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Research Application Summary

Characterization of water absorption properties of a partial bio-composite made from cotton stalk fibres and phenol formaldehyde resin

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Abstract

Cotton stalks are a by-product of cotton farming and about two to three tonnes of cotton stalks are generated per hectare of land farmed. In this research, fibres extracted from waste cotton stalks using natural retting and decortication were used to fabricate a bio-composite. Normally, these wastes are disposed of on the farmland through incineration thus polluting the air through emission of harmful greenhouse gases. In accordance with sustainable development goals, there is a need to sustainably manage forests and combat desertification which can be better achieved through intensification and greater use of agricultural by-products. This can be achieved by using waste cotton stalks to make fibreboards as a replacement material for some solid wood applications. Cotton stalks are agricultural waste generated after cotton harvesting and tend to harbour parasites such as the pink bollworm and destructive polyphagous mealybug when left on farmland. Hand layup technique was used to fabricate the partial bio-composite. The cotton stalk fibre mass fraction (M_f) varied across five levels between 10.96% – 38.11%. The fabricated composite was subjected to water absorption tests which was carried out at intervals of 2, 4 and 24 hours. Regression analysis was carried out using Minitab software to ascertain effect of varying fibre content on water absorption. Composite density was maintained between 644 - 1004 kg/cm^3. The water absorption varied from 64.94% to 94.97% increasing with fibre loading due to the hydrophilic nature of the cellulosic cotton stalk fibres for the first two hours of the composites being submerged in water thereafter followed by a period of very slow and consistent water uptake. The developed composite compared well to standards and proved to have suitable properties that give it potential end uses in partition boards, and for furniture applications.

Key words: Composites, cotton, decortication, tensile strength, water absorption properties

Résumé

Les tiges de coton sont un sous-produit de la culture du coton et environ deux à trois tonnes de tiges de coton sont produites par hectare de terres de coton. Dans cette recherche, les fibres extraites des déchets de tiges de coton par rouissage naturel et décorticage ont été utilisées pour fabriquer un bio-composite. Normalement, ces déchets sont éliminés des terres agricoles par incinération polluant ainsi l'air à travers l'émission de gaz à effet serres. Conformément aux objectifs de développement durable, il faut promouvoir une gestion durable des forêts et lutter contre la désertification ce qui passerait par l'intensification et une plus grande utilisation des sous-produits agricoles. L'utilisation des déchets de tiges de coton pour fabriquer des panneaux en fibres comme matériau de remplacement pour certaines applications en bois massif répond bien à cette exigence. Les tiges de coton sont des déchets issus de la récolte du coton et ont tendance à abriter des parasites tels que le ver rose du cotonnier et la cochenille lorsqu'ils sont laissés sur le champ. La technique de drapage à la main a été utilisée pour fabriquer le bio-composite. La fraction de masse de fibres de tige de coton (Mf) a varié de 10,96% à 38,11% entre cinq niveaux. Le composite fabriqué a été soumis à des tests d'absorption d'eau qui ont été effectués à des intervalles de 2, 4 et 24 heures. L'analyse de régression a été réalisée en utilisant le logiciel Minitab pour déterminer l'effet de la variation de la teneur en fibres sur l'absorption d'eau. La densité composite a été maintenue entre 644-1004 kg / cm3. L'absorption d'eau variait de 64,94% à 94,97% augmentant avec la charge de fibres en raison de la nature hydrophile des fibres cellulosiques des tiges du coton, pendant les deux premières heures de l'immersion des composites dans l'eau, et suivie d'une période d'absorption d'eau très lente et constante. Le composite développé est conforme aux standards et a des propriétés appropriées qui offrent de potentiel de produits finaux dans la partition des tableaux et la fabrication de meubles.

Mots clés: Composites, coton, décorticage, résistance à la traction, propriétés d'absorption d'eau

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Background

The use of natural fibres materials in composites has increased due to their relative cheapness, their ability to recycle and that they compete well in strength per weight of materials used (Aji *et al*., 2009). The bio-degradability of plant fibres contributes to a healthy ecosystem while their low cost and high performance fulfils the economic interest of the industry. Our environment is being polluted due to the great use of synthetic fibre as reinforcement for polymer composites to reduce environment burden. Natural cotton is cultivated primarily for textile fibres, and little use is made of the cotton plant stalk. The cultivation of cotton generates plant residues equivalent to three to five times the weight of the fibre produced (Reddy and Yang, 2009). The cotton stalk is a great resource as a raw biomass material for manufacturing value-added bio-composite products (Tao *et al.,* 2011). Cotton stalks can be fabricated into composites such as fibreboard which can help to alleviate the problem of dwindling forest resources as it is an alternative to solid wood boards. This will contribute to meeting the Sustainable Development Goals (SDG 15) which emphasises the preservation of natural resources.

The term fibreboard includes hardboard, medium density fibreboard (MDF) and insulation boards. Fibre boards have several advantages such as having nearly double the strength of particle board, denser than plywood, can be painted, can be drilled and screwed, good insulator, sound proofing attributes, fungus/mold resistant, flammable but difficult to ignite and can be recycled.

Asgekar *et al.* (2013) measured the water absorption of coir fibre and phenol formaldehyde composite board range. The water absorption of the fabricated composite was between 47.81% to 101.75% for a board of 6mm thickness (Asgekar *et al*., 2013). The fibre volume fraction was varied between 10% - 50% respectively. Water absorbed in composites is generally divided into free water and bound water. Water molecules that are contained in the free volume of the composite are free to travel through the micro voids and holes and identified as free water, whereas, water molecules that are dispersed in the fibre-matrix and attached to the polar groups of a fibre are known as bound water. Water can penetrate into the cellulose network of the fibre and into the capillaries and spaces between the fibrils and less bound areas of the fibrils. Water may attach itself by chemical links to groups in the cellulose molecules. According to research by Zhong (2007) sisal fibre reinforced with urea formaldehyde resin composite absorbed water from 5% to 90% for fibre volume fraction of between 30% - 70% respectively (Zong and Wei, 2007).

Objectives

The objective of this study was to fabricate a partial bio-composite from cotton stalk fibres and phenol formaldehyde resin and characterize its water absorption properties.

Methodology

The cotton stalk fibres were extracted by use of water retting and mechanical decortication (Nkomo *et al*., 2016). The phenol formaldehyde resin used was sourced from Resinkem in South Africa. The composite was fabricated in a mould of dimensions 25cm*24cm*5cm for the length, width and thickness respectively using hand layup technique. The fibre mat was laid and pre-compressed then the resin poured over the fibre mat. The resin was distributed evenly by use of a roller. The mould was then closed under pressure and put in an oven at 130°C for 45mins.

Experimental design. For fabrication of the partial bio-composite the fibre mass fraction was varied from 0% to 38.11%. The target density of the composite was between 644-1004 kg/m^3

Water absorption properties. The water absorption test was done according to ASTM D570. The samples were immersed in water for 2, 4 and 24 hours at room temperature. The initial weight and final weight of samples was taken on a precise 4 digit balance to calculate the water absorption percentage. The water absorption was calculated using Equation 1.

$$\text{Percent water absorption} = \frac{W_a - W_i}{W_i} X\ 100 \qquad (1)$$

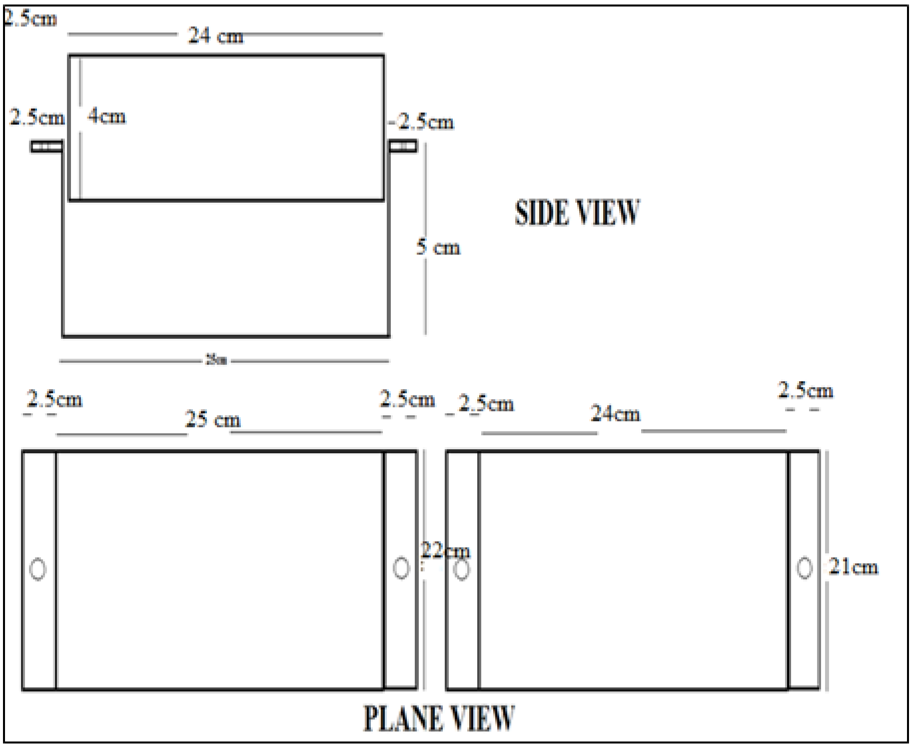

Figure 1. Schematic of mould used for fabrication of composite

Table 1. Experimental design for composite fabrication

No.	Fibre mass fraction %	Fibre weight g	Resin ml	Resin volume fraction %	Resin weight g
1	0%	-	140ml	100%	155.4
2	10.96%	25	140ml	89.04%	155.4
3	19.76%	50	140ml	80.24%	155.4
4	26.98%	75	140ml	73.02%	155.4
5	33.00%	100	140ml	67.00%	155.4
6	38.11%	125	140ml	61.89%	155.4

Where: W_a – final weight and W_i – initial weight

Statistical analysis. Regression analysis was carried out using Minitab software to find relationship between water absorption (%) and fibre mass fraction (M_f).

Results

The water absorption was recorded at intervals of 2, 4 and 24 hours. Figure 2 shows the recorded water absorption with time for the fabricated cotton stalk composite.

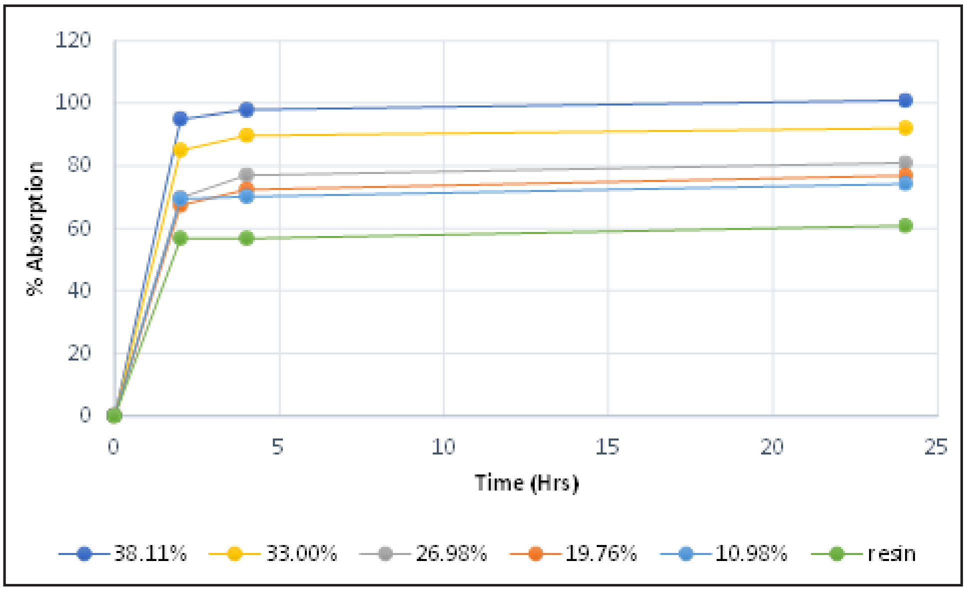

Figure 2. Graph showing water absorption of bio-composite with time

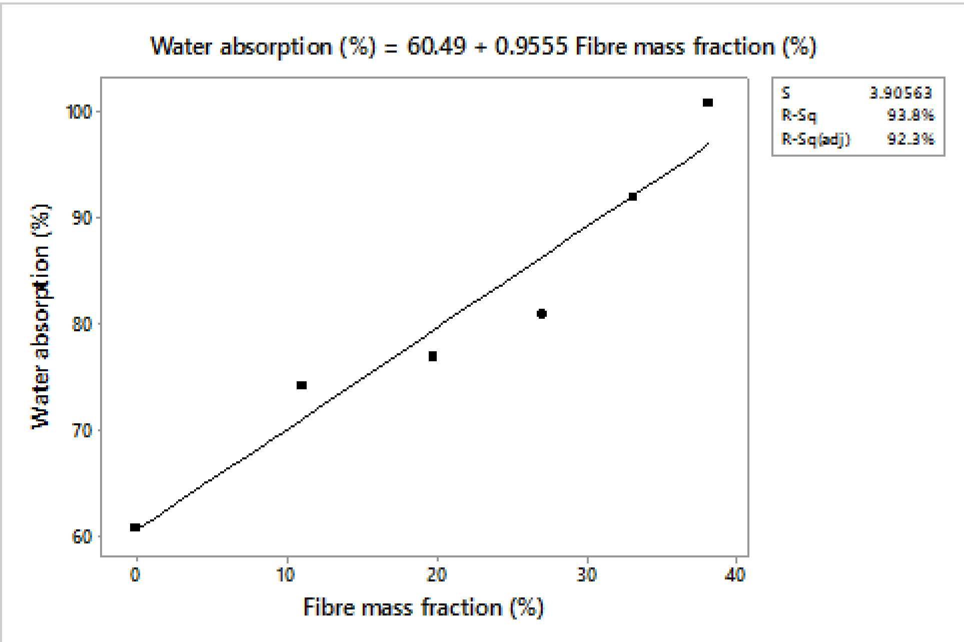

Figure 3. Variation of water absorption with fibre mass fraction (M_f)

Discussion

Water absorption is an important parameter of fibreboards that determines where it can be used. The bio-composite that had the highest fibre mass fraction of 38.11% absorbed the most water in two hours the absorption recorded was 94.97% and in the next two hours this absorption increased by 2.96%. In 24 hours the total absorption was 100.02%. This high absorption could be attributed to the extremely high fibre content in the composite. The 33% fibre mass fraction composite absorbed less than the 38.11% fibre mass fraction composite and had total absorption of 92.10%. The 26.98% fibre mass fraction composite absorbed 78.85% water due to the lower fibre content. The 10.98% fibre mass fraction composite which had the least fibre content absorbed the least water at 74.31% absorption.

During the first two hours, more than half of the final absorbed water occurred. This was followed by a period of very slow and consistent water uptake. This is consistent with most fibre and particle boards. The higher initial water absorption rate can be explained by the diffusion phenomenon, like a fluid migration, where the water spreads itself through the capillaries, vessels and cellular walls of the cotton stalk fibres (Tao *et al.*, 2012). Two forms of water up-take patterns were present: interstitial water and bound water. The interstitial water is contained in the cellular cavities and bound water is retained in the cellular walls. The rate of water absorption depends on the difference between the saturation water content and the water content at a given time, which is the driving force. The moisture diffusion into the fibres takes place because of moisture gradient between the surface and the centre. As absorption proceeds, the water content increases, diminishing the driving force and consequently the absorption rate. Generally, the interstitial water molecules are relatively weaker than the bound water molecules, thus, water will migrate from the more concentrated medium towards the less concentrated one. The graph in Figure 2 shows a fitted line plot for maximum water absorption of fabricated composite against the varying fibre mass fraction.

The trend line shows that the water absorption increases with increase in fibre loading. Natural fibres are hydrophilic in nature due to the presence of large number of hydroxyl groups and hence tend to absorb a lot of water. Water absorption increased as the fibre loading increased and this can be explained by the theory of void over volume of the board where the fibres were not fully bound by the phenol formaldehyde resin and hydroxyl properties by the fibre. Higher fibre loaded samples would be expected to contain a greater diffusivity due to higher cellulose content. Generally, the water absorption increased with immersion time until equilibrium condition was reached. The hydrophilic swelling of the cotton stalk fibres leads to the composite swelling. When the composite swells, there was some micro cracking of the brittle phenol resin. This resulted in water penetrating deeper into the composite and further fibre absorption due to the micro cracks caused by fibre swelling. The higher the water absorption created swelling stresses which weakened the composite board. The water molecules actively attack the interface, resulting in deboning of fibre and matrix (Tay *et al.*, 2012).

A simple linear regression was calculated to predict water absorption for cotton stalk and phenol formaldehyde resin composite based on the fibre mass fraction. A significant regression equation was found at ($F(1, 4) = 60.70$, $p < .001$), with an R^2 of 93.82% and shown in Equation 2.

Water absorption (%) = 60.49 + 0.9555M_f .... (2)

This model applies to randomly laid cotton stalk fibre composite. This model was formulated assuming a linear relationship between water absorption and fibre mass fraction after checking that it does not violate any laws of linear regression.

Conclusion

In conclusion the fabricated composite with different proportions of cotton stalk fibre loading had water absorption that varied between 64.94%- 94.97% for the first two hours of being submerged in water. The water absorption was found to increase with increase in fibre loading. These properties made the fabricated board suitable for end uses such as flooring, decking, ceiling boards, furniture, door panels and partitioning boards however it would be unsuitable for applications where board is exposed to constant sources of moisture.

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