# FABRICATION AND CRUSHING BEHAVIOR OF HIGHLY VENTED HONEYCOMB STRUCTURES

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## Introduction

Honeycombs are cellular solids made from a collection of thin wall open prismatic cells nested together to fill a plane [1]. Exceptionally stiff and strong for their weight, they can also be multifunctional (do more than just support loads). Aerospace and other industries widely benefit from this form of construction [2]. When facing skins are attached to conventional honeycomb cores, the fabrication environment (e.g., humid air, VOC's, etc.) is trapped within. In space applications, release can contaminate sensitive equipment [2]. With time and exposure, the service environment can also be trapped (through ingress and diffusion). Aircraft control surfaces, helicopter rotor blades, etc., are all susceptible to moisture accumulation which adds weight, degrades adhesives, accelerates corrosion, steams/freezes, etc. [3]. Pressurize/depressurize and heat/cool cycles exacerbate the issue. Perforated, slotted, or drilled honeycombs are available [2] but most have limited fluid throughput, they cost more, and holes tend to concentrate stress.

## Truss Wall Honeycomb

Mechanical properties are influenced by base material, its distribution, imperfections, and defects. The most weight efficient structures favor structural hierarchy (elements/members which themselves have structure) [4]. Cancellous bone, fibrous composites, and the Eiffel tower are all hierarchical. When deformation is dominated by sub structure bending, neither relative stiffness nor strength benefit from hierarchy. However, when elements/members are favorably oriented (e.g., space truss), the first few levels of order (number of levels of scale with recognized structure) can yield dramatic strength to weight improvements (many short elements/members resist buckling better than a few long one's) as well as improved safety though redundancy. Although, specific stiffness remains largely unchanged. Hierarchical truss concepts can extend to highly vented honeycomb structures, Fig. 1, with added functionality (space for fuel storage, coolant flow, wiring, etc.).

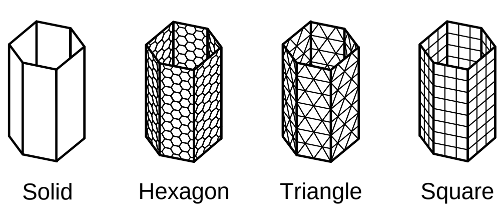


Figure 1. Solid wall and various truss wall honeycombs.

## Fabrication

Many porous sheet types, joining methods, and wall/cell geometries are possible. Plain square wire cloth (type 304 stainless steel) with 0.17 mm (0.0065 in) diameter wires and 11.8 mesh/cm (30 mesh/in) was bias cut, cleaned, and then lightly sprayed with a mix of -140 mesh Nicrobraz® 51 brazing filler metal (Ni-25Cr-10P) and Nicrobraz® Cement 520 (Wall Colmonoy, Madison Heights, MI). Strips were heated (ramp at $15^0$C/min; hold at $550^0$C for 1 hr with Ar purge to volatilize the cement; hold at $1100^0$C for 1 hr in vacuum to braze) in a Ti gettered vacuum furnace (6 in diameter quartz tube; diffusion pumping system with $LN_2$ trap; vacuum capability < $10^{-6}$ Torr). After cooling, strips were corrugated, sprayed, stacked, and brazed again. The test sample, Fig. 2, had 6.4 mm (0.25 in) cells, was 51.2 mm x 45.2 mm x 76.5 mm (thick) with 31.5 g mass (0.178 g/cm$^3$ or 11.1 pcf). With 7.9 g/cm$^3$ for type 304 stainless steel [5], relative density ~ 2.3%. Commercial expansion process honeycomb made from 0.064 mm (0.0025 in) aluminum alloy foil with 6.4 mm (0.25 in) cells offered comparison. The test sample was 54.9 mm x 43.0 mm x 76.3 mm (thick) with 12.9 g mass (0.0716 g/cm$^3$ or 4.5 pcf). With 2.7 g/cm$^3$ for aluminum alloys [5], relative density ~ 2.7%.

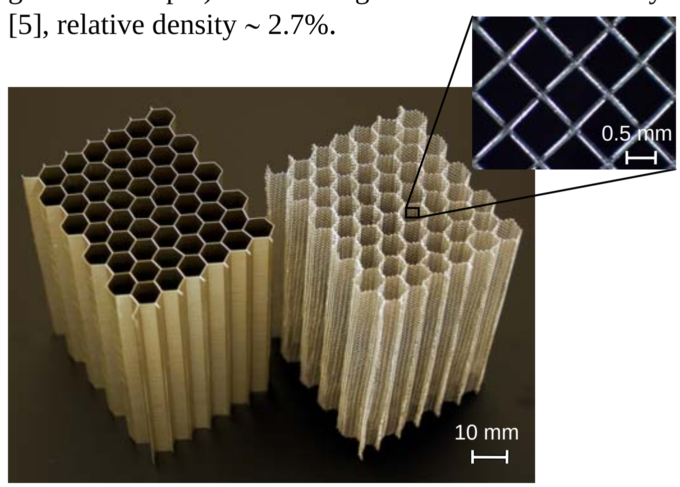


Figure 2. Solid wall (left) and truss wall (right) honeycomb test samples. Microscopic view of a porous truss wall (upper right).

## Crushing Behavior

An Instron (Norwood, MA) 8802 test system equipped with a ±25 kN load cell, flat compression platens, and FastTrack™ 8800 digital control/acquisition was used. Samples were pre-loaded to 45 N (ASTM D 7336/D 7336M - 07), then crushed at 5 mm/min. Photographs and load - actuator displacement (stress - strain), Figs. 3 and 4, were digitally recorded. Bare compressive strength for the solid wall honeycomb was 4.83 MPa at 0.57%, crush strength was ~1.7 MPa, and absorbed energy at 75% stroke was 1.30 J/cm$^3$ or 18.2 J/g. For the truss wall honeycomb, the values were 1.20 MPa at 4.21%, ~1.1 MPa, and 0.84 J/cm$^3$ or 4.7 J/g.

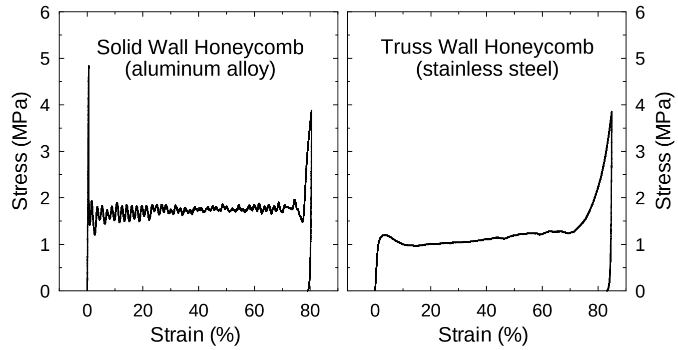


Figure 4. Stress-strain behavior for crushed solid wall (left) and truss wall (right) honeycombs.

## Discussion

Plastic buckling collapse stress scales with parent alloy yield strength [1]. Annealed type 304 stainless steel yields at 205 MPa [5] which is somewhat less than extra hard honeycomb foils like 5052-H39 or 5056-H39 (e.g., reported values for the H38 temper are 255 MPa and 345 MPa respectively [5]). In Fig. 4, divide stress by parent yield strength to reveal very similar normalized crushing performance. Additionally, the truss wall honeycomb is highly vented (much interconnected porosity), its walls can be tailored (e.g., bias oriented trusses resist shear for a good sandwich core), etc.

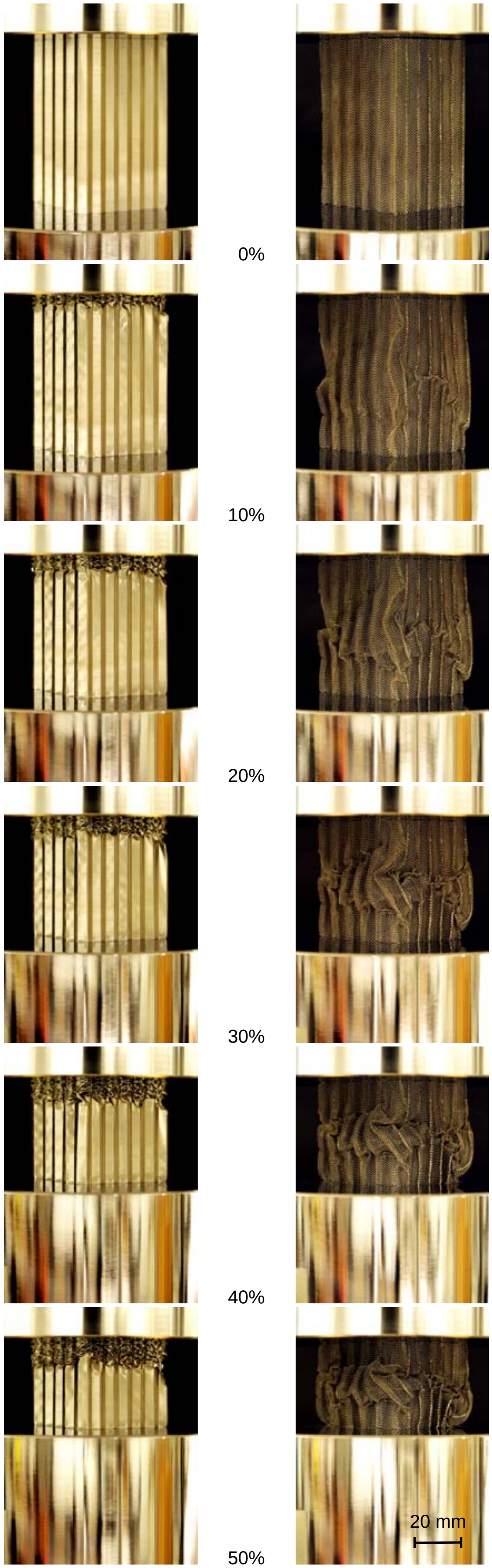


Figure 3. Crushing behavior for solid wall (left) and truss wall (right) honeycombs. Slight outer layer delaminations (right).


## Acknowledgements

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## References


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