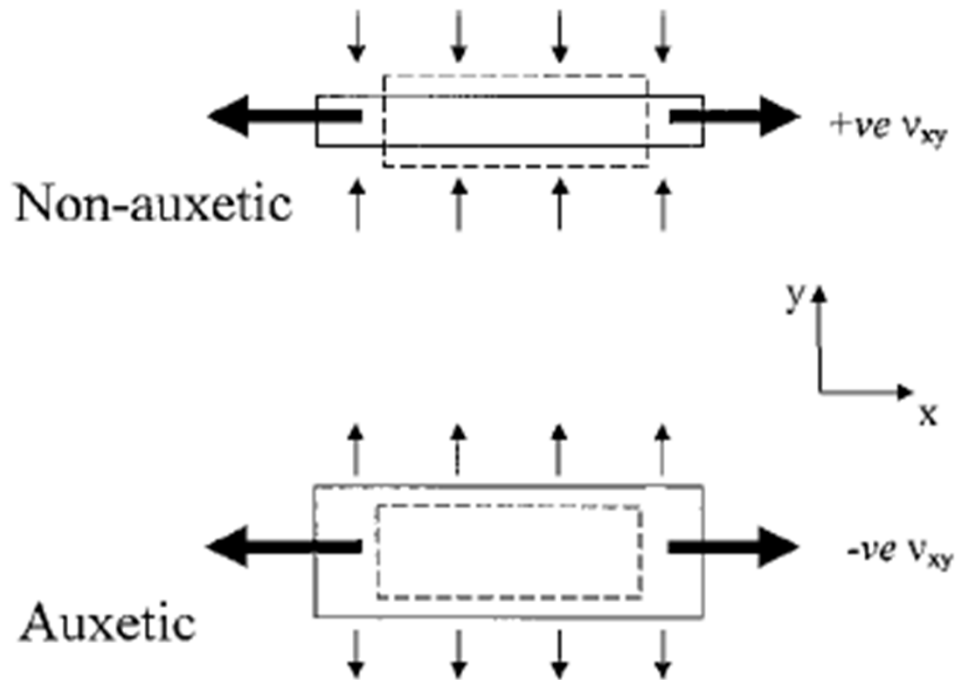


FEA of Auxetic honeycombs

F. A. Cosso

MAE656 Summer II 2012

About Auxetics

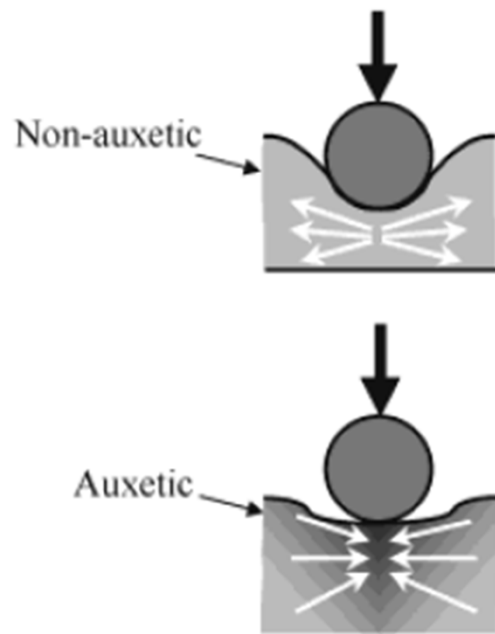


$$\nu = -\frac{d\varepsilon_{\text{trans}}}{d\varepsilon_{\text{axial}}} = -\frac{d\varepsilon_y}{d\varepsilon_x} = -\frac{d\varepsilon_z}{d\varepsilon_x}$$

Applications

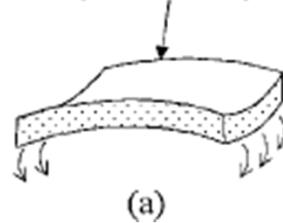
$$H \propto [(1 - \nu^2)/E]^{-x}$$

$x = 1$ – uniform pressure distribution
 $x = 2/3$ – Hertzian indentation

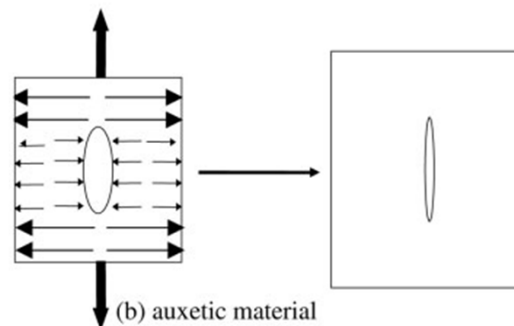
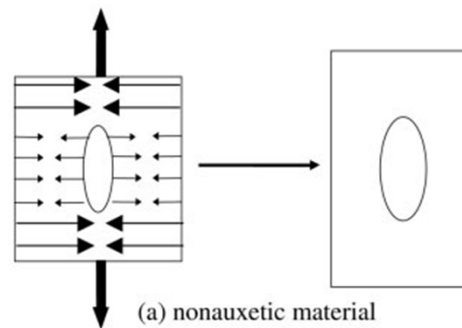
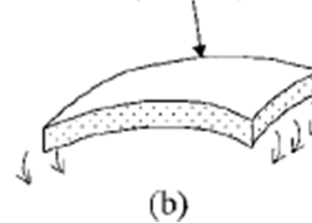


Indentation resistance

Anticlastic curvature
(non-auxetic)



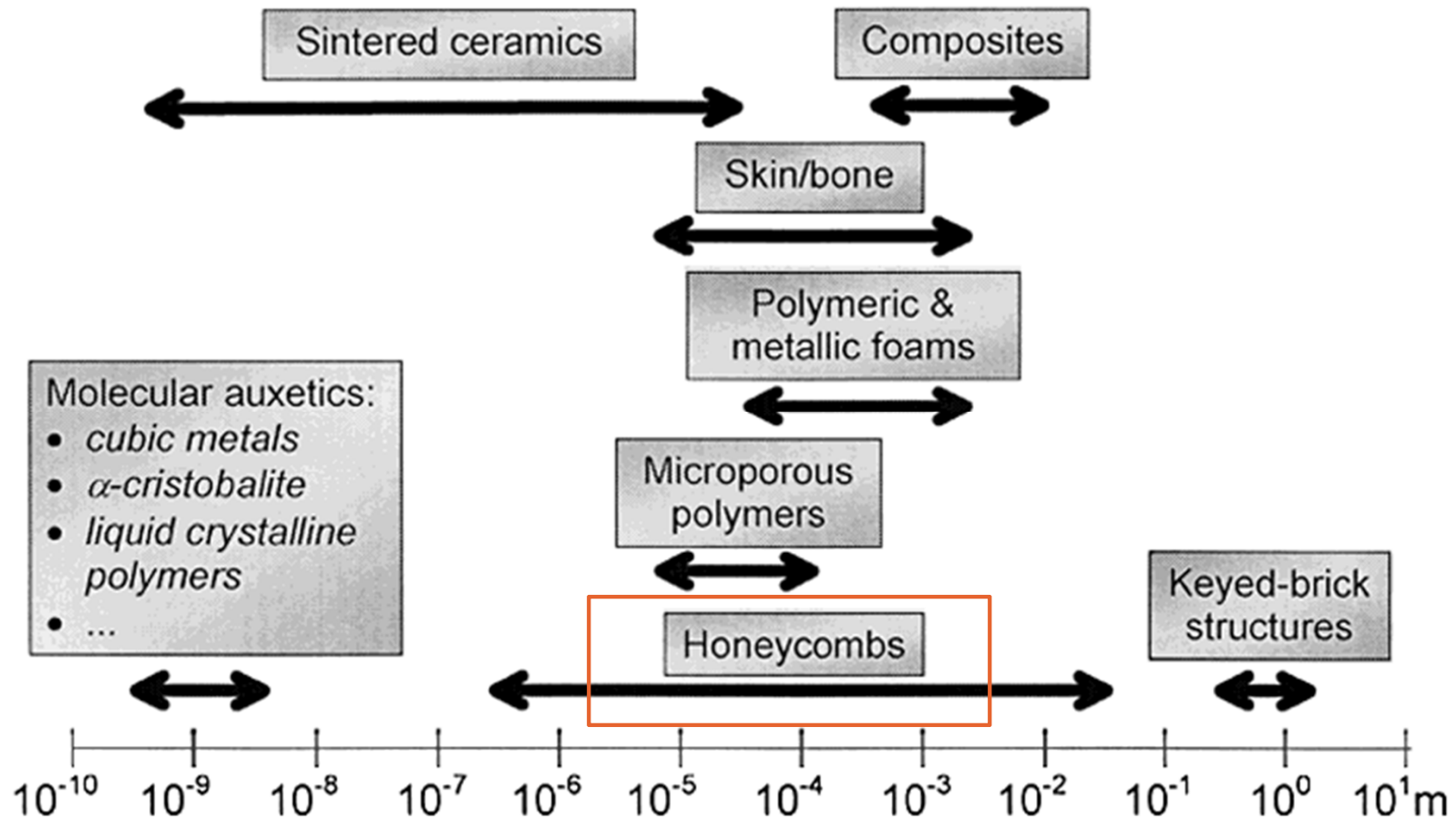
Synclastic curvature
(auxetic)



Films Tear resistance



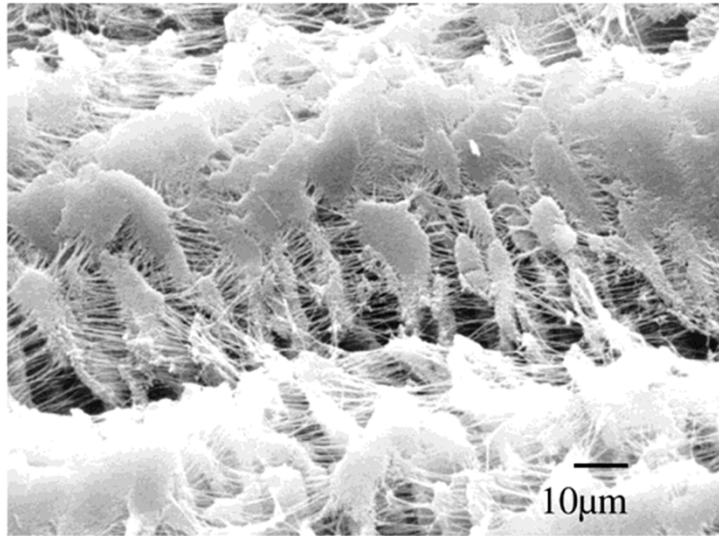
Auxetic Materials and Structures



Materials

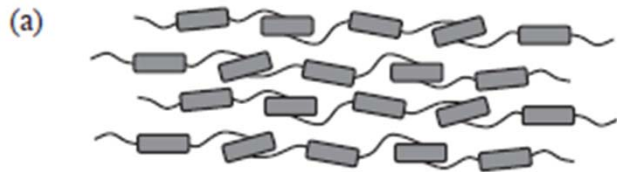
Structures

Auxetic Materials

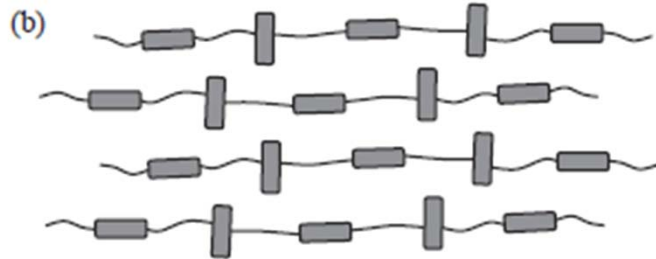


PTFE (Teflon)

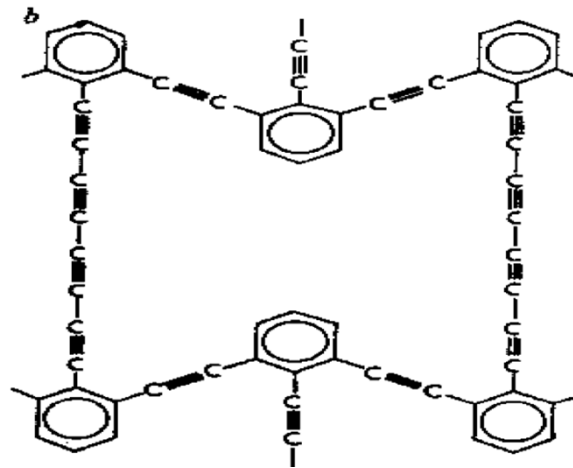
Auxetic Materials



We cannot model auxetic materials with FEA

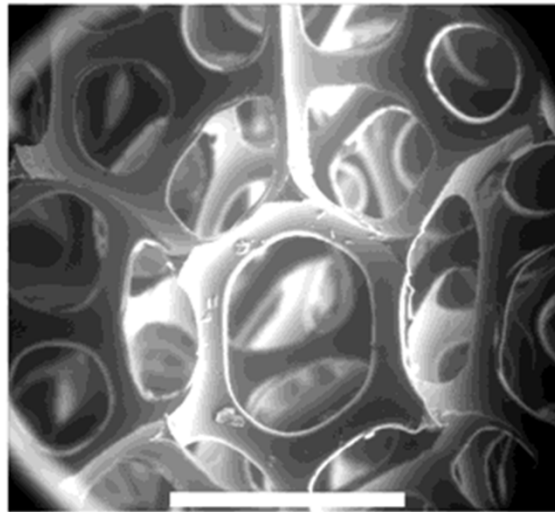


Liquid Crystals



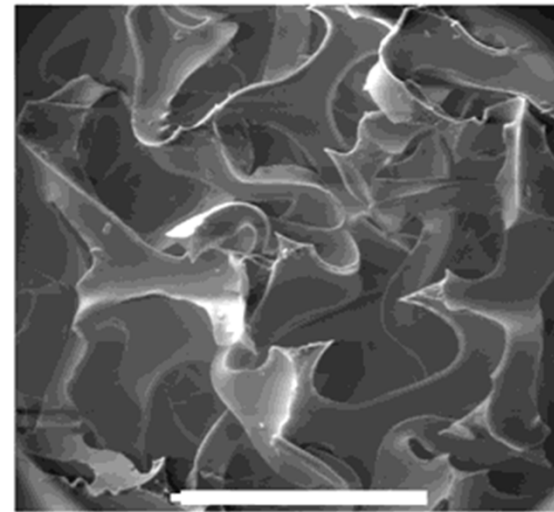
(1,4)-refexyne

Auxetic Structures



500 μm

Conventional foam



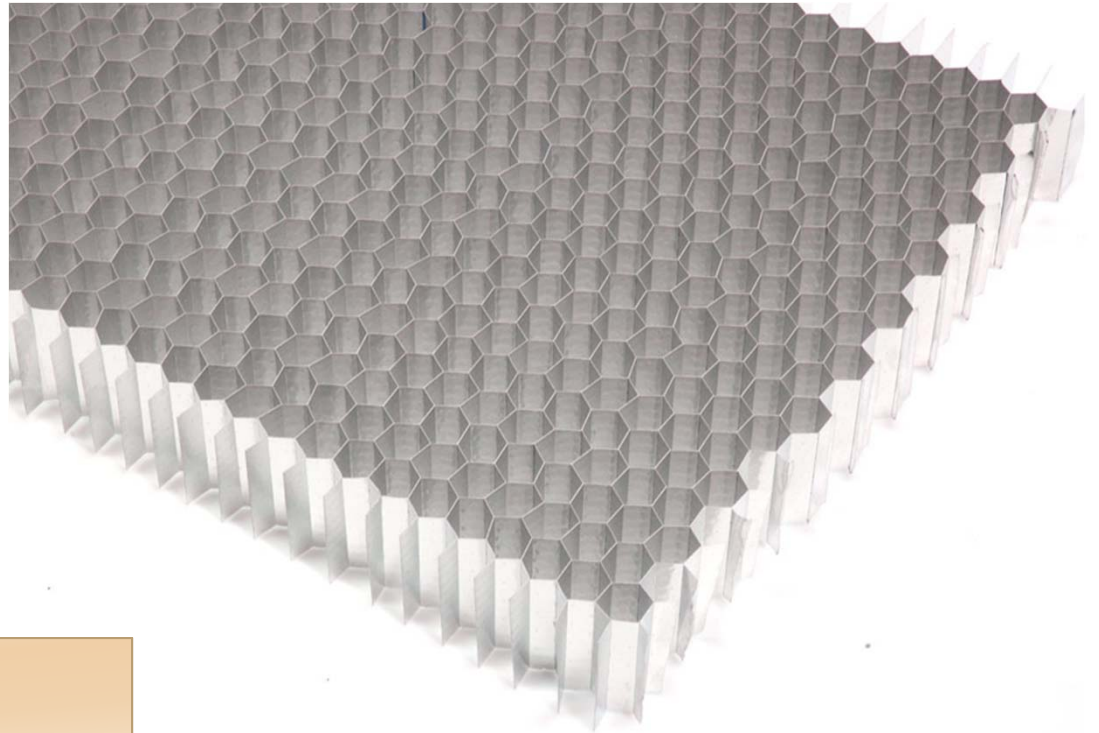
500 μm

Auxetic foam

3D and non periodic

Honeycombs

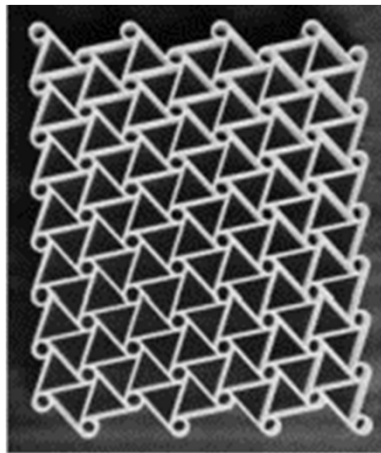
Traditional



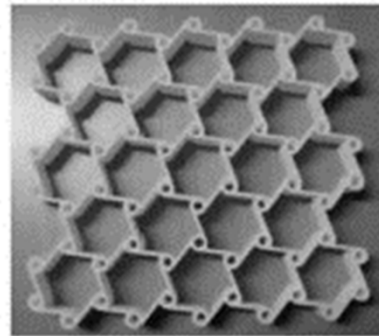
Low density
High out-of-plane compression
High out-of-plane shear properties

Honeycombs

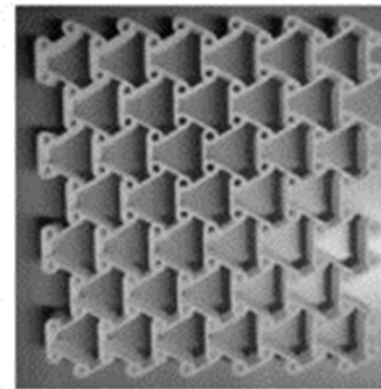
Auxetic



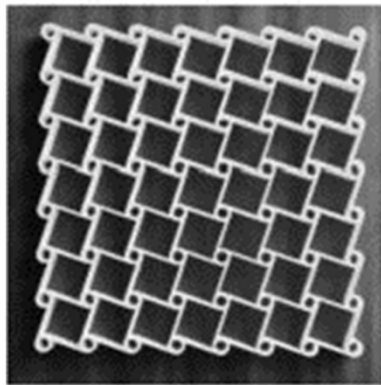
(a)



(b)



(c)



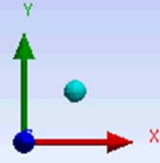
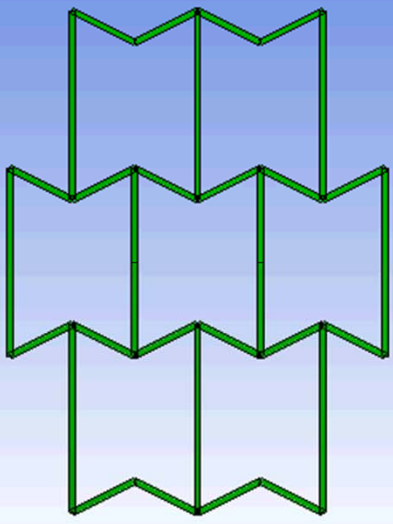
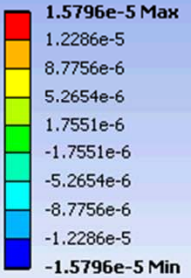
(d)



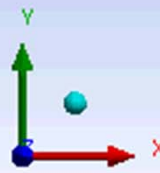
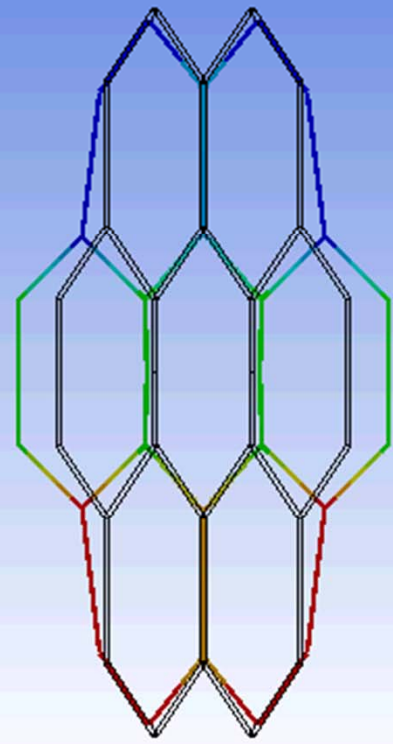
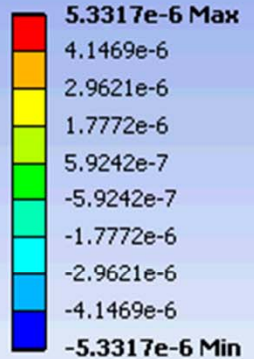
(e)

Aluminum foils
3D printing

A: Beams
 Y Axis - Directional Deformation
 Type: Directional Deformation(Y Axis)
 Unit: m
 Global Coordinate System
 Time: 0
 8/8/2012 2:40 PM



A: Beams
 Y Axis - Directional Deformation
 Type: Directional Deformation(Y Axis)
 Unit: m
 Global Coordinate System
 Time: 1
 8/8/2012 2:55 PM



Model

Material: Aluminum

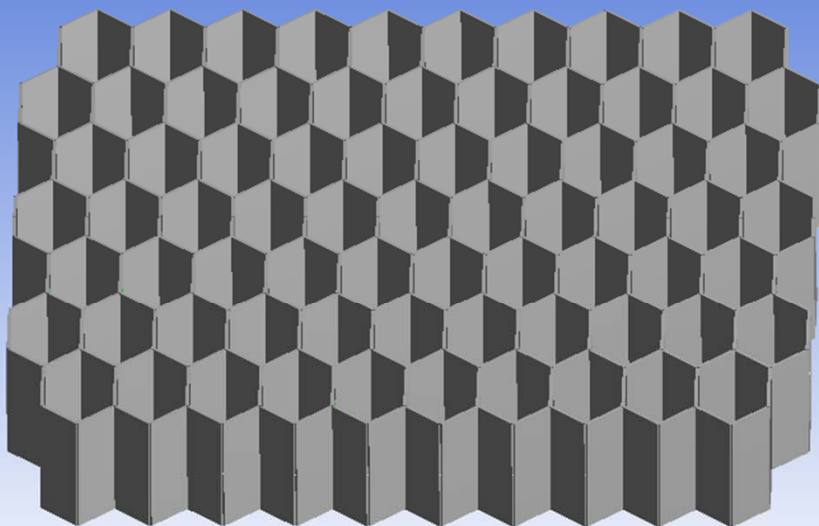
Elements: Beams

Mesh: 1 Element per wall. 2 Elements in middle walls

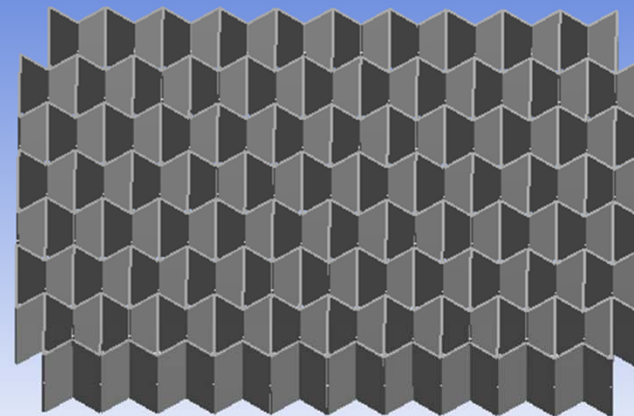
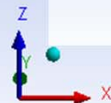
Geometry: Varies

Boundary Conditions: Pull in x direction.

Divisions
Borders



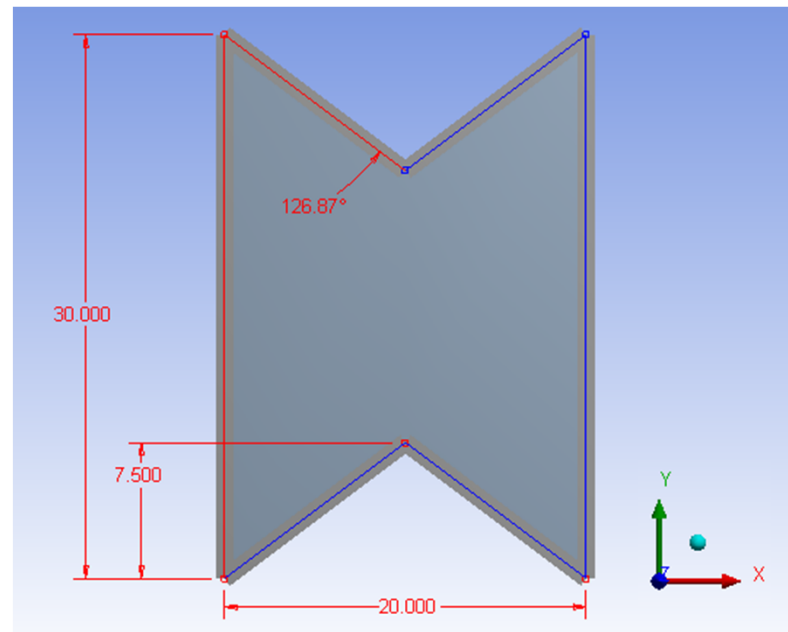
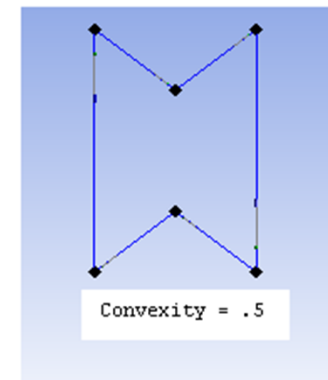
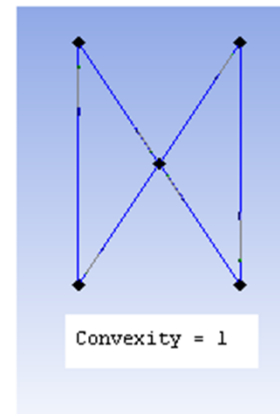
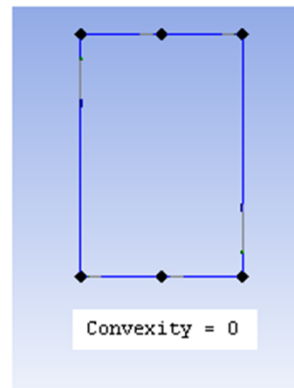
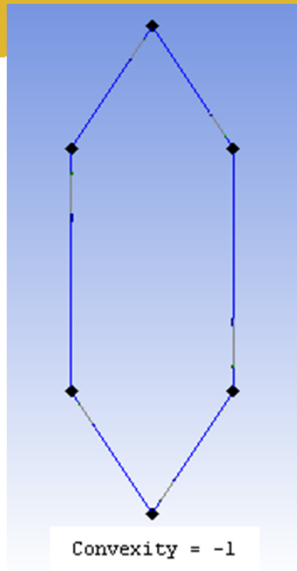
0.00 25.00 50.00 75.00 100.00 (mm)



0.00 25.00 50.00 75.00 100.00 (mm)



Geometry



Beam Cross-section

- Wall thickness: 1mm
- Height: 30mm

Geometry

Details View

Details of Point1	
Point	Point1
Type	Construction Point
Definition	Manual Input
# Points generated	6

Point Group 1 (RMB)

<input type="checkbox"/> FD8, X Coordinate	-10 mm
<input type="checkbox"/> FD9, Y Coordinate	-15 mm
<input type="checkbox"/> FD10, Z Coordinate	0 mm

Point Group 2 (RMB)

<input type="checkbox"/> FD11, X Coordinate	10 mm
<input type="checkbox"/> FD12, Y Coordinate	-15 mm
<input type="checkbox"/> FD13, Z Coordinate	0 mm

Point Group 3 (RMB)

<input type="checkbox"/> FD14, X Coordinate	-10 mm
<input type="checkbox"/> FD15, Y Coordinate	15 mm
<input type="checkbox"/> FD16, Z Coordinate	0 mm

Point Group 4 (RMB)

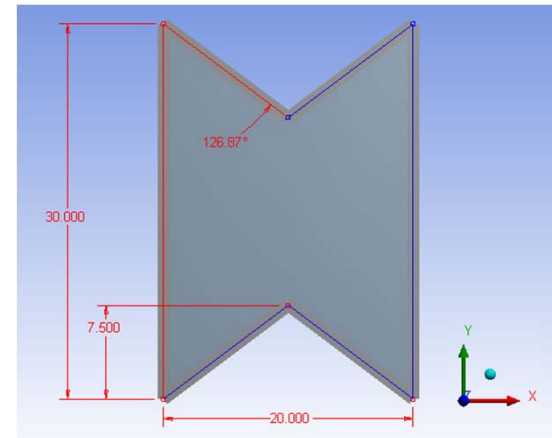
<input type="checkbox"/> FD17, X Coordinate	10 mm
<input type="checkbox"/> FD18, Y Coordinate	15 mm
<input type="checkbox"/> FD19, Z Coordinate	0 mm

Point Group 5 (RMB)

<input type="checkbox"/> FD20, X Coordinate	0 mm
<input checked="" type="checkbox"/> FD21, Y Coordinate	-28.5 mm
<input type="checkbox"/> FD22, Z Coordinate	0 mm

Point Group 6 (RMB)

<input type="checkbox"/> FD23, X Coordinate	0 mm
<input checked="" type="checkbox"/> FD24, Y Coordinate	28.5 mm
<input type="checkbox"/> FD25, Z Coordinate	0 mm



Parameter Manager

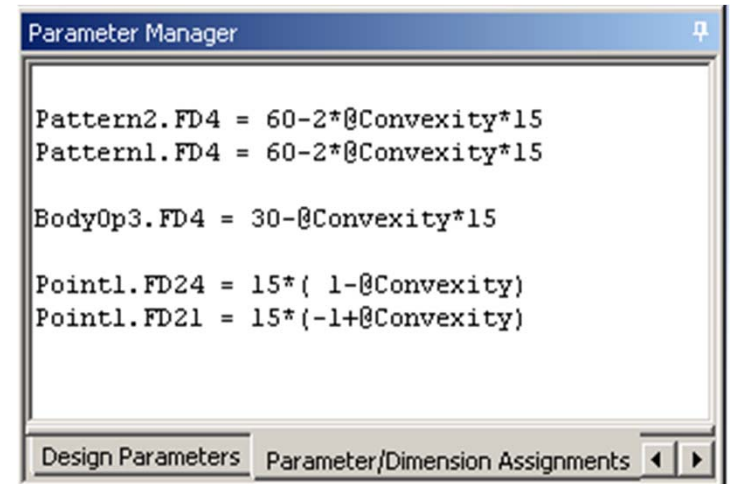
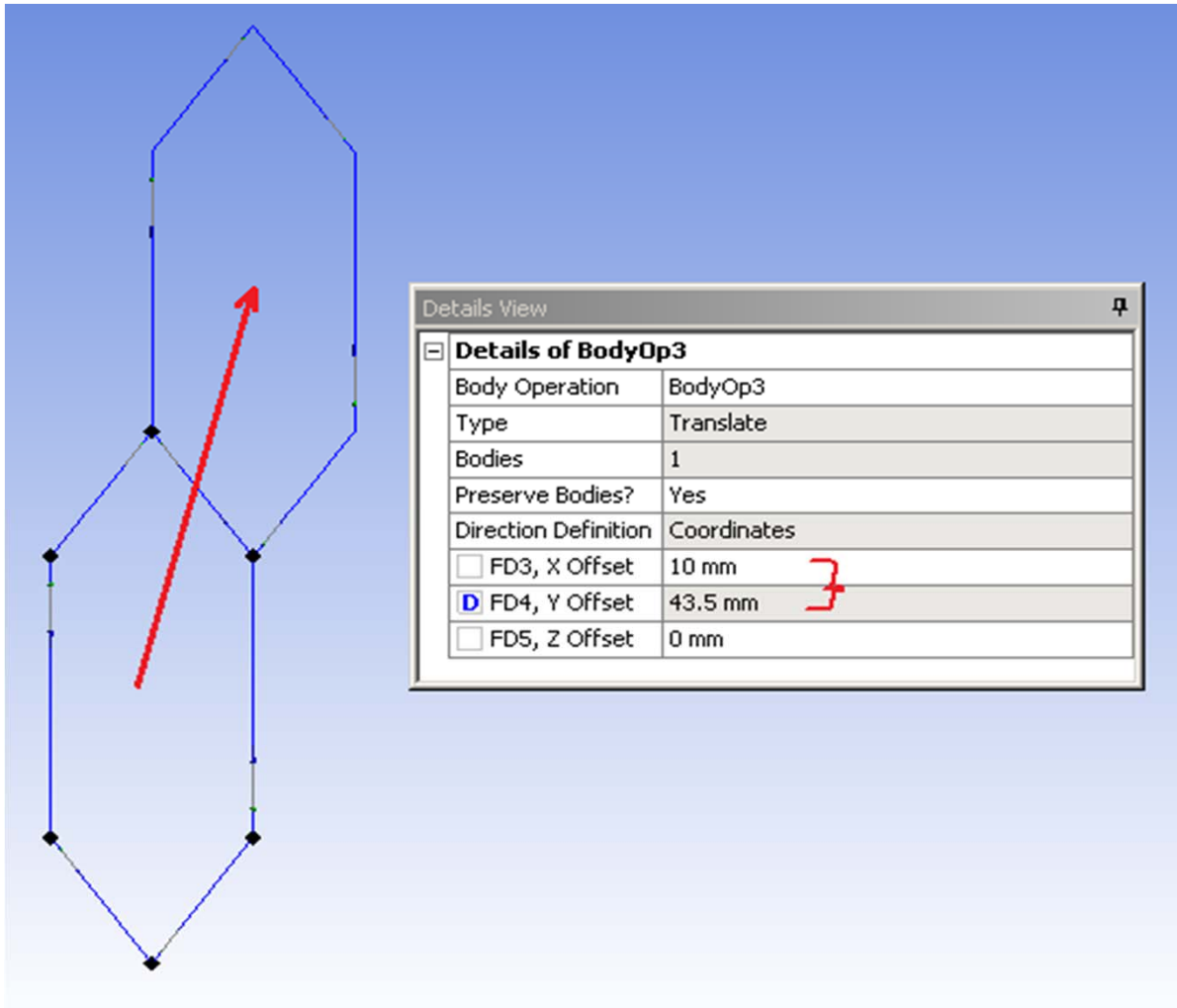
```
Pattern2.FD4 = 60-2*@Convexity*15
Pattern1.FD4 = 60-2*@Convexity*15

Body0p3.FD4 = 30-@Convexity*15

Point1.FD24 = 15*( 1-@Convexity)
Point1.FD21 = 15*(-1+@Convexity)
```

Design Parameters Parameter/Dimension Assignments

Geometry



Geometry

The image shows a CAD software interface with a hexagonal pattern of blue lines. A red L-shaped arrow indicates the direction of the pattern. Two windows are open: 'Details View' on the left and 'Parameter Manager' on the right.

Details View

Details of Pattern1	
Pattern	Pattern1
Pattern Type	Rectangular
Geometry	1 Body
Direction	2 Points
<input type="checkbox"/> FD1, Offset	20 mm
<input type="checkbox"/> FD3, Copies (>0)	5
Direction 2	3D Edge
<input checked="" type="checkbox"/> FD4, Offset 2	87 mm
<input type="checkbox"/> FD5, Copies 2 (>0)	1

Parameter Manager

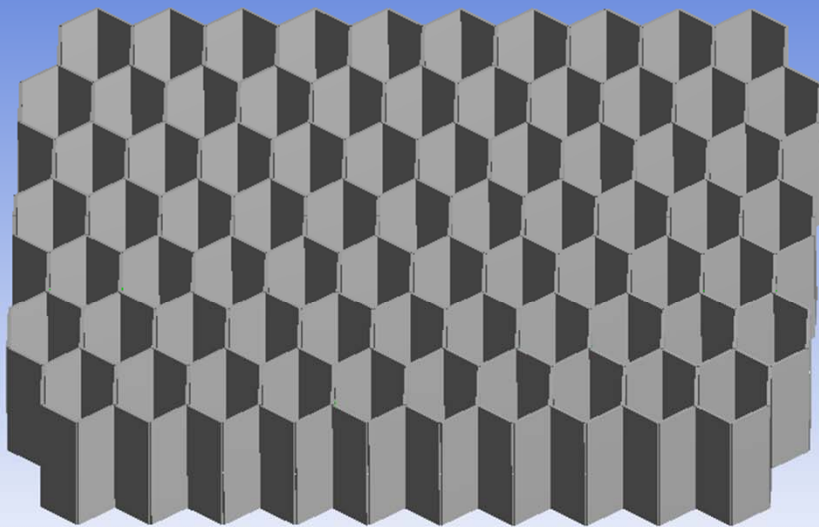
```
Pattern2.FD4 = 60-2*@Convexity*15
Pattern1.FD4 = 60-2*@Convexity*15

BodyOp3.FD4 = 30-@Convexity*15

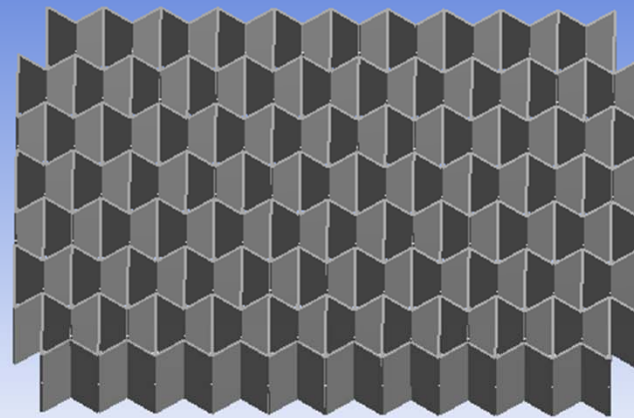
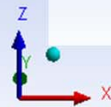
Point1.FD24 = 15*( 1-@Convexity)
Point1.FD21 = 15*(-1+@Convexity)
```

Design Parameters | Parameter/Dimension Assignments

Parametric



0.00 50.00 100.00 (mm)
25.00 75.00



0.00 50.00 100.00 (mm)
25.00 75.00



Parametric

Table of Design Points						
	A	B	C	D	E	F
1	Name ▾	P3 - Convexity	P4 - Y Axis - Directional Deformation Minimum ▾	P5 - X Axis - Directional Deformation Minimum ▾	<input type="checkbox"/> Exported	Note ▾
2	Units		m	m		
3	DP 74	-2	-1.6379E-06	2E-05	<input type="checkbox"/>	
4	DP 73	-1.9	-1.7267E-06	2E-05	<input type="checkbox"/>	
5	DP 72	-1.8	-1.8256E-06	2E-05	<input type="checkbox"/>	
6	DP 71	-1.7	-1.9365E-06	2E-05	<input type="checkbox"/>	
7	DP 70	-1.6	-2.0615E-06	2E-05	<input type="checkbox"/>	
8	DP 69	-1.5	-2.2035E-06	2E-05	<input type="checkbox"/>	
9	DP 68	-1.4	-2.3661E-06	2E-05	<input type="checkbox"/>	
10	DP 67	-1.3	-2.5541E-06	2E-05	<input type="checkbox"/>	
11	DP 66	-1.2	-2.7738E-06	2E-05	<input type="checkbox"/>	
12	DP 65	-1.1	-3.0339E-06	2E-05	<input type="checkbox"/>	
13	DP 64	-1	-3.3465E-06	2E-05	<input type="checkbox"/>	
14	Current	-0.9	-3.729E-06	2E-05		
15	DP 1	-0.8	-4.2073E-06	2E-05	<input type="checkbox"/>	
16	DP 2	-0.7	-4.8215E-06	2E-05	<input type="checkbox"/>	
17	DP 3	-0.6	-5.6364E-06	2E-05	<input type="checkbox"/>	
18	DP 4	-0.5	-6.7645E-06	2E-05	<input type="checkbox"/>	
19	DP 5	-0.4	-8.4184E-06	2E-05	<input type="checkbox"/>	
20	DP 6	-0.3	-1.1049E-05	2E-05	<input type="checkbox"/>	

Only after the model has been validated!
Make sure the results make sense!

Boundary Conditions

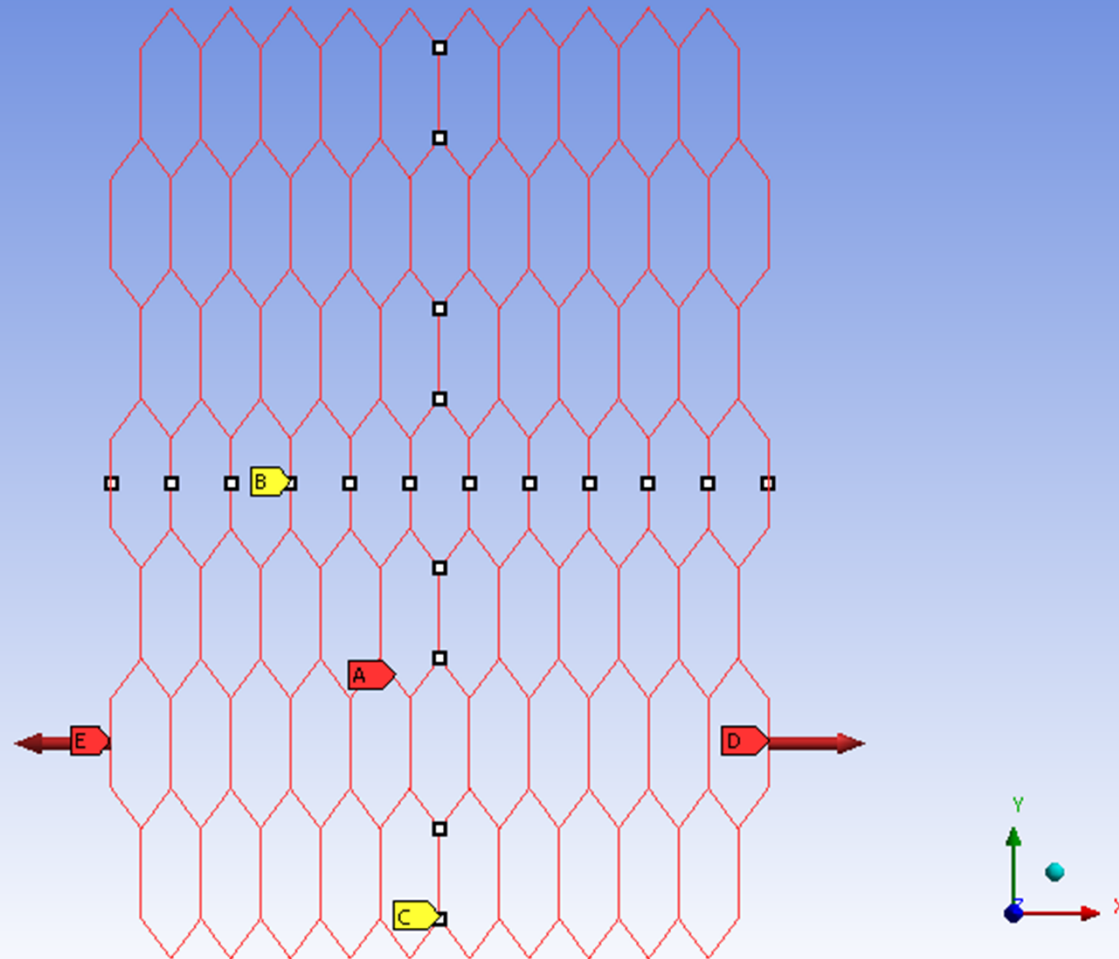
A: Beams

Static Structural

Time: 1. s

8/9/2012 8:39 AM

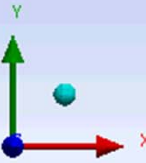
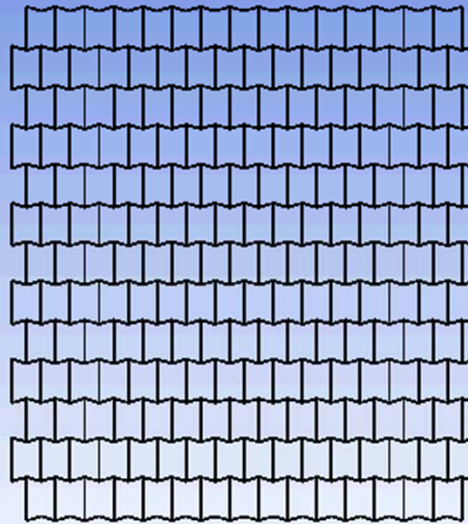
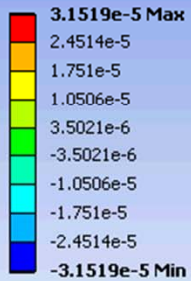
- A** NoZ
- B** SymY
- C** SymX
- D** PlusX
- E** MinusX



Border Effects

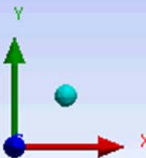
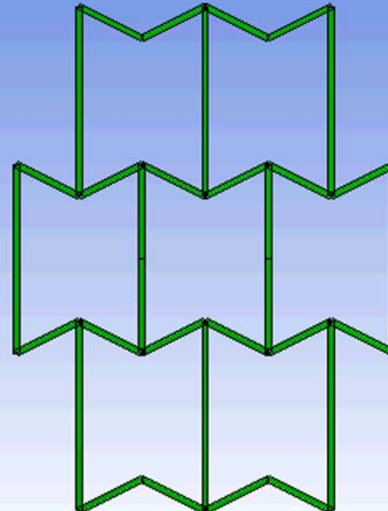
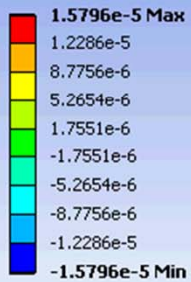
A: Beams

Y Axis - Directional Deformation
Type: Directional Deformation(Y Axis)
Unit: m
Global Coordinate System
Time: 0
8/8/2012 3:44 PM

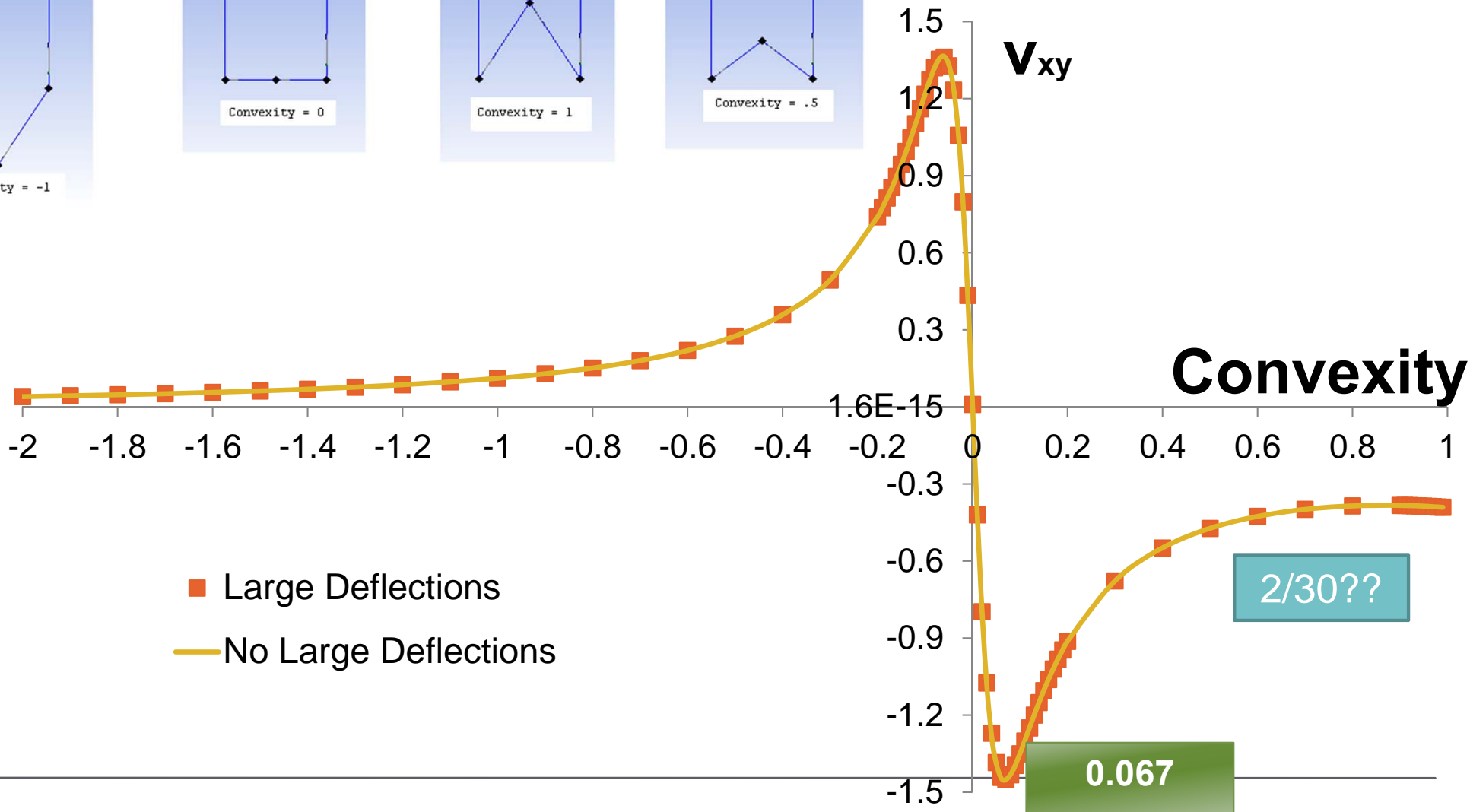
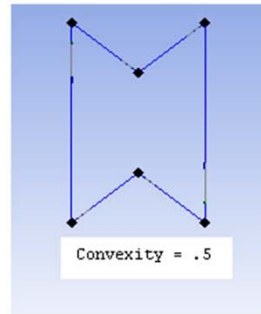
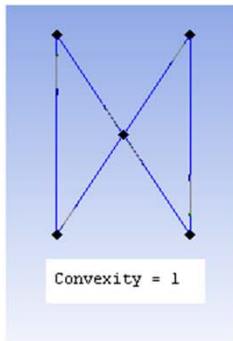
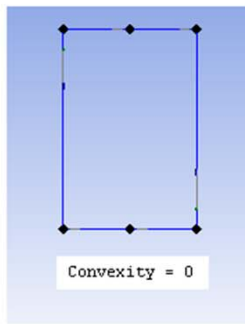
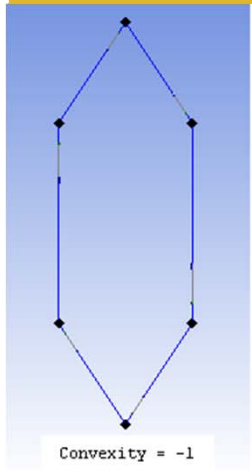


A: Beams

Y Axis - Directional Deformation
Type: Directional Deformation(Y Axis)
Unit: m
Global Coordinate System
Time: 0
8/8/2012 2:40 PM



Poisson's Ratio vs. Convexity



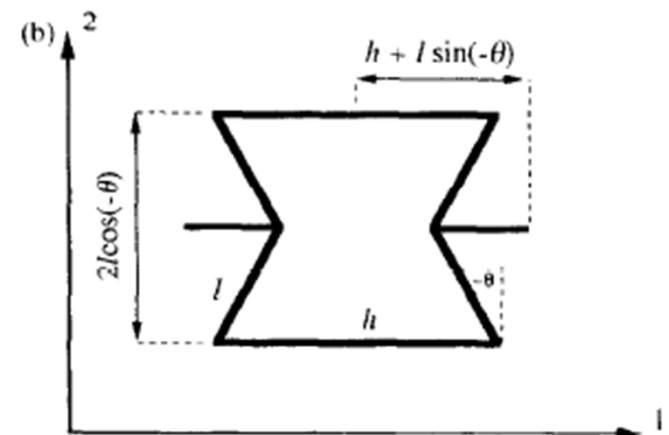
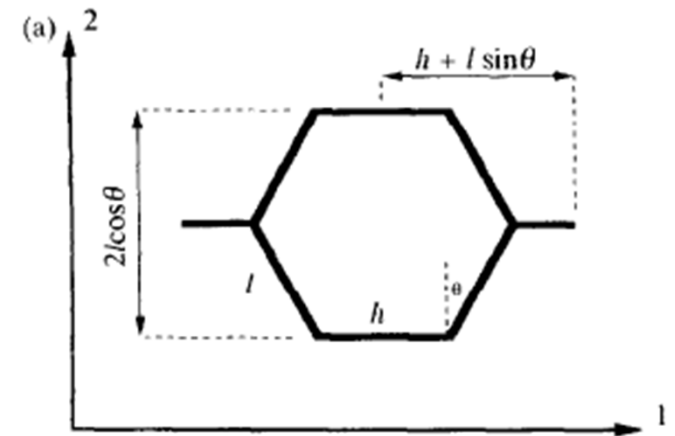
Results

$$\begin{aligned}v_{12} &= \frac{1}{v_{21}} = -\tan(\theta) \frac{X_1}{X_2} \\ &= -\tan(\theta) \frac{l \sin(\theta)}{h - l \cos(\theta)}\end{aligned}$$

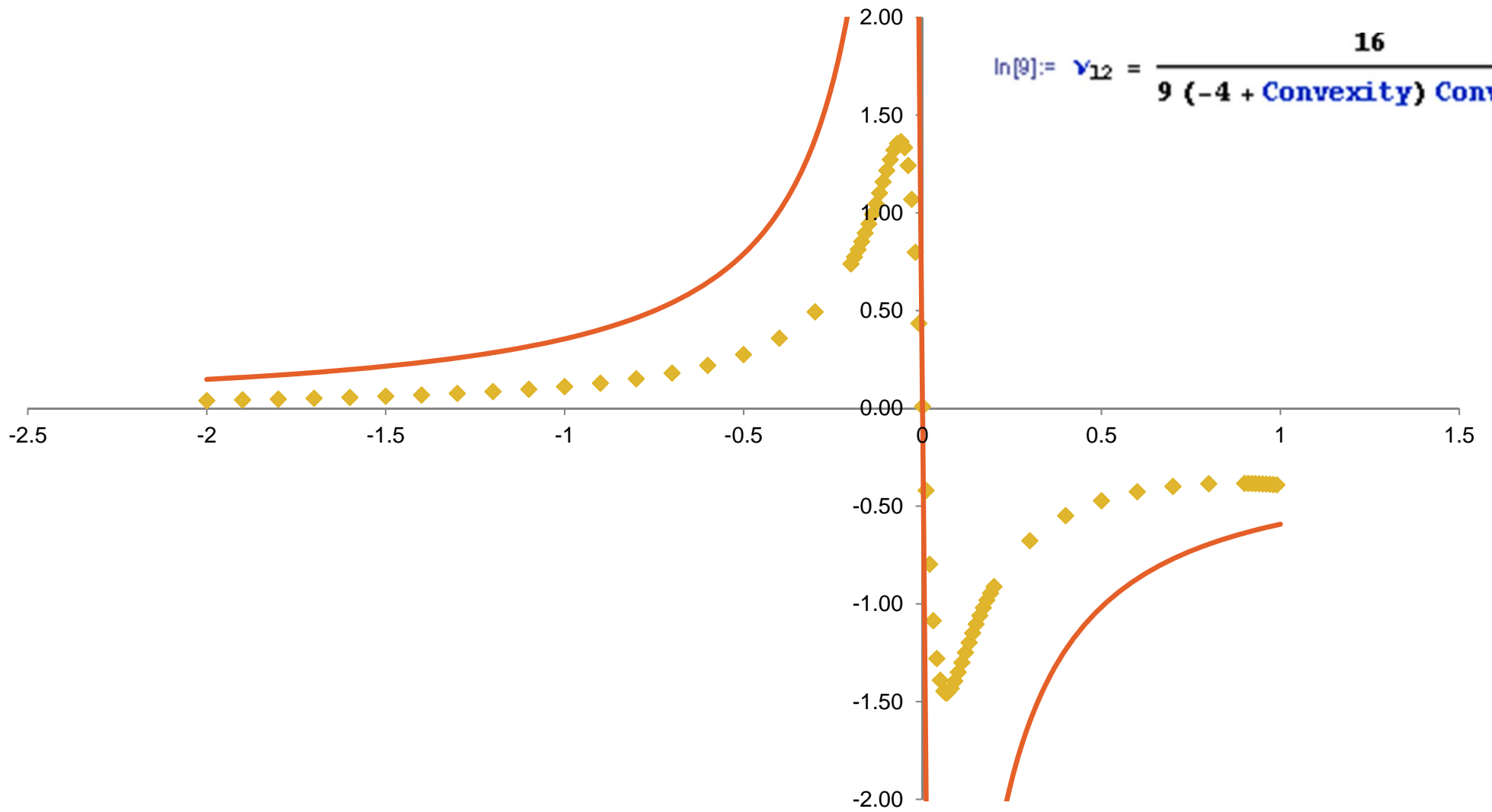
Auxetic: $0^\circ < \theta < 90^\circ$

Conventional: $90^\circ < \theta < 180^\circ$

Magic Formula



Results



$$\text{In[9]:= } v_{12} = \frac{16}{9(-4 + \text{Convexity}) \text{Convexity}}$$

Results

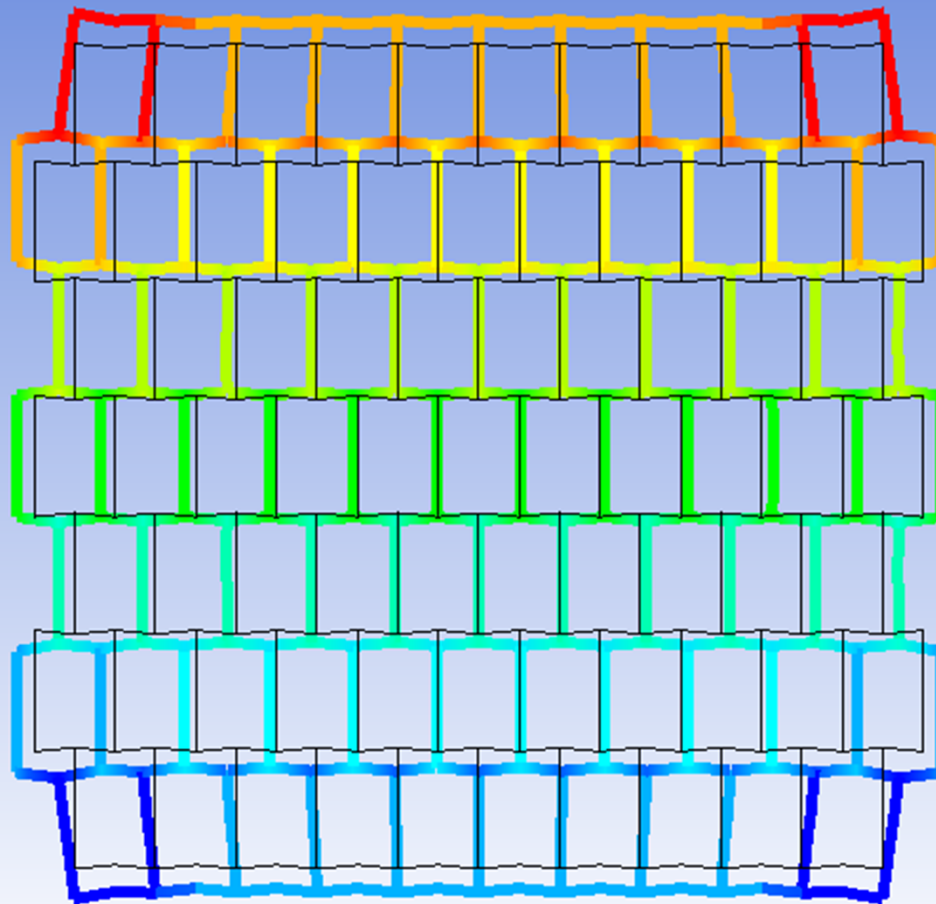
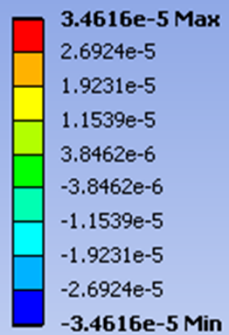
Convexity	DespY	DespX	SizeY	SizeX	StrainY	StrainX	PoissonXY
-2	-1.64E-06	2.00E-05	0.225	0.11	-7.28E-06	1.82E-04	0.04
-1.9	-1.73E-06	2.00E-05	0.219	0.11	-7.88E-06	1.82E-04	0.04
-1.8	-1.83E-06	2.00E-05	0.213	0.11	-8.57E-06	1.82E-04	0.05
-1.7	-1.94E-06	2.00E-05	0.207	0.11	-9.35E-06	1.82E-04	0.05
-1.6	-2.06E-06	2.00E-05	0.201	0.11	-1.03E-05	1.82E-04	0.06
-1.5	-2.20E-06	2.00E-05	0.195	0.11	-1.13E-05	1.82E-04	0.06
-1.4	-2.37E-06	2.00E-05	0.189	0.11	-1.25E-05	1.82E-04	0.07
-1.3	-2.55E-06	2.00E-05	0.183	0.11	-1.40E-05	1.82E-04	0.08
-1.2	-2.77E-06	2.00E-05	0.177	0.11	-1.57E-05	1.82E-04	0.09
-1.1	-3.03E-06	2.00E-05	0.171	0.11	-1.77E-05	1.82E-04	0.10
-1	-3.35E-06	2.00E-05	0.165	0.11	-2.03E-05	1.82E-04	0.11
-0.9	-3.73E-06	2.00E-05	0.159	0.11	-2.34E-05	1.82E-04	0.13
-0.8	-4.21E-06	2.00E-05	0.153	0.11	-2.75E-05	1.82E-04	0.15
-0.7	-4.82E-06	2.00E-05	0.147	0.11	-3.28E-05	1.82E-04	0.18
-0.6	-5.64E-06	2.00E-05	0.141	0.11	-4.00E-05	1.82E-04	0.22
-0.5	-6.76E-06	2.00E-05	0.135	0.11	-5.01E-05	1.82E-04	0.28
.....

Only after the model has been validated!
Make sure the results make sense!

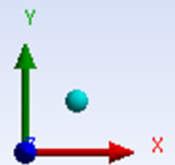
Optimum

A: Beams

Y Axis - Directional Deformation
Type: Directional Deformation(Y Axis)
Unit: m
Global Coordinate System
Time: 1
8/8/2012 8:40 PM



Convexity 0.067



Squares

ANSYS
14.0

A: Beams

X Axis - Directional Deformation

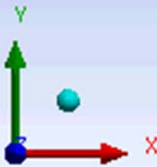
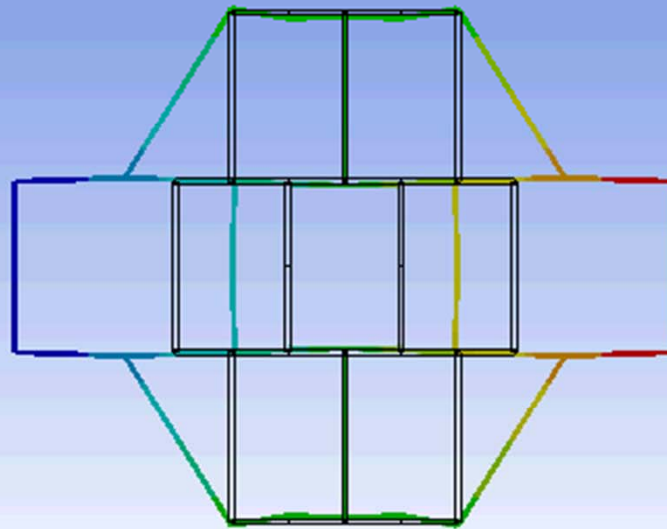
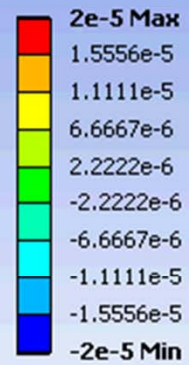
Type: Directional Deformation(X Axis)

Unit: m

Global Coordinate System

Time: 1

8/8/2012 2:58 PM



Conclusions

- Auxetic materials present a rather unique property that can be exploited in several applications.
 - A FEA for reentrant hexagonal aluminum honeycombs determined the optimum convexity at 0.067.
 - Lots of graphics and animations were produced and will be uploaded to youtube.com
 - Periodic Boundary conditions are the way to go in this cases to prevent Border Effects.
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Questions?

