

ABSTRACT

The advancement of additive manufacturing (AM) has opened new opportunities for designing lightweight, energy-efficient, and structurally optimized components. However, the inherent anisotropy and layer-dependent weaknesses of 3D-printed polymers pose challenges in achieving reliable mechanical performance under cyclic and long-term loading. This dissertation addresses these challenges through a three-part investigation focused on improving the structural integrity, fatigue resistance, and long-term durability of 3D-printed polymers using experimental characterization, digital image correlation (DIC), and statistical analysis.

Chapter 2 examines the influence of infill patterns, densities, and mesh modifiers on the tensile and fatigue performance of Tough PLA specimens fabricated by fused filament fabrication (FFF). A full-factorial experimental design was implemented to quantify the effects of grid and honeycomb infill structures combined with line and sine modifiers under multiple stress ratios. Digital image correlation was employed to capture strain localization and fracture progression. Results revealed that optimized combinations of mesh modifiers and infill density enhanced tensile strength by up to 20% and improved fatigue life by over 40%, with grid-sine configurations exhibiting the most balanced performance.

Chapter 3 investigates the creep and time-dependent deformation of 3D-printed polymers under sustained loading. The effects of infill pattern, density, and applied stress level were analyzed across 30 creep tests supported by DIC-based strain mapping. Honeycomb infill structures demonstrated the highest creep resistance, attributed to efficient multidirectional load distribution and uniform strain fields. Statistical evaluation via analysis of variance (ANOVA) confirmed that infill geometry and stress level significantly affect creep rate, whereas density primarily influences failure time. The findings establish a clear relationship between internal architecture and long-term mechanical stability in 3D-printed materials.

Chapter 4 extends the investigation to accelerated creep prediction in 3D-printed polyethylene terephthalate glycol (PETG) components using the Stepped Iso-Stress Method (SSM). The method effectively predicted long-term creep behavior within significantly reduced testing timeframes, achieving less than 5% deviation from conventional 24-hour creep tests. The

study also validates SSM as a reliable accelerated testing framework for polymer-based additive manufacturing materials, providing an efficient alternative for lifetime assessment.

Overall, this dissertation presents a systematic framework that integrates experimental mechanics, full-field strain measurement, and statistical modeling to enhance the mechanical and time-dependent behavior of 3D-printed polymers. The findings contribute to the development of design guidelines for optimizing infill geometry, material selection, and accelerated testing protocols, supporting the implementation of 3D-printed structures in load-bearing and long-duration engineering applications.