Optimal Material and Topology Design of Fiber Reinforced Composite Structures and their Direct-Ink Write Fabrication Process

Felipe Fernandez[†‡], **W. Scott Compel**[‡], **James P. Lewicki**[‡], **Daniel A. Tortorelli**[*†‡]

[†] Department of Mechanical Science and Engineering
University of Illinois at Urbana-Champaign, IL, USA
e-mail: dtortore@illinois.edu

[‡] Lawrence Livermore National Laboratory, Livermore, CA, USA
e-mail: tortorelli2@llnl.gov

ABSTRACT

In a previous work [1, 2], we demonstrated a practical method for the optimization of fiber reinforced composite structures fabricated via 3D printing. The particular printing process is direct ink writing in which discontinuous carbon fibers in an epoxy resin are extruded through a moving nozzle to build up a structure. Since the fibers are primarily aligned in the flow direction, the printing trajectory influences the structural properties of the composite structure layer-by-layer. To accommodate this process in our design/fabrication optimization, 1) the toolpaths of each layer were defined by contours of a level-set function, 2) manufacturing constraints and the material model were defined in terms of the level-set function and 3) the level-set function was optimized. Results were validated by fabricating and testing the optimized designs and comparing them to non optimized designs.

Our prior work was over a fixed topology and hence we did not fully exploit the design freedom afforded by additive manufacturing. Here, we incorporate topology optimization into our design paradigm. This is accomplished by adding a volume fraction field to our design space which is discretized by B-splines. This parameterization, which is independent of the finite element mesh, provides a precise description of the design's boundary and introduces a length-scale into the otherwise ill-posed topology optimization problem. We subsequently redefine our material model and manufacturing constraints with these two design fields, i.e. the level set and volume fraction. To ensure optimality and computational efficiency, we use nonlinear programming algorithms to traverse the design space. Gradients of the cost and constraint functions are computed via an adjoint sensitivity analysis. We ultimately obtain the toolpaths to produce our optimized designs, fabricate our designs and test them for validation purposes.

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REFERENCES

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[2] Y. Saito, F. Fernandez, D.A. Tortorelli, W.S. Compel, J.P. Lewicki, and J. Lambros (in press). *Experimental validation of an additively manufactured stiffness-optimized short-fiber reinforced composite clevis joint.* Experimental Mechanics Special Issue on "Mechanics of Additively Manufactured Materials".