Periodic Pyramidal Core Sandwich Structures

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Background / Motivation

Periodic cellular solids offer:

- High stiffness to weight ratio compared to a monolithic plate of the same material
- Large deformation to densification, thus large energy absorption capacity
- Increased surface area, yielding considerable heat dissipation and heat transfer capabilities, and good electrical conductivity

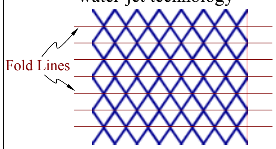
Possible applications include but are not restricted to:

- Auto industry
- Aerospace industry
- Military applications

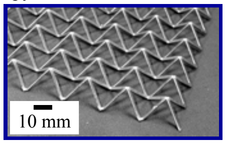
This study will focus on Periodic Pyramidal Core Sandwich Structures, which are a family of cellular solids with extremely high stiffness.

Proposed Manufacturing Procedure

Step 1:
Stock sheet material is perforated using abrasive water-jet technology



Step 2:
Perforated sheet is bent along naturally-occurring fold lines using three-point loading and displacement control to produce desired periodic pyramidal core

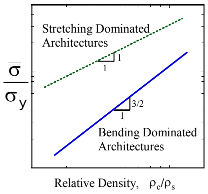


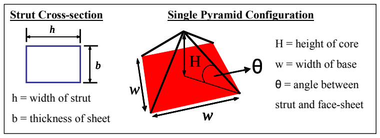
Step 3:
Core material is bonded to face sheets via adhesive bonding, diffusion bonding, or vacuum brazing, to produce sandwich structure

This manufacturing process allows the pyramidal core sandwiches to be easily mass-produced for a given application!

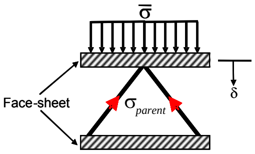
Analytical Modeling[2]

The pyramidal core can be idealized as an array of stretch-governed struts. This is the primary source of stiffness for these structures.





Work Balance Model



In this model, the external work done to the core is balanced with the internal work done by the struts due to deformation.

Considering geometry, the peak collapse load, $\bar{\sigma}_{peak}$, of the core can be determined.

$$\bar{\sigma}_{Peak} = 2\frac{bh}{H^2}\frac{\sin^3\theta}{\cos^2\theta}\sigma_{Parent}$$

Core Response — Core Geometry factor — Yield Strength of Parent Material

Thus, information about the yield strength of the parent material is critical in core design and analysis because the work-balance model is based on the stress or energy necessary to yield the struts in the periodic sandwich structure.

Experimental Results

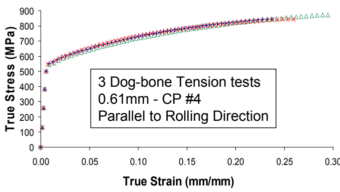
Titanium has the following characteristics which make it ideal for these structures:

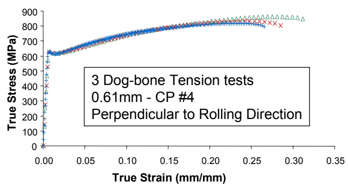
- Additional stiffness to weight advantages to that of steel or aluminum
- A unique ability to diffusion bond, which simplifies manufacturing of these structures on a large scale, and increases the bond strength of the core and face sheet material

Currently, the study will focus on various thicknesses of Ti-6Al-4V alloy, due to its market availability and good strength to ductility ratio, as well as Grade 4 Commercially Pure Titanium (CP #4), due to its high ductility and low cost.

Standard tension tests have been conducted to determine the basic mechanical properties of CP #4.

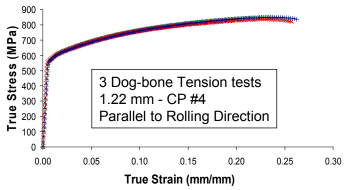
0.61mm - CP #4 Test Results

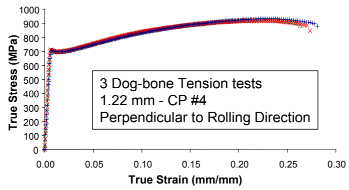




Specimen #	E GPa	(51mm gage) Elongation %	0.2% Offset Yield Strength MPa	Tensile Strength MPa
1R	100.0	?	538	879.8
2R	106.2	?	538	843.3
3R	98.6	21.9	538	843.9
Average:	**101.6**	**21.9**	**538**	**855.7**
St. Dev:	4.0	0.0	0	20.9
1P	104.8	?	627	861.9
2P	108.9	?	627	832.2
3P	114.5	25.0	627	818.4
Average:	**109.4**	**25.0**	**627**	**837.5**
St. Dev:	4.8	0.0	0	22.2

1.22mm - CP #4 Test Results





Specimen #	E GPa	(51mm gage) Elongation %	0.2% Offset Yield Strength MPa	Tensile Strength MPa
1R	111.7	25.5	558	848.0
2R	125.5	24.5	558	836.9
3R	106.2	23.5	558	849.5
Average:	**114.5**	**24.5**	**558**	**844.8**
St. Dev:	9.9	0.0	0	6.9
1P	120.7	23.5	703	924.1
2P	139.3	25.5	703	918.6
3P	117.9	23.5	703	932.1
Average:	**125.9**	**24.2**	**703**	**924.9**
St. Dev:	11.6	0.0	0	6.8

Summary of Results for CP #4

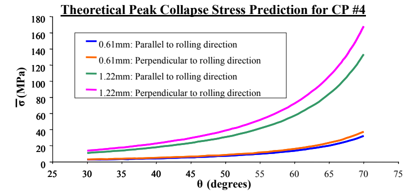
- Yield Strength perpendicular to the rolling direction is consistently greater than yield strength parallel to rolling direction for both thicknesses
- There is a 12.1% increase in yield strength perpendicular to the rolling direction as thickness increases from 0.61mm to 1.22mm

Similar tests will be conducted for all thicknesses of Ti-6Al-4V that are being considered in this study.

Predicted Core Properties

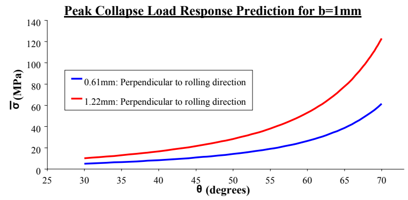
Assuming a typical square strut geometry, the preliminary model and experimental results have been used to predict the core collapse response for CP #4.

For all cases, θ was varied from 30º to 70º, and strut length was set to 10mm.



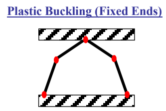
This graph shows that $\bar{\sigma}_{peak}$ increases with increasing θ and σ_{YS}. This follows that $\bar{\sigma}_{peak}$ increases with increasing thickness of the core material as well.

The following graph shows theoretical peak collapse stress results for a rectangular strut geometry of CP #4. In this case, θ was varied from 30º to 70º, strut length was set to 10mm, and b=1mm.



This graph shows that $\bar{\sigma}_{peak}$ for a given θ is less for a rectangular strut geometry as compared to that of the square strut geometry of the same thickness above.

Unfortunately, due to the slenderness ratio of the struts in the core, it is possible that failure may occur due to elastic or plastic buckling, thus this model may not always be valid.



A second generation analytical model which can capture both possible buckling modes will be developed and applied.

Experimental peak collapse load data will be compared to theoretical data obtained from analytical models when cores are fabricated.

Future Work

Titanium Bonding Study

Double-lap shear tests, as well as interface microscopy will be conducted.

Adhesion methods will include:

- FM-94 film adhesive
- Diffusion bonding
- Aluminum Vacuum Brazing

Adhesion interfaces will include:

- CP #4 to CP #4
- CP #4 to Ti-6AL-4V
- CP #4 and Ti-6Al-4V to Al-Sic MMC1

Periodic Pyramidal Core Sandwich Study

Compression, multi-axial loading, and strain-rate sensitivity tests will be conducted.

- Inherent mechanical properties of sandwich structures will be evaluated and reported
- Core dimensions will be varied
- Second generation work-balance models will be constructed and applied
- Specific core designs will be optimized to meet the needs of applications

1: This is a metal matrix composite which is made by MC-21 corporation.

2: Information obtained from "Pyramidal Core Structures" by Marc Zupan, currently in preparation.