MECHANICAL CHARACTERIZATION OF THERMOPLASTIC COMPOSITES FOR 3D-PRINTED COASTAL STRUCTURES

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MOTIVATION

Coastal engineering has been fundamentally constrained by the material and fabrication limitations of traditional construction methods. Coastal protection structures—breakwaters, seawalls, groins, and artificial reefs—have predominantly relied on large concrete placement, quarried rock armoring, geotextile bags, and steel sheet piling. These traditional approaches and materials are cost prohibitive, difficult to install and remove, and restrict geometric complexity. Additionally, the mass and permanence of traditional structures prohibit iterative design and limit the development of short-term structures such as flood barriers or artificial reefs.

Additive manufacturing (AM) methods and materials have advanced significantly in recent decades, spanning multiple scales from desktop-scale fused deposition modeling to large-format systems (Saleh Alghamdi et. al., 2021). At the component scale, AM of conventional thermoplastics has been demonstrated in oceanographic applications such as underwater robotic components and biological replicas (Mohammed, 2016). At construction scale, Large Format Additive Manufacturing (LFAM) using concrete or ceramics has been employed to fabricate artificial reef structures for marine ecosystem restoration (Yoris-Nobile et. al., 2023).

Potential applications of LFAM with thermoplastics in the coastal environment remain largely unexplored. LFAM with thermoplastics faces two primary limitations for coastal applications: degradation of mechanical properties (e.g., Chaudhary et al., 2023) and environmental impacts of long-term deployments (e.g., Gewert et al., 2015). However, emerging LFAM materials show particular promise for short-term coastal structure applications. Dahltram T-100GF, a glass fiber-filled recycled PETG (Polyethylene Terephthalate Glycol) thermoplastic engineered by Airtech 3D, is available in pellet form specifically designed for LFAM. This material offers tensile strengths exceeding 70 MPa and flexural strengths exceeding 100 MPa, making it potentially viable for designing lightweight, modular, topology-optimized short-term coastal structures (Figure 1).

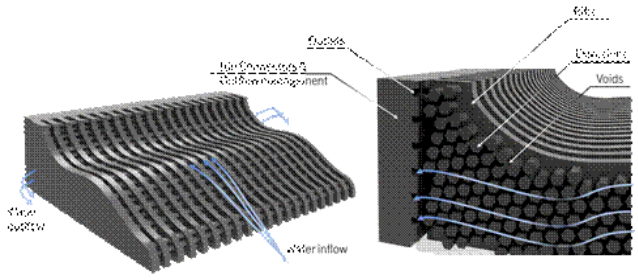


Figure 1 – Conceptual schematic of a modular coastal resilience structure.

OBJECTIVES

This study will detail the manufacturing process and quantify the mechanical properties of Dahltram T-100GF and similar materials as fabricated by an in-house LFAM system, with a discussion of efficacy for coastal applications subject to realistic wave loading and environmental conditions. The primary goal of mechanical testing will be to assess whether environmental aging degrades material properties by directly comparing specimens tested with and without environmental exposure. The results of the data analysis will be used to inform numerical finite element models that simulate the mechanical behavior of 3D-printed thermoplastic composite structures deployed in coastal environments.

MANUFACTURING SYSTEM

This research utilizes the Structural Waves Engineering and Learning Laboratory (SWELL), housed in Jacobs School of Engineering at UC San Diego (Figure 2). SWELL is equipped for hybrid additive (i.e., 3D printing) and subtractive (i.e., milling) manufacturing, allowing for fabrication of complex, topology optimized structures. SWELL is built around a 6-axis KUKA KR 210 R3300 robotic arm, mounted on a linear rail, providing 7 degrees of freedom over a 4x2.5x3 (length x width x height) meter build volume. The system's hybrid functionality allows automatic change of tool between a CEAD S-25 extruder for additive manufacturing using pelletized material fed from a 200L dryer, and an HSD ES951 electromechanical spindle for subtractive manufacturing and surface finishing. Print monitoring is achieved via two primary sensor systems mounted on the robotic arm. An LMI laser scanner captures high-resolution 3D geometry of deposited layers to assess dimensional accuracy and layer adhesion. Dual Optris Xi410 Infrared Cameras monitor thermal profiles from multiple fields of view during deposition, enabling analysis of cooling rates and thermal gradients.

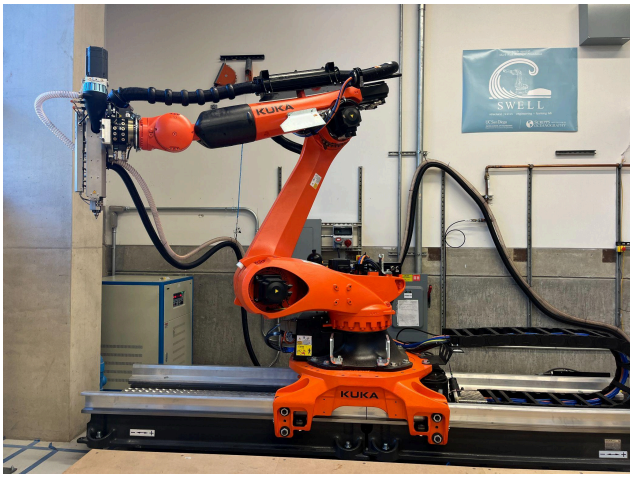


Figure 2 – Structural Waves Engineering and Learning Laboratory (SWELL).

MECHANICAL AND ENVIRONMENTAL TESTING

Test specimens will be fabricated using the SWELL LFAM system with variation of key manufacturing parameters (e.g., Solomon et. al., 2021) including extrusion temperature, rate of deposition, and bead diameter (Figure 3a). Test specimens will undergo coastal environment exposure including continuous saltwater immersion and UV radiation to quantify effects on mechanical properties (e.g., Amza et. al., 2021). This conditioning of test specimens will be performed at the Scripps Institution of Oceanography research pier, where in-situ sensors will provide measurements of seawater temperature, salinity, and UV radiation levels. Exposure duration will mimic typical deployment durations for short-term (7-14 days), seasonal (1-3 months), and potentially longer-term structures (>6 months). Mechanical tests will include coupon tensile testing per ASTM D638, three-point bending tests per ASTM D790, and plate bearing testing per ASTM D953.

Coupon tensile testing will include specimens oriented 0°, 45° and 90° relative to print direction (Figure 3b). Tensile coupons and bearing plates will be painted with a speckle pattern for feature recognition (Figure 3c) and utilize a Digital Image Correlation (DIC) system to provide full-field displacement and strain measurements, and assess failure mechanisms (e.g., Chen et. al., 2025). Tensile and plate bearing tests will be performed using an MTS 810 Material Test System (Figure 3d), while flexural tests will additionally utilize a 3-point bending fixture. Tensile and plate bearing tests will include variation of layer height, interlayer time, deposition rate, and deposition temperature to assess their effects on mechanical properties. Flexural tests will include effects of layer height and interlayer time only.

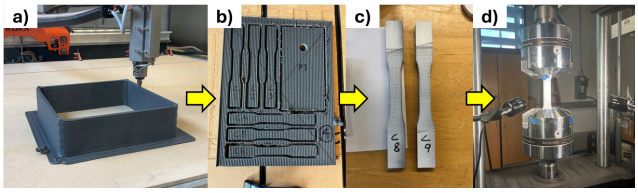


Figure 3 – Material testing workflow: a) Controlled manufacturing in SWELL; b) Milled tensile coupons (0° and 90°) and bearing plate; c) Tensile coupon surface finishing and preparation for DIC system; d) Tensile coupon testing using MTS Universal Testing Machine.

DATA ANALYSIS

Relationships between manufacturing parameters, environmental exposure, and key mechanical properties (i.e., yield strength, ultimate tensile strength, Young's modulus, Poisson's ratio) will be evaluated and reported. Additionally, material properties will be compared to other conventional materials utilized in coastal structures. These results will be used to inform numerical finite element models that simulate the mechanical behavior of 3D-printed thermoplastic composite structures deployed in coastal environments. Recommended manufacturing parameters and potential use cases of glass fiber-filled LFAM thermoplastics in the coastal environment will be discussed.

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