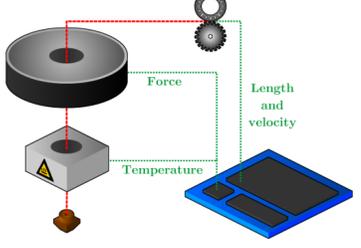


Effect of Rotational Nozzle on Material Extrusion and Deposition

EQUIPMENTS AND METHODOLOGY

Sensor Equipped System



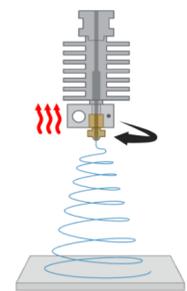
- Real time force, filament speed and nozzle temperature measurement and visualization.
- Stepper motor driving and controlling system to provide up to 4000rpm torque.

Nozzle Driven and Control

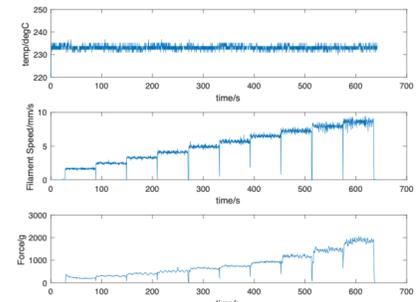


Open Air Extrusion

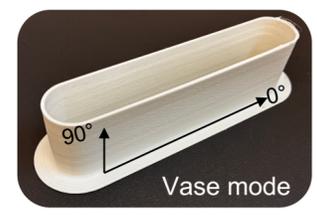
- An open-air extrusion experiments at 235°C with step-wise increasing flow rate for processing window determination.
- Flow rate: 4-22 mm³/s
- Nozzle rotational speed: 0-2000 rpm



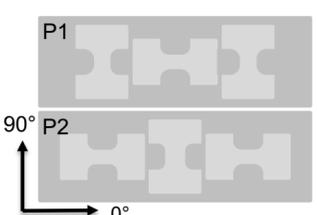
In-line Data Acquisition



Single Wall Model



Specimen Preparation



Waterjet Cutting

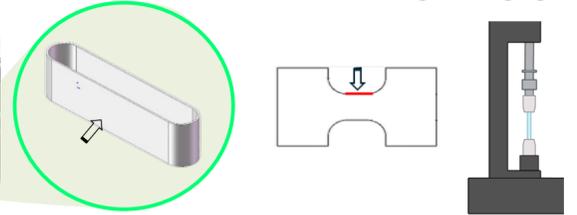


- Standing single-wall printing with vase mode for printing process and performance study.
- Two flat walls are used to water jet cut tensile bars along 90° and 0° directions.
- Flow rate: 8 and 16 mm³/s | Nozzle rotational speed: 0-1500 rpm

High-Speed Monitoring



Tensile Testing & Imaging



- In-situ monitoring deposition process by high-speed camera from the side view.
- Cross-section of tensile bar and top surface pattern of two-layer samples imaging.
- Tensile testing to measure inter-layer bonding and bead strength.

Zijie Liu, Tim Osswald, Allen Roman

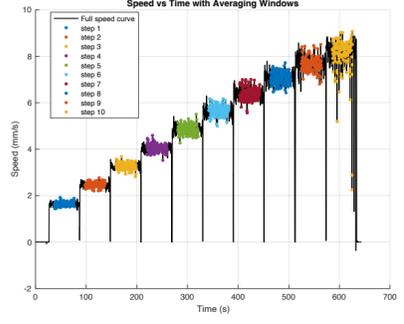
Polymer Engineering Center,
University of Wisconsin, Madison, WI, USA

OVERVIEW

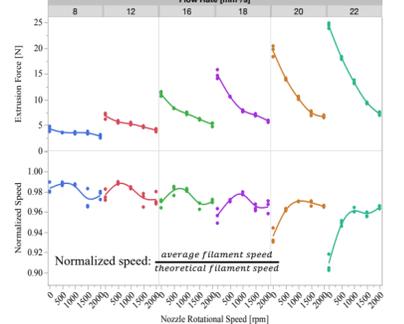
- Quantify and compare extrusion mechanics by measuring extrusion force and filament feed speed during both open-air extrusion and actual deposition.
- Evaluate the effects of nozzle rotation on longitudinal strength and interlayer bonding by comparing the tensile strengths of specimens cut parallel and perpendicular to deposition direction from standing single-wall printed structures.
- Assess dominant failure modes and correlate these features with printing conditions through optical microscopy imaging of tensile specimen neck cross sections.
- Elucidate deposition and rotation dynamics using high-speed, in-situ imaging to directly observe filament formation, bead morphology, and periodic deposition behavior.

RESULTS

Data Postprocessing

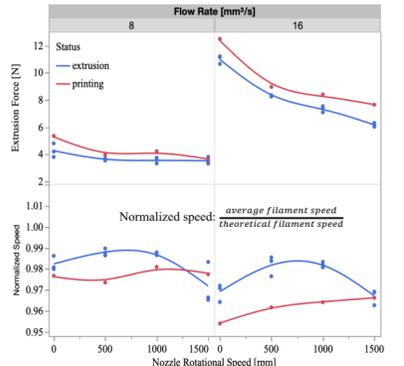


Extrusion force and speed

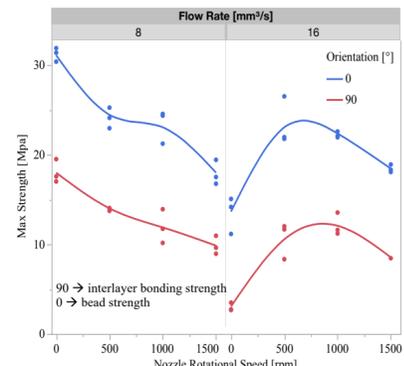


- Data (highlighted) used for average speed/force ignored the first and the last 10s.
- With nozzle spinning, the larger the flow rate, more significant drop of force.

Extrusion v.s. Printing



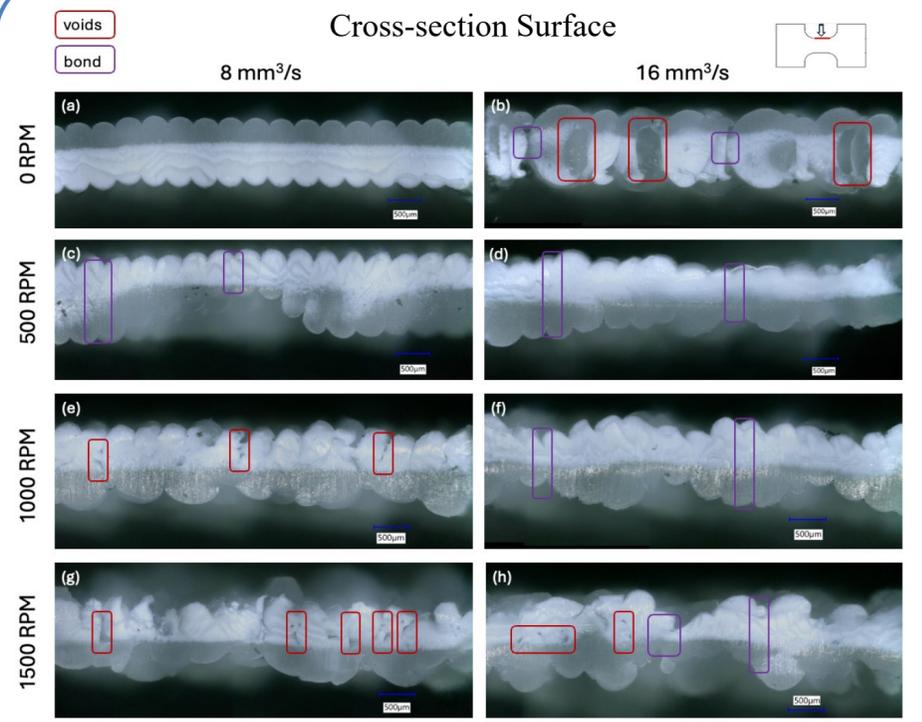
Tensile strength



- Deposition requires higher force but ends up higher under-extrusion than extrusion. Intimate contact pressure caused by limited space between nozzle and substrate.
- Across flow rates, rotational speed affects 0° and 90° samples differently:
At low flow rates, higher rpm reduces strength
At high flow rates, strength first increases with rpm and then decreases.

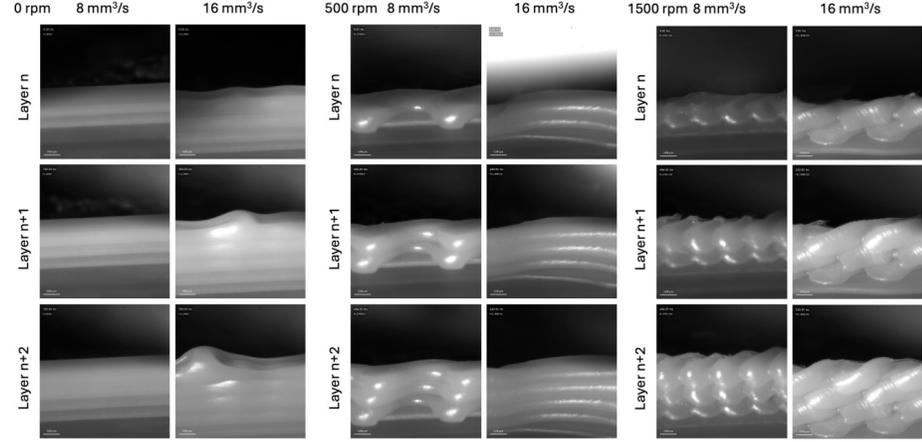
IMAGING

Cross-section Surface

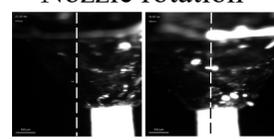


- Under 0 rpm 16 mm³/s, voids and inconsistent bond width attributes to under extrusion.
- Under 8 mm³/s flow rate, 500 rpm leads to bond width variations, 1000 rpm and 1500 rpm cause more interlayer voids → lower interlayer bond strength.
- Under 16mm³/s flow rate, nozzle rotation leads to less voids, but the bond width variation still exists.

Side Surface



Nozzle rotation



- For low flow rate:
Eccentric rotation → curved beads → various bond width
High rotational speed + discontinuous bead → lower strength
- For high flow rate:
high shear rate → lower viscosity → lower under-extrusion
→ better interlayer bonding at low rpm