified that samples ST4 and S5 that possess higher bending strength at peak, fracture and modulus are those samples with strong adhesion among the constituents that constitute the composites.

The use of phosphate bond materials apart from cement has been highly encouraged, especially in areas of applications where compressive strength is not priority. Starch and natural rubber are sources of phosphate bond polymeric materials that can generally provides a lower modulus of elasticity compared to more brittle conventional cement and ceramic bonded materials. The flexible bonding mechanism results in higher impact resistance. Phosphate bond can be used to produce wood-based composite products with enhanced fire resistance, mildew resistance, dimensional stability and durability. These qualities of the starch as binder have aided the good flexural properties response obtained in this research.

*3.2. Water Absorptivity*

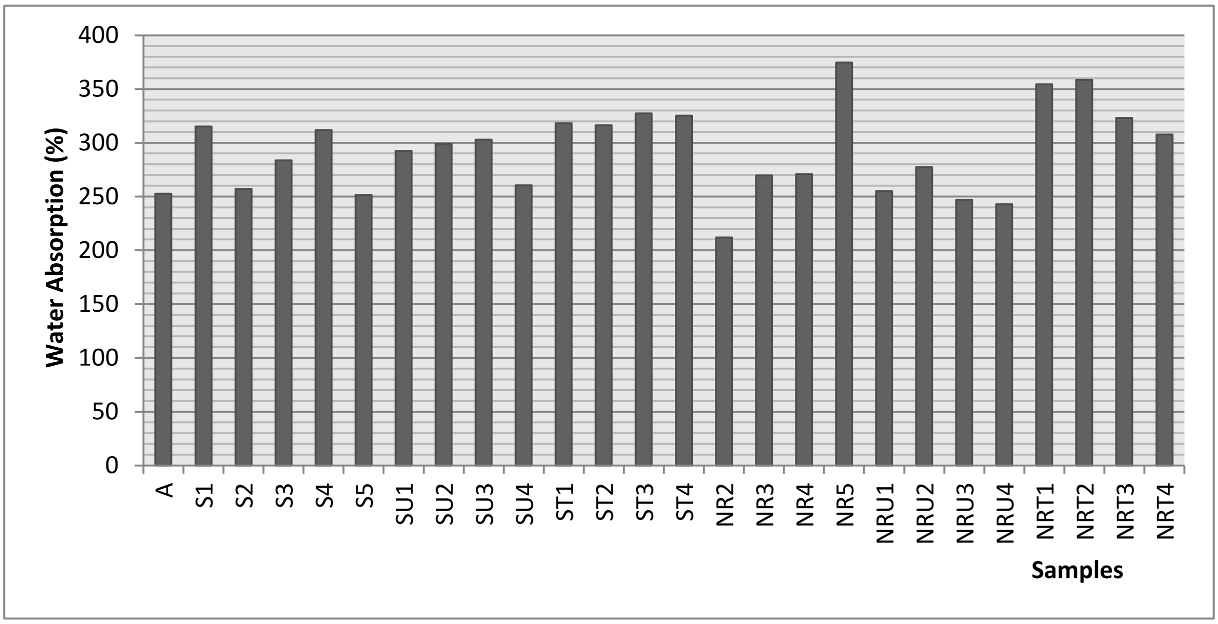


Fig. 6 Graph of water absorption for the samples after 7 hours of immersion

It was observed from Figure 6 that shows the comparative study of the percentage water absorptivity of the samples. It was observed that, the rate of water absorption increases with increase in the amount of starch and natural rubber as binders as well as rattan particulate addition in starch bonded samples while it decreases as the amount of rattan particulate added increases in both treated and untreated conditions in natural rubber samples. The addition of untreated rattan particulate gave better water repellent tendency than the treated samples. This shows that the addition of the rattan can help reduce the water absorption tendency of the developed composites. Considering the three major component considered, the untreated samples gave the best set of results followed by the natural rubber addition only. The rattan was a very strong and tough material commonly used as furniture material. The result show that NR2 with composition (360:40) possess the best water repelling property after 7th hours of soaking in water with absorption of 212% followed by NRU4 with a value of 243% compare to sample A with a value of 253%. The results depict the real interpretation of how it should be since starch and paper tends to absorbed water more than natural rubber in their environments.

## 4. Conclusion

The thrust of this work was to make use of the potentials that abound in biodegradable materials as well as waste products around the globe for the development of strong and low cost engineering materials for ceiling and/or partitioning boards. Having investigated the effects of cassava starch and natural rubber on the bending and water absorption properties of rattan particulate reinforced paper pulp based composites, the following observations were obtained:

- The used of cassava starch slurry as binders for rattan particulate reinforced paper based composites impart better bending properties on the composites while natural rubber imparts better water repellent property.
- By treating the rattan fibre with KOH, the flexural properties of the composites can be enhanced when bonded with cassava starch slurry while the untreated fibre will enhanced the water repellent property in natural rubber bonded composites.
- Samples, $ST_4$, $S_5$ and $NR_2$ are potential materials for ceiling or partitioning boards applications with respect to their areas of strong impart.
- Natural rubber bonded composites will the best materials when considering specific strength properties due to its low density compare to starch.

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