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Enhancing Fatigue Resistance of Polylactic Acid through Natural Reinforcement in Material Extrusion

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Abstract: This research paper aims to enhance the fatigue resistance of polylactic acid (PLA) in Material Extrusion (ME) by incorporating natural reinforcement, focusing on rotational bending fatigue. The study investigates the fatigue behavior of PLA in ME, using various natural fibers such as cellulose, coffee, and flax as potential reinforcements. It explores the optimization of printing parameters to address challenges like warping and shrinkage, which can affect dimensional accuracy and fatigue performance, particularly under the rotational bending conditions analyzed. Cellulose emerges as the most promising natural fiber reinforcement for PLA in ME, exhibiting superior resistance to warping and shrinkage. It also demonstrates minimal geometrical deviations, enabling the production of components with tighter dimensional tolerances. Additionally, the study highlights the significant influence of natural fiber reinforcement on the dimensional deviations and rotational fatigue behavior of printed components. The fatigue resistance of PLA was significantly improved with natural fiber reinforcements. Specifically, PLA reinforced with cellulose showed an increase in fatigue life, achieving up to 13.7 MPa stress at 70,000 cycles compared to unreinforced PLA. PLA with coffee and flax fibers also demonstrated enhanced performance, with stress values reaching 13.6 MPa and 13.5 MPa, respectively, at similar cycle counts. These results suggest that natural fiber reinforcements can effectively improve the fatigue resistance and dimensional stability of PLA components produced by ME. This paper contributes to the advancement of additive manufacturing by introducing natural fiber reinforcement as a sustainable solution to enhance PLA performance under rotational bending fatigue conditions. It offers insights into the comparative effectiveness of natural fibers and synthetic counterparts, particularly emphasizing the superior performance of cellulose.

Keywords: Material Extrusion; polylactic acid; natural fibers; fatigue behavior; dimensional accuracy

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1. Introduction

Additive manufacturing is a growing technology with broad applicability across multiple industries. One of the most established additive manufacturing technologies is ME (Material Extrusion). This technology is characterized by its ability to work with a wide range of materials [1–3].

The versatility of ME technology has allowed its use in many industries. It can be used in industries with less-demanding tolerances and requirements to advanced sectors such as automotive, medical, and aerospace [1,4–9].

One of the most widely used materials for ME applications is PLA (polylactic acid), which has been extensively researched. However, pure PLA has limitations in terms of its mechanical properties [10]. This makes it less suitable for advanced sectors such as aerospace, where materials with more demanding properties are required [11].

Combining PLA with continuous carbon fiber reinforcements has been stated to be an effective strategy for improving the mechanical properties of the material [3]. Carbon fiber is known for its high strength and stiffness, making it an excellent reinforcement for

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