Adhesion Mechanics: Strength & Energy Metrics

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The following images have been prepared over my teaching career.
This file contains figures that are scheduled to appear in:

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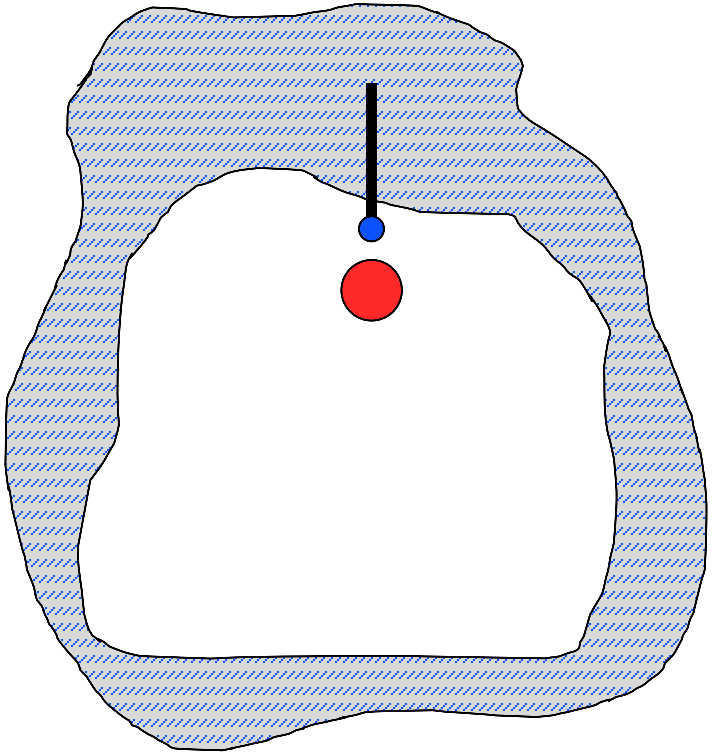
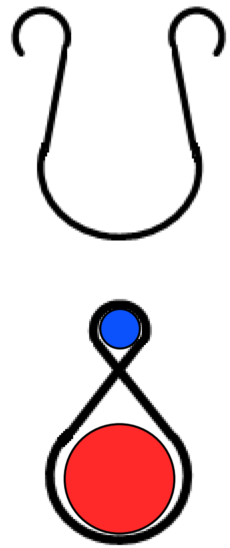
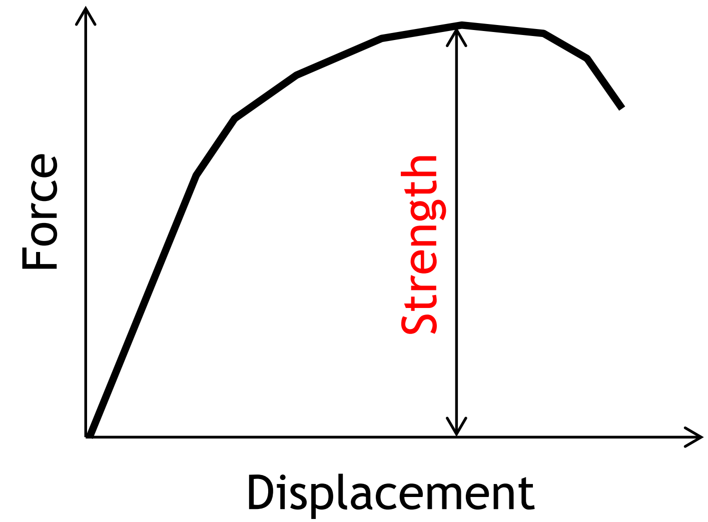
Chapter 14: Standard Test Methods and Their Need to Evolve

By: Aaron M. Forster, Christopher C. White, and David A. Dillard







$$\frac{Force}{Clip} = \frac{Weight/km}{Clip/km}$$

Design Criterion:

$$\frac{Force}{Clip} \leq \frac{Strength}{F.S.}$$

Illustration of a simple strength-based design might be used for determining allowable force per clip for spring wire clips supporting the umbilical cable for the mine. See Lolie *v.* Ohio Brass Co. (502 F.2d 741, 1974), which inspired this example used in my adhesion classes.

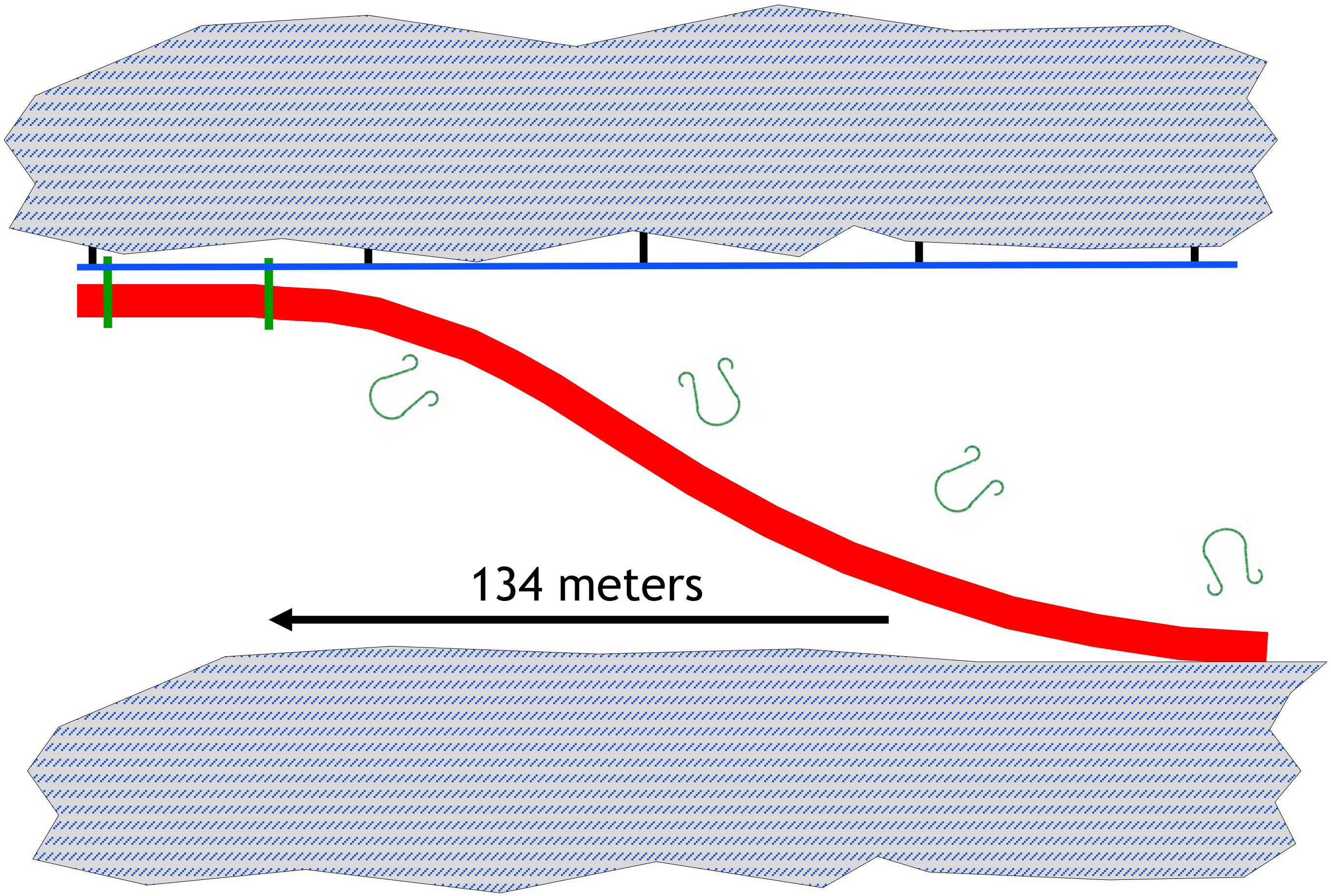
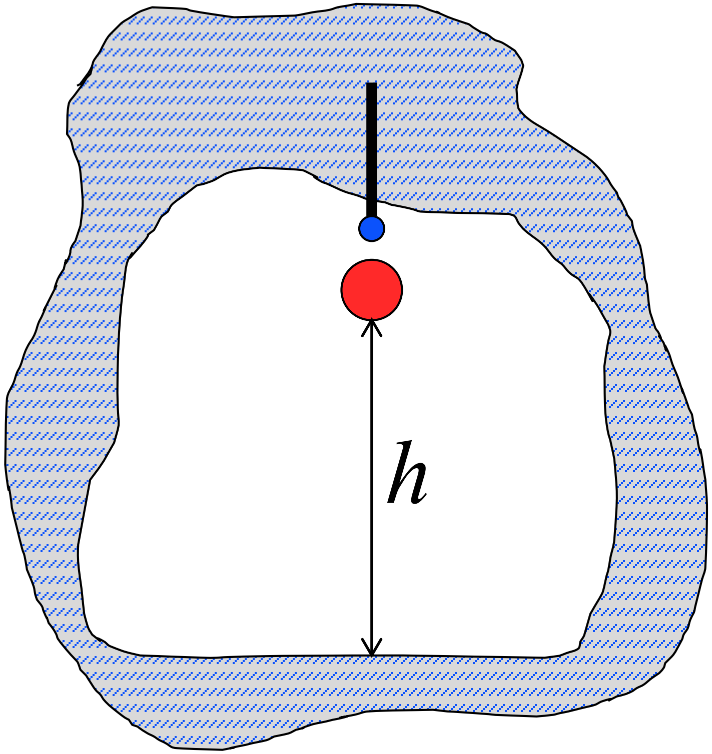
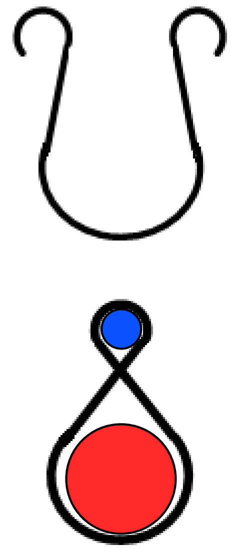
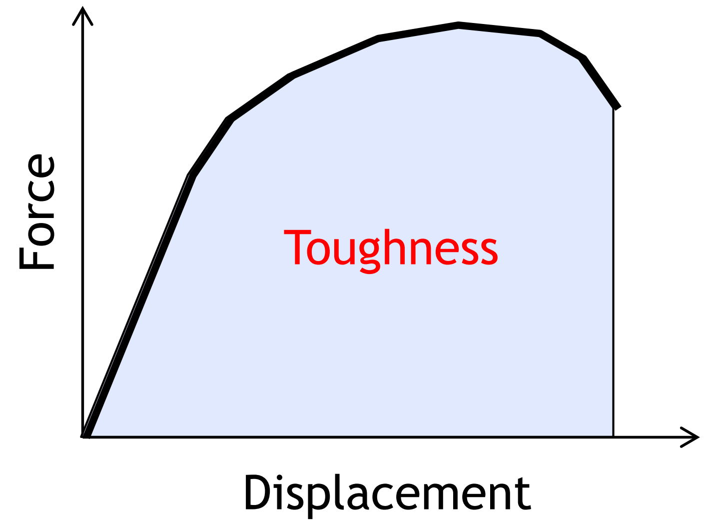


Illustration of unzipping failure mode when the umbilical cable for the mine was accidentally struck by a heavy rail being unloaded by workers. Failure propagated rapidly approximately 134 meters before striking another worker and killing him. See Lolie *v.* Ohio Brass Co. (502 F.2d 741, 1974), which inspired this example used in my adhesion classes.





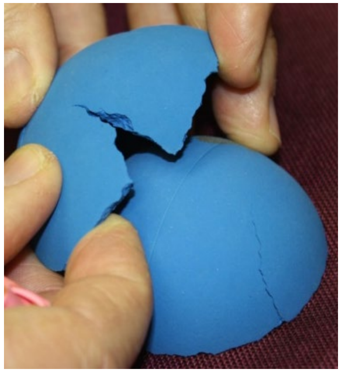


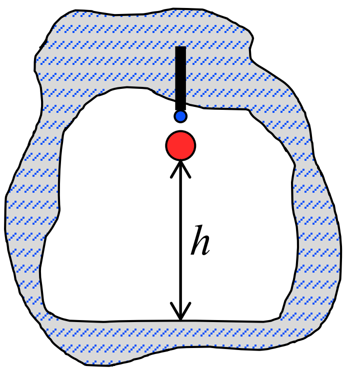
$$\frac{Energy}{Clip} = \frac{Weight/km}{Clip/km} \cdot h$$

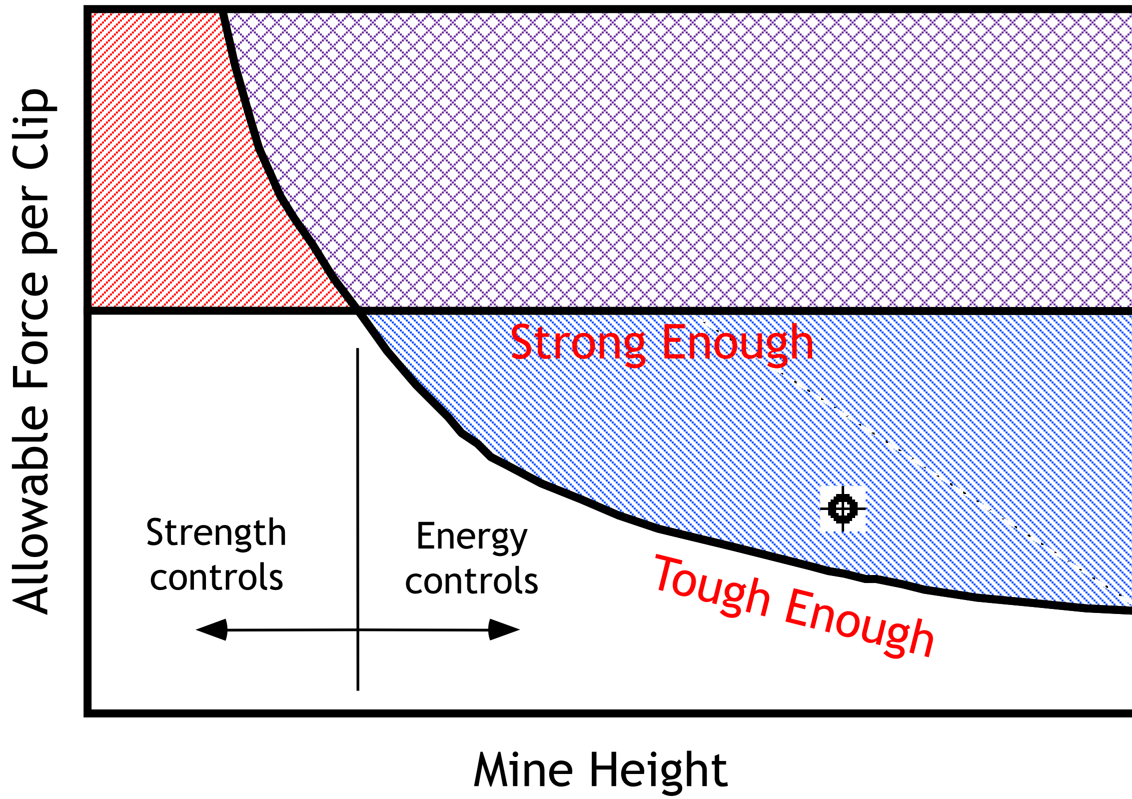
Design Criterion:

$$\frac{Energy}{Clip} \leq \frac{Toughness}{F.S.}$$

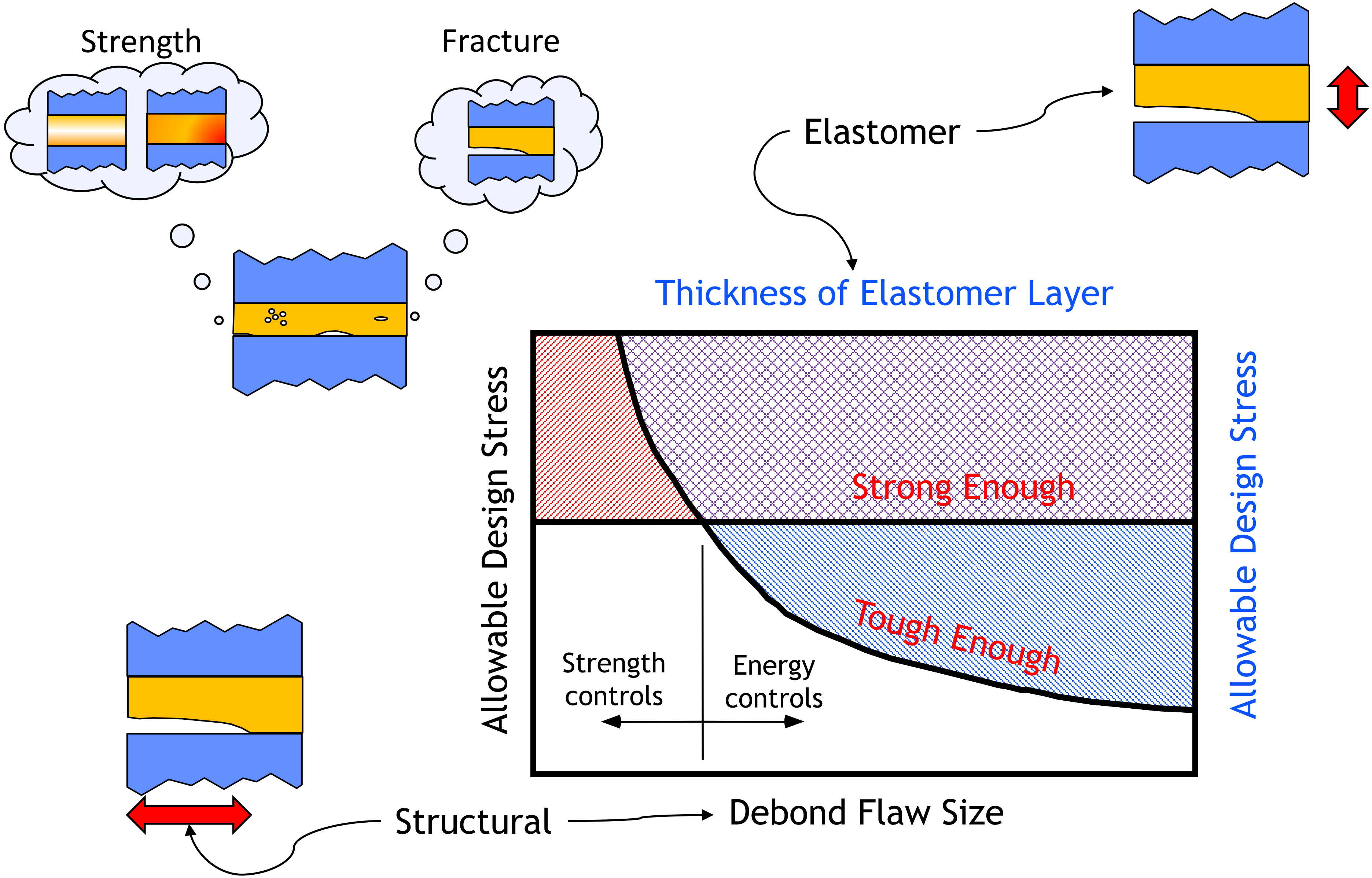
Illustration of a simple energy-based design that could have been used for determining allowable force per clip for spring wire clips supporting the umbilical cable for the mine. Being an energy analysis, an added length scale is needed, here the height of the mine through which the cable could fall, reducing its potential energy, a portion of which could be delivered to propagate an unzipping failure. See Lolie *v.* Ohio Brass Co. (502 F.2d 741, 1974), which inspired this example used in my adhesion classes.



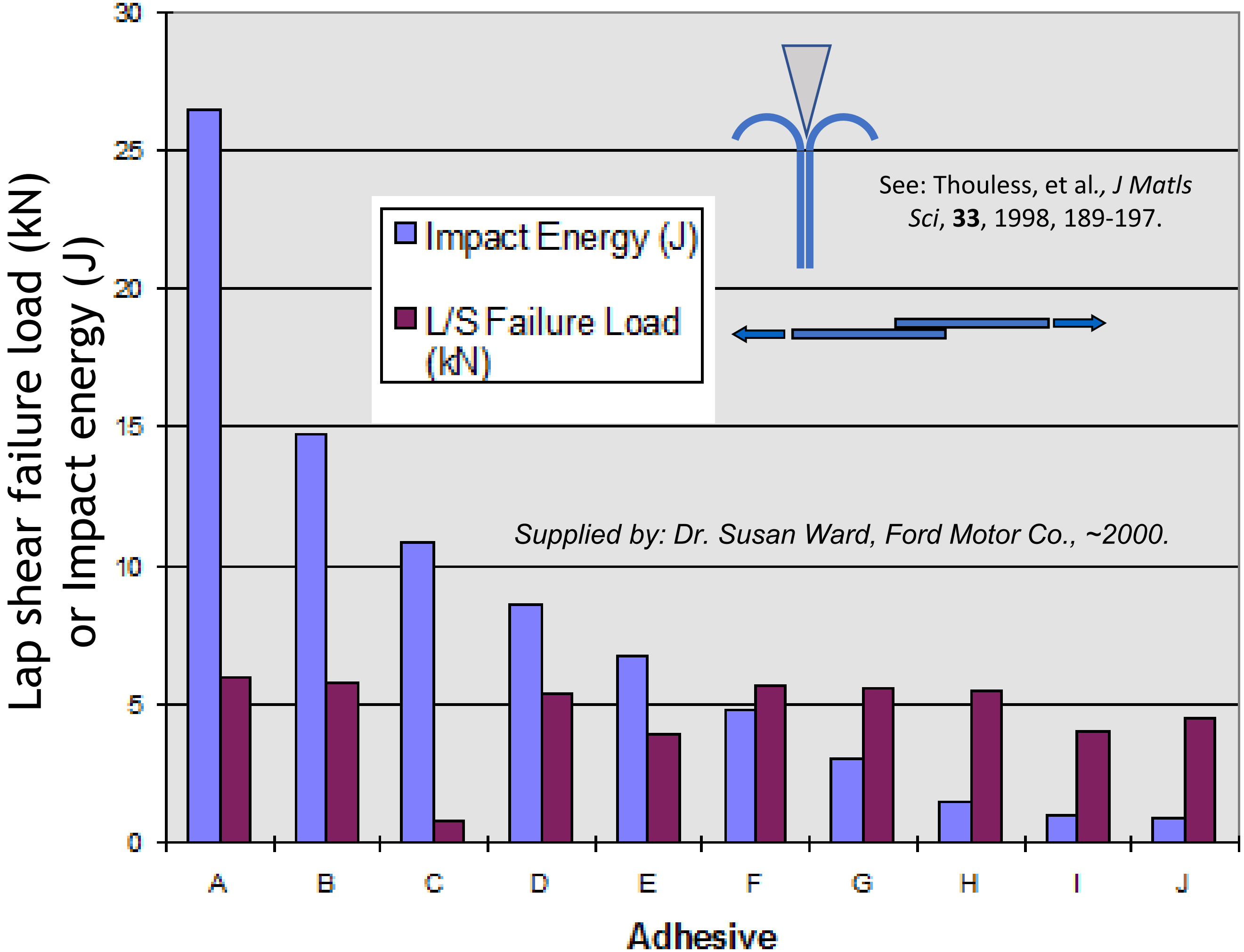




Comparison of hypothetical strength-based and energy-based design approaches that might be used for determining allowable force per clip for spring wire clips supporting the umbilical cable for the mine. The operating point of the mine was below the strength envelope (safe) but above the energy envelope, resulting in a catastrophic accident ‘when something went wrong’. Racquetballs seem quite strong, but are relatively fragile when cracks are introduced. See Lolie *v.* Ohio Brass Co. (502 F.2d 741, 1974), which inspired this example used in my adhesion classes.

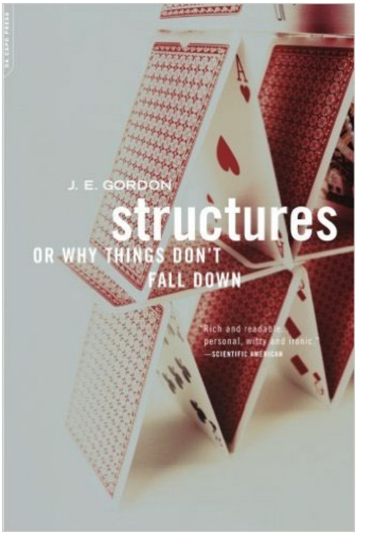


Comparison of hypothetical strength-based and energy-based design approaches that might be used for determining allowable design stresses in adhesively bonded joints. The relevant length scale for energy-based or fracture mechanics analysis is often crack length or size for structural adhesives, but may be the thickness of the adhesive layer for soft or elastomeric adhesives under some loading conditions.



"The worst sin in an engineering material is not lack of strength or lack of stiffness, desirable as these properties are, but lack of toughness, that is to say, lack of resistance to the propagation of cracks". … J. E. Gordon

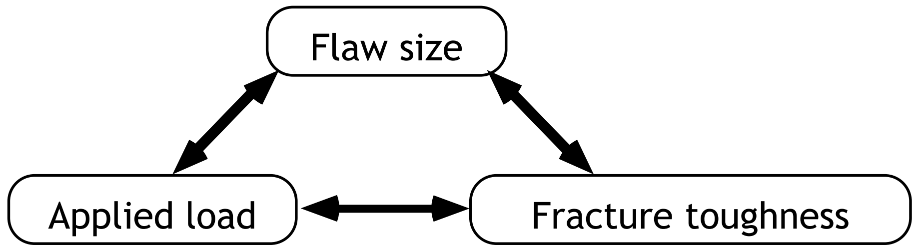
Da Capo Press, 2003, first published in 1978

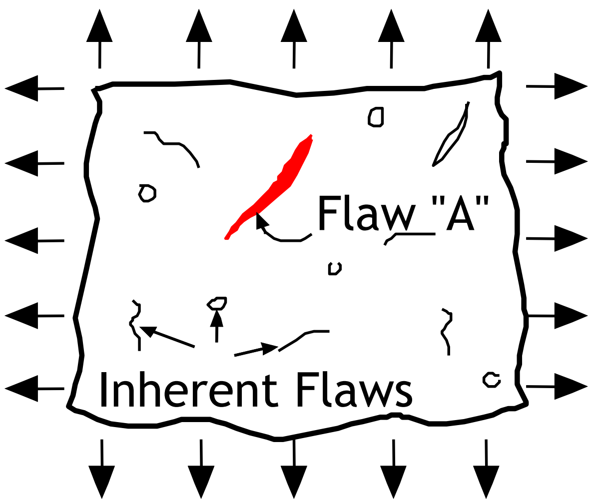


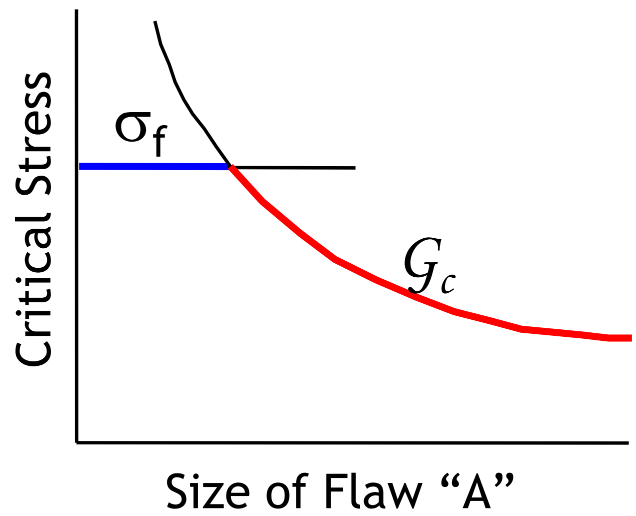
Comparison of lap shear (L/S) strengths and energies of failure for bonded specimens subjected to rapid loading with a wedge (see Thouless, et al., *J Matls Sci*, **33**, 1998, 189-197.) Base image supplied by Susan Ward with permission to reuse. Prof. Kinloch often quotes J. E. Gordon from *Structures or Why Things Don't Fall Down, 1978*, reminding us of the importance of energy dissipation capabilities in material fracture.

Strength Criterion:

Fracture Criterion:







Whereas strength criteria may focus on comparing anticipated stresses to some ‘strength’ metric, fracture criteria involve an additional length scale, such as length of a flaw. Depending on large the most critical flaw is (here Flaw “A”) is in relation to other inherent flaws, both strength and fracture-based criteria may have relevance. See also Dillard, "Joint Design: strength and fracture perspectives", *Handbook of Adhesion*, D. E. Packham, 2nd Edition, John Wiley & Sons, Ltd., 2005, 269-270.