



1. Rigid syntactic foams typically exhibit elastic behavior falling somewhere between viscoelastic thermoplastics and elastic metals. Given this knowledge, important inferences can be drawn about syntactic foam from classical studies of elastic materials. This note continues the discussion of properties found in Technical Note 600-3.

2. The three principal elastic moduli and their ratio of proportionality, known as Poisson's Ratio, are listed below. The factors are related in such a way that, knowing any two of the four variables, the other two can be calculated.

- E** = Elastic Modulus, also known as Young's Modulus, psi
- K** = Bulk Modulus, also known as the Triaxial Modulus, psi
- G** = Shear Modulus, also known as Torsional Modulus, psi
- μ** = Poisson's Ratio, dimensionless

3. The relationships among the three elastic moduli and Poisson's Ratio **μ** are:

Knowing:	<b>E, μ</b>	<b>K, μ</b>	<b>G, μ</b>
<b>E =</b>	-----	$3K(1-2\mu)$	$2G(1+ \mu)$
<b>K =</b>	$E/[3(1-2\mu)]$	-----	$[2G(1+ \mu)]/[3(1-2\mu)]$
<b>G =</b>	$E/[2(1+ \mu)]$	$[3K(1-2\mu)]/[2(1+ \mu)]$	-----

4. If Bulk Modulus **K** is held constant, then both **E** and **G** decline as **μ** becomes greater, while elongation-to-break increases. Note that **μ** cannot reach 0.50 as long as the material in question remains a solid.

Value of <b>μ</b> :	0.10	0.27	0.33	0.40	0.45
<b>E vs. K</b>	<b>E = 2.4 K</b>	<b>E = 1.38 K</b>	<b>E = 1.02 K</b>	<b>E = 0.60 K</b>	<b>E = 0.30 K</b>
<b>G vs. K</b>	<b>G = 1.09 K</b>	<b>G = 0.54 K</b>	<b>G = 0.38 K</b>	<b>G = 0.21 K</b>	<b>G = 0.10 K</b>
Typical Examples	Concrete	Cast Iron	Mild Steel	Nylon	Rubber
Typical Elongations	0.0%	1.0-5.0%	10-15%	15%-30%	50-100%

Note that any effects of elevated temperature are ignored by assuming elastic moduli decline with temperature at the same rate as strength, so that a given strain is no more likely to cause damage at elevated temperature than at room temperature.

5. Both Young's Modulus **E** and elongation-to-break are readily measured in an Instron or similar testing machine, and the Bulk Modulus **K** must be sufficient to prevent volumetric compression exceeding 1.0% at maximum depth. Given these data points, then the other elastic properties can be estimated with reasonable accuracy.

**E** = Elastic Modulus, psi, from Instron test data

**K** = Bulk Modulus, psi, = 100 x (hydrostatic pressure at rated service depth)

**G** = Shear Modulus, psi, calculated from **E** and  $\mu$ .

$\mu$  = Poisson's Ratio, dimensionless, estimated from elongation-to-break

6. The following forces and resulting strains acting on *C-THERM* syntactic foam insulation are thought to be representative of actual service:

<u>Forces Acting on Insulation</u>	<u>Resulting Strain, %</u>
Hydrostatic Pressure	1.0 - 2.0
Curing Exotherm and Shrinkage	1.0 - 2.0
Thermal Expansion and Contraction	1.0 - 2.0
Mechanical Flexure and Movement	<u>2.0 - 4.0</u>
Estimated Total Strain	5.0 - 10.0%

Therefore, an elongation-to-break value of at least 10% is desirable, with 15 - 20% or more preferred. This in turn implies a Poisson's Ratio of at least 0.40.

7. A rule of thumb says that no material passes the Simulated Service Vessel (SSV) test at 3,000 psig unless it has a tensile strength of at least 1,000 psi. An explanation can be found in Paragraph 4, where Shear Modulus **G** is about one-third of Bulk Modulus **K**. If three-dimensional strain under hydrostatic pressure leads to shearing stress in the insulation, then it stands to reason that resisting shear stress requires strength equal to at least one-third the hydrostatic pressure.

8. Another performance issue is that bond lines between successive pours are typically not as strong as the base material, forming planes of potential weakness. The rule of thumb here says that adhesive strength between layers must be at least half the tensile strength of the base material if separation under hydrostatic pressure is to be avoided. Returning to Paragraph 4, a possible explanation is that Shear Modulus **G** is indeed less than half of both **E** and **K**. It is significant that the relationship becomes less favorable as elongation diminishes.

9. These examples illustrate how knowledge of elastic properties can help to understand behavior of syntactic foam in service. In particular, they show that increasing Poisson's Ratio  $\mu$  permits Bulk Modulus **K** to remain high while allowing Young's Modulus **E** and Shear Modulus **G** to be relatively low. This in turn maximizes elongation-to-break and minimizes the danger of cracking under adverse conditions. The new *C-THERM* HE line of high elongation epoxy thermal insulation embodies these principles, and continuing research is under way to make these materials perform even better.