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Title: Advancing Sustainable Manufacturing through Multi-Material Additive Manufacturing

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ABSTRACT

Background: Sustainable engineering focuses on designing and manufacturing products that meet current needs without compromising future generations or the environment, emphasizing waste reduction, resource conservation, and ecological balance. Additive Manufacturing (AM), particularly Multi-Material Additive Manufacturing (MMAM), offers significant potential for sustainability through material efficiency and functional integration. However, MMAM faces challenges including material compatibility, bonding issues, residual stress, and process control complexities.

Objective: This study aims to present a novel MMAM strategy combining virgin polylactic acid (vPLA) with recycled polylactic acid (rPLA) in a layered configuration to simultaneously improve mechanical performance and enhance sustainability in 3D printed components.

Methods: Components were fabricated using vPLA and rPLA in layered configurations. Mechanical testing (tensile strength, elongation, tensile modulus) was performed. Thermal analysis assessed degradation temperatures and residue. Full-field strain mapping, digital microscopy (DM), and scanning electron microscopy (SEM) were employed to investigate microstructural characteristics, interlayer adhesion, and failure mechanisms.

Results: Mechanical testing revealed that vPLA as the exterior material significantly improved tensile strength and elongation (10–25%) over single-material prints, while tensile modulus depended on material distribution. Thermal analysis indicated both vPLA and rPLA degrade around 330∘C, with rPLA showing higher end-of-degradation temperatures (461.7∘C) and increased residue, suggesting improved thermal stability. Strain mapping, DM, and SEM confirmed that vPLA-rich regions exhibited superior interlayer adhesion with fewer defects, whereas rPLA-dominated areas showed higher porosity and brittle failure.

Conclusion: These findings underscore that strategic material placement in MMAM can effectively mitigate the inherent deficiencies of recycled polymers, reducing reliance on virgin materials. This work contributes to broader sustainability objectives by enhancing energy efficiency and promoting a circular economy within AM, establishing a robust foundation for industrial implementations and future eco-efficient FDM processes.

(250-300 words)

BIOGRAPHY

Dr. Nida Naveed is a distinguished academic and industry professional with extensive experience in engineering education and research. She currently serves as a Senior Lecturer at the University of Sunderland, UK.

Prior to her current role, Dr. Naveed held the position of Programme Leader in Engineering at NCG Newcastle College Group, UK. She also contributed to research as an Honorary Associate (Researcher) in the Department of Engineering and Innovation at The Open University (OU), UK.

Her academic journey includes a fully funded MPhil leading to a PhD in Materials Engineering from The Open University, UK, supported by Rolls Royce Limited, the East Midlands Development Agency (EMDA), and The Open University. She also holds a Master's (MEng) in Structural Engineering and a Bachelor's (BEng) in Civil Engineering from NED Engineering University. Further enhancing her pedagogical qualifications, she completed a Postgraduate Certificate of Education (PGCE) in Mathematics and Numeracy Specialists from Teesside University, UK.

Dr. Naveed is a Chartered Engineer (CEng), a Member of the Institution of Engineering and Technology (MIET), UK, and a Senior Fellow of the Higher Education Academy (SFHEA), UK.

Her research expertise lies in sustainable engineering, multi-material additive manufacturing (MMAM), polymer composites, hybrid materials, material characterisation, and the mechanical behaviour of materials. She is a prolific author of peer-reviewed articles published in leading journals and is dedicated to fostering the next generation of engineers by mentoring numerous Masters and PhD students.

You can learn more about Dr. Naveed's work through her university profile and her publications on Google Scholar.