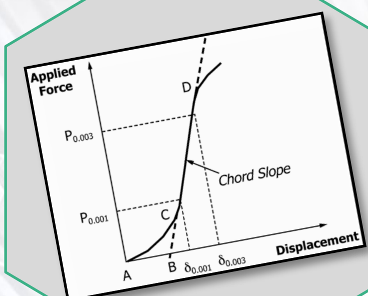
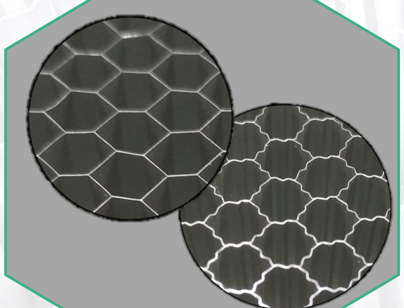
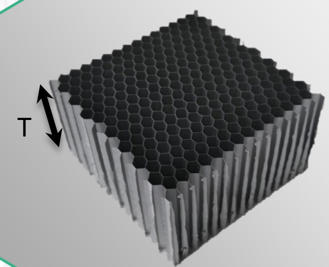
Out of plane elastic compressive behavior of Metallic honeycomb structure

CONTENT

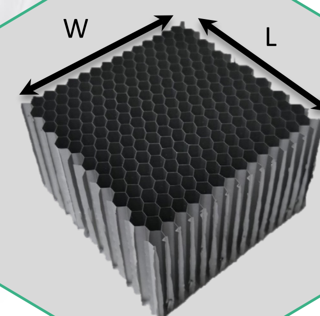


Applied Force
D
$P_{0.003}$
Chord Slope
$P_{0.001}$
C
A
B
$\delta_{0.001}$
$\delta_{0.003}$
Displacement

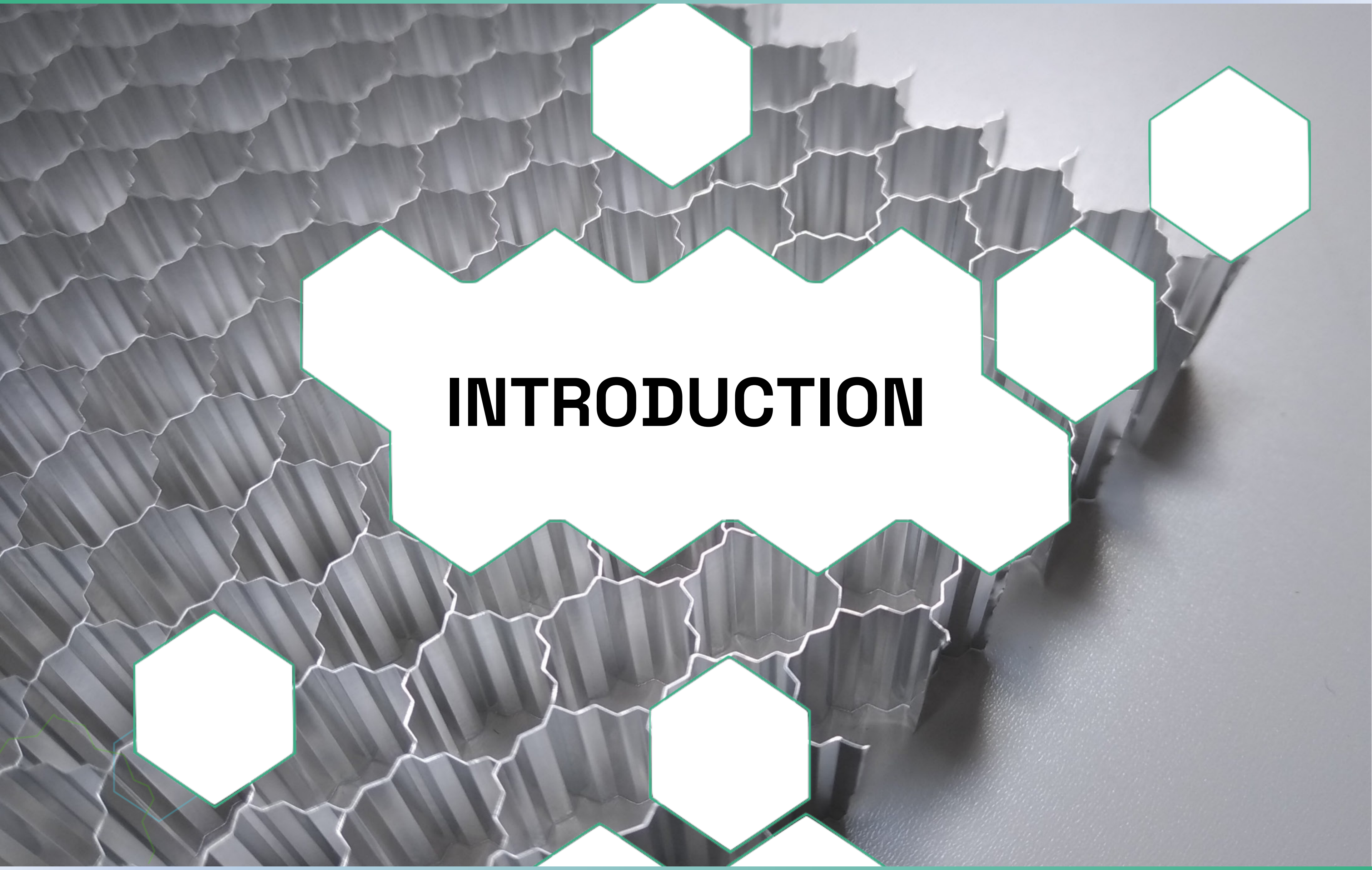




T

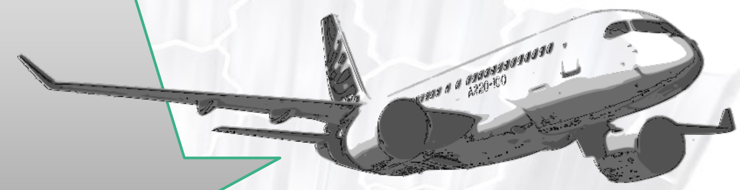


W
L



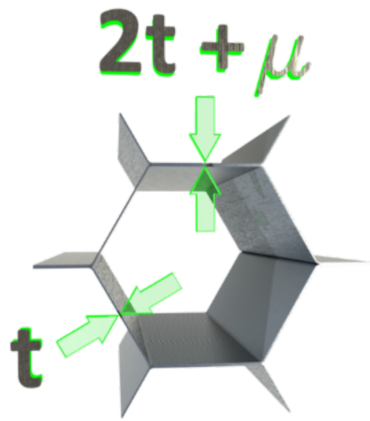
INTRODUCTION

Sandwich Structures

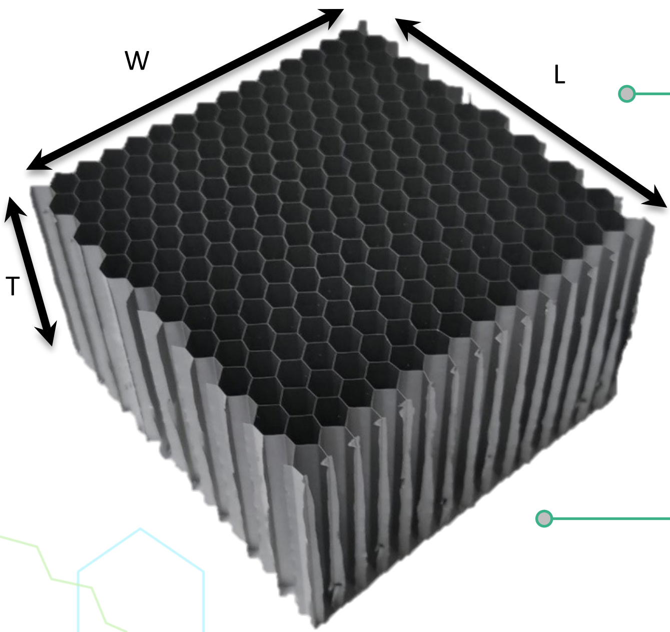


- Behavioral knowledge of parts
- Prediction of use limits
- Definition of Safety Coefficients

Honeycomb structure



Periodical open structure



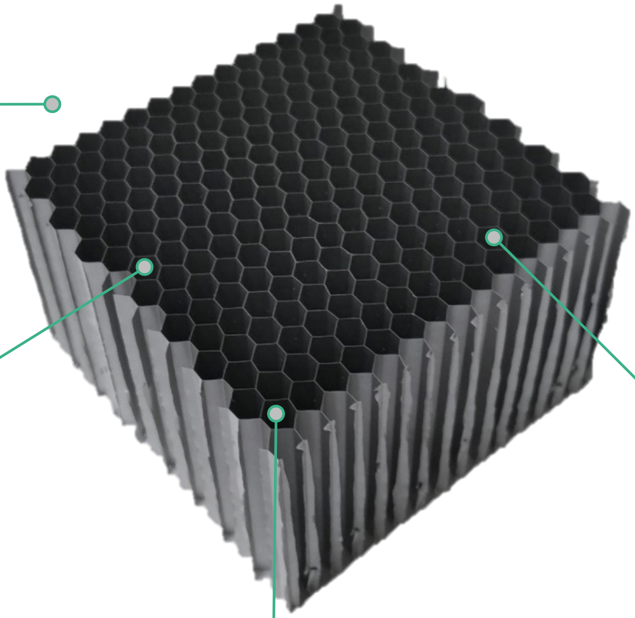
Non-homogeneous structure

High Anisotropy

Complex Mechanical Behavior

Honeycomb structure

Model

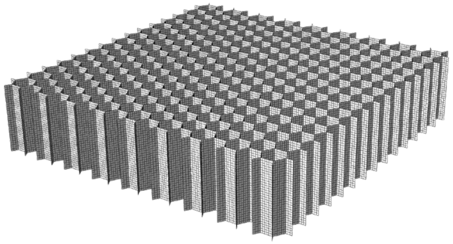


Calculations - Theory

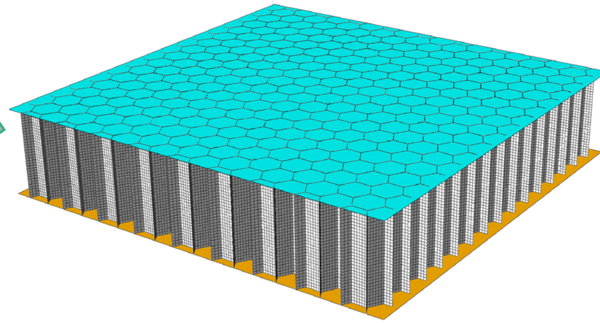
Experimental

F.E.M.

F.E.Modelisation



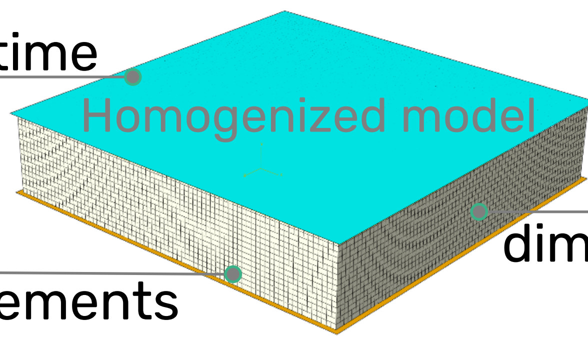
Mesomodel



- Heavy implementation
- Large files
- Long computation times

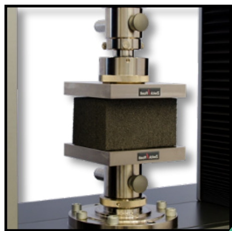
HOMOGENIZATION

- Reduced calculation time

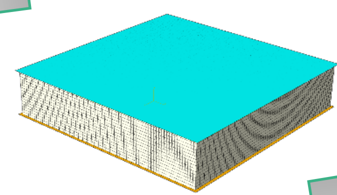


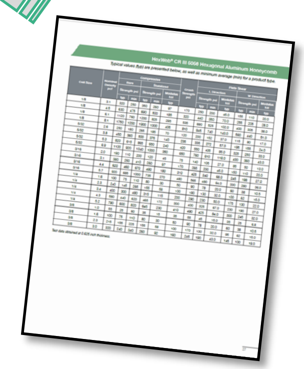
- Modeling of large dimensions parts simplified
- Reduced number of elements

Determination of input data



1. Experimental data:
   (integrator's tests)

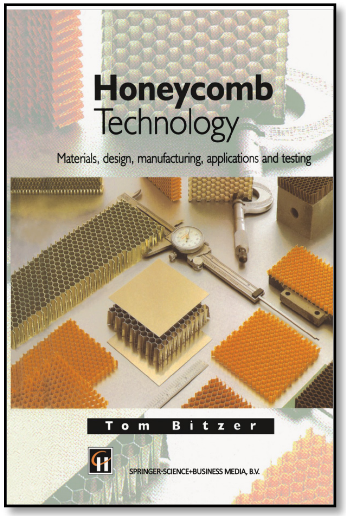




2. Manufacturer's data:
   (manufacturer's tests)

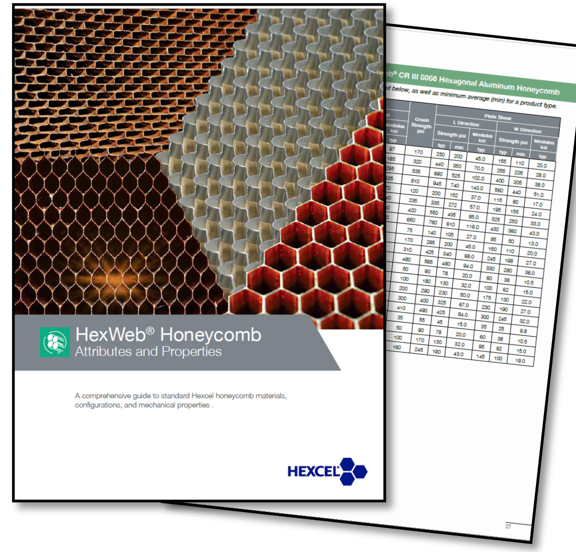
HexWeb® Honeycomb Attributes and Properties

Determination of input data



Tom Bitzer
Hexcel Corporation
Dublin, CA
USA

1997 → 2019



HexWeb® Honeycomb Attributes and Properties

3/8	1.0	55	25	60	35	15	35	55	45	15.0	35	25	6.8
3/8	1.6	100	75	110	80	30	50	90	78	20.0	60	38	10.5
3/8	2.3	215	155	225	155	58	100	170	130	32.0	95	62	15.0
3/8	3.0	320	240	340	260	92	160	245	190	43.0	145	100	19.0

HexWeb® Honeycomb Attributes and Properties

Test data obtained at 0.625 inch thickness.

Unique and constant thickness

Determination of input data

When defining the properties of honeycomb core the following points should be taken into consideration:-

$E_X \approx E_Y \approx 0$

A very small value may be necessary to avoid singularity.

$\mu_{xy} \approx \mu_{xz} \approx \mu_{yz} \approx 0$

$G_{xy} \approx 0$

$G_{xz} = G_L$ = shear modulus in ribbon direction

$G_{yz} = G_W$ = shear modulus in transverse direction

$E_Z = E_C$ = compressive modulus of core material

HexWeb$_{TM}$ HONEYCOMB SANDWICH DESIGN TECHNOLOGY

HexWeb® CR III 5056 Hexagonal Aluminum Honeycomb

Typical values (typ) are presented below, as well as minimum average (min) for a product type.

Cell Size	Nominal Density pcf	Compressive					Crush Strength psi	Plate Shear					
		Bare		Stabilized				L Direction			W Direction		
		Strength psi		Strength psi		Modulus ksi		Strength psi		Modulus ksi	Strength psi		Modulus ksi
		typ	min	typ	min	typ		typ	min	typ	typ	min	typ
1/8	3.1	320	250	350	260	97	170	250	200	45.0	155	110	20.0
1/8	4.5	630	475	690	500	185	320	440	350	70.0	255	205	28.0
1/8	6.1	1120	760	1200	825	295	535	690	525	102.0	400	305	38.0

HexWeb® Honeycomb Attributes and Properties

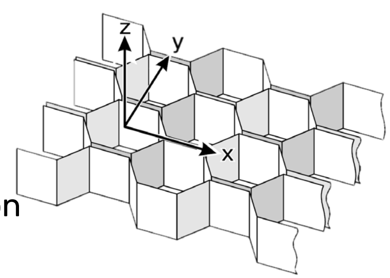
E_C G_L G_W

+

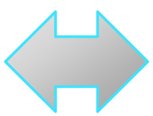
$\sigma_x = \sigma_L$ = shear strength in ribbon direction

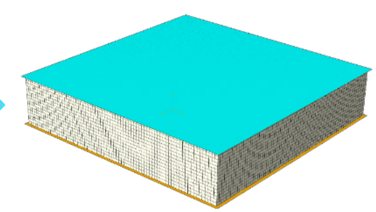
$\sigma_y = \sigma_W$ = shear strength in transverse direction

$\sigma_z = \sigma_C$ = compressive strength in thickness direction



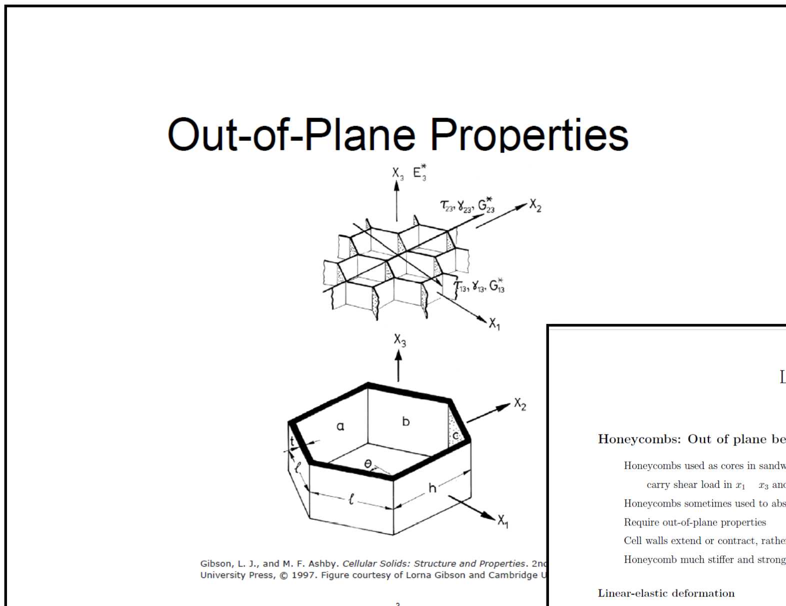
HexWeb HONEYCOMB SANDWICH DESIGN TECHNOLOGY





Out of plane properties of honeycomb (open source)

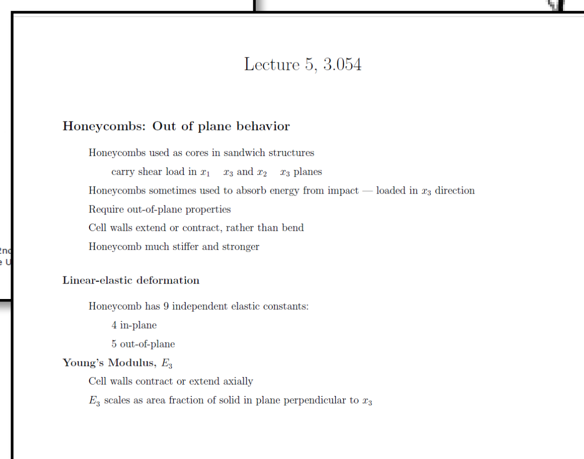
Gibson & Ashby: Cellular solids: structure and properties.



Out-of-Plane Properties

Gibson, L. J., and M. F. Ashby. *Cellular Solids: Structure and Properties*. 2nd
University Press, © 1997. Figure courtesy of Lorna Gibson and Cambridge U

3



Lecture 5, 3.054

Honeycombs: Out of plane behavior

Honeycombs used as cores in sandwich structures

carry shear load in x_1 x_3 and x_2 x_3 planes

Honeycombs sometimes used to absorb energy from impact — loaded in x_3 direction

Require out-of-plane properties

Cell walls extend or contract, rather than bend

Honeycomb much stiffer and stronger

Linear-elastic deformation

Honeycomb has 9 independent elastic constants:

4 in-plane

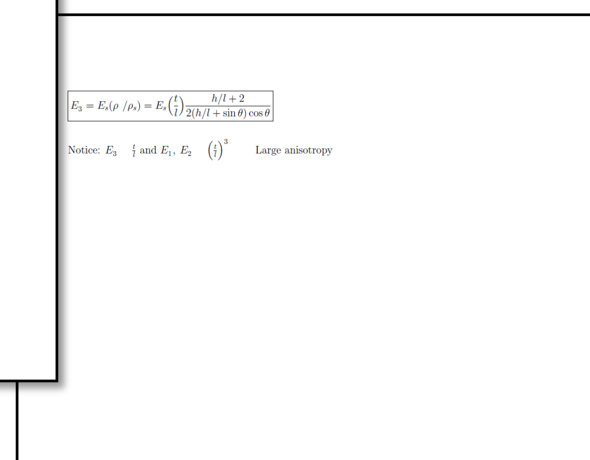
5 out-of-plane

Young's Modulus, E_3

Cell walls contract or extend axially

E_3 scales as area fraction of solid in plane perpendicular to x_3

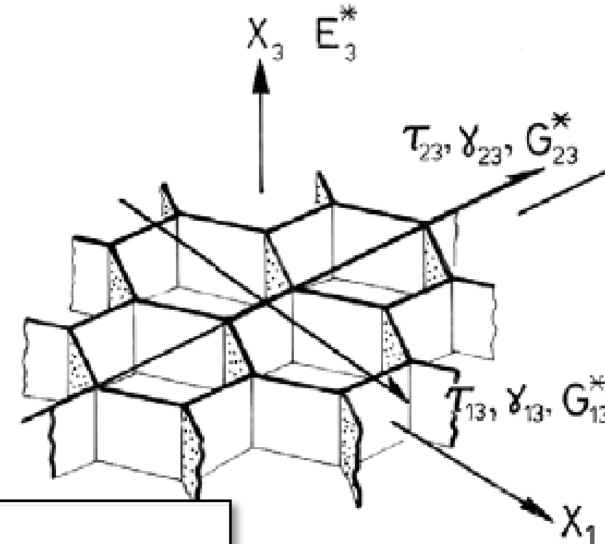
1



$$\boxed{E_3 = E_s(\rho\ /\rho_s) = E_s\left(\frac{t}{l}\right)\frac{h/l + 2}{2(h/l + \sin\theta)\cos\theta}}$$

Notice: E_3 $\frac{t}{l}$ and E_1, E_2 $\left(\frac{t}{l}\right)^3$ Large anisotropy

2



Out of plane properties of honeycomb

Gibson & Ashby: Cellular solids: structure and properties.

Young's Modulus, E_3

$$E_3 = E_s(\rho \;/\rho_s) = E_s\left(\frac{t}{l}\right)\frac{h/l+2}{2(h/l+\sin\theta)\cos\theta}$$

Cell walls contract or extend axially

E_3 scales as area fraction of solid in plane perpendicular to x_3

At fixed density:

- E_C is a constant **independent** of cell configuration,
- E_C is a constant **independent** of core thickness,
- E_C is a constant **independent** of size of the part.

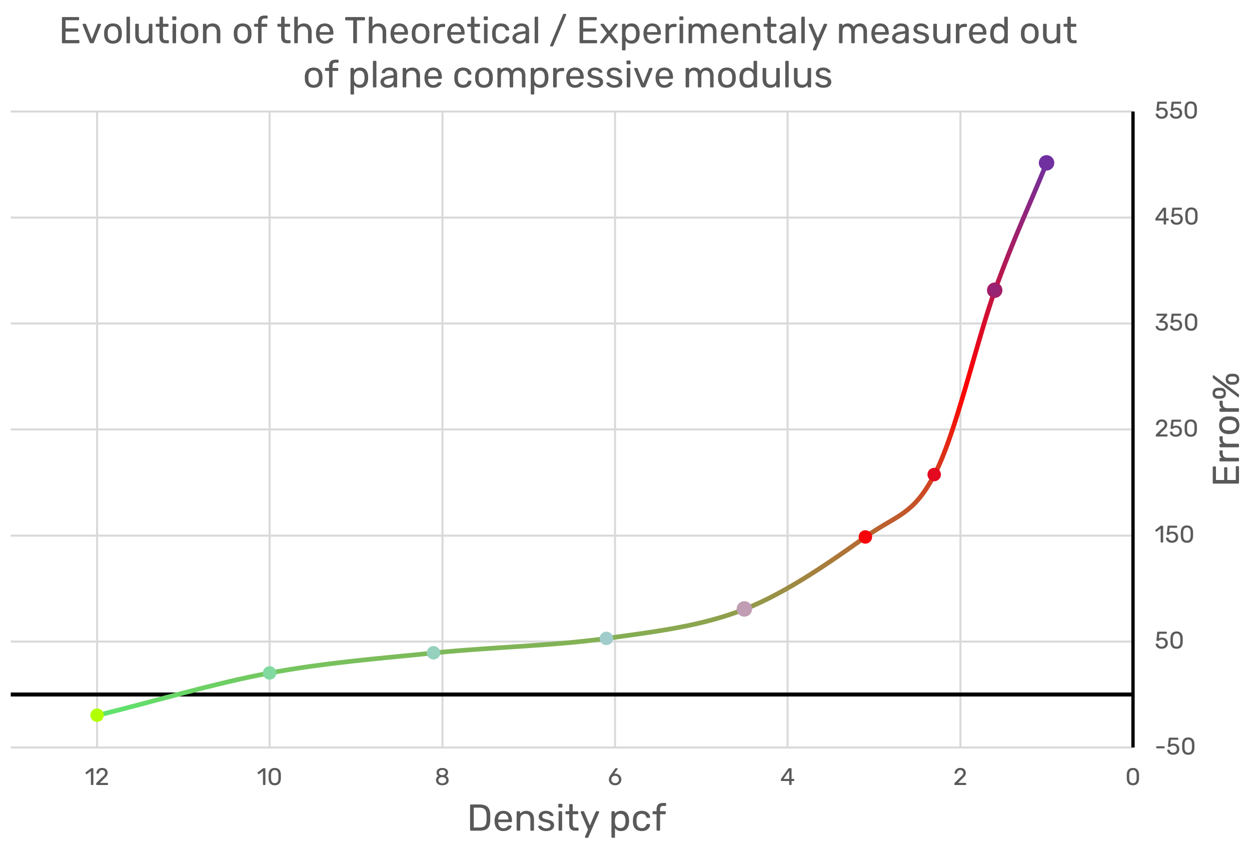
Out of plane compressive modulus of AA5052 Honeycomb

Data (Hexcel)			Converted Data		Theoretical Value*	
Denomination Cell-size -Alloy - Foil Gauge	Nominal density	Compressive Modulus ksi	*Density kg.m^{-3}*	*Compressive Modulus MPa*	Compressive Modulus ksi	Error %
1/8 - 5052 - .003	12,0	900	*192,0*	*6207*	722	-19,8
1/8 - 5052 - .0025	10,0	500	*160,0*	*3448*	601	+20,3
1/8 - 5052 - .002	8,1	350	*129,6*	*2414*	487	+39,2
1/8 - 5052 - .0015	6,1	240	*97,6*	*1655*	367	+52,9
1/8 - 5052 - .001	4,5	150	*72,0*	*1034*	271	+80,4
1/8 - 5052 - .0007	3,1	75	*49,6*	*517*	186	+148,6
3/8 - 5052 - .0015	2,3	45	*36,8*	*310*	138	+207,4
3/8 - 5052 - .001	1,6	20	*25,6*	*138*	96	+381,2
3/8 - 5052 - .0007	1,0	10	*16,0*	*69*	60	+501,5

*

$E_3 = E_s\,(\rho / \rho_s)$	$E_C = E_s\,(\rho / \rho_s)$
$E_s = 70000$ MPa	$E_s = 10150$ ksi
$\rho_s = 2700$ kg.m^{-3}	$\rho_s = 168{,}75$ pcf

Out of plane compressive modulus of AA5052 Honeycomb

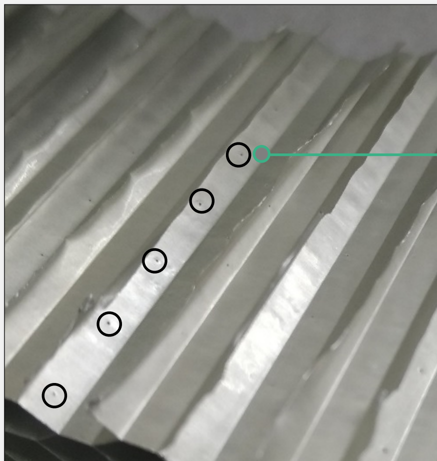


As the density decreases, the difference between the theoretical and the experimental compressive modulus increases.

Out of plane compressive modulus of AA5052 Honeycomb

- Two major influence factors:

1. Imperfections:



Microperforation of cell walls

The sensitivity to imperfection increases as the cell wall thickness decreases

cf. corrugation of cork cell walls

2. Overestimated modulus of aluminum foil:


NASA/TM—2018-219753

Properties of 5052 Aluminum for Use as Honeycomb Core in Manned Spaceflight

Bradley A. Lerch
Glenn Research Center, Cleveland, Ohio

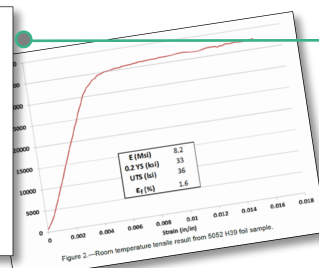


Figure 2.—Room temperature tensile result from 5052 H39 foil sample.

The modulus of thin gauge aluminum foil is lower than that of the corresponding solid

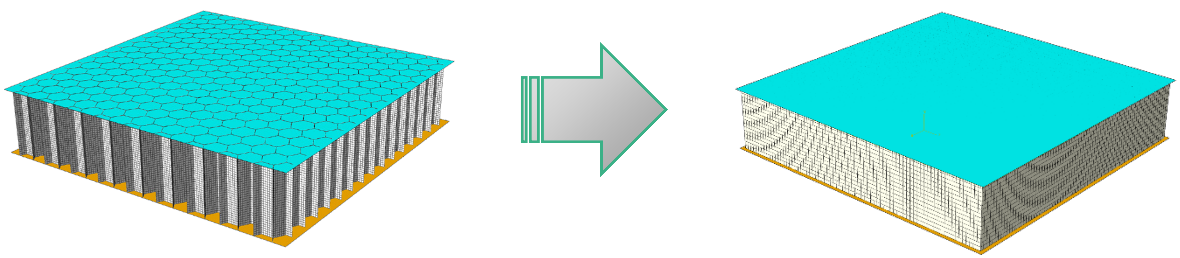
Implementation of the honeycomb homogenized model

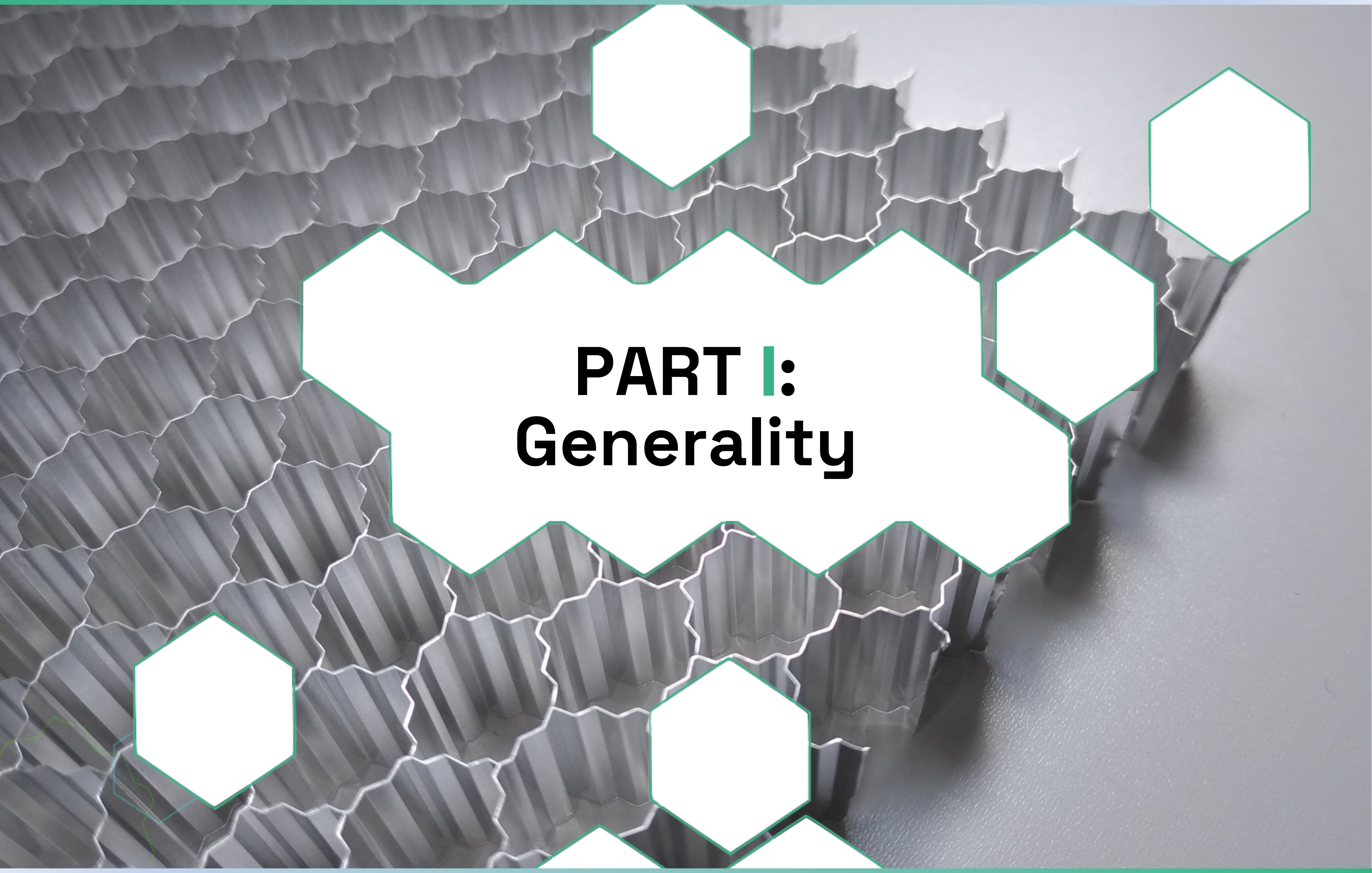
Definition of elastic constants

Experimental data and/or literature

Linear invariant elastic behavior

Structural imperfections not taken into account





PART I: Generality

Out of Plane Compressive Modulus

Standard ASTM C365 – MIL STD 401 B

Quasi-static Conditions

Designation: C365/C365M – 16

Standard Test Method for Flatwise Compressive Properties of Sandwich Cores

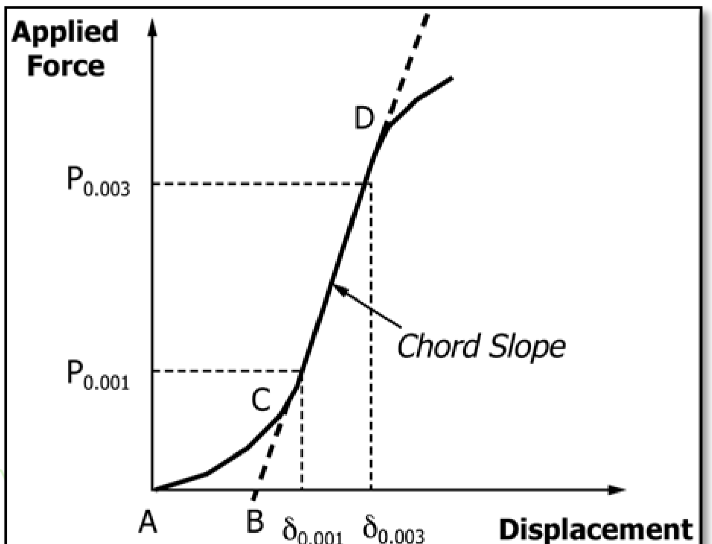
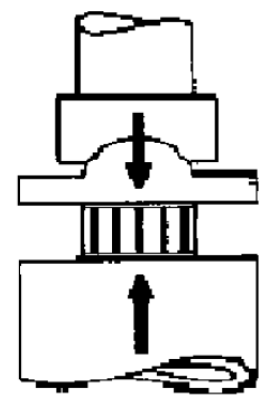


FIG. A1.1 Core Material with Hookean Region

Test Methods

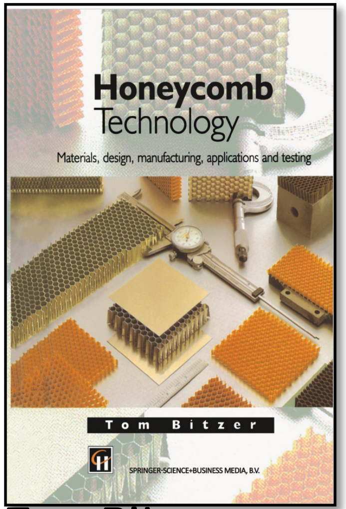
The standard specimen size for bare and stabilized compressive tests is 3" L x 3" W x 0.625"T (76.2mm x 76.2mm x 15.875mm) 3" L x 3" W x 0.500"T (76.2mm x 76.2mm x 12.7mm) for nonmetallic cores. For cell sizes 1/2 inch or larger, a 4" L x 4" W (101.6mm x 101.6mm) or even a 6" L x 6" W (152.4mm x 152.4mm) specimen size is used to reduce the error developed by edge effect on small samples. Stabilized compressive specimens are normally prepared by bonding 0.032" AL (0.8128mm) 5052 thick facings to each side.

Compressive Test



HexWeb® Honeycomb Attributes and Properties

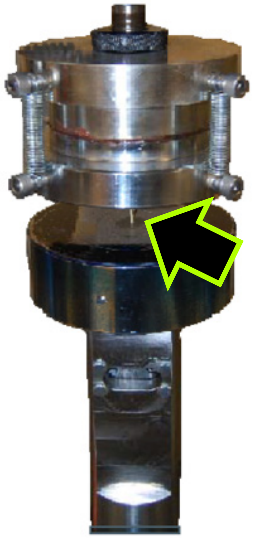
Protocol *(part II, III and IV)*



Tom Bitzer
Hexcel
Corporation
Dublin, CA
USA

"…To determine the compressive modulus, one method that works very well is to drill a small hole through the center of the sample. A rod attached to a ***transducer*** *is then inserted through the hole.*
It is ***not good practice to use the test machine cross-head*** *travel to obtain the specimen's deformation.*
The modulus values determined this way will normally be quite low, as little as one-third the actual value…"

- Quasi static conditions: 0.02 in.min^{-1}
- Extensometer (LVDT)
- One spherical seat (self-aligning) platen

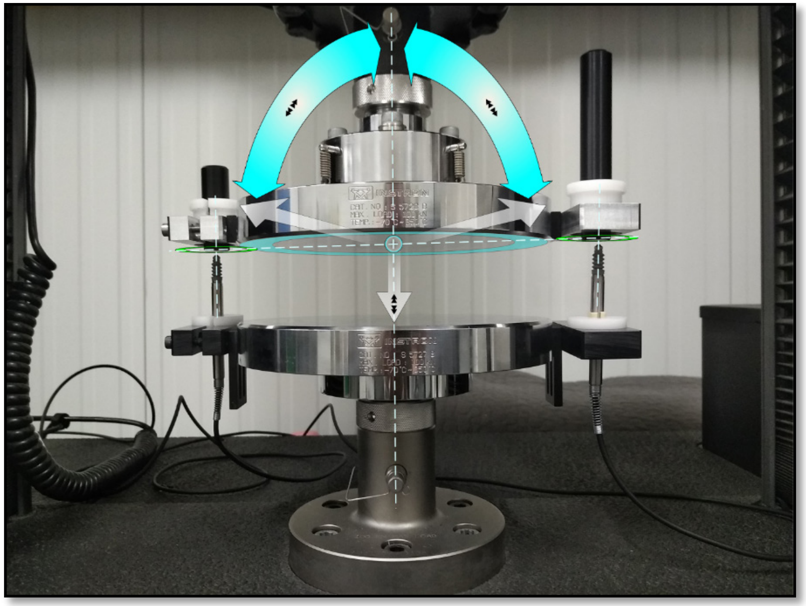


Protocol *(part II, III and IV)*

Method

Drilling a hole can create defect in the specimen

No compliance correction (direct measurement of displacement is chosen: LVDT)



INSTRON 5982 – 100 KN

Quasi static conditions:0.5 mm.min^{-1}
0.02 in.min^{-1}

Spherical seat (self-aligning) platen
center of rotation positioned on the underside of the upper plate

Two extensometers (LVDT)
diametrically opposite, average displacement

Specimens

Section of 75 x 75 mm^2 2.95 x 2.95 in^2

Stabilized specimens glued with Redux 609 300gsm supported adhesive On 0.8mm 0.03 in thick aluminum skins

Raw material

5056 honeycomb specimen:

CRIII 3/16-5056-.0007-2.0

4.8mm-5056-18µm-32kg.m^{-3}

Manufacturer data

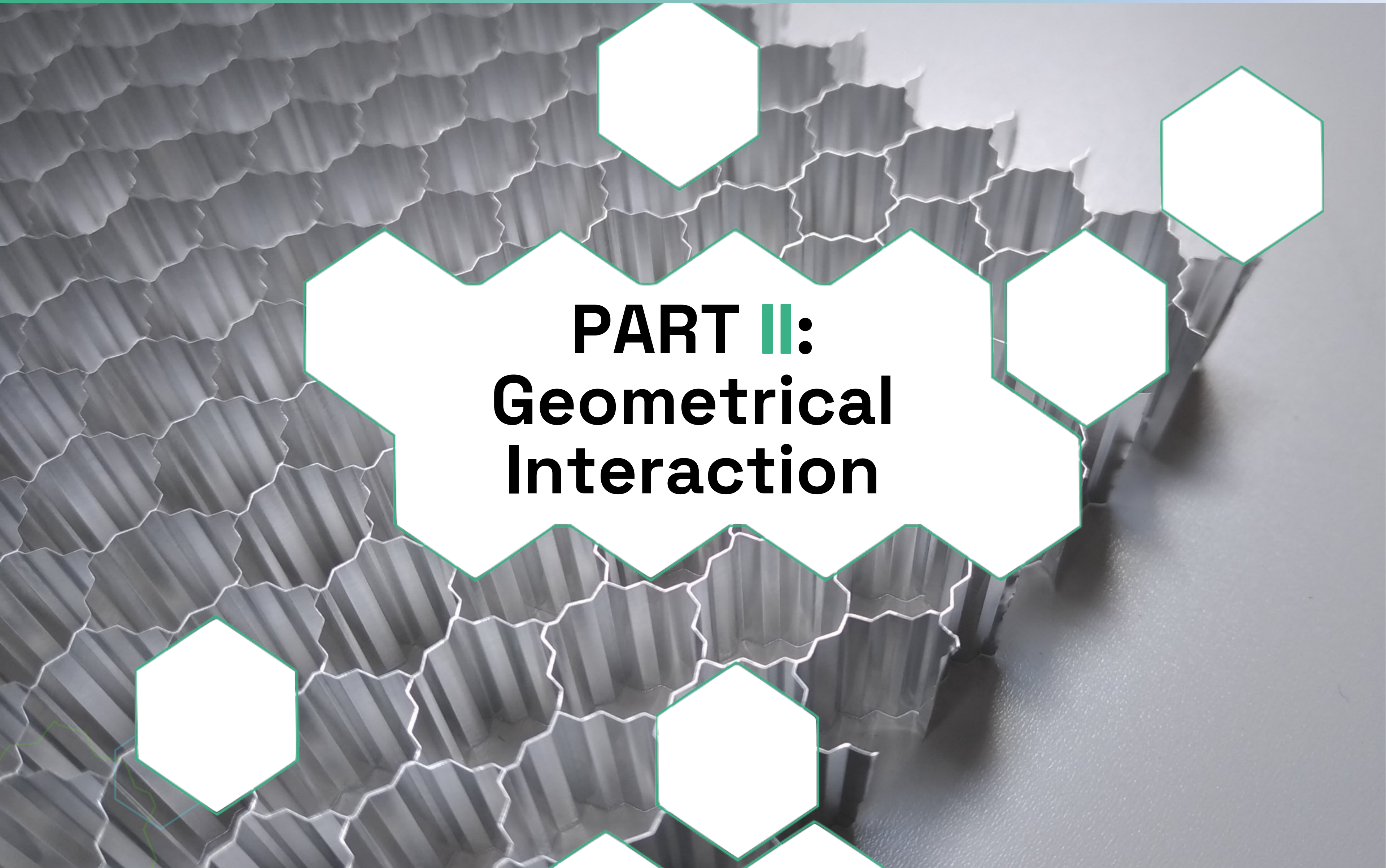
HexWeb® CR III 5056 Hexagonal Aluminum Honeycomb

Typical values (typ) are presented below, as well as minimum average (min) for a product type.

Cell Size	Nominal Density pcf	Compressive Bare Strength psi typ	Compressive Bare Strength psi min	Compressive Stabilized Strength psi typ	Compressive Stabilized Strength psi min	Compressive Stabilized Modulus ksi typ	Crush Strength psi	Plate Shear L Direction Strength psi typ	Plate Shear L Direction Strength psi min	Plate Shear L Direction Modulus ksi typ	Plate Shear W Direction Strength psi typ	Plate Shear W Direction Strength psi min	Plate Shear W Direction Modulus ksi typ
5/32	2.6	250	180	265	185	70	120	200	152	37.0	115	80	17.0
5/32	3.8	450	360	500	375	140	235	335	272	57.0	195	155	24.0
5/32	5.3	820	615	865	650	240	420	550	435	85.0	325	250	33.0
5/32	6.9	1120	920	1340	1000	[illegible]	650	760	610	118.0	430	360	43.0
3/16	2.0	190	110	200	120	45	75	140	105	27.0	85	50	13.0

HexWeb® Honeycomb Attributes and Properties

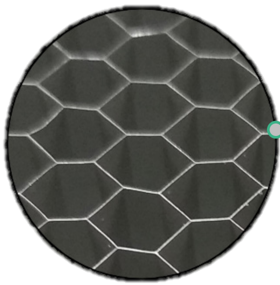
typ. Compressive modulus E_c **45ksi ≈ 310MPa**



PART II: Geometrical Interaction

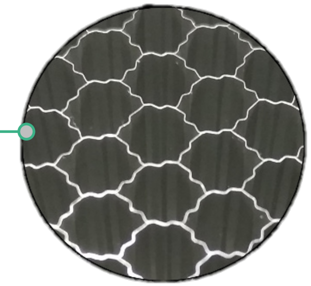
Specimens

Hexcel 5056-3/16-0.0007-2.0
Dim: 75 x 75 x 15,875 mm^3
L 2,95 x W 2,95 x T 0,625 in^3

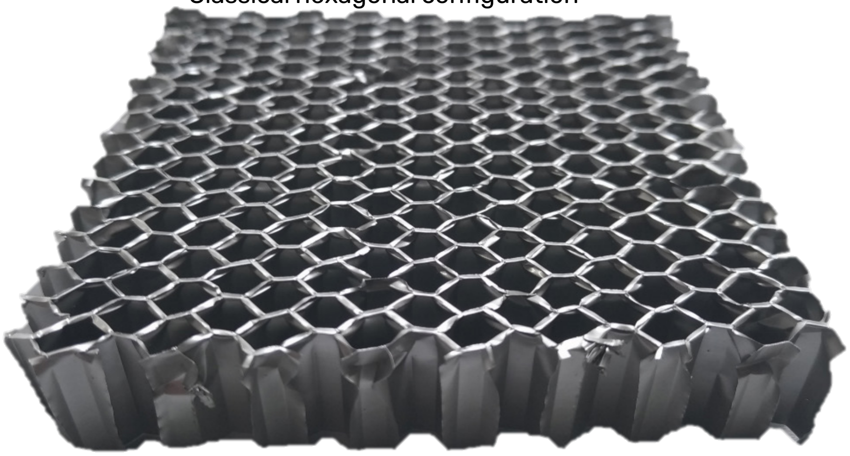


Classical hexagonal configuration

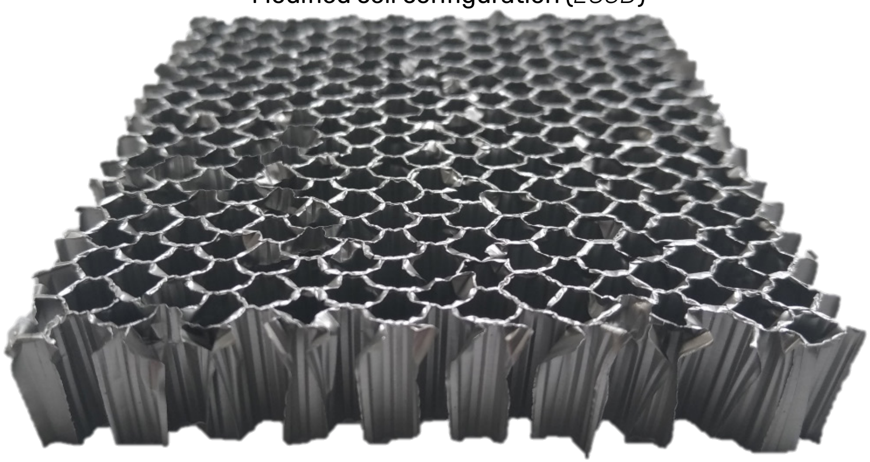
Full corrugated configuration



Classical hexagonal configuration



Modified cell configuration (*EC3D*)



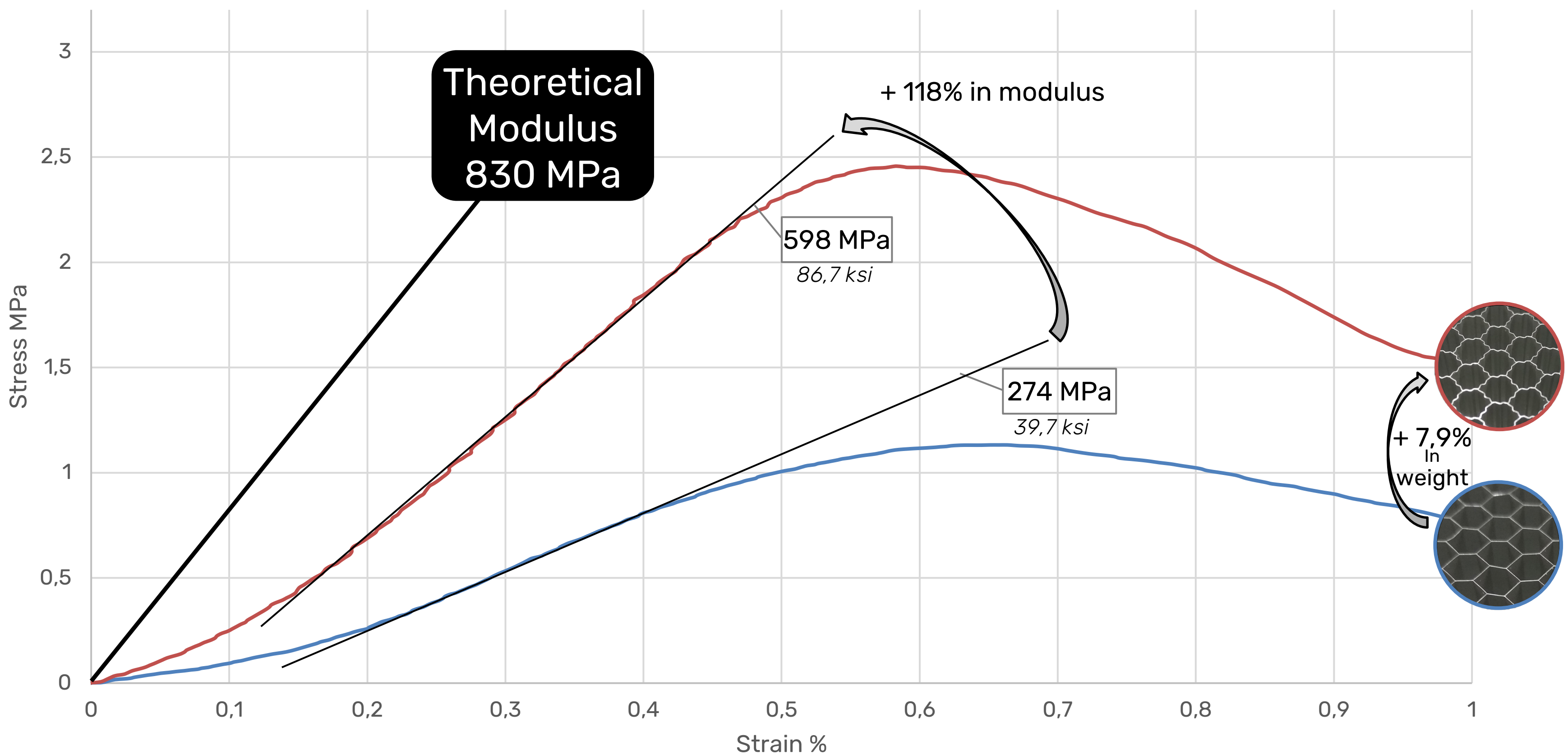
Weight measured: 3,15 g
Density: 35,2 kg.m^{-3} 2,2 pcf

Weight measured : 3,40 g
Density: 38,0 kg.m^{-3} 2,37 pcf

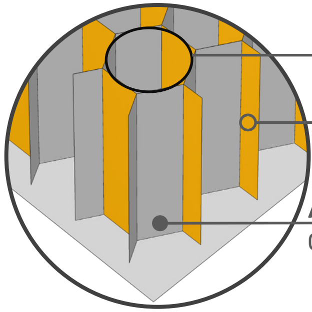
+ 7,9%

Experimental results

Bare compression Thickness T:15,9mm (75x75mm^2) L 2,95x W 2,95x T 0,625 in^3



Numerical correlation

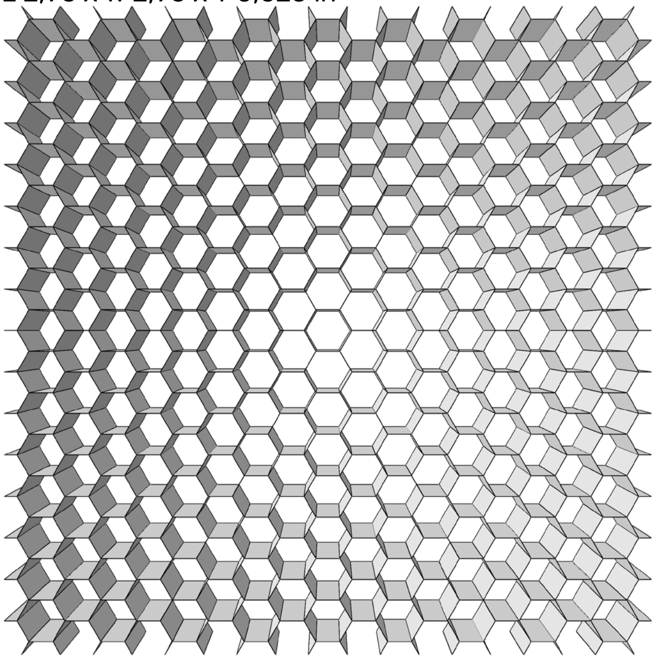


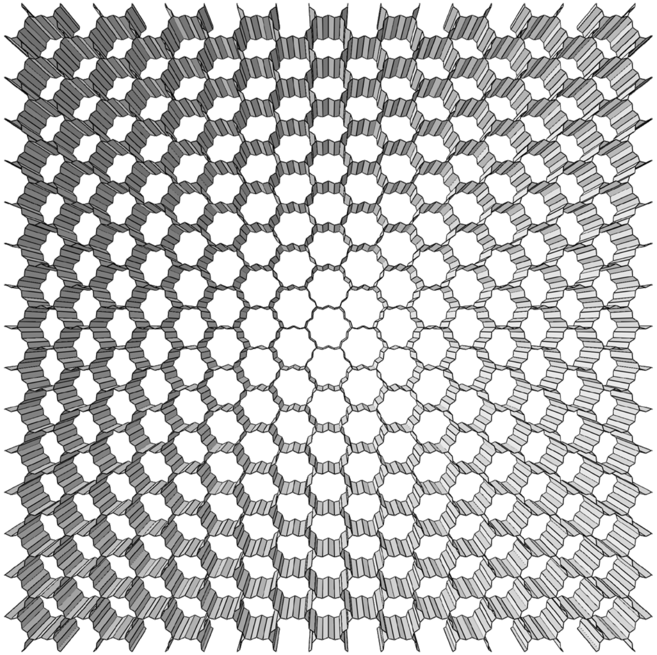
Ø cell = 4.8mm 3/16

Aluminium double cell wall
36 µm 0,0014 in

Aluminium single cell wall 18 µm
0,0007 in

Dim: 75 x 75 x 15,875 mm^3
L 2,95 x W 2,95 x T 0,625 in^3





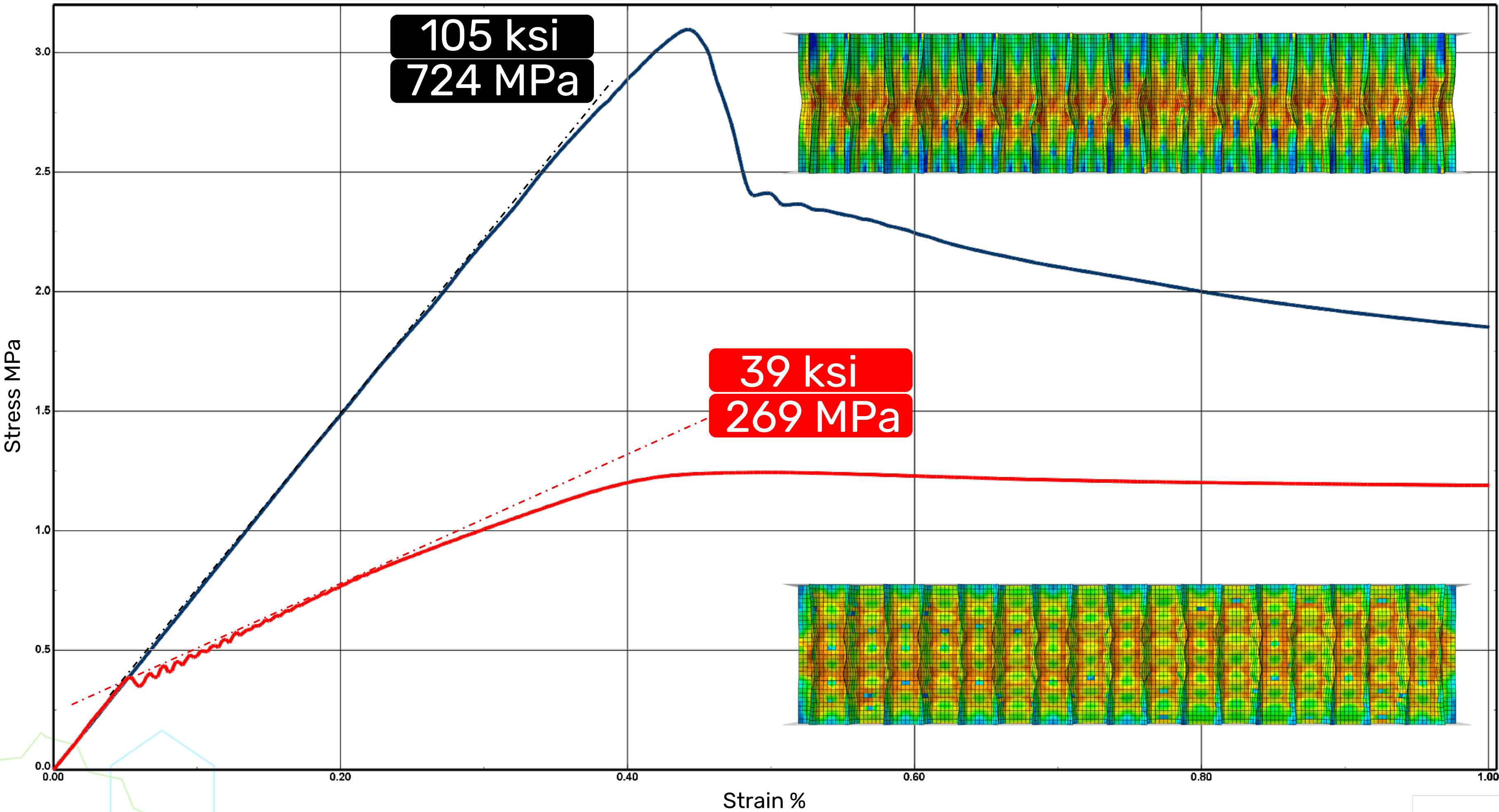
Theorical weight: 2,40 g
Density: 26,9 kg.m^{-3} 1,7 pcf

+ 6,7%

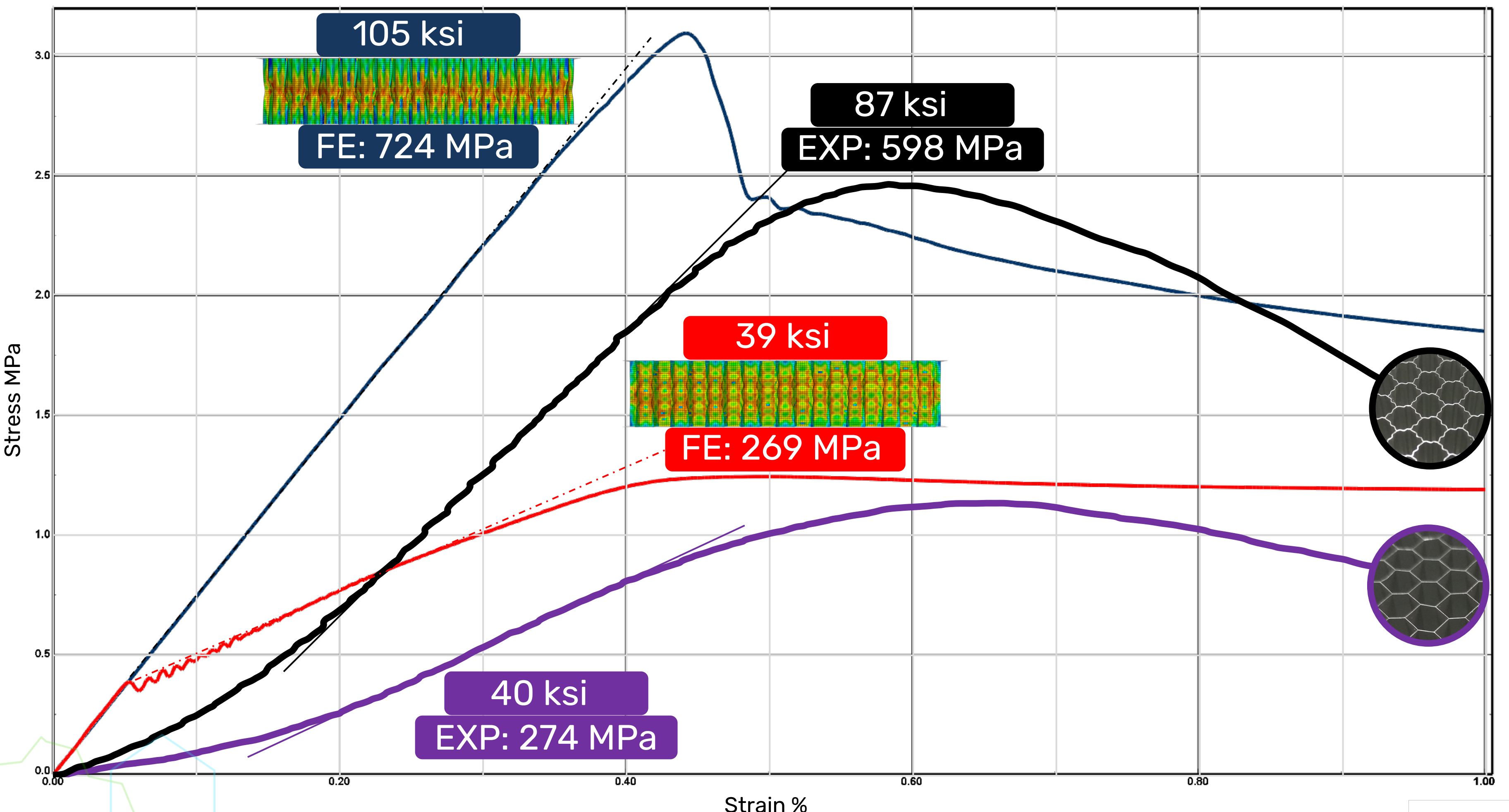
Theorical weight: 2,56 g
Density: 28,7 kg.m^{-3} 1,8 pcf

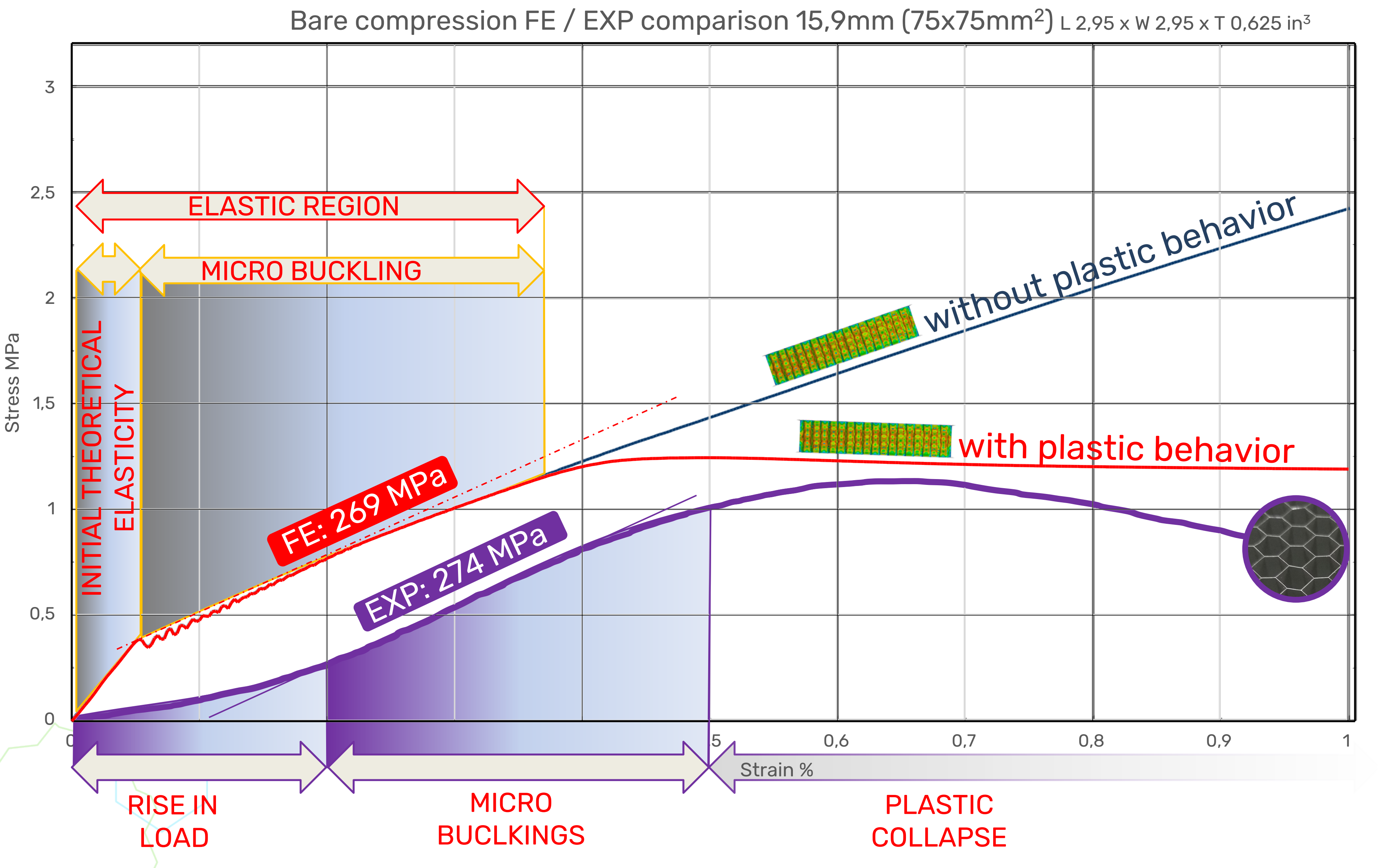
Only nominal aluminum foil thickness is implemented, the oversize and overweight due to anticorrosion treatment is not taken into account

GEOMETRICAL INTERACTION



Bare compression FE / EXP comparison 15,9mm (75x75mm²) L 2,95 x W 2,95 x T 0,625 in³

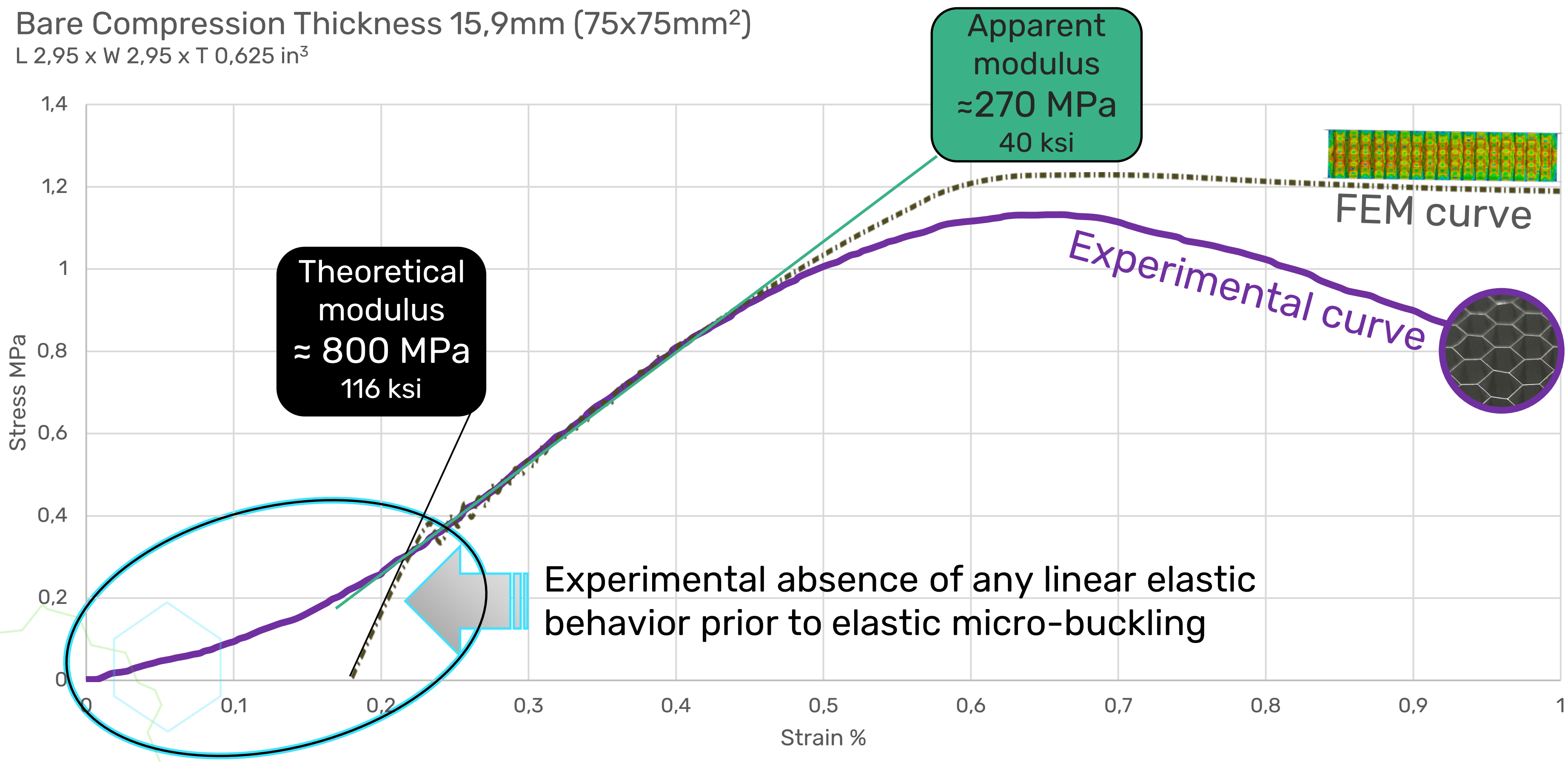




Bare compression FE / EXP comparison 15,9mm (75x75mm²) L 2,95 x W 2,95 x T 0,625 in³
3
2,5
2
1,5
1
0,5
0
Stress MPa
ELASTIC REGION
MICRO BUCKLING
INITIAL THEORETICAL ELASTICITY
without plastic behavior
with plastic behavior
FE: 269 MPa
EXP: 274 MPa
0,6
0,7
0,8
0,9
1
Strain %
RISE IN LOAD
MICRO BUCKLINGS
PLASTIC COLLAPSE

Numerical modeling correlates with experimental test

The linear elastic region prior to elastic micro-buckling can't be experimentally observed



Experimental tests are well correlated by numerical models

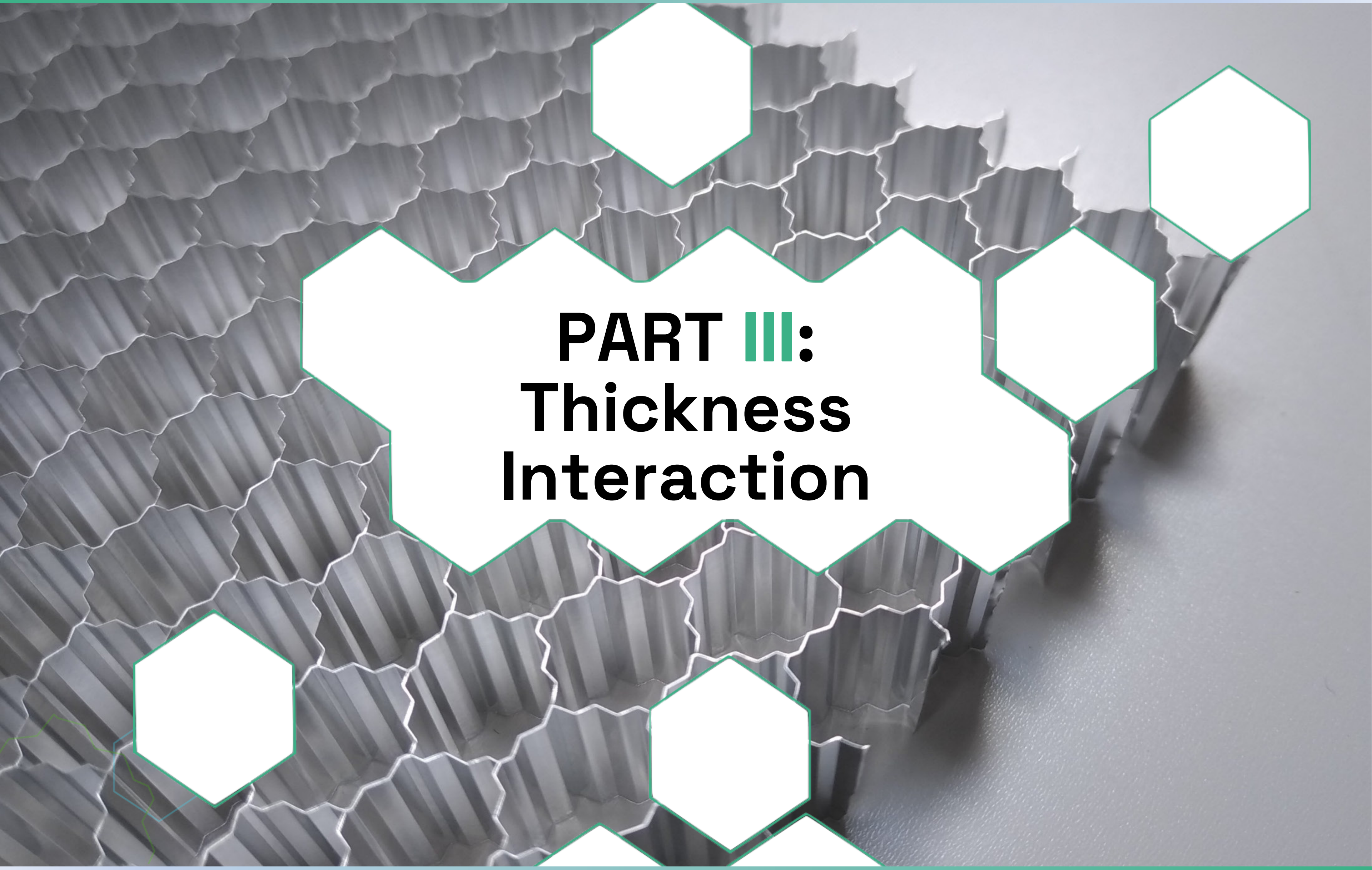
An 8% increase in weight leads to an almost +120% increase in compressive modulus

Both experiment and numerical tests indicate:

Cell configuration influences the compressive modulus of the structure

The compressive modulus measured differs from the theoretical one

E_c is not invariant and constant

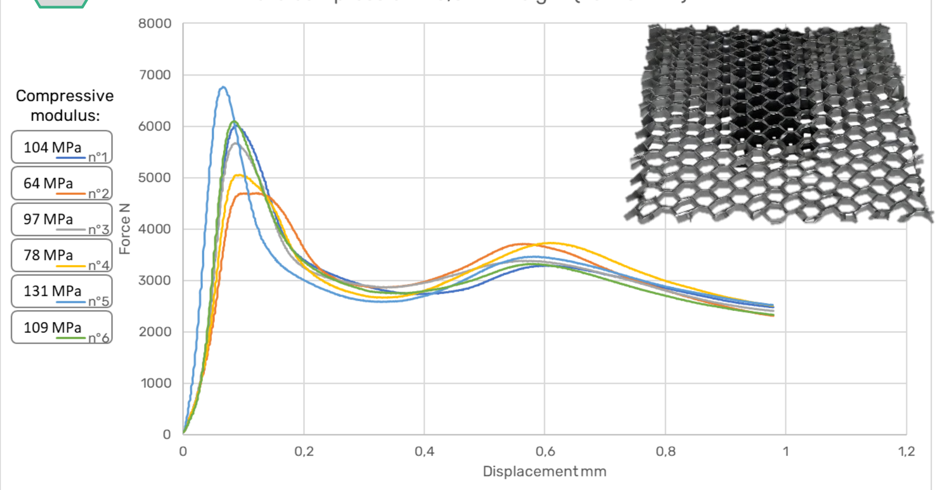


PART III: Thickness Interaction

T=5,0 mm 0,197 in

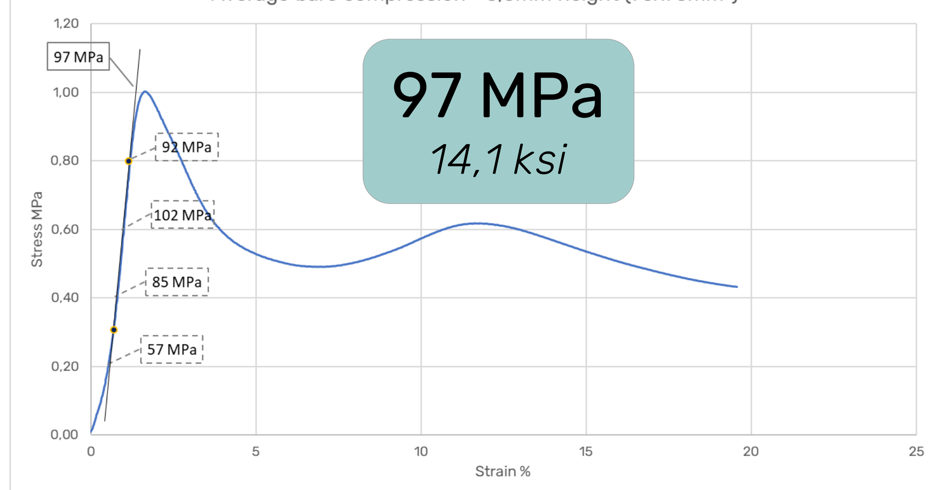
Bare compression

Bare compression - 5,0mm height (75x75mm²)



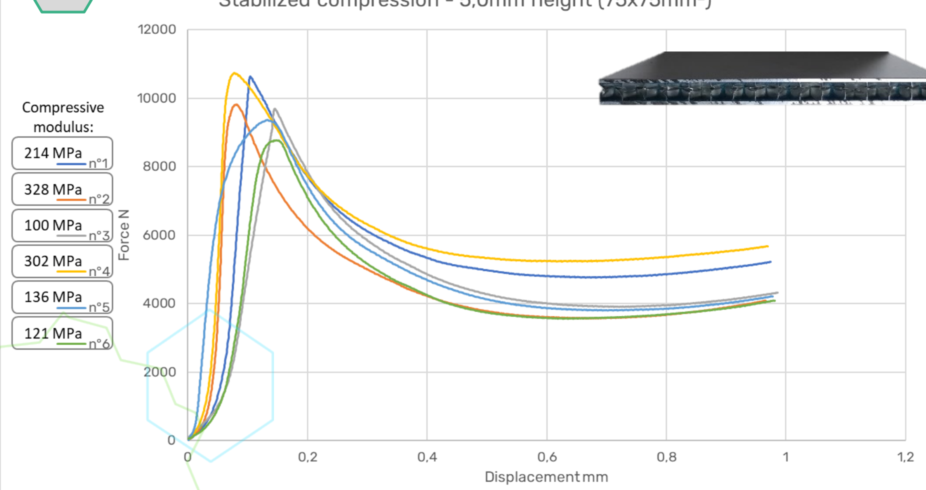
Average value

Average bare compression - 5,0mm height (75x75mm²)



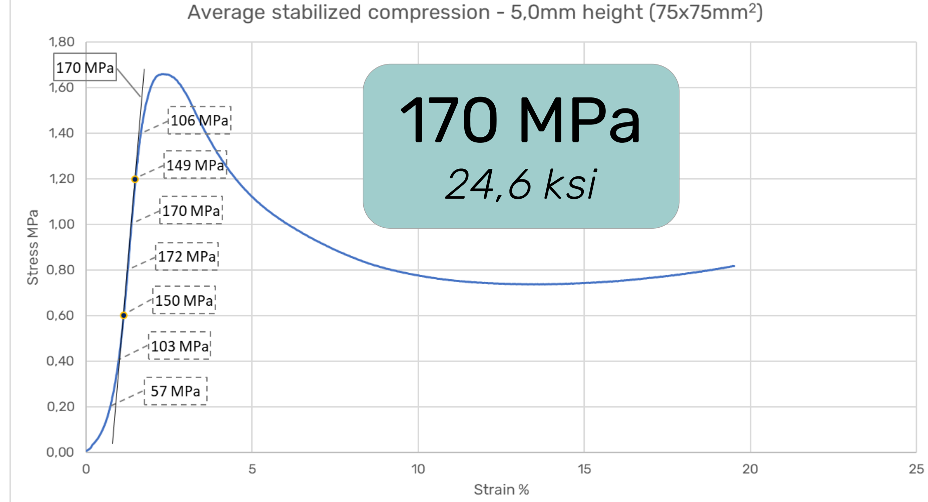
Stabilized compression

Stabilized compression - 5,0mm height (75x75mm²)



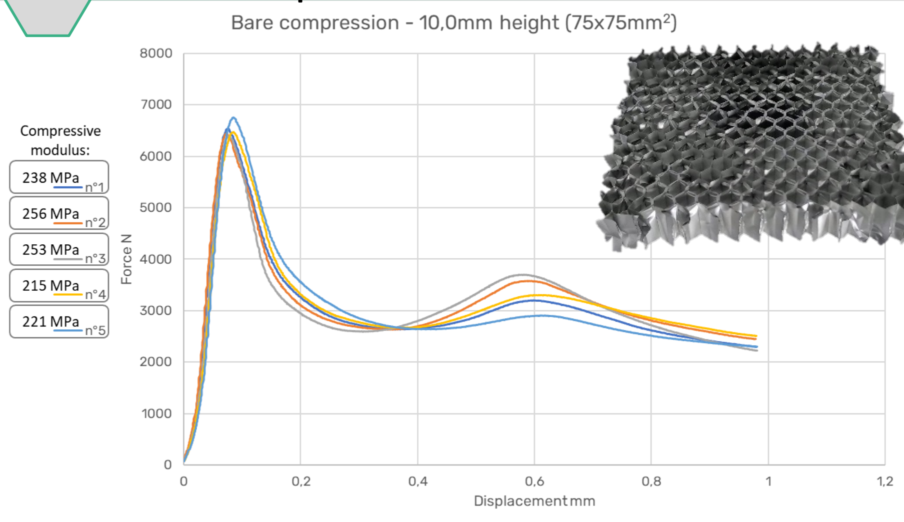
Average value

Average stabilized compression - 5,0mm height (75x75mm²)

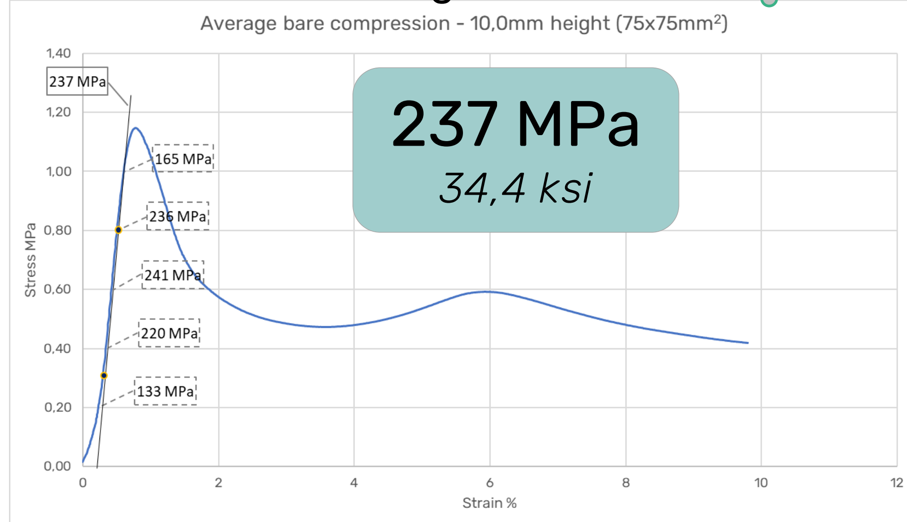


T=10,0 mm 0,394 in

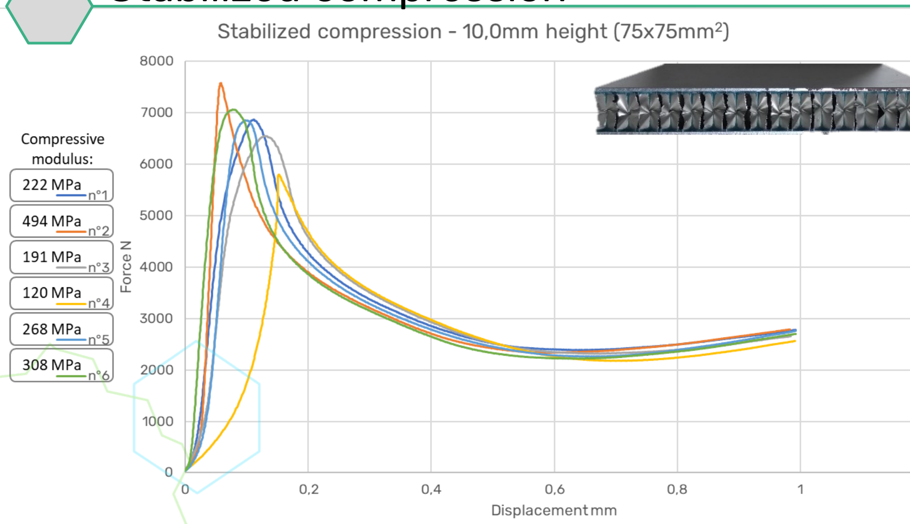
Bare compression



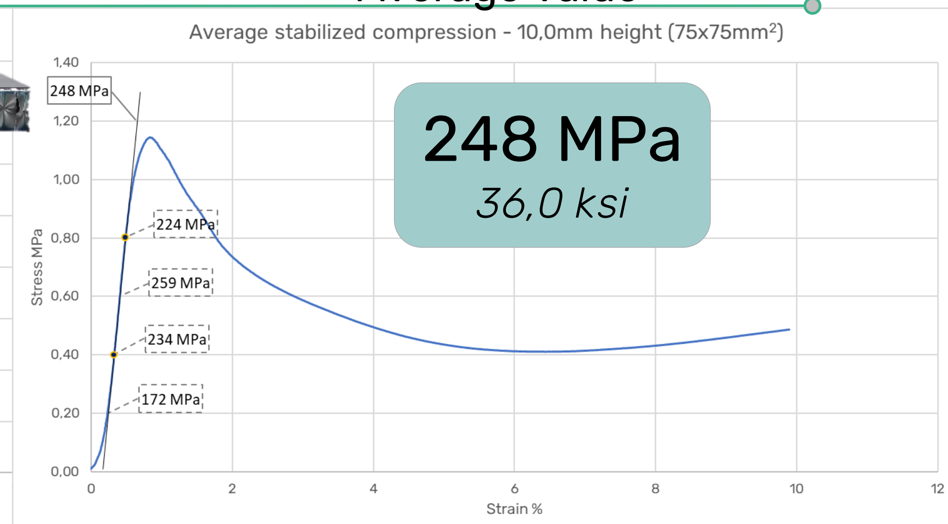
Average value



Stabilized compression

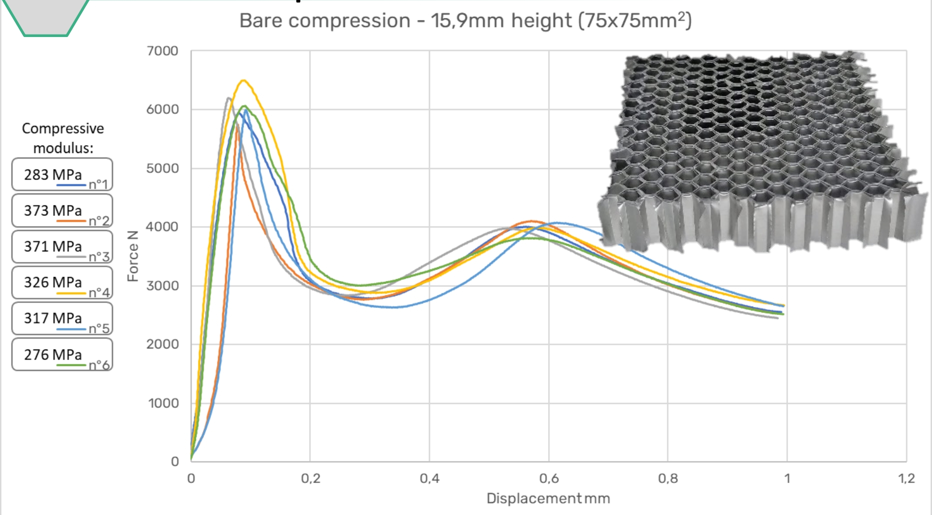


Average value

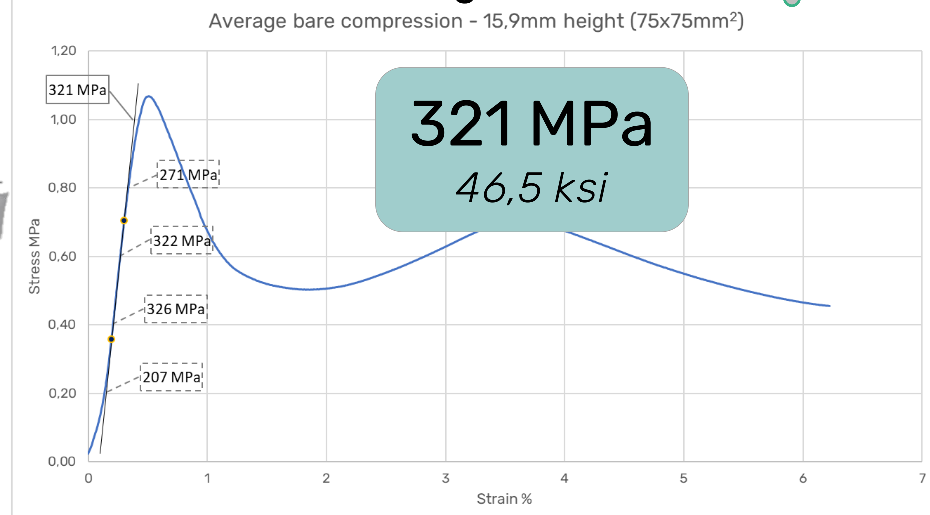


T=15,9 mm 0,625 in

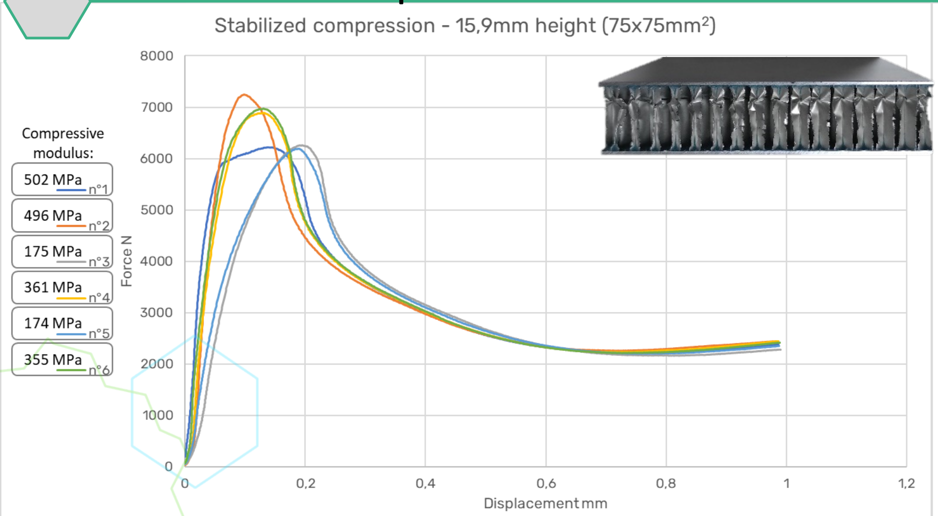
Bare compression



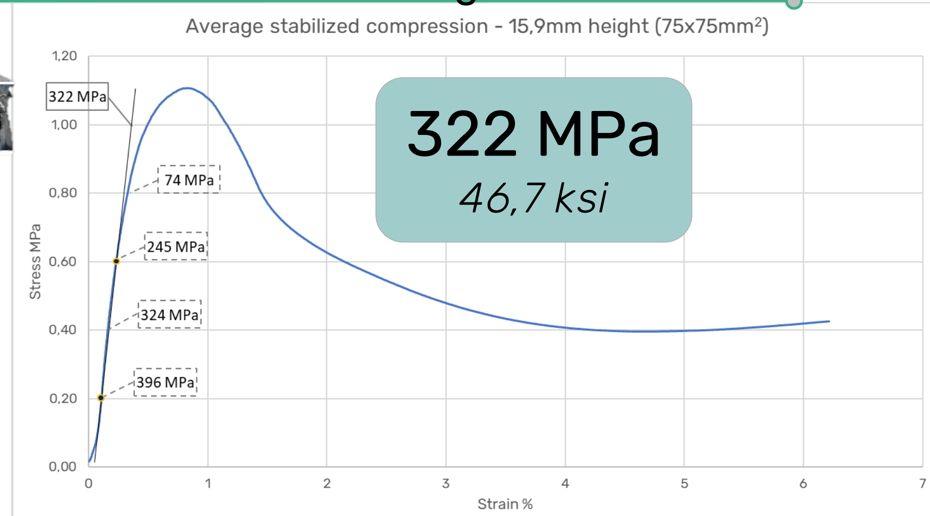
Average value



Stabilized compression



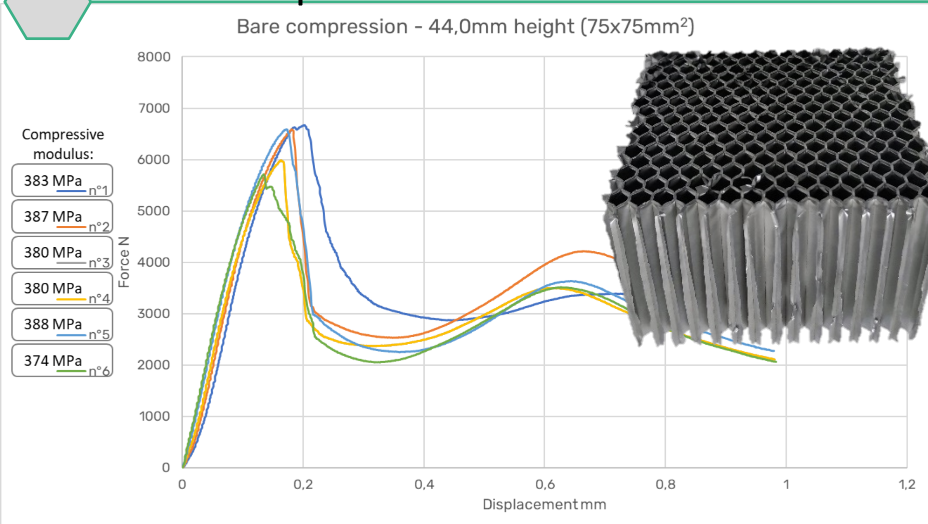
Average value

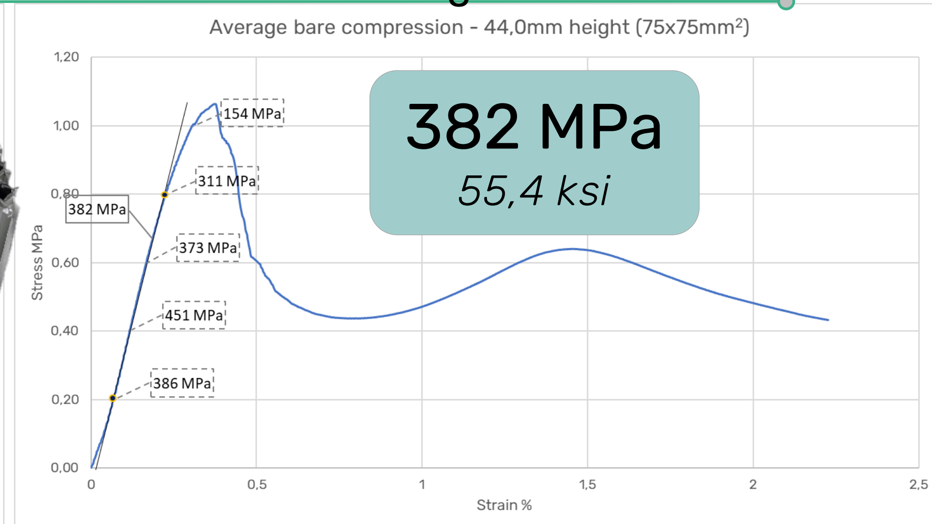


T=44,0 mm 1,732 in

Bare compression

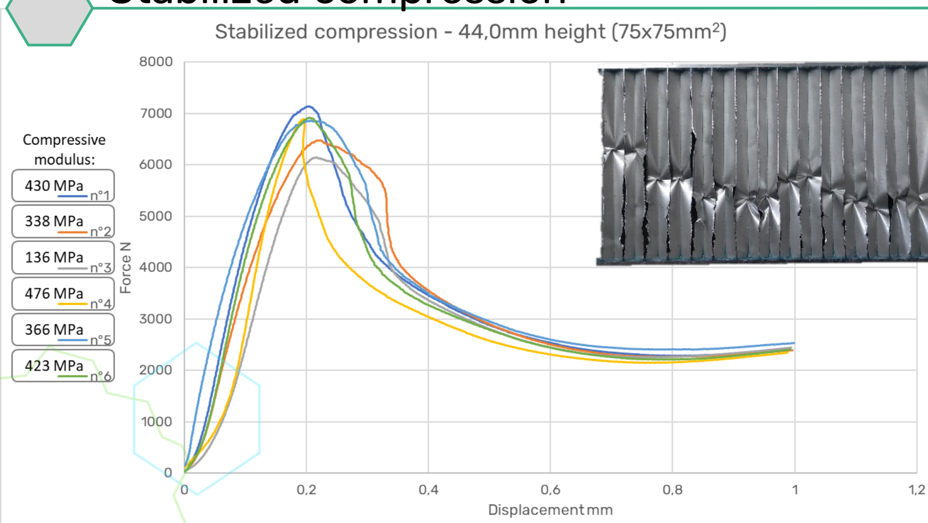
Average value

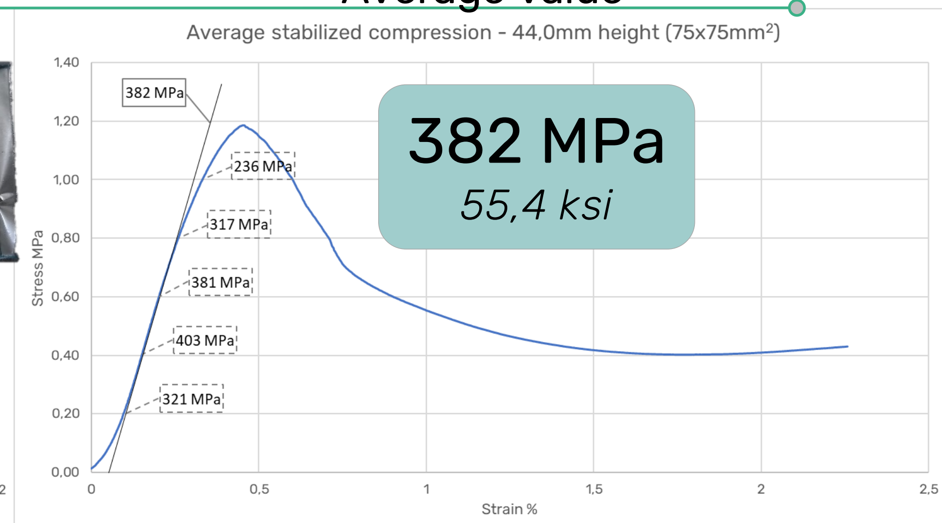




Stabilized compression

Average value

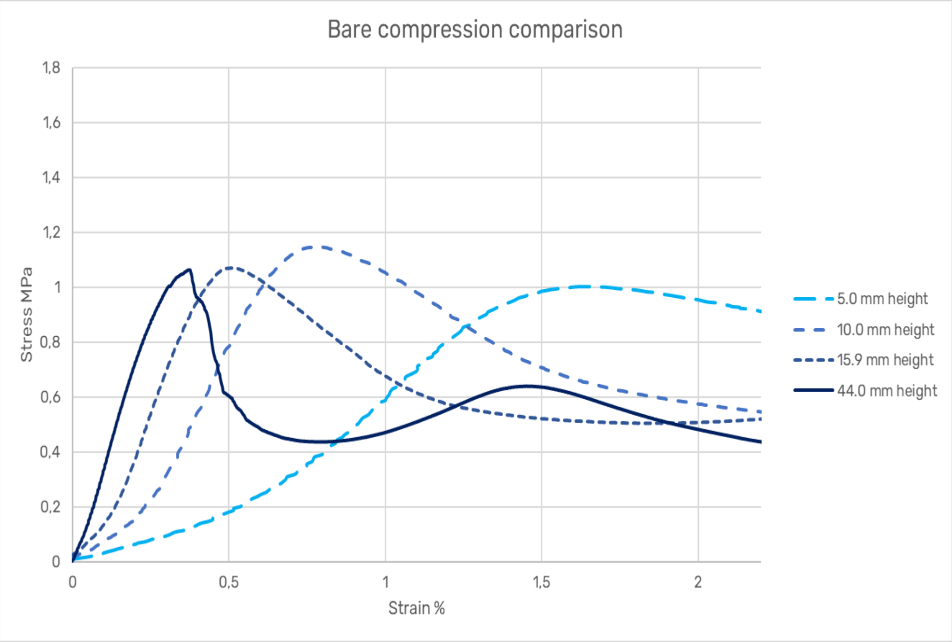


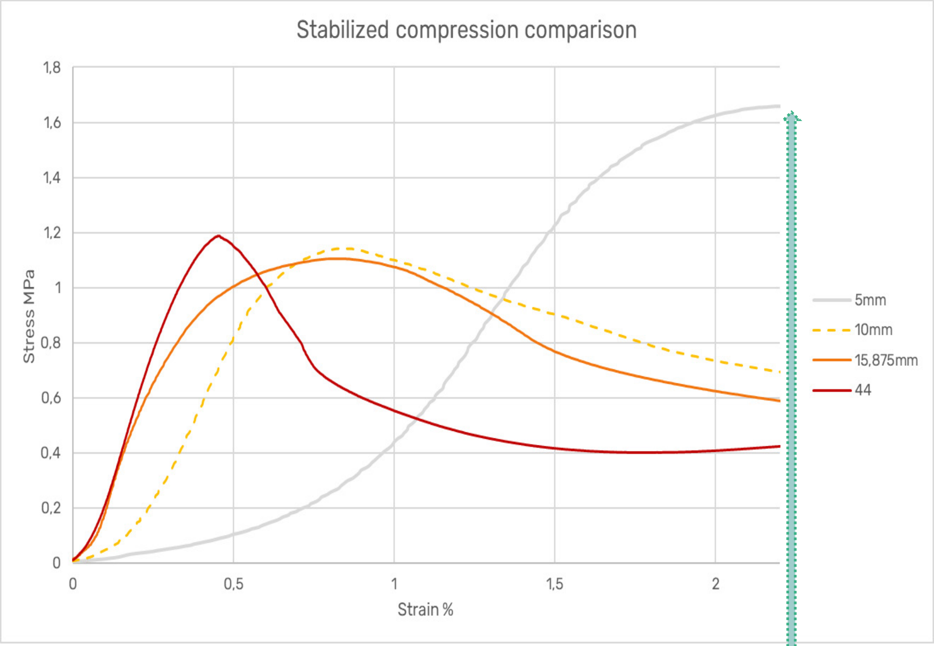


THICKNESS INTERACTION

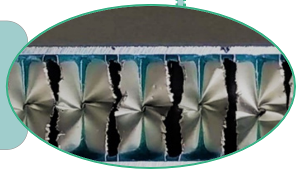
Out of plane Compressive Modulus Evolution *Hexcel 5056-3/16-0.0007-2.0*

Thickness	EC3D Experimental Bare Compression	EC3D Experimental Stabilized Compression	Hexcel Stabilized Compression
5,0 mm / *0,197 in*	97 MPa / *14,1 ksi*	170 MPa / *24,6 ksi*	-
10,0 mm / *0,394 in*	237 MPa / *34,4 ksi*	248 MPa / *36,0 ksi*	-
15,9 mm / *0,625 in*	321 MPa / *46,5 ksi*	322 MPa / *46,7 ksi*	310 MPa / *45 ksi*
44,0 mm / *1,732 in*	382 MPa / *55,4 ksi*	382 MPa / *55,4 ksi*	-

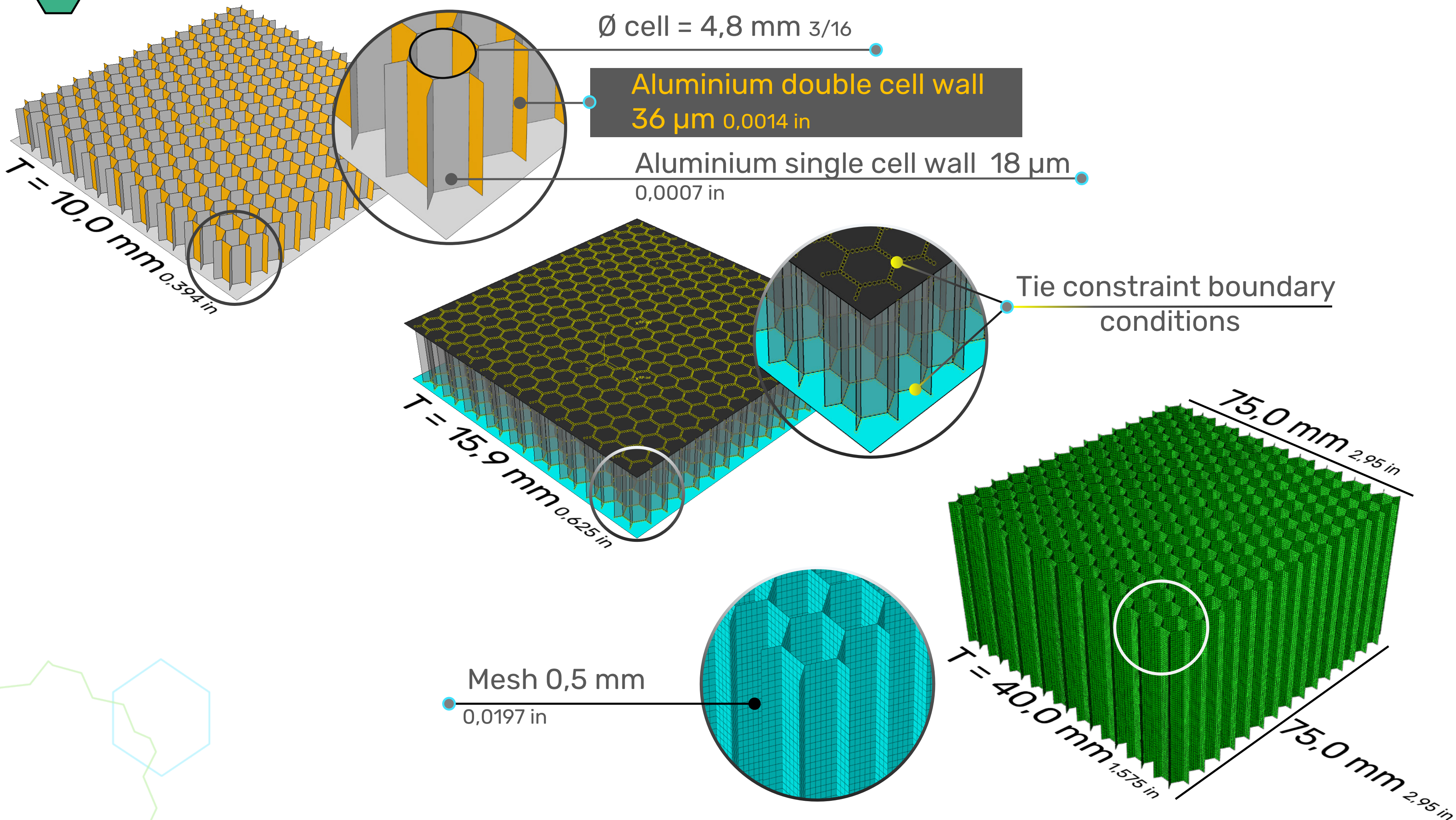




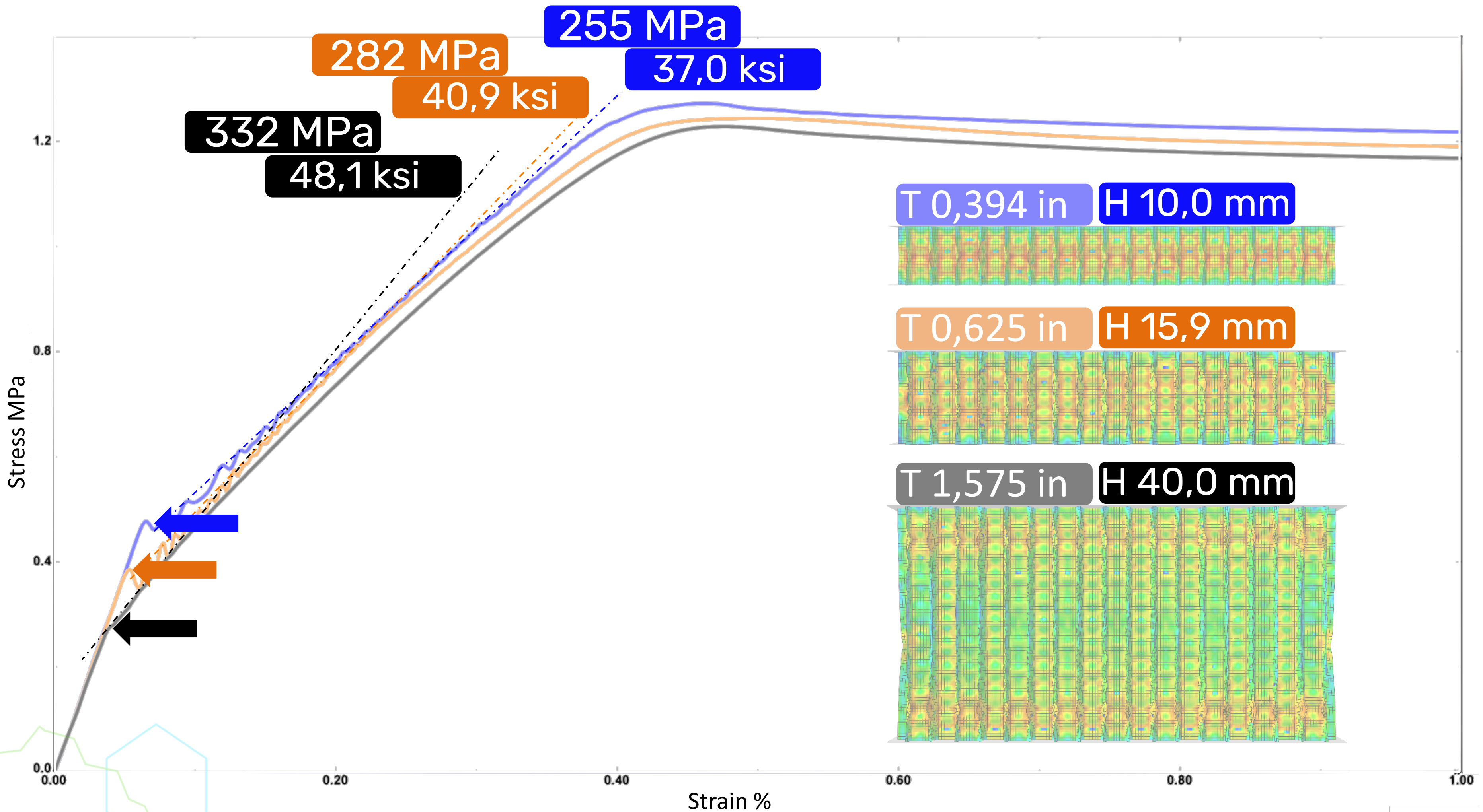
Influence of adhesive on compressive strength for stabilized 5mm thin samples



Numerical implementation



THICKNESS INTERACTION



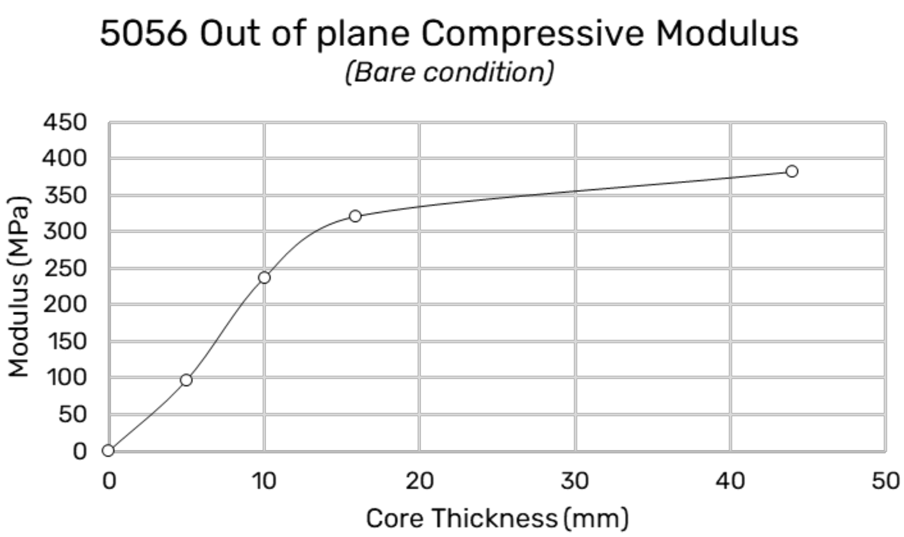
THICKNESS INTERACTION

Plastic collapse occurs at a lower strain as core thickness increase
This phenomena is measured on both bare and stabilized tests

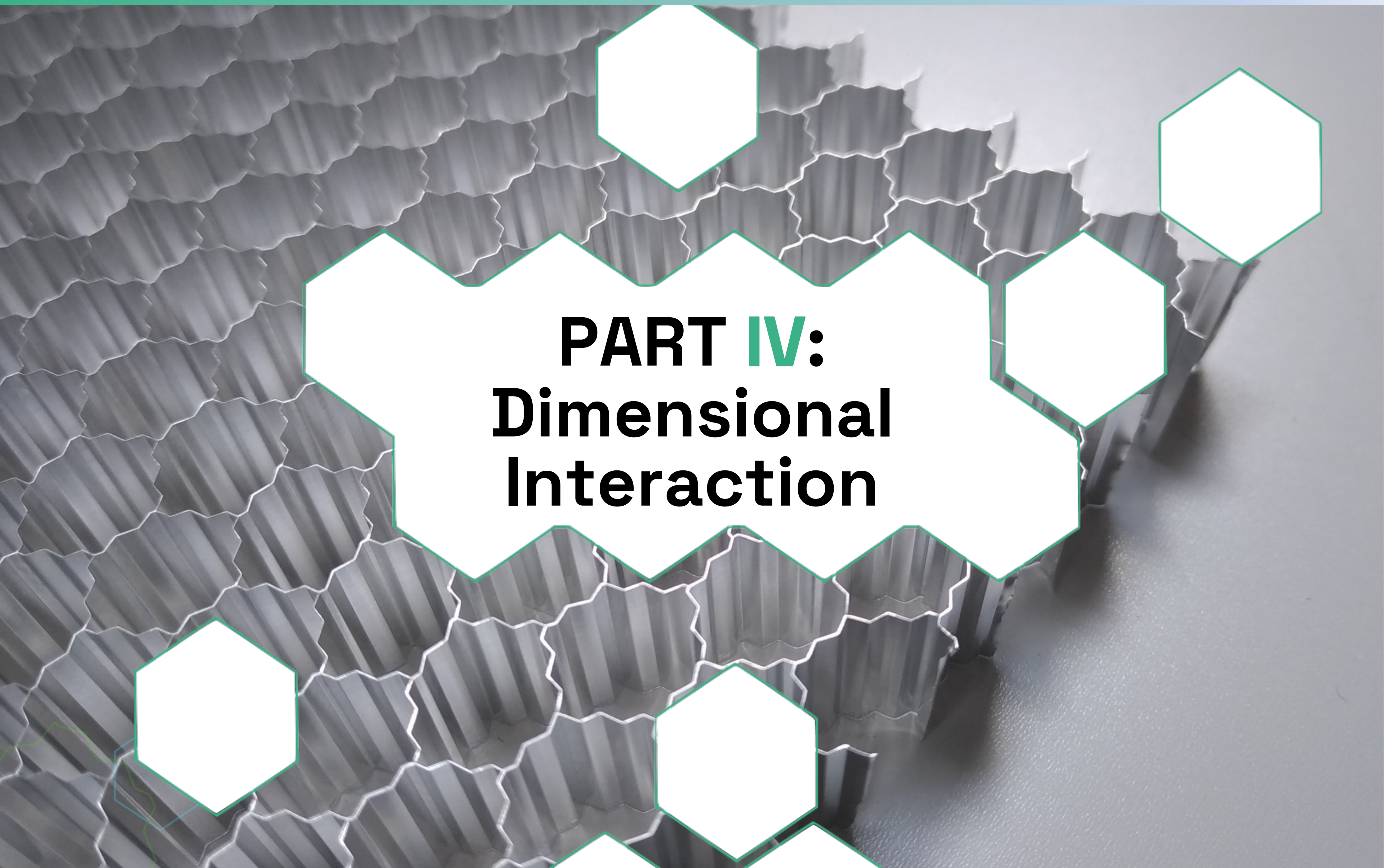
Core thickness influence on out of plane compressive modulus
is measured and the onset of micro-buckling is numerically correlated

Classical compressive normalized tests are carried out at constant thickness

The typical compressive modulus measured at T = 0,625 in
is only valid for this thickness



Negligible core thickness influence on out of plane compressive strength
Except for thin stabilized core , due to adhesive menisci reinforcement

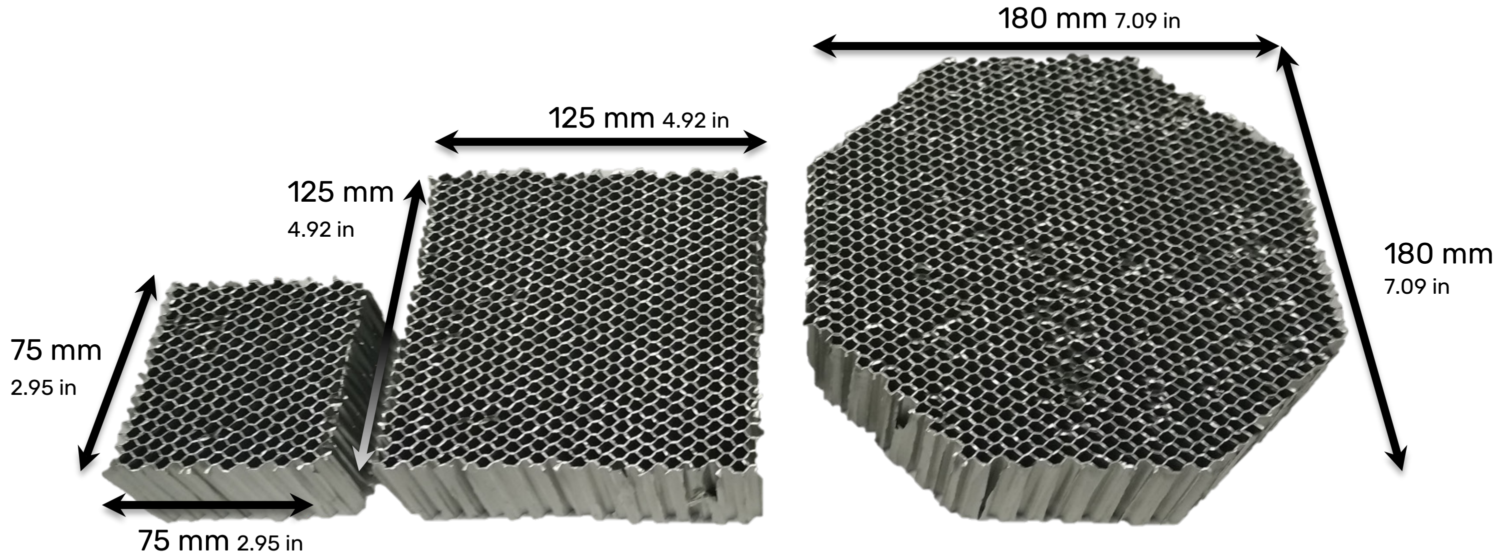


PART IV: Dimensional Interaction

Hexcel 5056-3/16-0.0007-2.0

Thickness: 44,0 mm 1,575 in

Hexagonal Classical Configuration



S_1=5625 mm^2

8.72 in^2

S_2=15625 mm^2

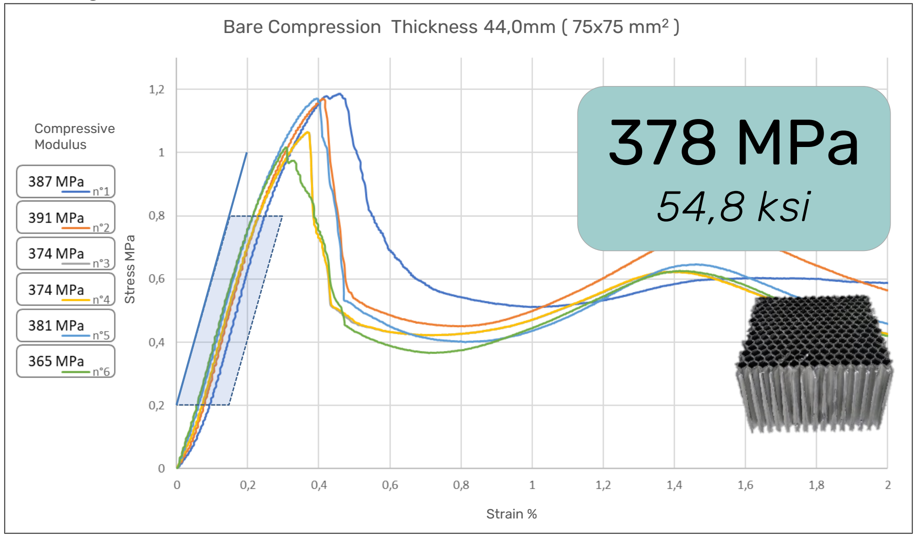
24.22 in^2

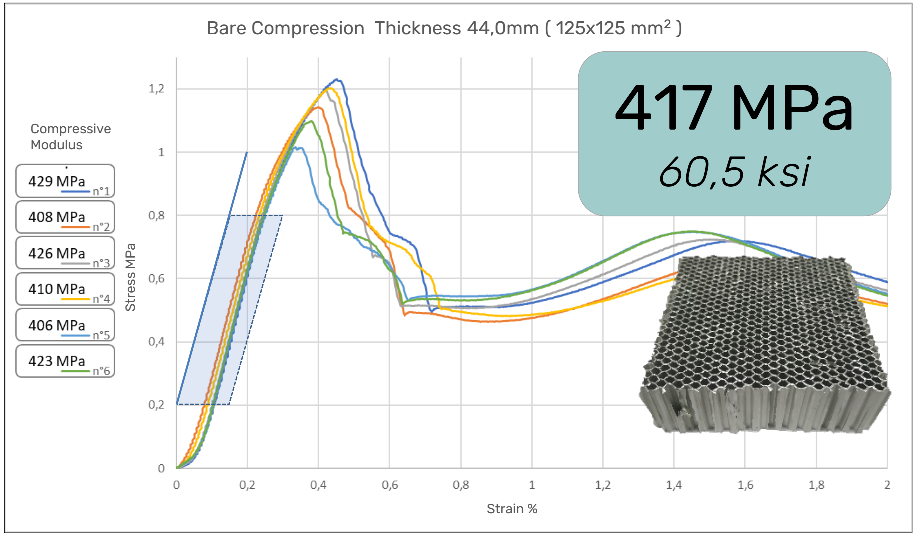
S_3=26841 mm^2

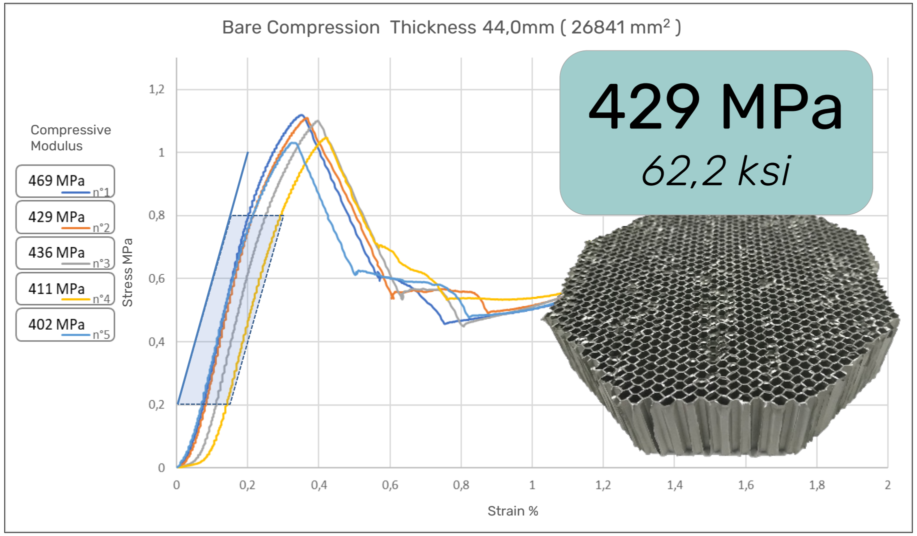
41.60 in^2

Hexcel 5056-3/16-0.0007-2.0 — Thickness: 44,0 mm 1,575 in

Hexagonal Classical Configuration







Hexcel 5056-3/16-0.0007-2.0   Thickness: 44,0 mm 1,575 in

Hexagonal Classical Configuration

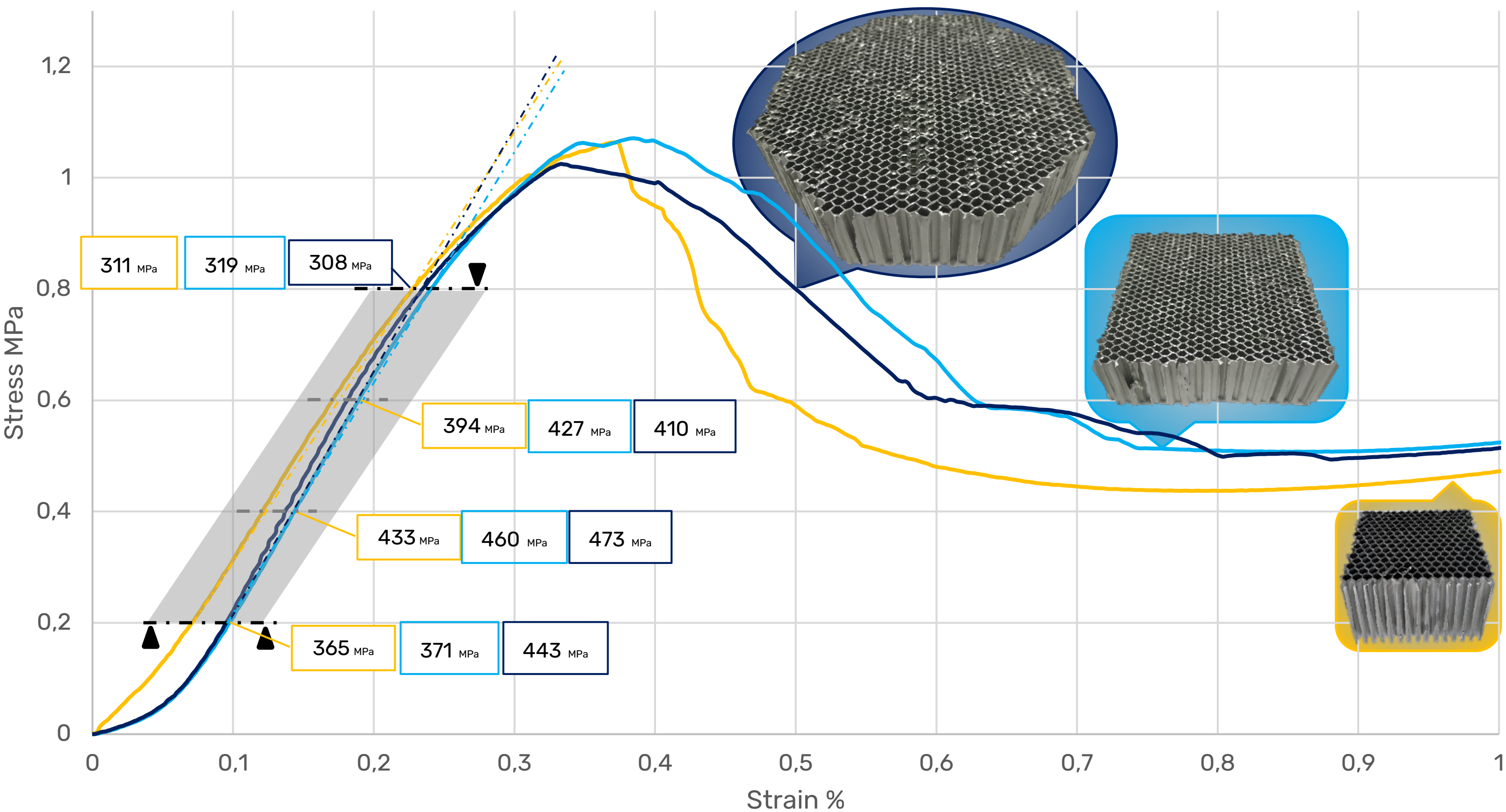
Average Bare Compression Thickness 44,0mm (5625 mm² / 15625 mm² / 26841 mm²)

Compressive Modulus:

378 MPa n°1

417 MPa n°2

429 MPa n°3



Compressive modulus is slightly influenced by
The dimensions of the specimen

Test adapted to the dimensions of the final part
Must be carried out

CONCLUSION

Typical compressive modulus data are thickness dependent

At least for metallic honeycomb structures

Compressive modulus is not constant
It must be considered as a variable

At least for metallic honeycomb structures

Future works needs to be done…

Thank you
FOR YOUR ATTENTION