MULTI-MATERIAL COMPONENT OPTIMIZATION VIA HYBRID MANUFACTURING

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The timely fabrication of large, complex metallic structures is a persistent challenge for America's industrial base. Delivery schedules for large parts, i.e one to two feet cube and larger, are routinely defined in months and years; introducing unacceptable risk and cost for most products. On-going work is addressing these challenges through the development of a large-scale hybrid metal manufacturing system, Figure 1, which combines multi-material metal inert gas (MIG) deposition, fringe projection metrology, part handling and five-axis machining. MIG deposition is performed using a Fronius dual-wire cold metal transfer (CMT) welding head mounted to a Kuka KR50 six-axis robotic manipulator with 2.5m reach. Metrology of parts is performed using a GOM ATOS-Q 8M with a fixed focal lens configuration providing a 350mmx260mm field of view and a nominal image resolution of 100μm. The part is moved between the deposition and metrology stations using a Kuka KP2-HV rotary-tilt stage mounted onto a Kuka KL4000 linear stage. Parts are moved from the rotary-tilt-linear positioner into a Haas UMC 750 five-axis machining center using a Kuka KR250 robot with 2.7m reach.

The resulting hybrid manufacturing cycle introduces design opportunities for complex, multi-material part topographies that provide improved throughput, accuracy and performance over conventional components. Current work is exploring the design space for large, high aspect ratio part geometries using first principles and Sandia National Laboratories' Plato Analyze topology optimization (TO) software platform,

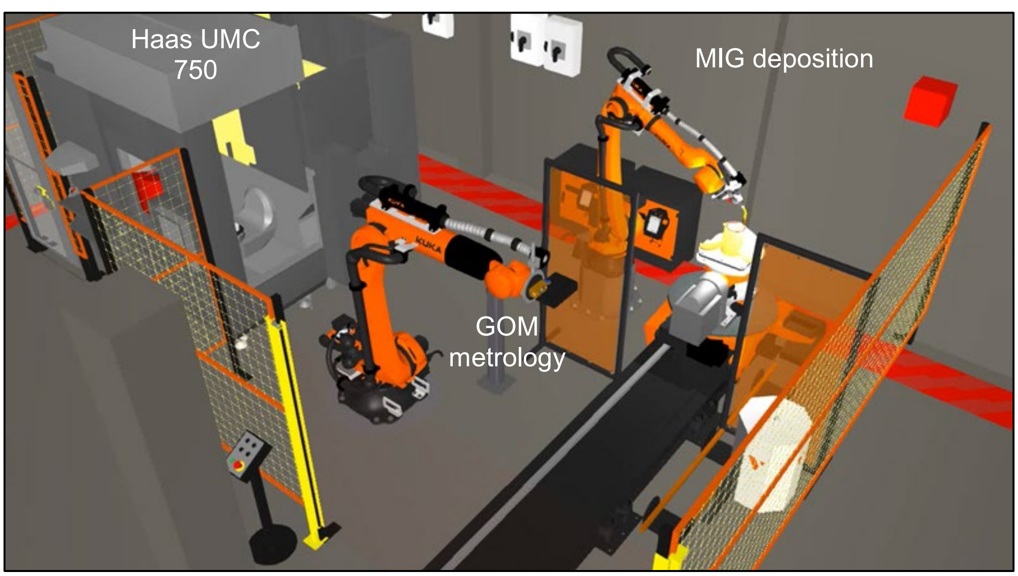

Figure 1. Large-scale hybrid manufacturing cell integrating wire-arc deposition, fringe projection metrology and five-axis machining.

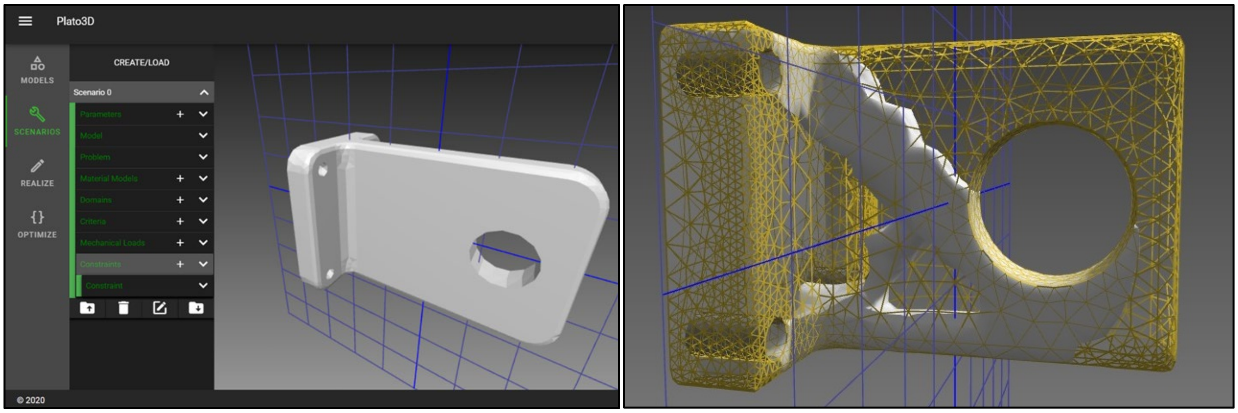

Figure 2. Sandia's Plato Analyze GUI interface and design volume (left) with resulting optimized bracket geometry (right).

Figure 2. Plato is a powerful and flexible research platform that has facilitated direct collaboration with developers exploring new optimization capabilities pertinent to large-scale structures and complex operating environments.

Initial work is using compliance minimization to reduce material use and fabrication time for large structures under load. The design process starts with a solid model representation, ex. Solid Works, that is converted into a tetrahedron mesh saved as an Exodus file using Coreform Cubit. Meshing is a critical step as element size directly influences the accuracy and fidelity of the optimization, as well as the number of computation cycles required to perform the optimization. Design analyses are constrained to elastic material response, so that elastic modulus and Poisson's ratio are the only required material inputs. Stainless steel was utilized as the material exemplar for the optimization presented herein.

Design intent is focused on high-aspect ratio geometries that combine solid, exterior thin-walls with complex internal structures. The objective is to design structures printed with a nominally constant exterior wall thickness. The dual-wire capabilities of the Fronius CMT head then facilitates the fabrication of interior structures that leverage a different material and/or a different wire diameter for finer resolution features. This wall / core configuration is relatively simple to construct in Cubit. In Plato, optimizations are then performed establishing the wall geometry as a fixed material block, while optimization is performed using only the core volume, Figure 3. Load constraints involve fixing displacements on one end and a uniform 30MPa pressure load applied downward to the top surface, Figure 4.

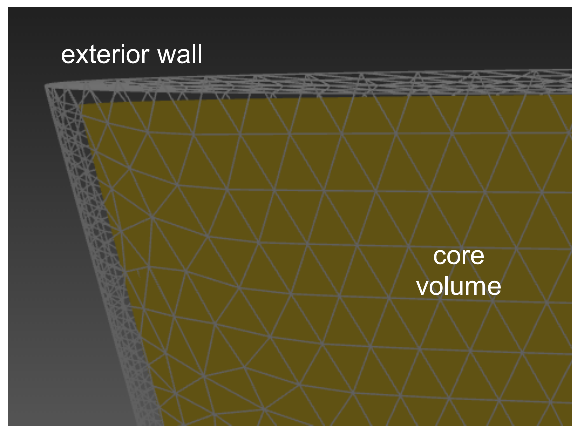

Figure 3. Plato design optimization representations showing the fixed, external wall (transparent mesh) and the internal core volume (yellow mesh volumes).

Since mesh resolution is critical in resolving feature geometries, the average voxel size generated in Cubit was roughly 170µm, producing a model with approximately 2.15 million mesh elements. The core volume represented 95% of original total, so that the sold wall represented 5% of the original total volume. During optimization, the core volume was then constrained to be 50% of its original volume, or 47.5% of total original structure.

Figure 5 shows the resulting optimized geometry. From a simple cantilever beam-bending model, stresses are highest near the fixed displacement constraint and the exterior surfaces. Accordingly, Plato located solid material at the fixed root of the geometry. Intuitively, ribbed structures were also formed along the length of the interior core, perpendicular to the load direction.

Initial design boundaries were not informed by

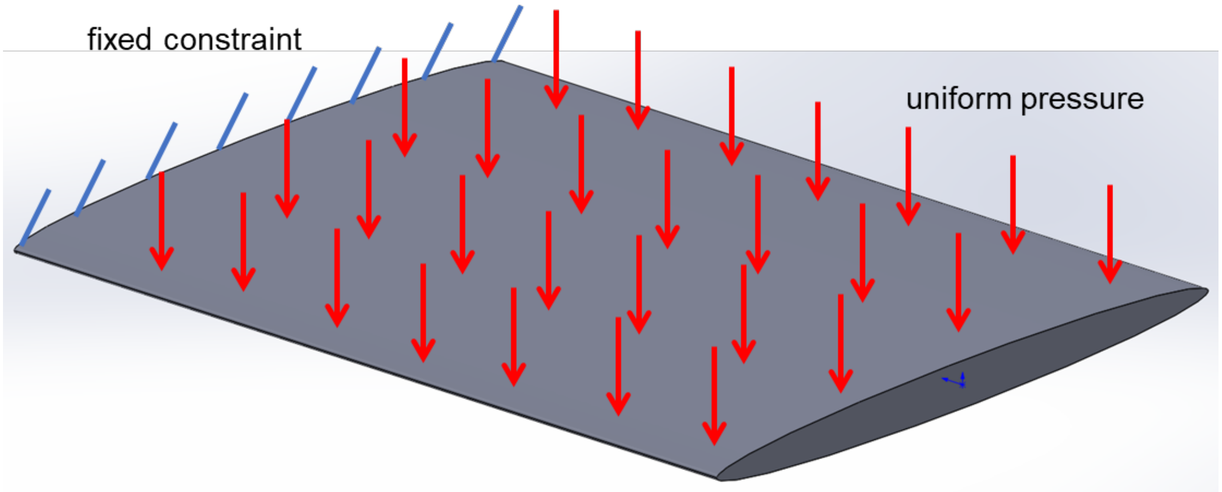

Figure 4. Geometry and load conditions for a simple, 120mm wide, 140mm long and 8mm thick ellipsoid.

Figure 5. Resulting optimized geometry for the ellipsoid, looking down on the loaded face. The fixed displacement constraints of the geometry are represented on the left end.

manufacturing constraints as one intent of the work is to quantify manufacturing research opportunities and needs. Design concepts are intended for demonstration, however, using the new large-scale hybrid metal manufacturing system. Realized part constructions will be informed and constrained by the hybrid manufacturing system's capabilities. Feature resolution, build angle and material interfaces are commonly limited in additive manufacturing, and will be considered in on-going work. The overlap of desired design topographies and manufacturing capabilities remains indeterminant, but will be quantified during prototype fabrication cycles. Future work will also examine the use of Pareto curves to balance design stiffness and maximum principal stresses to generate mass minimized designs. Further, different load scenarios will be performed using point and non-uniform distributed loads on top and bottom surfaces.

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