Research Article

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Enhancing 3D printing with composite filaments incorporating electronic waste: a study on flexural and compression strength

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Abstract: Fused deposition modeling (FDM) has emerged as the preferred method for creating three-dimensional (3D) models with minimal waste. To enhance the mechanical strength of the 3D-printed models using FDM, researchers have explored composite filaments. This study aims to advance electronic waste (EW) recycling for effective waste management by fabricating a composite filament by incorporating EW as a filler particle for FDM application. The composite filament merges polylactic acid with printed circuit board (PCB) particles sourced from EW. Physical properties like flexural and compression strength were evaluated. The samples were printed following ASTM D790 and ASTM D695 standards, using default parameters such as a 100 % infill rate, rectilinear pattern, and a layer thickness of 0.2 mm. The optimal printing temperature of 200 °C for the samples was determined through flowability testing. Subsequently, the dimensional stability and surface roughness of the printed samples were assessed, demonstrating that the inclusion of filler particles enhanced dimensional stability and decreased surface roughness. The results of this study show that a composite filament containing 3 wt% EW-PCB exhibits enhanced flexural strength and a notable increase in flexural modulus. Similarly, the filament containing 3 wt% EW-PCB exhibited a 35 % increase in bulk modulus compared to the filament without EW, attributed to the presence of metals in the PCBs. The micromorphological analysis was performed on the tested samples using field emission scanning electron microscopy.

Keywords: electronic waste; composite filament; fused deposition modelling; flexural strength; bulk modulus; surface roughness

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1 Introduction

In recent years, significant progress has been made in technologies designed for creating complex shapes through 3D printing. Among these, the FDM technique stands out as a preferred method in research, particularly for non-laser applications, owing to its affordability and ease of maintenance (Liu et al. 2019a). The FDM method involves shaping thermoplastic materials into filaments, which are then melted through the printer's extruder nozzle. These molten polymers are deposited as multiple layers to construct a 3D model of the specified part. During the printing process, the physical properties of the printed samples are influenced by different process parameters of the FDM machine (Dizon et al. 2017; Yogeshwaran and Das 2022). Recently, more cost-effective and rapid techniques have emerged in FDM, capable of achieving superior print quality. These advancements are constantly reshaping the approach to product design, manufacturing processes, and consumer utilization (Chapiro et al. 2016; De Leon et al. 2016).

In this context, several materials such as acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG), polylactic acid (PLA), polyvinyl alcohol (PVA), and polycarbonate (PC) are frequently utilised as filaments for FDM processes. For instance, PLA is a biodegradable material derived and processed from plants like corn and sugarcane. The discarded pieces of PLA that didn't succeed during the 3D printing process can be recycled with virgin PLA (Lanzotti et al. 2019). Recycling scrap PLA has the potential for up scaling the material for 3D printing applications, thus minimizing environmental impact. Additionally, some waste materials may be mixed with PLA, forming filaments that can be used in FDM techniques. This approach

The addition of filler to PLA resulted in fluctuations in the flexural properties of some of the composite filaments. The 30 wt% wood/PLA filament achieved a flexural stress of 40.4 MPa (Liu et al. 2019b), compared to the 103 MPa strength of plain PLA filament (Liu et al. 2019). This represents a 30 % reduction in strength due to the influence of the filler material. Similarly, the flexural strength of SCBF and LGF composite filaments was also reduced. The presence of the biomass filler material may decrease the rigidity of the PLA, as illustrated in Figure 9(a). For a material to be effective under flexural load, it should exhibit high rigidity. Comparing the induced stress of composite filaments, it is shown that EW-PCB/PLA has less induced stress compared to plain PLA (Liu et al. 2019; Liu et al. 2019b). However, the filler content in PLA is relatively low. In other composite filaments, the biomass filler particles typically reduce the strength of the PLA. In contrast, EW-PCB particles enhance the flexural strength of the material.

The compression stress of different fillers combined with PLA is depicted in Figure 9(b). The study compares the performance of ASP, WSP, and EW-PCB with PLA under compression loads. Materials with a high bulk modulus under compression are generally preferred. As shown in Figure 9(b), the compression stress of PLA with various biomass fillers and EW-PCB is highlighted. The ASP filler demonstrated superior compression stress (Song et al. 2020). This improvement is likely due to the chemical treatment of ASP particles before blending with PLA, which enhances the bonding and results in excellent strength. Although WSP fillers also underwent chemical treatment, they did not match the performance of ASP (Song et al. 2019). The EW-PCB filament showed better performance compared to WSP. Increasing the quantity of EW-PCB in the mix enhanced the rigidity of the printed parts, whereas the strength of WSP decreased. Overall, EW-PCB particles outperformed biomass fillers in flexural and compression load tests. However, plain PLA filaments exhibited the highest performance compared to all composite filaments. The properties of the extruded filaments were influenced by the quality and grade of the pellets used.

4 Conclusions

The composite filaments with (0, 1, and 3 wt%) EW-PCB/PLA were successfully extruded and evaluated for their printing accuracy, surface morphology roughness, flexural strength, and compression strength. Flexi PLA F2110 was used as a plasticizer to enhance adhesion between the filler EW-PCB particles and virgin PLA. Due to that, the composite filament with EW-PCB revealed an improved resistance against bending and compression. Increasing the quantity of EW-PCB and flexi PLA F2110 improves 40 % the flexural and 35 % the bulk moduli. This indicates that EW-PCB particles provide good resistance against flexural and compression loads. The flexural strength of PLA was reduced by 30–40 % due to the presence of flexi PLA F2110. This reduction was mitigated by adding EW particles (1 and 3 wt%).

The filler particles also influence dimensional accuracy by reducing the material flow rate through the nozzle during printing. This is caused by the friction generated by the EW particles at the extruder nozzle. The issue was rectified by infusing plasticizer into the composite filaments. The measured ASR and RSM of the composite filaments indicate that filler particles affect the smoothness of the surface. The presence of fillers (3 wt% of EW) in the filaments resulted in a 9–10 % increase in ASR and RSM.

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