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Assembled Composite Lattice Structures: Towards Ideal Performance in Large-Scale Applications

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Architected lattice materials exhibit ultra-light density with strength and stiffness on the order of common engineered solid materials. These lattice materials are appealing for thermal, chemical, and electrical applications due to high-surface area and low conductivity, and potentially extend the utility of engineered stochastic foams. Relatively high stiffness at ultra-light density makes them appealing for aerospace structural applications [1].

Accepted and useful theoretical tools for designing lattice architectures exist [2] [3], but recent work has highlighted how practical factors such as node geometry and manufacturing method can strongly influence continuum behavior [4]. Additionally, literature has demonstrated the potential of assembly methods for mass manufacturing of meso-scale lattice materials, leveraging highly controlled traditional manufacturing processes to achieve nearly ideal relative stiffness performance. Reversibly assembled uni-directional CFRP lattices [5] and snap-fit assembled CFRP octet [6] have shown linear stiffness scaling with relative density, matching or exceeding performance of state of the art ceramic micro-lattices [7]. Potentially extending the application domain reached by conventional micro-lattices, assembled lattices demonstrate additional benefits such as an unconstrained build-envelope, re-configurability, and discrete repairability for meso-scale applications.

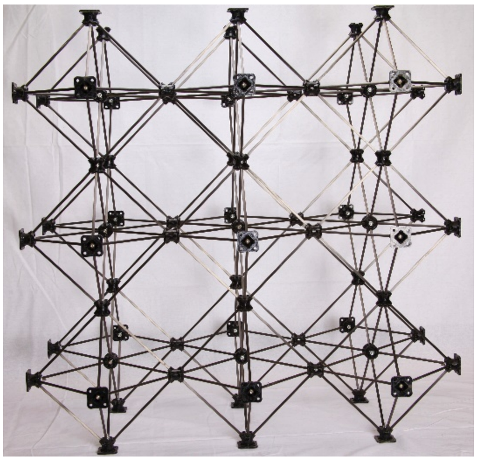

Figure 1. A 3x3x2 unit cell sample of the assembled pultruded carbon fiber lattice

Our work is presented in two parts. First, we show an ultra-light (5.1 mg/cc) cuboctahedral lattice (1.3% relative density)(Figure1) assembled from hollow, pultruded carbon fiber reinforced polymer rods (density=0.38 g/cc, modulus=18.3MPa), the stiffest ultra-light material currently published (16 MPa) (Figure 3). The pultruded struts had small load bearing bar bell ends adhered, then were fastened into octahedral volumetric pixel (“voxel”) units by mechanical assembly of nodes that captured the strut ends. These voxels were then fastened to each other with stainless steel bolts and nuts (Figure 2). Designed to be reversibly assembled for re-use in space structural missions, this lattice also demonstrates reconfigurability and outstanding packing efficiency, both high-value characteristics for space applications [8]. We compare the performance of this lattice to that which is predicted by theoretical frameworks [2] [3] and show how the node design, mass cost from assembly hardware, and strut manufacturing affects the achieved performance. A scaling limit for the mass cost for a given node design is derived to help formalize design trade-offs.

Second, we use this example, as well as evaluation of previous assembled lattice examples, to establish some best-practice design principles for assembled lattices, placing high value on manufacturability and the preservation of constituent material properties throughout manufacturing. Though assembly has the potential to effectively use a wide variety of high-quality constituent materials, we show how the node connection design, strut design, and the method of fabrication can govern how close a lattice gets to ideal behaviour as predicted by theoretical frameworks [2] [3].

Figure 2. Detail of the node connection

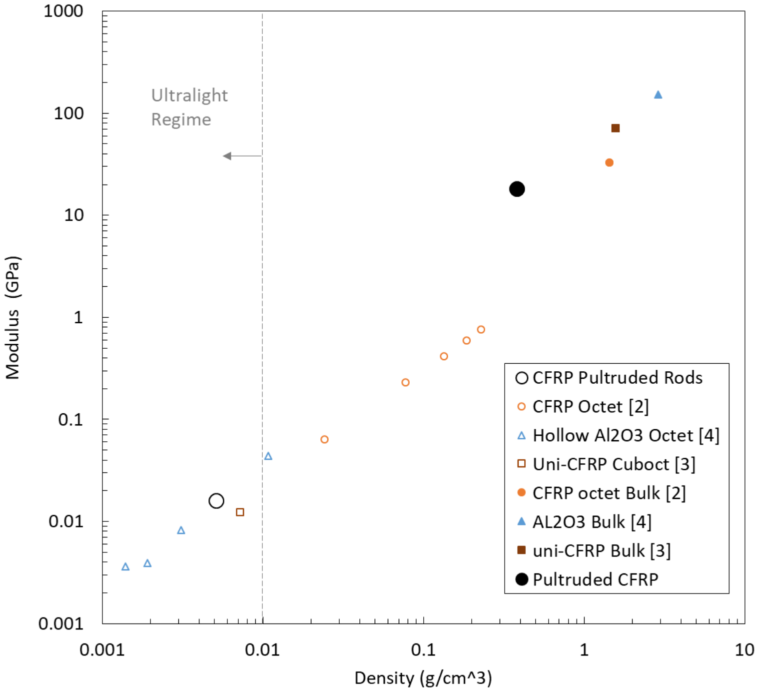

Figure 3. Ashby chart comparing published state of the art ultra-light lattices and assembled lattices

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