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IMPACT OF NOZZLE LENGTH AND EXTRUSION SPEED ON TENSILE PROPERTIES OF FFF-PRINTED FILAMENTS

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ABSTRACT

Fused Filament Fabrication (FFF), also known as Fused Deposition Modeling, is the most widely used additive manufacturing technique. This process involves the extrusion of a thermoplastic polymer through a heated, movable nozzle, depositing filaments layer by layer to build a part. Despite its widespread growth across industries, FFF adoption remains limited in applications requiring high-performance components. Strength reduction in FFF-printed parts is primarily attributed to poor interfacial bond quality (caused by rapid cooling rates and low interlayer pressure) and the meso-scale effects of extruded filament geometry, including void formation between filaments. While these factors have been extensively studied, the influence of the extrusion process on the extruded filaments themselves, the fundamental building blocks of the final part, remains largely underexplored. This complex extrusion process involves several key phenomena, including polymer chain alignment, followed by chain relaxation upon exiting the nozzle, resulting in a behavior known as die swell. While challenging to model, this process can be studied experimentally. Nozzle length and extrusion speed are key parameters that significantly impact the extent of chain alignment inside the nozzle. In this study, Polylactic acid (PLA) filaments were extruded through nozzles with two different lengths (13 mm and 20 mm) and at two extrusion speeds (5 mm/s and 10 mm/s), followed by mechanical testing to assess their tensile behavior. The results indicate that while the ultimate tensile strength remains unchanged, the filaments become significantly more brittle at higher extrusion speeds, exhibiting a reduced strain at break by up to 70%. To further investigate this behavior, Differential Scanning Calorimetry was performed to assess potential differences in the microstructure. The results showed a similar overall degree of crystallinity (~20%), with a slight decrease in the first melting peak observed for filaments extruded at higher speeds. Additionally, confocal laser microscopy was employed to analyze the surface roughness of the filaments, which is influenced by extrusion instabilities. The surface roughness decreases with longer nozzle lengths, which could potentially improve interfacial bond quality by providing better filament contact during deposition. These findings highlight that small variations in extrusion conditions can significantly affect the extruded filament properties. This underscores the importance of further exploring the properties of extruded filaments to develop a more comprehensive understanding of the factors that influence final part quality in FFF printing.