Fused Deposition Manufacturing of Multiple Materials (FD3M)

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This research seeks to increase the capability of the fused deposition modeling (FDM) process by enabling dynamic coextrusion of multiple materials. The research investigated a hot end including a multilayer manifold and rotating valve pin with the objective to enable dynamic blending of multiple materials (e.g. varying electrical or mechanical properties and gradients in part printing) as well as in-line coextrusion of the deposited roads (e.g. conductive wires for electrical circuits or hollow flexible tubes for pneumatic actuators). The research was highly productive including several design iterations, heat and flow simulations, and experimental verification to a technology readiness level of 3 (proof of concept). Significant advances were made in (1) design for additive manufacturing of components with internal flow channels and insulating members, (2) thermal isolation of hot end sections, and (3) control system development including concurrent control of multiple extruders. The hot end concept design was fundamentally sound design but found to be limited by the minimum resolution supported by production technologies as well as the relatively low flow rates of the FDM process. Critical design decisions were made to enable the performance of the research including the switch to a single sided valve pin and the opening of flow channels to 3 mm in order to ensure robust production of the procured manifold and valve pins. The thermal isolation of both the R0.4 and R0.6 designs was excellent. Coaxial and tri-clover designs were proven to be feasible, though a lack of concentricity was observed due to the lack of axisymmetric flow in the shell material provided by the lower manifold layer. Performance limitations of the system were also identified related to the temperature control in the extruder adaptors as well as the drive limitations of the extruders themselves. With the knowledge gained, new hot end designs were developed based on a spiral flow manifold design that is less than a quarter the size of the original manifold design.

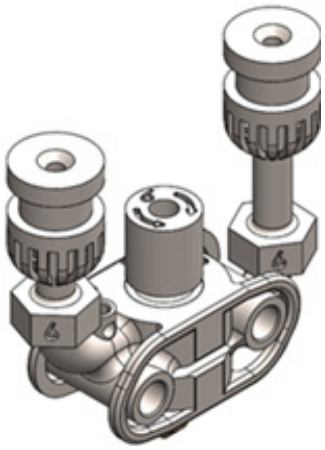
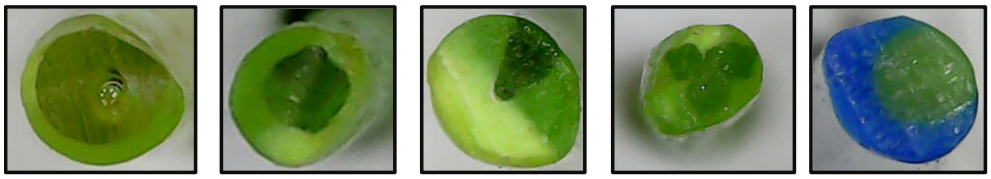


Figure 1: Hot end with valve. Materials admitted through the left and right ports are selectively admitted to the nozzle via valve ports designed similar to a hydraulic proportional valve.



(a) Co-Ex: 25% ABS: 230°C 75% PC: 240°C

(b) Co–EX: 50% ABS: 230°C 50% PC: 240°C

(c) Co-Ex: 75% ABS: 230°C 25% PC: 240°C

(d) Tri-Clover: 50% ABS: 230°C 50% PC: 240°C

(e) Co–EX: 50% TPE: 230°C 50% PA6: 250°C

Figure 2: Extruded samples from FD3M system of Figure 1