ECOLOGICAL COMPOSITES USING BACTERIAL CELLULOSE AND FILLER AS A SUSTAINABLE ALTERNATIVE TO CEMENT

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ABSTRACT

Population growth, economic development, and urbanization result in significant solid waste generation, particularly in urban areas. Unfortunately, sustainable waste management is often neglected, leading to environmental challenges. One potential solution is to replace traditional components of construction materials with reusable elements. Fibre-cement, which incorporates organic and mineral fibers, is being researched to enhance its properties, including the addition of plant-based fibers for insulation and impact resistance. Bacterial Cellulose (BC) emerges as a promising alternative. Produced by microorganisms, BC possesses exceptional structural properties and is both biodegradable and renewable. When combined with Filler (F), commonly used as a filling material, it enhances material compactness by facilitating distribution. This study examined the feasibility of composites for eco-friendly roofing tiles using BC and F, analyzing their adhesion with other components. These findings suggest their potential as sustainable roofing materials.

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

1 INTRODUCTION

Cementitious cracks, often resulting from external forces, thermal deformations, and concrete shrinkage, are critical factors compromising the durability of concrete structures. In particular, plastic shrinkage of concrete is responsible for approximately 80% of early cracks, allowing the infiltration of harmful substances such as sulfates and chlorides, which accelerates deterioration through an interconnected pore system. These cracks reduce the lifespan of structures by facilitating corrosion and have a significant economic impact due to the need for maintenance and repair. The development of alternative materials has recently become essential to mitigate such damage [2]. Wet curing offers a promising solution by promoting the hydration of unhydrated cement particles and the precipitation of calcium carbonate, thereby extending the lifespan of structures. Materials and methodologies for wet curing in cementitious materials are still being studied, including organic and vegetable fibers or the implementation of hydrogels in mortar production[3].

Bacterial Cellulose (BC), for example, is a pure polymer produced by microorganisms such as Acetobacter, Aerobacter, Escherichia, Komagataeibacter, and Sarcina. It consists of three-dimensional nanofibrils that make it highly flexible, resistant, and capable of high water absorption and retention. BC is biodegradable and renewable, allowing its use in various industrial sectors [4]. The traditional Hestrin-Schramm method for cellulose production [5] is expensive, prompting the search for alternative methods, such as agricultural and industrial byproducts. This not only optimizes production but also reduces environmental impact and expands application possibilities[6].

When used, the Filler (F) plays an essential role in improving the mechanical and physical properties of construction materials while reducing dependence on non-renewable materials. Considerable research over the past 15 years on using limestone in ordinary concrete indicates that, besides improving cement cost-effectiveness, replacing mineral fibers with F can enhance workability, stability, and concrete durability [7]. Recently, the development of high-strength cementitious materials and the use of superplasticizers have driven interest in microfillers, such as ultrafine fillers, which improve particle packing quality and rheological and mechanical properties of the cementitious system [8].

This work aims to promote the production of sustainable composites using BC obtained from agro-industrial waste and incorporating F as a reinforcing material, striving for an eco-friendly composite. It presents an innovative process for manufacturing eco-friendly roofing tiles, highlighting improvements in components and properties, with potential applications in the construction industry.

2 MATERIAL & METHODS

Bacterial Cellulose Production and Maintenance Media

The bacterial strain used for producing bacterial cellulose (BC) in both synthetic and alternative solid media was *Komagataeibacter hansenii* UCP1619. The alternative medium was prepared using ripe tomato pulp, a readily discarded residue even after ripening, which still contains high nutrient content. The tomato-to-water ratio was 1 tomato per 100 ml of water. The medium was supplemented with sucrose to maximize cellulose production. After autoclaving (121°C, 15 min), the bacteria were inoculated for BC production. The pre-inoculum was prepared from microbial growth in liquid HS[6] medium, and the inoculum was prepared in flasks containing the alternative medium with tomato pulp, statically incubated for 14 days at 30°C.

Eco-Friendly Roofing Tile Production

For manufacturing eco-friendly composites, deionized water, high performance CP V-ARI Portland cement (C), filler (F), and BC were used. The water-cement ratio was 7-4. The presented proportions are relative to the mass 150g of the mold used as detailed in Table 1. Cellulose was applied after wet grinding. Initially, the composites were produced in flat plate format, later to be used in the desired application format for uniform material distribution. The mechanical tests conducted on the samples were manual; the samples were manually flexed and tensioned to obtain qualitative results. The adhesion of the materials was analyzed according to the presentation of the material, specifically whether the sample disintegrated after drying (by releasing components from its backside or not).

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

Materials	Samples (%)					
	A1	**A2**	**A3**	**A4**	**A5**	**A6**
BC	38,00	-	45,00	45,00	60,00	-
W	17,00	25,00	25,00	25,00	-	36,00
C	30,00	45,00	30,00	-	-	64,00
F	15,00	30,00	-	30,00	40,00	-
WT (g)	23.28	22.26	21.85	20.15	20.76	23.73

3 RESULTS & DISCUSSION

The prepared composites, as shown in Figure 1, focused on the interaction between BC and F with C, analysing the composite formation and material fixation within the BC fibers.

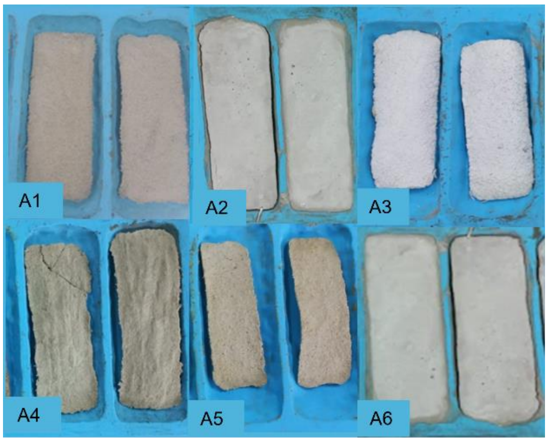

Figure 1 Prepared composites. (A1 = BC, W, C, F; A2 = W, C, F; A3 = BC, W, C; A4 = BC, W, F; A5 = BC, F; A6 = W, C)

The prepared composites, as shown in Figure 1, focused on the interaction between BC and F with C, analysing the composite formation and material fixation within the BC fibers.

The prepared mortars were effective in composite formation. Composite A1, containing all components, had an average dry weight of 23.28 g. It was observed that the composite maintained its firm structure and demonstrated resistance to breakage. This performance can be attributed to the presence of F as reinforcement, along with BC, which, by retaining water, ensured effective wet curing.

Composite A2, with an average dry weight of 22.26 g, demonstrated that the absence of BC did not compromise composite formation, as it still contained W. When removed from the mold, the composite maintained its structure and did not break, although it exhibited less flexibility and an extremely dry appearance due to the lack of BC. This can be explained by rapid curing. During curing, better compaction with fewer bubbles was observed, and after drying, the composite did not show voids when split in half. This effective use of F did not significantly affect the water content or drying time of the composite. Additionally, limestone fillers contributed significantly to improving mortar properties.[10]

On the other hand, composite A3, weighing 21.85g and without the use of F as reinforcement, facilitated the interaction between W, BC, and C, allowing improvements to the standard mortar. This interaction maintained a constant water content during curing, thus enabling the possibility of wet curing. The extremely fine C, diluted in W, permeated the pores and adhered to the BC fibers, enabling more effective interaction. This occurred without calcium carbonate precipitation, although potential microcrack formation was observed.

Composite A4, weighing 20.15g and consisting exclusively of BC, F, and W, eliminated the need for C as the main material. Although BC provided some flexibility to the composite, it broke when subjected to excessive bending. However, F demonstrated an interaction as effective as C with BC. The composite did not experience precipitation issues during the curing process, which proceeded adequately due to BC's water retention properties, highlighting the alternative of a C-free composite for the market.

Sample A5, containing W and C, had an average weight of 20.76g after drying. The absence of water did not affect composite formation, as BC provided the necessary moisture. The composite exhibited greater compaction and firmness, and upon being split in half, no voids or microcracks were found. BC acted as a network that held the F in place.

Finally, composite A6, composed only of C and W in the normal ratio of 7/4, had an average dry weight of 23.73g. This sample served as a comparative average for cementitious properties.

4 CONCLUSION

Mortar composites have proven effective in various formulations. Composite A1, containing all components, stood out for its strength and firmness, benefiting from F reinforcement and BC's water retention capacity for wet curing. Composite A2, without BC, still exhibited good robustness, indicating the effectiveness of F and limestone fillers in improving properties. Composite A3, lacking F, demonstrated effective interaction between components for wet curing. Sample A4, composed solely of BC and F, showed the feasibility of a C-free composite, despite fragility in flexural tests. Sample A5, excluding W and C, revealed significant compaction, emphasizing BC's crucial role as support for F. It is worth noting that additional tests such as contact angle, permeability, and Scanning Electron Microscopy (SEM), along with warping resistance and bending with the appropriate equipment. And more detailed characterization of the mechanical properties of the developed materials, through the tensile load at break (N) and compression (N), the maximum deformation (%) and Young's modulus (MPa) will be determined following the ASTM D882 method. These tests will be conducted to confirm these properties and validate that these results indicate different approaches for developing more sustainable and efficient mortar composites in the construction industry.

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