Preliminary experimental investigation into the use of biofibres and biopolymers in solar panel support truss systems

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Introduction

Over the past few years, there has been a significant expansion of the clean energy industry. According to New Energy Finance (2016), $ 285.9 billion was invested in 2015 in renewable energies, taking it above the previous record of $ 278.5 billion reached in 2011 [1]. In the same way, solar energy has become an important source of renewable energy as an alternative to reduce the volume of carbon emissions and the uncertainty adverse impact of inflated fossil fuel prices [2].

However, the frequent occurrence of global disasters causes the current solar products in the hurricane belt to be destroyed during violent storms. In this scenario, Terrasol Geosolar Inc. has identified a unique opportunity to offer a solar energy infrastructure for weather ravaged areas of the world, aiming to provide reliable and economic energy to government emergency response centers, hotels, commercial operations and private residences.

Terrasol's solar canopy is engineered to withstand Category 5 hurricane winds and remains electrically sound after being completely submersed during storm surge floods. Made from carbon fibre, which is non-corrosive unlike aluminum or steel, the product has 20 years of life expectancy and conforms to the American Society of Civil Engineers' (ASCE) standards.

Figure 1: Hurricane-resistant solar panel structure designed by Terrasol Geosolar Inc.

Aiming to gain competitive advantage with an eco-friendly product, Terrasol Geosolar Inc. decided to focus on the use of natural fibres and bio-based resins in the composition of the solar panel structure. However, biocomposites are prone to degradation when applied to outdoor environments, due to the effect of moisture and weathering [3]. This article summarizes the literature review about the advantages and challenges of using biocomposites for structural applications. It also presents the effects of the plastination process of natural fibres on moisture absorption, recently developed by Composites Research Network (CNR) laboratory.

Literature Review

The current growth in environmental awareness is leading society to change its habits, reusing resources and using renewable products. This enhances the use of natural fibres reinforced polymers composites or biocomposites as alternative to synthetic and non-renewable materials, achieving similar or even better properties [4].

Table 1: Mechanical properties of synthetic and natural fibres [3].

Fibre Property	Glass	Carbon	Flax	Hemp	Bamboo
Density (g/cm^3)	2.55	1.80	1.45	1.48	1.40
Tensile strength (MPa)	2000-2400	3530-4900	800-1500	550-900	750-950
Stiffness (GPa)	70-74	230	55-75	40-65	30-50
Elongation at break (%)	3.0	1.5-2.1	1.5-2	1.6	1.9

Vegetable fibres can be extracted from different parts of plants, such as bast, fruit, grass, stem, leaf and seed [7 - 8]. Bast and leaf fibres exhibited better values of tensile strength as compared to other types of fibres, mainly due to higher cellulose content [6]. In terms of structural applications, flax fibres reinforcing composites offer the best combination of low cost, light weight and high strength and stiffness [5].

On the other hand, natural fibres face a higher risk of degradation when subjected to outdoor applications as compared to synthetic fibers. This varies for each type of natural fiber according to the polymeric composition of your cell wall. High levels of Lignin and Hemicellulose provide natural fibres lower resistance to Ultraviolet (UV) degradation, thermal degradation, moisture absorption and flammability [5].

Fibre treatments through the alkalization process, silane and maleic anhydride have shown good results in improving moisture durability by reducing fibre hydrophilicity, improving fibre/matrix bonding and/or plugging water penetration pathways in fibre [5].

In addition, UV stabilizers such as polyurethane can be incorporated into the polymer during biocomposites manufacturing to retard weathering effects [7]. However, some studies indicate that treated fibres reinforcing polymers are more vulnerable to mechanical degradation by weathering than untreated fibres [5].

In this context, a recent research by CRN confirmed the feasibility of applying the plastination technique to

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natural fibres, with the objective of hindering their moisture degradation [8].

Plastination of Natural Fibres

A recent feasibility study conducted by CRN [8] investigated the effectiveness of plastination in reducing the moisture degradation of bamboo. They found that plastinated bamboo had better mechanical properties than virgin (untreated) bamboo both before and after accelerated moisture exposure. These initial results indicated that plastination has the potential to be a useful treatment for natural fibres used in outdoor applications.

Plastination is a technique which was originally developed by Dr. von Hagens in 1977 [9] to preserve human and animal remains for teaching anatomy. He used this technique to replace the water and fats in the tissues of the remains with a curable polymer.

Dr. von Hagens [9] presented the four main steps involved in the plastination process: fixation, dehydration, forced polymer impregnation, and polymer curing. In fixation, a specimen is treated with a preserving chemical like formaldehyde and dissected. The dehydration step is typically done through freeze substitution at -25 °C to replace the water in the specimen with a solvent like acetone. Additionally, another acetone bath at room temperature is used afterwards to remove the fats in the specimen. The forced impregnation step involves placing the acetone-filled specimen into a vacuum chamber containing a curable polymer. Originally done at -25 °C, the pressure is then slowly lowered so that the acetone boils and is replaced by the polymer. Finally, the polymer is cured.

One common plastination method, later developed by Dr. Henry [10], is called the room temperature technique. It follows all the same steps as the originally developed method, except that the vacuum impregnation step is completed at room temperature rather than at -25 °C. In this case, the polymer used is a multi-part silicone rubber. The specimen is cured by applying a catalyst spray and covering it in a plastic wrap.

The room temperature technique was the method used by the CRN in their feasibility study [8]. It was slightly altered by skipping the fixation step and fat removal bath - bamboo does not require dissection and has no fat. Although this technique demonstrated good moisture degradation resistance in bamboo, it still needs to be improved so that it can be used on different natural fibres and in an industrial setting. Figure 2 shows an image with silicone (white) present in the cross-sectional view of plastinated bamboo.

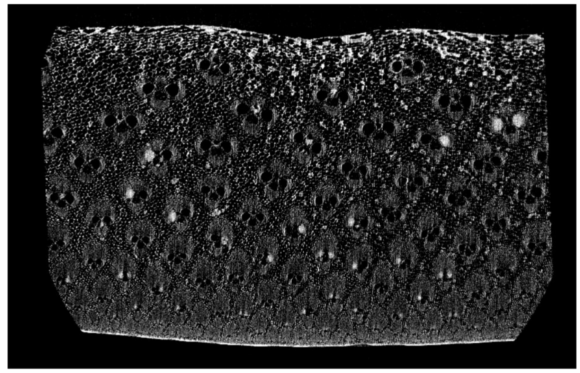

Figure 2: Micro-CT image of the cross-sectional view of plastinated bamboo

Some of the current issues with this plastination process, as it is applied to bamboo, are that it is lengthy, requires a freezer, and the silicone does not cure very effectively when using the catalyst spray. Currently, the plastination process is being optimized by the CRN to address these issues and to investigate how the plastination process can be used with natural fibres other than bamboo.

Plastination Optimization Results

To optimize the natural fibre plastination process, different experiments were conducted focusing on simplifying and accelerating the plastination process.

Firstly, the polymer was changed from a multi-part, spray-cured silicone to a one-part silicone which cures at 130 °C. This drastically improved the curing step in the process as the one-part silicone only requires 15 minutes to cure. The previous, multi-part silicone required at least two days to cure and there was still liquid silicone present within the bamboo.

Furthermore, the acetone dehydration step was changed to be conducted at room temperature rather than at -25 °C. At the higher temperature, the process was faster and did not require a freezer.

Finally, the polymer impregnation set-up - including a vacuum chamber, vacuum pump, vacuum gauge, hose, and connections - was improved. This made the impregnation more precise and sped up the chamber evacuation. The new set-up can be seen in Figure 3.

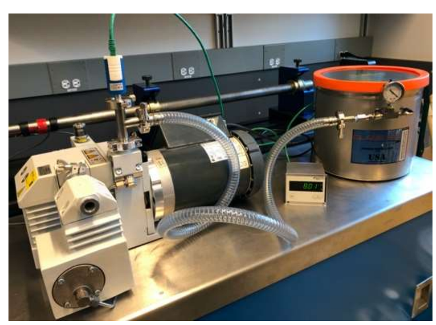

Figure 3: New forced polymer impregnation set-up for plastination

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There is still more work to be done to optimize the plastination process for natural fibres. This includes lowering the viscosity of the silicone being used to speed up the vacuum impregnation step and applying the optimized plastination method to a greater variety of natural fibres.

Conclusions and Future Work

After the literature review, flax, hemp, and bamboo natural fibres were selected for Terrasol's solar canopy, due to their good mechanical properties in comparison to synthetic fibres.

After the plastination process is optimized, the next steps involve subjecting untreated and plastinated fibres-reinforced biopolymer composites to accelerated moisture and UV radiation conditions (ASTM D5229 and ASTM D429 standards). Then the mechanical performance of materials before and after extreme weathering conditions and Category 5 hurricane winds will be evaluated.

By completing this project, the CRN will be using their technical and academic skills to collaborate with an industrial partner in creating a new, sustainable product.

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