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ECOLOGICAL ROOF TILES USING BACTERIAL CELLULOSE, TEXTILE WASTE, AND SUGARCANE BAGASSE

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ABSTRACT

As urban and economic growth continues, the generation of solid waste escalates, necessitating sustainable management practices. An effective strategy involves replacing traditional building materials with reusable alternatives, such as fibrocement, which incorporates organic and mineral fibers. While plant fibers, like Plant Cellulose (PC), are pivotal in the industry, their escalating demand poses environmental risks. The emergence of cellulose production by microorganisms, like bacteria, offers a viable solution; Bacterial Cellulose (BC) possesses great structural properties while being both biodegradable and renewable. The textile industry, facing fibrous waste production, is motivated to explore the reuse of these materials in crafting sustainable products, including roofing tiles. This study explored the feasibility of composites utilizing BC, Polyamide (PA), and Sugarcane Bagasse (SCB) (*Saccharum officinarum*) as eco-friendly roofing tiles, highlighting BC's significant role in enhancing material adhesion. The composites made from the filler and BC, supplemented with PA or SCB, demonstrated interesting results in terms of flexibility and rigidity, indicating promising prospects for further examination and validation as sustainable tile materials.

Keywords: Solid Waste. Construction Industry. Polyamide. Nanocellulose. Biotechnology.

1 INTRODUCTION

The population growth, economic development, and urbanization are causing shifts in production and consumption patterns, resulting in increased generation of solid and agroindustrial waste, especially in urban areas. Unfortunately, sustainable management of these wastes has been neglected, leading to environmental challenges[1]. One response to these challenges is the substitution of traditional building material components with reusable elements, as seen in the case of fibrocement, which incorporates organic and mineral fibers in its composition. Research is underway to enhance its properties, including adding plant fibers, which improve thermal and acoustic insulation and enhance impact resistance[2].

Plant fibers, such as Plant Cellulose (PC), play a crucial role in the industry; however, the increasing demand has led to environmental issues due to excessive wood consumption. To mitigate these impacts, studies suggest the production of cellulose by microorganisms, such as bacteria of the *Aerobacter, Escherichia, Komagataeibacter, and Sarcina* genera, as a viable alternative[3]. Bacterial Cellulose (BC) is a pure polymer, with three-dimensional nanofibrils that provide high strength, flexibility, and water absorption capacity. Moreover, it is biodegradable and renewable, offering potential applications in various industrial sectors[4]. Conventional cellulose production using the Hestrin-Schramm5 medium is costly, prompting the search for alternative means, such as agricultural and industrial by-products, including food waste, to enhance production and reduce environmental impact and expand application possibilities[6].

Considering the global increase in solid waste production, waste management has become a crucial environmental concern. This is particularly pertinent in industries such as fashion, which stands out as a major contributor due to the various production stages involved, including fiber harvesting, cleaning, spinning, and dyeing. Additionally, the sugarcane industry produces Sugarcane Bagasse (SCB) as a by-product of ethanol and sugar manufacturing[7]. These industrial sectors generate significant volumes of fibrous waste. Therefore, the reuse of these waste materials in creating new fiber-based materials is gaining importance, with many researchers dedicating efforts to this area.

This work aims to promote the production of sustainable roofing tiles by utilizing BC, produced from agroindustrial waste, and incorporating textile waste from beachwear, such as polyamide (PA) and SCB, as reinforcement materials. The results demonstrate an innovative process for manufacturing ecological tiles, highlighting improvements in components and properties, with potential applications in the construction sector.

2 MATERIAL & METHODS

BC producing microorganisms and maintenance media

The BC-producing microorganism utilized in a synthetic and alternative solid medium was the bacterium *Komagataeibacter hansenii* UCP1619. The alternative medium was formulated with ripe tomato pulp, a readily discarded residue even after ripening, yet still rich in nutrients, at a ratio of 1 tomato per 100 mL of water[9]. The medium was supplemented with sucrose to maximize cellulose production. Following sterilization of the medium via autoclave (121°C, 15 min), the bacterium was incubated to initiate BC production. The pre-inoculum was prepared from microorganism growth in liquid HS medium[5], and the inoculum was then inoculated into flasks containing the alternative medium with tomato pulp, statically incubated for 14 days at 30°C.

Production of Eco-Friendly Roofing Tiles

For the manufacture of eco-friendly roofing tiles, deionized water, high performance CP V-ARI Portland cement (C), limestone filler (LF), BC, SCB, and PA sourced from the beachwear industry were used. The cellulose was applied after being shredded under moist conditions. The tiles were initially produced as flat plates to analyze the material's performance. Later, the mold shape might be changed to a commercial tile mold. The bagasse fibers were prepared by shredding and sieving, while the polyamide was prepared by heating glycerin and adding fabric pieces until complete dissolution, then processed in a blender and sieved to obtain the fibers. The water-cement ratio was 7-4. The remaining materials followed the proportion in relation to the mass 150g of the mold used, as shown in Table 1. The mechanical tests on the samples were performed manually; the samples were manually flexed and subjected to tension to obtain qualitative results. The adhesion of the materials was evaluated based on their post-drying behavior, specifically assessing whether the samples disintegrated by releasing components from their backside.

Table 1 Sample composition (BC = Bacterial Cellulose; W = Water; C = Cement; LF = Limestone Filler; PA = polyamide; SCB = Sugarcane Bagasse; WT = Weight).

	Samples (%)												
Materials	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**
BC	40	40	40	40	40	40	40	50	-	50	50	-	-
W	15	15	15	16	17	17	17	-	-	-	-	30	30
C	25	25	25	28	-	-	-	30	40	30	30	50	50
LF	10	10	10	16	31	31	31	10	40	10	10	-	-
PA	05	10	-	-	06	12	-	05	10	10	-	20	-
SCB	05	-	10	-	06	-	12	05	10	-	10	-	20
WT (g)	27.74	24.23	23.05	22.15	20.76	20.55	20.15	22.31	-	21.98	22.05	22.73	22.56

3 RESULTS & DISCUSSION

The compositions of the prepared composites, as shown in Table 1, are presented in Figure 1. The presence or absence of reinforcing materials such as PA and SCB were evaluated for each combination to determine whether there would be material fixation to the CB fibers, adherence to the cement used, and overall material characteristics.

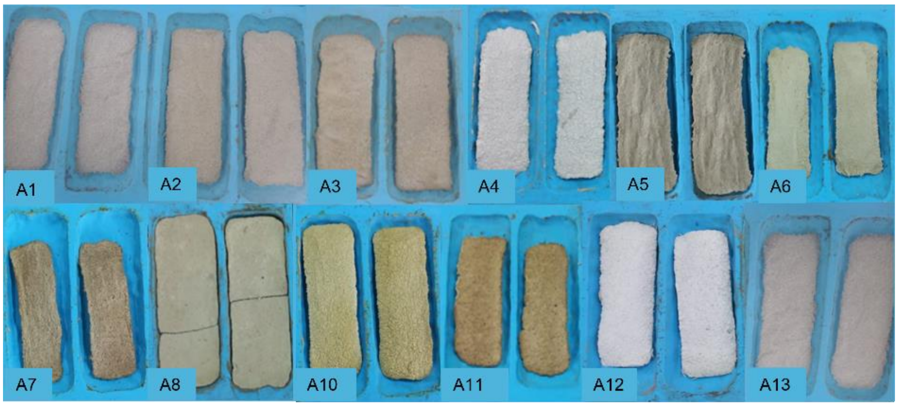

Figure 1 Prepared mortars. (A1 = BC, W, C, LF, PA, SCB; A2 = BC, W, C, LF,PA; A3 = BC, W, C, LF, SCB; A4 = BC, W, C, LF; A5 = BC, W, LF, PA, SCB; A6 = BC, W, LF,PA; A7 = BC, W, LF, SCB; A8 = BC, C, LF, PA, SCB; A9 = C, LF, PA, SCB; A10 = BC, C, LF, PA; A11 = BC, C,LF, SCB; A12 = W, C, PA; A13 = W, C, SCB)

The prepared mortars, as demonstrated in Figure 1, effectively formed the composites. Composite A1, which included all components, had an average dry weight of 27.74g. Effective material fixation was observed upon removal from the mold, as the composite did not disintegrate and exhibited resistance to breakage. This can be attributed to the presence of SCB reinforcing the cellulose fibers. The presence of PA was also noticeable, as the composite could be flexed. Sample A2, without SCB, had an average dry weight of 24.23g and showed less flexural strength, likely due to the absence of SCB. The removal of one reinforcing component did not affect the bonding of the other materials; it did not disintegrate upon removal from the mold and did not break easily. Sample A3, weighing 23.05g and without PA, exhibited greater rigidity and a coarser appearance. Despite not disintegrating during demolding and remaining intact when flexed, the material resisted bending. The absence of PA did not impact the fixation of SCB with the other materials.

Sample A4, without PA and SCB, weighing an average of 22.15g after drying, did not exhibit disintegration or ease of breakage. The absence of reinforcing materials did not interfere with the adhesion of C and LF to CB. This combination of materials resulted in a composite that lacked flexibility but was resistant to breakage, with an appearance similar to that of a typical dried mortar. Meanwhile, composite A5, without C, was successfully formed and, upon demolding, did not show signs of disintegration. This can be explained by the correct fixation of materials and the use of LF as a reinforcing material, allowing for the removal of C from the composition. As a result, the sample became even lighter, with an average weight of 20.76g after drying, while still demonstrating flexibility and resistance to breakage. Composite A6, with an average dry weight of 20.55g and lacking both C and SCB, exhibited significant flexibility and strength due to the absence of these materials that provided rigidity. It did not break or disintegrate upon removal from the mold, presenting a somewhat ‘plastic’ appearance that warrants further characterization. Composite A7, without C and PA, weighed an average of 20.15g after drying. It did not disintegrate upon removal from the mold and had a more rigid and resistant appearance. Although it did not break when flexed, it also lacked flexibility, resembling gypsum. Further characterization is needed to evaluate the properties of this composite.

On the other hand, sample A8, weighing an average of 22.31g when dry, was successfully formed. However, due to the absence of W in its composition, the interaction time between the materials may have been affected, resulting in a fragile composite that broke in half upon removal from the mold. Composite A9 could not be formed using only dry materials, as no binding material was present. Samples A10 and A11 were analyzed, with average dry weights of 21.98g and 22.05g, respectively. Both composites did not exhibit good material fixation, evidenced by the part in contact with the mold disintegrating. This could be attributed to the absence of W in their composition. Increasing the percentage of BC might help compensate for the lack of W. Composite A10, without W and SCB, although weakened by the absence of W, managed to form, and exhibited flexibility due to the presence of PA. On the other hand, composite A11, without W and PA, also affected by the lack of W, showed a more rigid and inflexible appearance, akin to a gypsum block in terms of lightness and texture. Samples A12 and A13 were used as a comparative average. Both were composed solely of C and W, reinforced with PA and SCB, with average dry weights of 22.56g and 22.28g, respectively. Superficially, no specific characteristics of the reinforcing material were perceptible in these samples.

4 CONCLUSION

In this study, composites reinforced with BC, PA, and SCB were tested for eco-friendly roofing tiles. BC improved adhesion between C and the reinforcing materials, giving the samples a smoother appearance. Successful substitution of C with F was observed in samples A5, A6, and A7, demonstrating the feasibility of a 100% C-free composite. However, sample A9, lacking both W and BC and composed solely of dry materials, could not be formed due to the absence of binding materials. PA contributed flexibility to the composites but did not bond easily with the other materials due to its nonpolar nature. SCB imparted greater rigidity to the composites due to the random arrangement of its fibers. Samples A6 and A7 stood out for effective material bonding and characteristics such as flexibility and rigidity. A more thorough assessment of mechanical properties through tensile load at break(N), compression(N), maximum deformation(N), and Young's modulus(Mpa) will be obtained using the ASTM D882 technique to confirm preliminary results. Additionally, these composites were selected for further characterization using techniques such as permeability, contact angle, thermogravimetry (TG), Scanning Electron Microscopy(SEM), and Fourier Transform Infrared Spectroscopy(FTIR) to validate their effectiveness as sustainable roofing tiles.

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