Influence of static load on the Young's modulus estimation of polymer foams

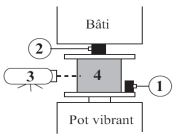
NICOLAS DAUCHEZ[1], THIBAUT VERNAY[1], Xinhe ZHANG[1], Frédéric ABLITZER[2]

[1] UNIVERSITÉ DE TECHNOLOGIE DE COMPIÈGNE
[2] UNIVERSITÉ DU MAINE, LE MANS

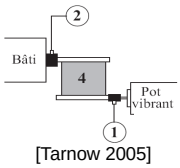
How to measure Young's modulus ?

2

- Young'modulus *E*
  - Quasistatic methods

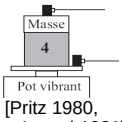


[Mariez 1996, Dauchez 2002]

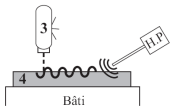


[Tarnow 2005]

  - Dynamic methods

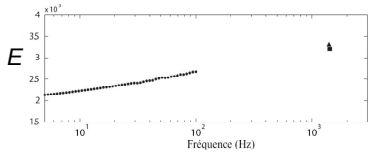


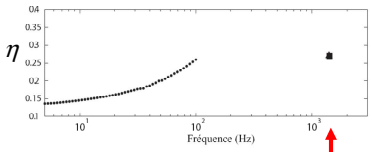
[Pritz 1980, Ingard 1981]



[Allard 2007]

Inertiel effect neglected
⇒ f < 100 Hz





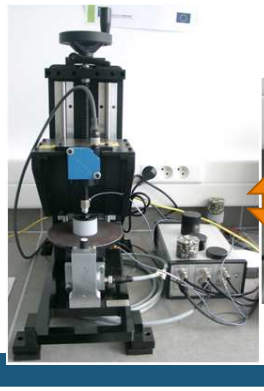
Results at resonances
⇒ Non linearities, few points

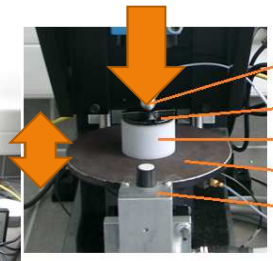
Quasistatic method

3

1. Static strain applied to the sample from 0.5 to 5 %
2. Sinusoidal strain of amplitude less than static strain to keep contact :

dynamic stiffness $k(\omega) = \frac{F(\omega)}{x(\omega)}$

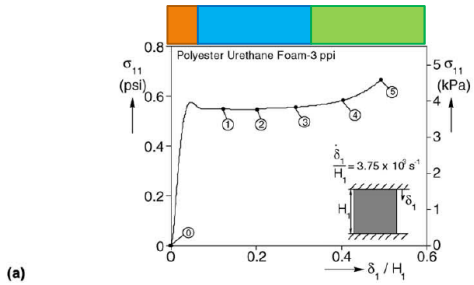




Why does it work ?

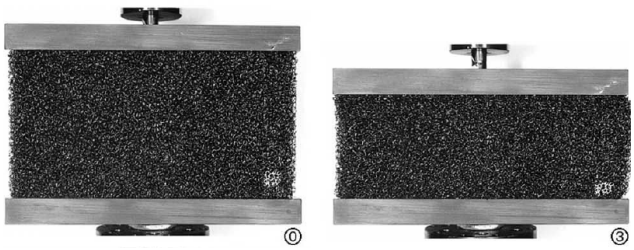
Typical static stress/strain curve (Gong, 2005)

4



A : Linear zone
⇒ **Young's modulus** from slope

B: Buckling
C: Densification



Typical static stress/strain curve modeling (Gong, 2005)

5

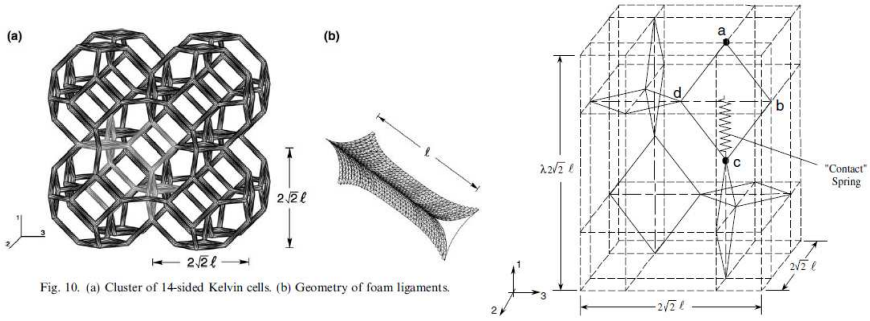
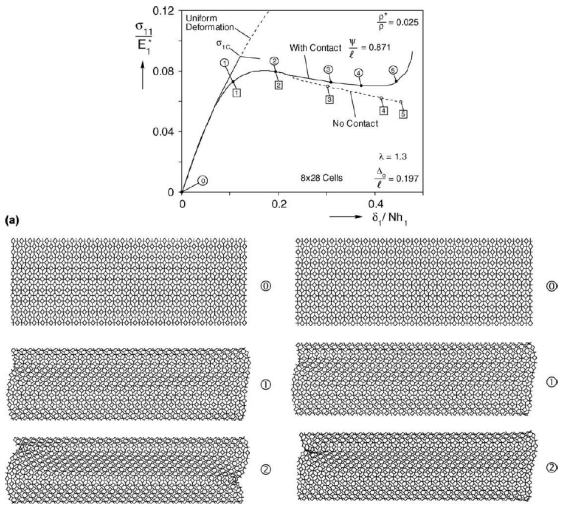


Fig. 10. (a) Cluster of 14-sided Kelvin cells. (b) Geometry of foam ligaments.

Kelvin cell | Variable beam section | Contact spring

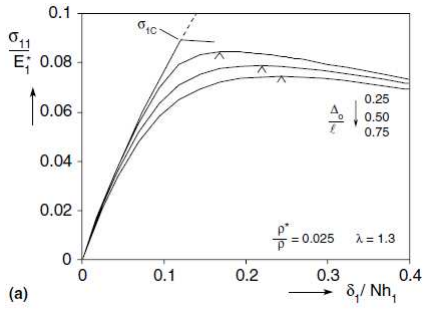
Typical static stress/strain curve modeling (Gong, 2005)

6



Typical static stress/strain curve modeling (Gong, 2005)

7



- Effect of imperfections on buckling
  - Lower critical stress
  - More progressive buckling ⇒ « **smaller » linear zone**
  - **Consequence on Young's modulus estimation ?**

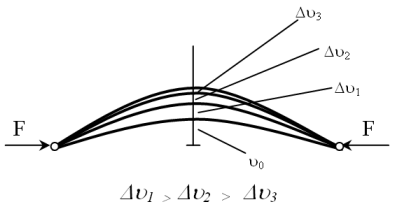
Effect of buckling

8

Modeling the microgeometry

9

- Cubic or Kelvin cell with distorsion
- Constant or variable beam section [Gong 2005, Hoang 2012]
- Geometric non linearity to get buckling effect
  - 1st using Ablitzer code developped for violin bow [2012]
  - 2nd using Abaqus

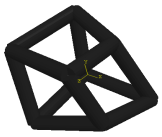


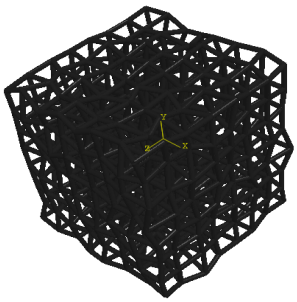
- Load case is recomputed at each strain step ⇒ **iterative computation**
- Convergence if F < Fcritical

Cubic cell

10

E	*nu*	*Density*	*Length*	*Radius*
3000 Mpa	**0.38**	**1300 kg/m3**	**0.203 mm**	**0.021**

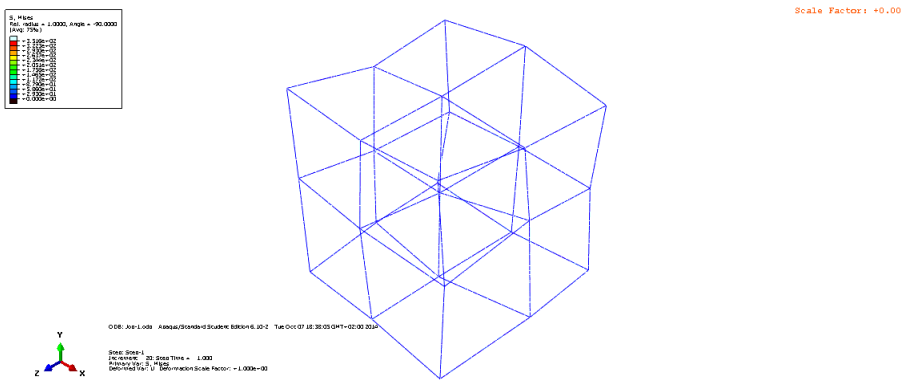




- Symmetric Dissymmetric (20%) 7^3 dissymmetric cells (20%)

Cubic cell under 1D compression

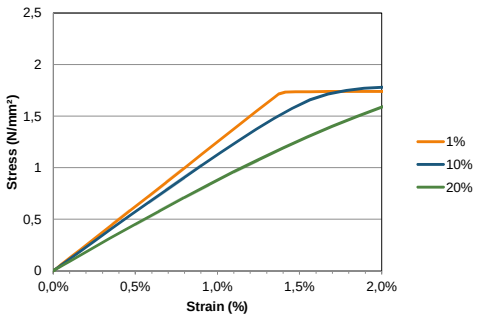
11



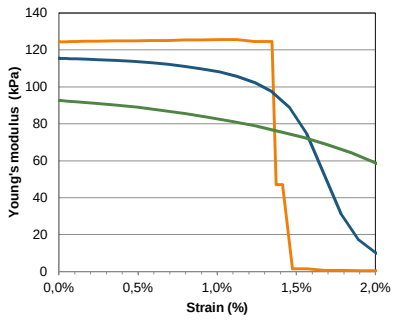
Cubic cell : effect of dissymmetry

12

Stress / strain



Young's modulus / strain

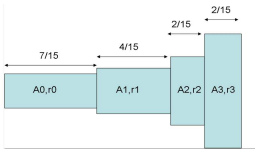


- Effect of buckling smoother with dissymmetry
- Stiffness decreases with strain
- Stiffness at null strain lowered by dissymmetry

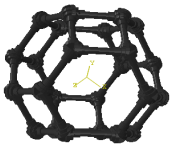
Kelvin cell

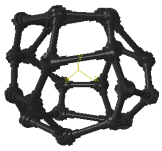
13

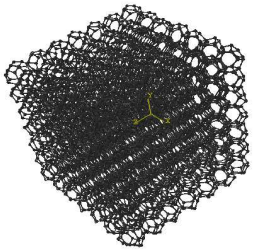
- Variable beam section (Gong, 2005)



E	*nu*	*Density*	*L*	*h*	*Mean radius*
3000 Mpa	**0.38**	**1300 kg/m3**	**0.203 mm**	**0.574 mm**	**0.021**



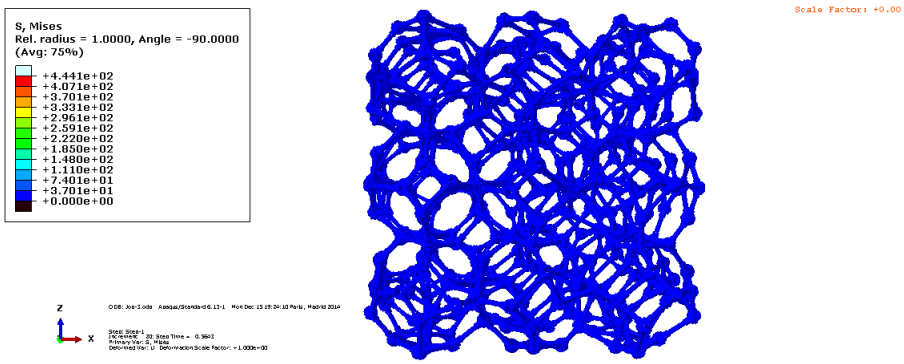




- Symmetric Dissymmetric (20%) 7^3 dissymmetric cells (20%)

Kelvin cell (20% dissym.) under 1D compression

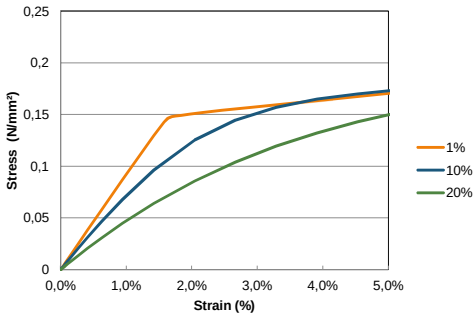
14



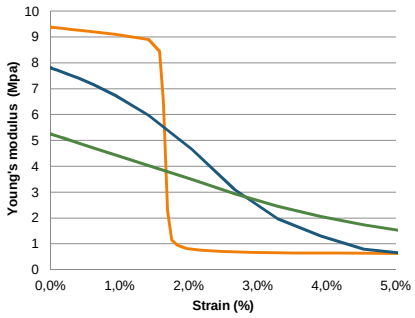
Kelvin cell : effect of dissymmetry

15

Stress / strain



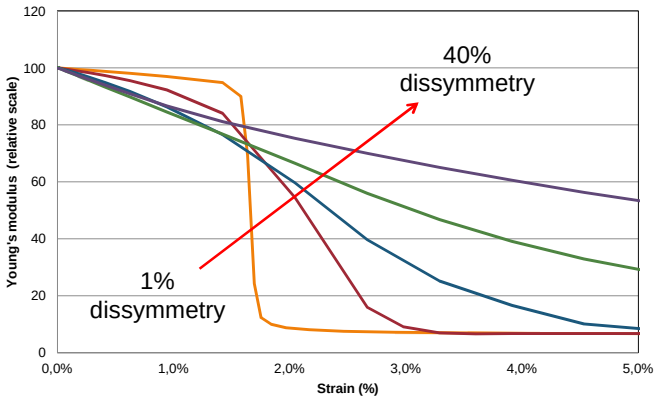
Young's modulus / strain



- Same tendency as cubic cell
- No plateau even without dissymmetry
- Stiffness at null strain more lowered by dissymmetry

Kelvin cell : effect of dissymmetry

16



Young's modulus is lowered more than 20% for a 1.7% strain

What happens experimentally ?

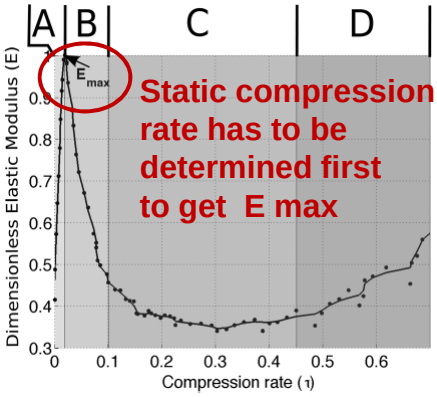
Effect of cutting imperfections

17

Young's modulus versus static strain (Geslain, 2011)

18

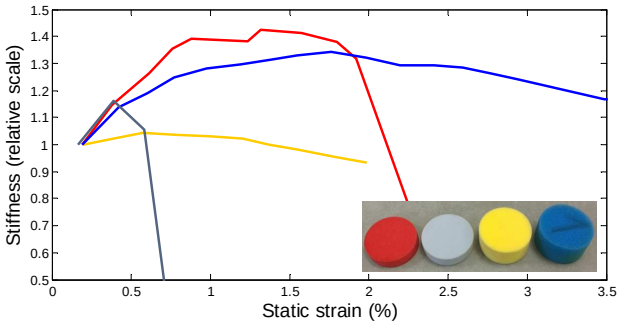
A : YOUNG'S MODULUS INCREASES !!
B : effect of buckling
C, D : densification



Static compression rate has to be determined first to get E max

Static stiffness versus static strain

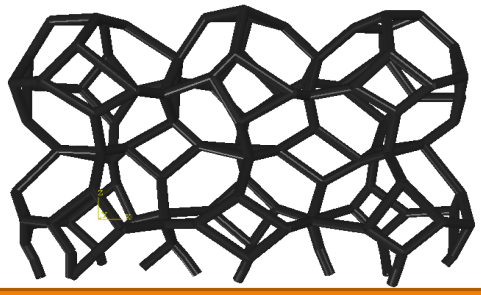
19



1. K max is found from 0.4 % to 2 %
2. Several slopes before and after « buckling »

Effect of cuting imperfections

20

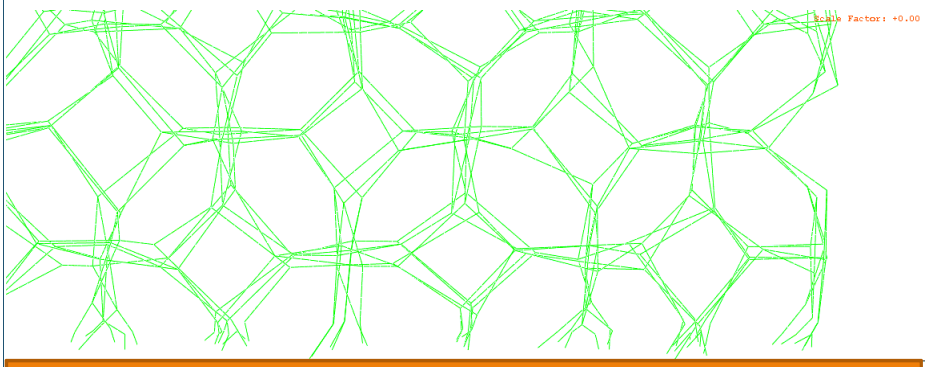


Still plate

- Only few beams are in contact at null strain

5% of cutting imperfection

21

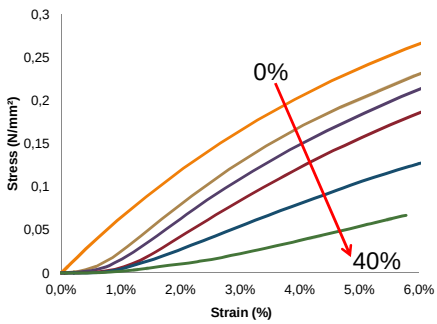


Still plate

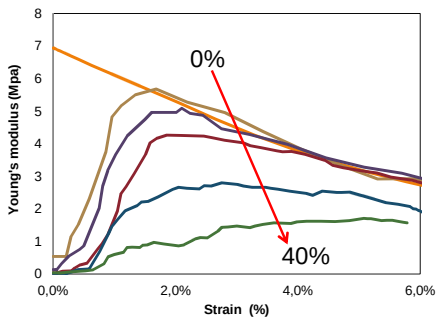
Effect of cuting imperfections

22

Stress / strain



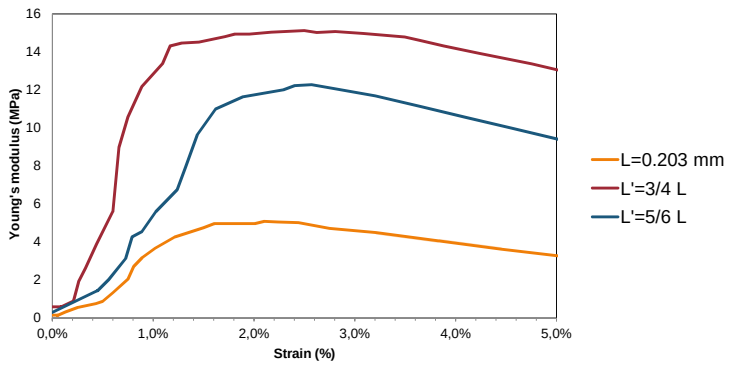
Young's modulus / strain



- Increase zone due to cutting imperfection
- For lower cutting imperfection (< 5%), Emax is on the initial buckling curve
- For higher cutting imperfection (> 10%), Emax is found even lower

Effect of beam ratio Length / Radius

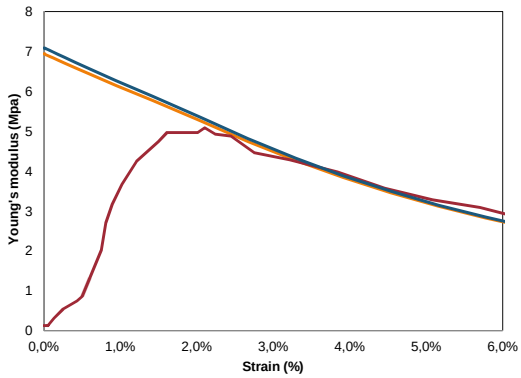
23

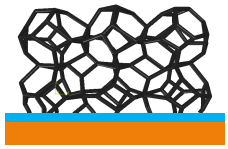


- Emax does not occur for the same static strain
- The Emax static strain is function of :
  - Morphologie of the cell
  - Cutting imperfections

Effect of cuting imperfections

24





- Bonding removes the « increase » zone
- and reduces the effect of cutting imperfections

Conclusion

25

1. Cutting imperfections can explain increase zone
2. Buckling effect occurs from the lowest static strain
3. Emax is always < E at null static strain
4. To get a good estimation of E :
   1. sample should be bonded
   2. dynamic strain should be applied around null static strain

Future works

- Test on several foams
- Revision of the measurement protocol

References

26

- Ablitzer, F., Dalmont, J.-P., and Dauchez, N. (2012a). Static model of a violin bow: Influence of camber and hair tension on mechanical behavior. J. Acoust. Soc. Am. *131*, 773–782.
- Ablitzer, F., Dauchez, N., and Dalmont, J.-P. (2012b). A Predictive Model for the Adjustment of Violin Bows. Acta Acust. United Acust. *98*, 640–650.
- Dauchez N., Etchessahar M., Sahraoui S., On measurement of mechanical properties of sound absorbing materials, 2nde Biot Conf. on Poromechanics, Grenoble , 2002
- Geslain, A., Dazel, O., Groby, J.-P., Sahraoui, S., and Lauriks, W. (2011). Influence of static compression on mechanical parameters of acoustic foams. The Journal of the Acoustical Society of America *130*, 818–825.
- Gong L., Kyriakides S., and Jang W.-Y. (2005). Compressive response of open-cell foams. Part I: Morphology and elastic properties. International Journal of Solids and Structures *42*, 1355–1379.
- Gong, L., and Kyriakides, S. (2005). Compressive response of open cell foams Part II: Initiation and evolution of crushing. International Journal of Solids and Structures *42*, 1381–1399.
- M. T. Hoang (2012). Modélisation et Simulation Multi-Échelle et Multi-Physique du Comportement Acoustique de Milieux PoroElastiques : Application aux Mousses de Faible Densité, PhD thesis, Université Paris-Est. French. tel-00799779v1