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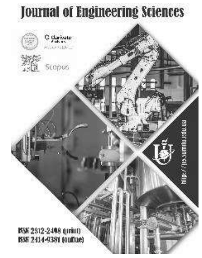

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Performance and Sustainability of PLA-Based Natural and Synthetic Fibre Composites in Fused Deposition Modelling: A Comparative Analysis

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Abstract. Recent research has proven that the mechanical properties of thermoplastic filaments, such as polylactic acid (PLA), used in fused deposition modelling (FDM), can be enhanced by incorporating natural (e.g., wood) and synthetic (e.g., glass) fibre reinforcements. However, these functional improvements may compromise sustainability – a dimension often neglected in composite research. This research aims to enhance the sustainability of PLA filament composites used in FDM. It examines the nature of the trade-offs between functionality and sustainability in PLA-wood and PLA-glass fibre composites compared to unreinforced PLA. Mechanical performance, including tensile strength and moisture absorption, was evaluated through standardized testing, while sustainability was analysed using the triple bottom line framework and life cycle assessment, encompassing the entire lifespan of the materials. Results showed that PLA reinforced with glass fibre exhibits a tensile yield strength of 45.3 MPa and an ultimate tensile strength of 50.4 MPa, which are approximately 43 % and 18 % higher, respectively, than unreinforced PLA: 31.5 MPa yield stress and 42.6 MPa ultimate tensile strength (UTS). Its compressive strength is also significantly greater at 108.2 MPa, compared to 61.5 MPa for PLA. The moisture absorption is similar to that of plain PLA at 0.6 %, slightly lower than wood fibre-reinforced PLA, which absorbs 1.9 %. The results suggest that glass-fibre-reinforced PLA offers superior mechanical properties while maintaining comparable moisture resistance and can be considered the most sustainable option where enhanced performance is critical, assuming PLA remains the base polymer. These findings inform material selection in FDM applications with a balance between performance and sustainable manufacturing.

Keywords: sustainable production, life cycle assessment, eco-friendly manufacturing, resource efficiency, sustainable composites.

1 Introduction

Fused deposition modelling (FDM) is a 3D printing technique known for its ability to produce complex geometries at a low cost. Its widespread popularity stems from the ability to rapidly fabricate intricate shapes while significantly reducing material waste, making it an ideal choice for diverse applications in prototyping and manufacturing [1]. Shapes are produced by extruding thermoplastic material through a temperature-controlled nozzle onto a platform layer-by-layer fashion [2] and guided by a digital computer-aided design (CAD) program to form a structural component [3].

As depicted in Figure 1, each layer bonds with the previous layer and solidifies as it is extruded.

The mechanism of operation necessitates that the materials of the filament have a low melting point to ensure smooth extrusion, making polymer filament one of the favourable choices for FDM. Polymer filaments are classified into plain polymer and composite.