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Topology Optimization of Anisotropic Components for Additive Manufacturing

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Although topology optimization (TO) and additive manufacturing (AM) have flourished independent of each other, there is significant interest today in integrating the two for several reasons: (1) designs stemming from TO are geometrically complex, and therefore hard to manufacture using traditional processes, but can often be additively manufactured. (2) the cost of fabricating parts through AM is proportional to the amount of material used, and material usage can often be reduced through TO, and (3) through TO and AM integration, one can potentially develop an automated pipeline from design concept to fabrication.

While these and other characteristics make TO and AM ideally suited for each other, there are several challenges that must be addressed. Material anisotropy and weakness along build direction, especially in AM processes such fused deposition modeling (FDM), is one such weakness. Material anisotropy is often neglected during TO, and the optimized designs will not perform as expected.

Material anisotropy manifests itself in two forms: (1) anisotropic constitutive properties that relate stresses and strains, and (2) anisotropic strengths that relate to the failure of the part. The focus of this talk is on the latter, i.e., anisotropic strength.

In TO, recall that for *isotropic* materials, the von Mises stress is often used as the failure criteria. This criteria is invalid for anisotropic materials, instead the Tsai-Wu stress criteria is proposed. Appropriate sensitivity analysis using Tsai-Wu stress criteria will be discussed, and a simple TO algorithm will be proposed for optimizing components with anisotropic strengths.

As a specific example, we will consider the strength summarized in Table 1 [2]. Observe that the strength along the build direction (Z) is 30% smaller than the strengths in the X and Y directions.

Table 1: Material strengths

Material	Xc (MPa)	Yc (MPa)	Zc (MPa)	Xt (MPa)	Yt (MPa)	Zt (MPa)	Syz (MPa)	Szx (MPa)	Sxy (MPa)
ABS (FDM)	38	38	35	29.62	29.62	19.80	10	10	10

To demonstrate the impact of the stress criteria, consider the C-bracket problem in Figure 1; the domain is discretized into 20,000 hexahedral elements. The objective is to find the strongest design while removing 50% of the material. Figure 1b illustrates the optimized topology using *isotropic* von *Mises criteria* with an yield strength of 25 MPa, while Figure 1c illustrates the optimized topology using the Tsai Wu criteria using the relative directional strengths summarized in Table 1.

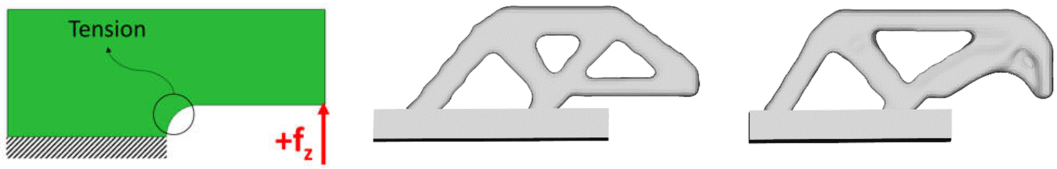

Figure 1: (a) Geometry and loading, (b) optimized using von Mises criteria, (c) optimized using Tsai-Wu criteria.

Four samples of each of the optimized designs was printed on an XYZ FDM printer with the same printing parameters. Then, a custom fixture was designed to carry out failure tests. Figure 2a illustrates the test setup, and Figure 2b illustrates the experimental results. As one can observe the part optimized using von Mises criteria fails much earlier than the one optimized using Tsai-Wu criteria. This suggests the importance of using the appropriate stress criteria for anisotropic materials. Future work will focus on other aspects such as de-bonding or brittle failure.

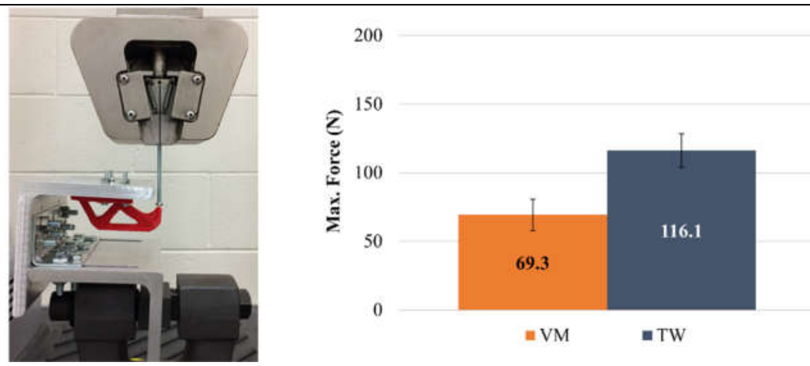

Figure 2: C-Bracket experimental set-up and results.

References

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[2] Sung Hoon Ahn, Changil Baek, Sunyoung Lee, and In Shup Ahn, "Anisotropic Tensile Failure Model of Rapid Prototyping Parts - Fused Deposition Modeling (FDM)," Int. J. Mod. Phys. B, vol. 17, no. 08n09, pp. 1510–1516, Apr. 2003.