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Experimental and Theoretical Investigation of Prestressed Natural Fiber-Reinforced Polylactic Acid (PLA) Composite Materials

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Abstract: In this work we demonstrate that the specific mechanical properties of polylactic acid (PLA) can be enhanced by leveraging a combination of (a) additive manufacturing (3D printing) and (b) initial post-tensioning of continuous natural-fiber reinforcement. In this study both tensile and flexural PLA specimens with different cross-sectional geometries were 3D-printed with and without post-tensioning ducts. The mechanical properties of two continuous reinforcing fiber strands (i.e., jute, flax) were experimentally characterized prior to threading, post-tensioning to a prescribed level of stress, and securing in place with 3D-printed anchors. The effect of fiber type, matrix cross-sectional geometry, number of reinforcing strands, and degree of post-tensioning on the specific mechanical properties (i.e., strength-, stiffness-, rigidity-to-weight) of PLA were investigated using both tensile and flexural mechanical testing. Experimental results confirmed that additive manufacturing alone can improve the specific tensile and flexural mechanical properties of PLA and that these properties are further improved *via* initial mechanical prestressing of natural fiber reinforcement. Data indicate increases of 116% and 62% for tensile specific strength and stiffness and 12% and 10% for flexural specific strength and rigidity, respectively, compared to solid, unreinforced PLA. A theoretical model of the prestressed composite tensile response was employed and found to accurately predict (<10% error) improvements in mechanical behavior.

Keywords: B. Mechanical Properties; D. Analytical Modeling; E. 3-D Printing; Natural Fibers (nominated keyword).

1. Introduction

Polymers and composites from renewable resources are being engineered for target applications in the automotive, construction, and packaging industries at historically high rates to address growing environmental concerns of a globally unsustainable dependence on petroleum-based resources and to counter the proliferation of synthetic polymers and plastics in the environment. A variety of natural alternatives to synthetic fibers (e.g., carbon, glass, aramid) and petroleum-based polymers (e.g., polypropylene, polyethylene) have been evaluated for natural fiber-