Tensile strengths of polyamide based 3D printed polymers in liquid nitrogen

M3PoB

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MOTIVATION

3D printing offers a new method of manufacturing thermoset and thermoplastic polymers. Deviations from well-known bulk material properties caused by this new method have yet to be extensively characterized at cryogenic temperatures, preventing adoption by the cryogenic industry. Polymers offer an alternative to conventional metal components due to, lower thermal conductivity, density, and cost - ideal for lightweight insulating designs at a variety of temperatures. In many cases, bulk strength of these polymers increases as temperature drops to cryogenic levels further improving their usefulness.

However, very little material property information is available for 3D-printed materials at low cryogenic temperatures. Material, printing method, and print orientation contribute significantly to strength properties of printed plastics and are examined in this study. Strength of printed specimens is dependent on material and print orientation and ultimately dictate the overall performance of a printed design. Two primary directions were studied: (1) x-y plane and (2) z-plane. We anticipated that the anisotropic properties are significant in determining how materials react to loads at low temperatures.

MATERIALS

We examined primarily polyamide (nylon) based plastics and one polyetherimide (ULTEM) to assess differences in selective laser sintering (SLS) and fused deposition modeling (FDM). Stratasys Ltd. provided tensile specimens of FDM-printed Nylon-12 and ULTEM. Paramount Industries provided SLS-printed Duraform EX, Duraform HST, Duraform PA, carbon-glass reinforced nylon-12, and nylon-11. Ten specimens, five in the x-y orientation and five in the z orientation were tested for each material.

METHODS

Samples were prepared and Omega strain gauges were attached using cyanoacrylate according to ASTM D638. A type I quarter bridge was used to estimate strain from the ratio of measured to excitation voltage. Elastic modulus was determined from the slope of the stress vs strain relationship where stress was determined from the applied load and cross-sectional area of the specimen.

Specimens were mounted in 350 mL disposable cups prior to testing. Slits made for mounting were sealed using Devcon 5-minute epoxy. In order to prevent yielding at the tabbed regions, a funnel system was rigged to provide a constant stream of liquid nitrogen (LN2) at both the top and bottom tabs (Figure 1). Tensile test measurements were conducted using a 1,000 lb. Instron load frame at a constant-crosshead speed of 2.0 cm/s. LN2 was added until thermal stress reached steady state then the specimens were axially loaded while LN2 was continually added until failure to keep the specimen at a 77K.

FIGURE 1. Specimen mounted in load frame. Note tubing that directs liquid nitrogen to upper and lower tabs to ensure uniform mechanical properties of material.

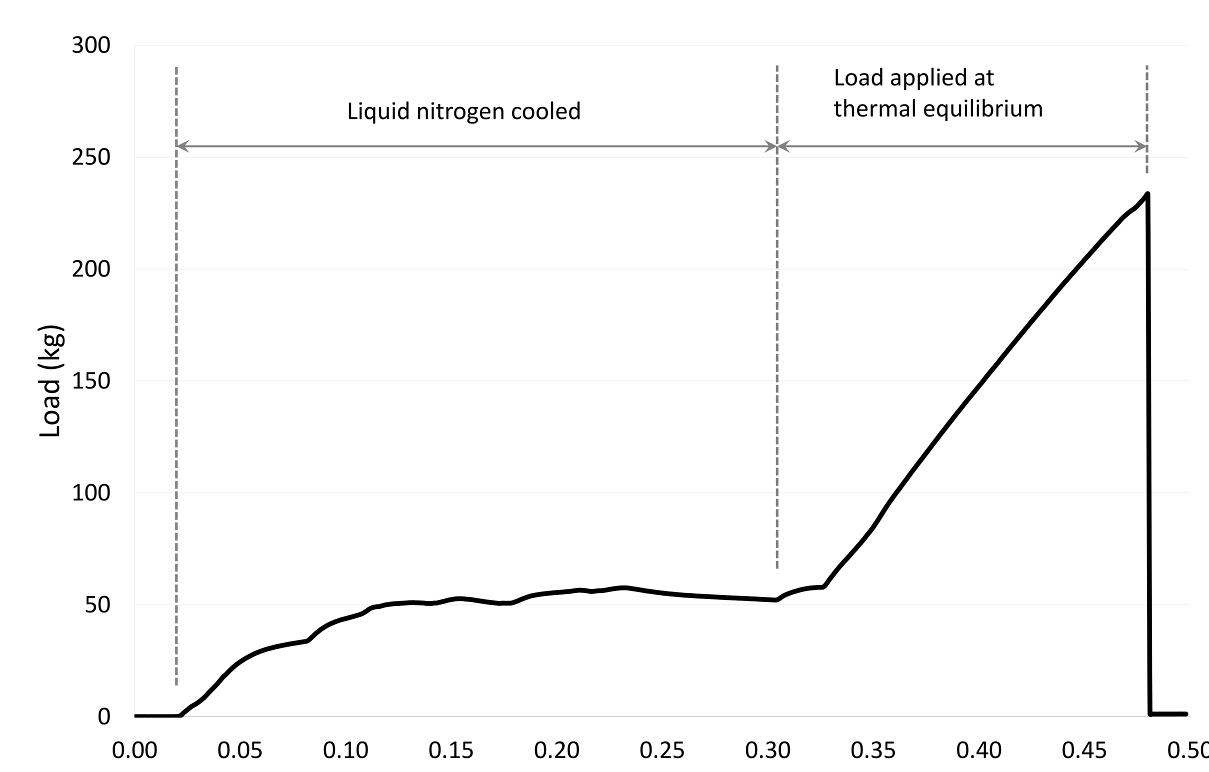

FIGURE 2. Sample is cooled with liquid nitrogen and load applied after measured load from thermal contraction has stabilized.

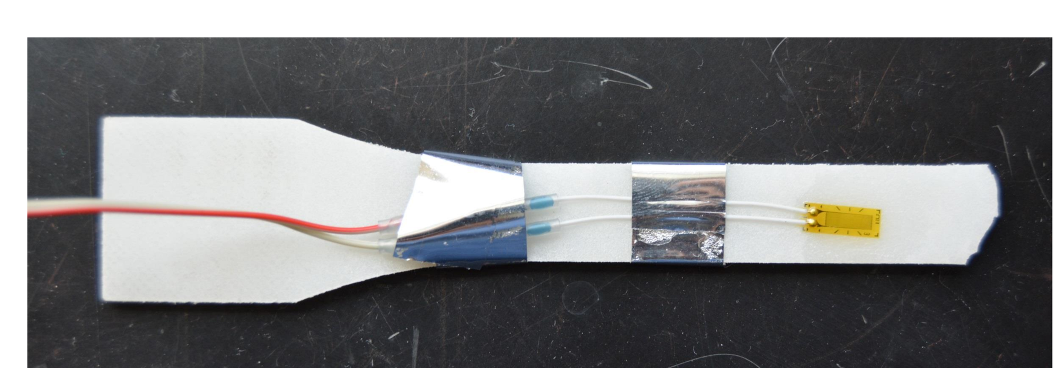

FIGURE 3. Typical strain gauge setup on tensile sample. Duraform EX shown after failure.

RESULTS

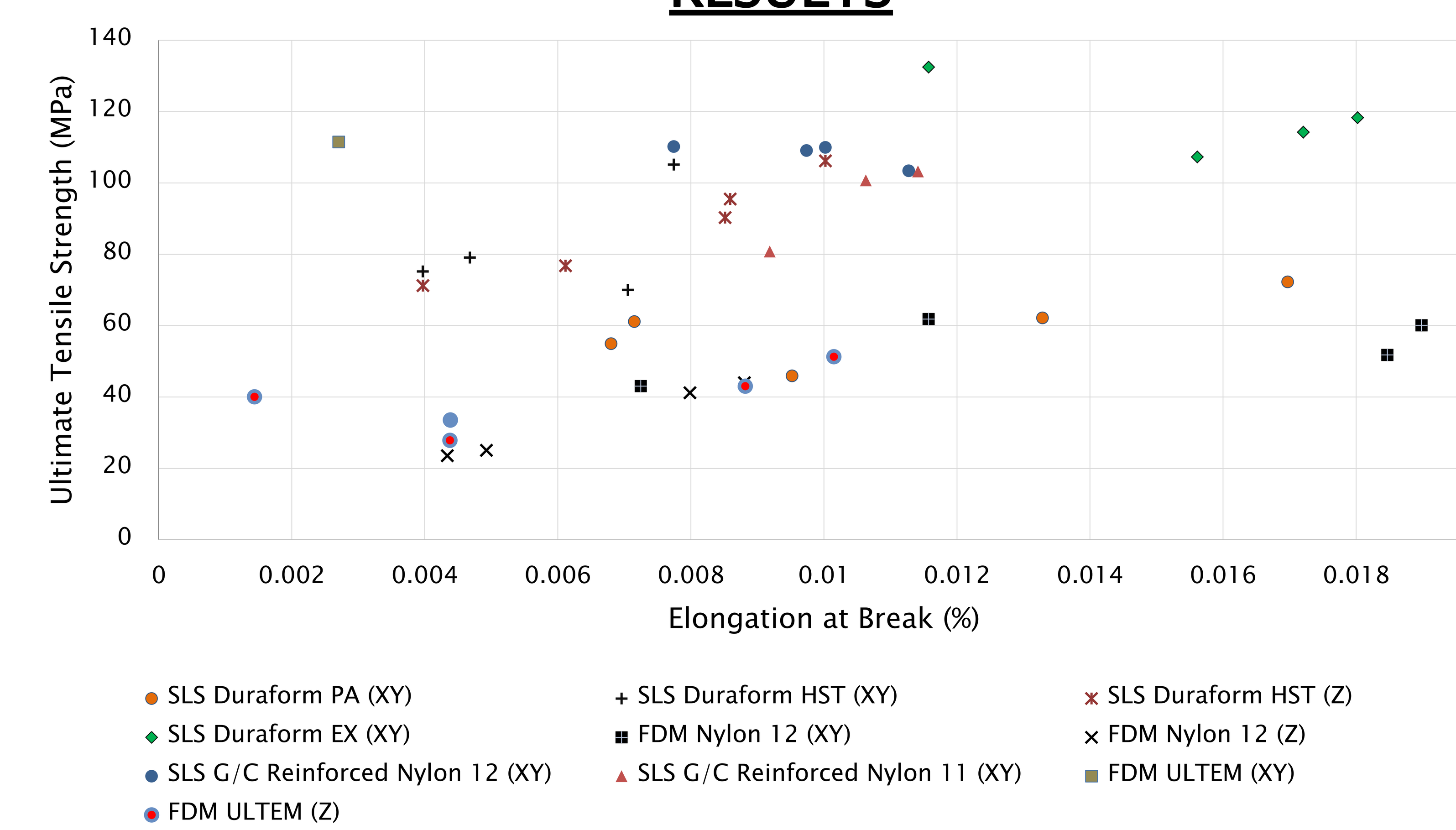

FIGURE 4. Distribution of ultimate tensile stress for 3D printed plastics at 77 K.

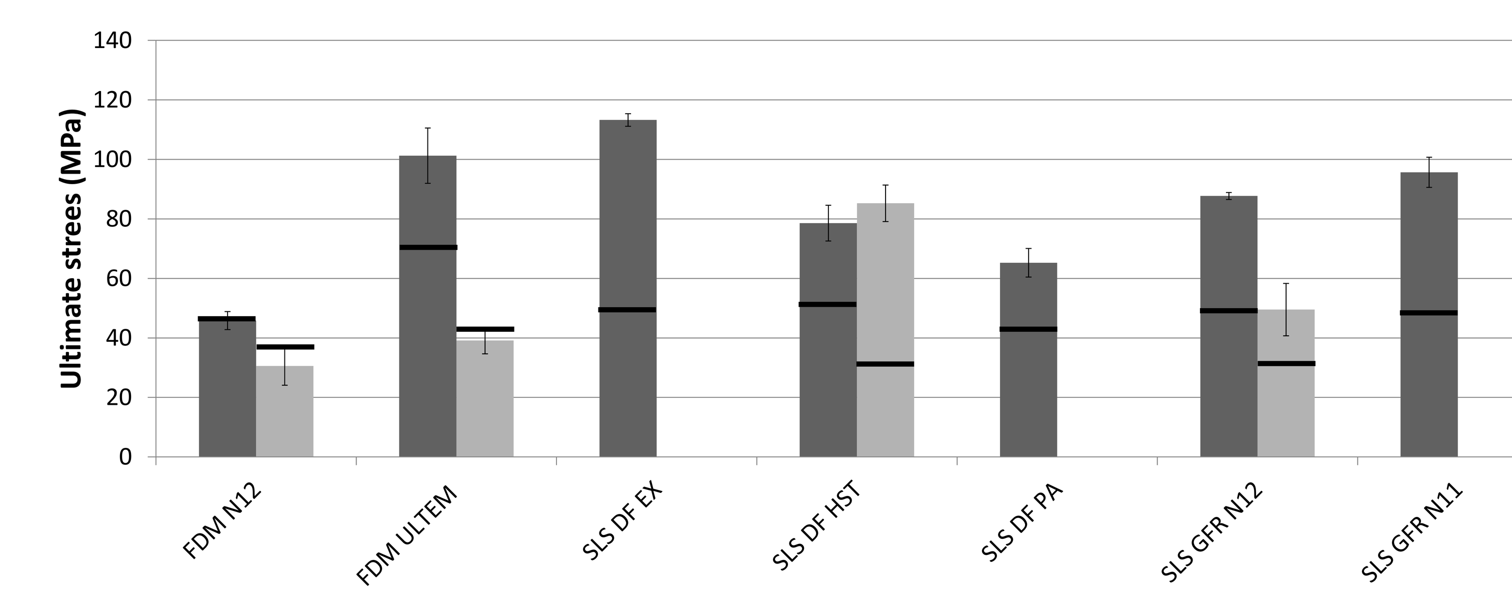

FIGURE 5. Average ultimate stress for XY and Z print directions at 77 K. Black horizontal bars represent manufacturers room temp values.

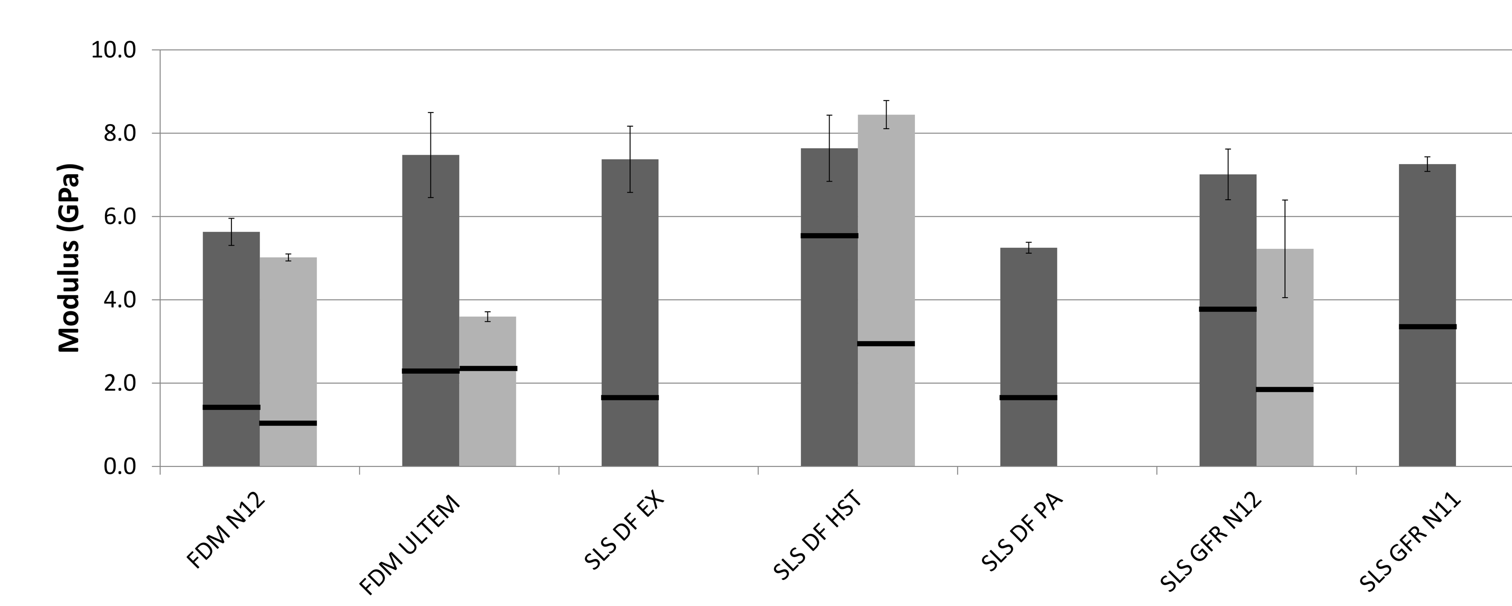

FIGURE 6. Average modulus for XY and Z print directions at 77 K. Black horizontal bars represent manufacturers room temp values.

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HYdrogen Properties for Energy Research

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