Mechanical Properties of Biocomposites for Sustainable Construction Practices

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Summary

Biocomposites are structural materials made from renewable resources that biodegrade in an anaerobic environment after their useful service life, thus reducing construction-related waste. These materials are being researched and developed to replace less eco-friendly structural and non-structural materials used in the construction industry. In this research, the mechanical behavior of a cellulose acetate hemp fiber (fabric) biocomposite material has been characterized experimentally. The biocomposites were found to have mechanical properties similar to structural wood. Measured material properties were used to evaluate the applicability of laminate plate theory and a nonlinear model was validated to predict biocomposite laminate plate response in tension. The biocomposites studied have the potential to be used for scaffolding, formwork, flooring, walls and for many other applications within buildings and within the construction process.

Keywords: biocomposite; sustainable; renewable material; biodegradable; fiber-reinforced polymer; natural fiber.

1. Introduction

Most construction practices and materials used within the building industry leave a large ecological footprint. For example, a large percentage of landfill volume results from construction & demolition debris. In 1996, building-related construction and demolition debris in the U.S. totalled 136 million tons compared to 210 million tons of municipal solid wastes discarded in the in the same year [1]. Biocomposites are materials manufactured from rapidly renewable natural fibers and biopolymers that both biodegrade in an anaerobic environment. By replacing more temporary and adjustable components of buildings with biocomposites, landfill waste will be limited when the interior designs within the building are adjusted or in seismic regions where non-structural damage may be significant after an earthquake.

2. Mechanical Properties of Cellulose Acetate Hemp Fiber Composites

In this research, the mechanical properties of cellulose acetate hemp fiber (CAH) composites were characterized to evaluate their potential for applications such as scaffolding, formwork and partition walls. CAH composites were manufactured by laminating bi-directional fabric and tested according to ASTM standards in tension, compression, shear and flexure. Laminate plates also were fabricated to evaluate performance and the ability of simple predictive models such as laminate plate theory to estimate tensile response.

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3. Discussion

3.1 Mechanical Properties

The mechanical properties of the CAH composites are compared to wood-based materials and synthetic composites in Table 1. The strength of CAH composites in tension and shear is comparable to structural lumber and exceeds the strength of plywood. The flexural modulus is 55% to 70% of that for lumber and plywood (parallel to grain).

The mechanical properties of the CAH composites are lower than those of synthetic composites. This result is expected because the mechanical properties of the synthetic matrix and fibers exceed those of the biocomposite components. In addition, scanning electron microscope studies of the failure surfaces of the CAH composites have shown that the matrix does not penetrate to the center of the yarn. Without a strong bond to the matrix, the hemp fibers will slip rather than stretch thereby, reducing the possible stiffness. Poissonís ratio for CAH composites is within the same range as that for the synthetic composites.

Table 1: Mechanical Properties of biocomposites and other materials

	CAH Composite	Lumber (Western Hemlock) [16]	Plywood (B-B Class 1) [17]	E-Glass/Epoxy Composite [18]	Carbon/Epoxy Composite [18]
Tensile Modulus (GPa)	4.71 ± 0.28	--	--	39	142 - 294
Tensile Strength (MPa)	60 ± 2	45.5 - 77.9	27	1080	590 - 2860
Strain at Failure in Tension (%)	4.2 ± 0.4	--	--	2.8	0.3 - 1.7
Poisson's Ratio (in tension)	0.26 ± 0.03	--	--	0.28	0.23 - 0.27
Shear Modulus (GPa)	0.77 ± 0.03	--	--	3.8	4.9 - 7.4
Shear Strength (MPa)	14.9 ± 0.6	5.93 - 8.89	1.0	89	49 - 83
Flexural Modulus (GPa)	6.24 ± 0.96	9.03 - 11.2	10.3*	--	130
Flexural Strength (MPa)	66 ± 2	45.5 - 77.9	27	--	1700

* Parallel to grain (modulus perpendicular to grain is E/35)

3.2 Potential Applications for Biocomposites

There are numerous potential applications for biocomposites within buildings (e.g. framing, wallboard, doors, flooring, decorative panelling) as well as in construction (e.g. formwork, scaffolding). CAH compositeís low modulus of elasticity suggests that their component design will be controlled primarily by deflection limits. To meet these limits, CAH composites can use a large cross-sectional area or for more efficient material usage, be shaped to have high geometric stiffness. In such optimizations it is desired to keep the stresses on the biocomposites within the linear-elastic range. From preliminary analysis it appears that a 5/8î plywood sheathing for formwork could be replaced by a similar thickness of biocomposite to meet deflection limits.

4. Conclusions

[1] Mechanical testing of CAH composites was performed and demonstrated that CAH biocomposites have strength properties comparable to structural lumber and higher than plywood. The modulus of elasticity of the CAH composites is lower than that for lumber and plywood parallel to grain. Due to the low modulus of elasticity, deflection limits are expected to control the design of CAH components. CAH composite components can be shaped to have high geometric stiffness to meet deflection limits while minimizing material use. Keeping the stresses on biocomposites within their elastic range to meet deflection limits will allow for the application of classical laminate plate theory to predict laminate response. Classical laminate plate theory has been demonstrated here to provide accurate predictions of experimental linear elastic response of biocomposite laminates in tension. Finally, from preliminary analysis it appears that a 5/8î p lywood sheathing for formwork could be replaced by a similar thickness of biocomposite to meet deflection limits.