Static & dynamic stresses from beam heating in targets & windows

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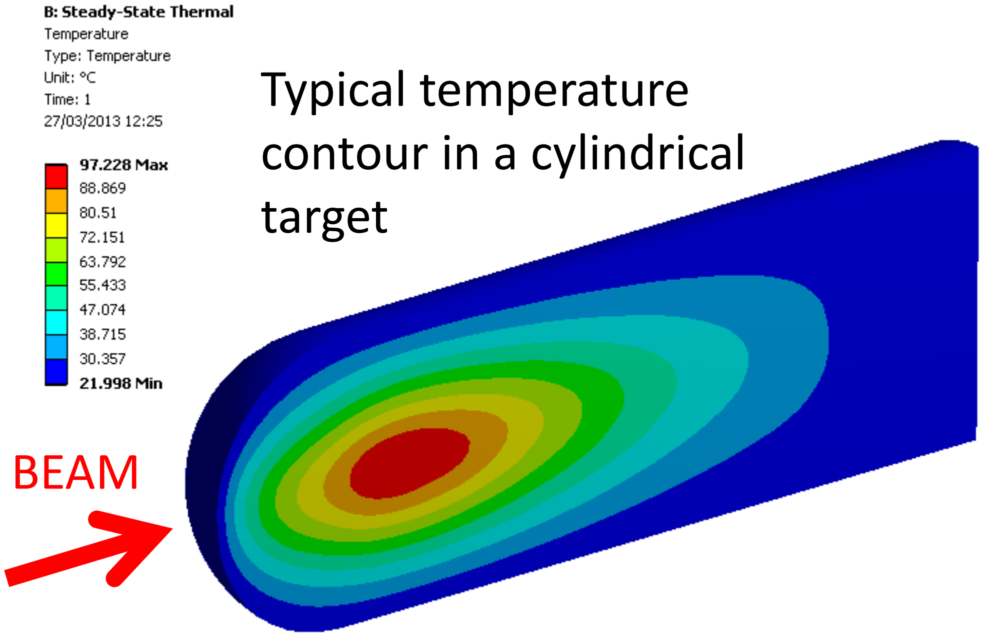
Elastic stress (non inertial)

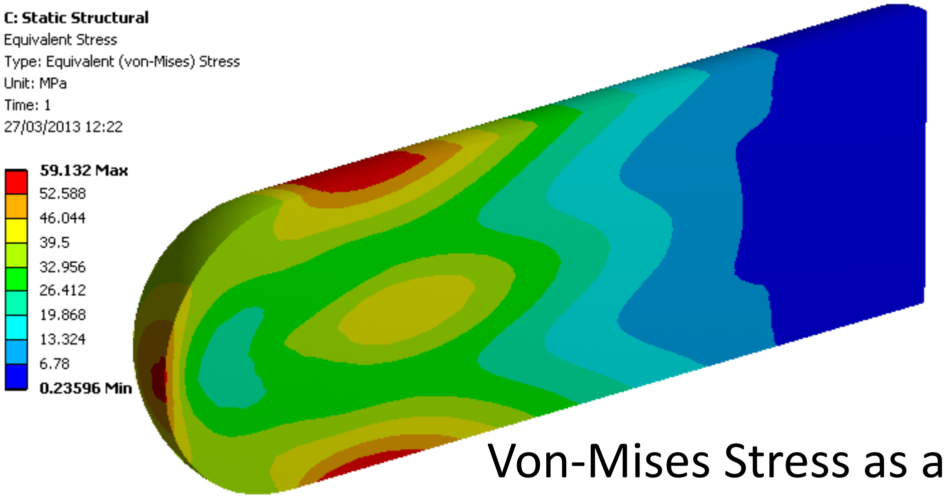
(reversible, small strain deformations)



Typical temperature contour in a cylindrical target

A ‘continuous’ beam results in constant heat power deposited within a target
The target is cooled resulting in a temperature gradient (which primarily depends on power deposition, thermal conductivity and geometry)

As a result of thermal expansion and the temperature gradient a stress field is setup within the target



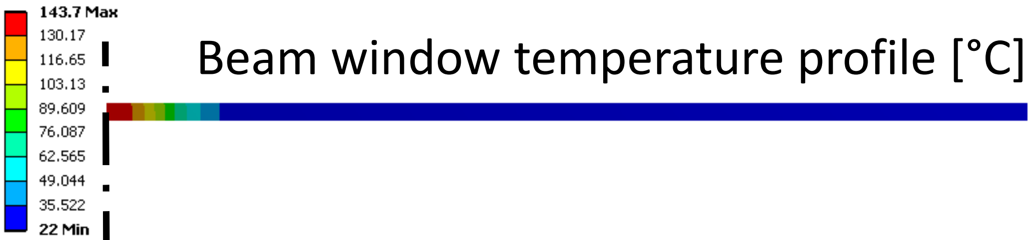
Von-Mises Stress as a result of temperature contour

Plastic stress (non inertial)

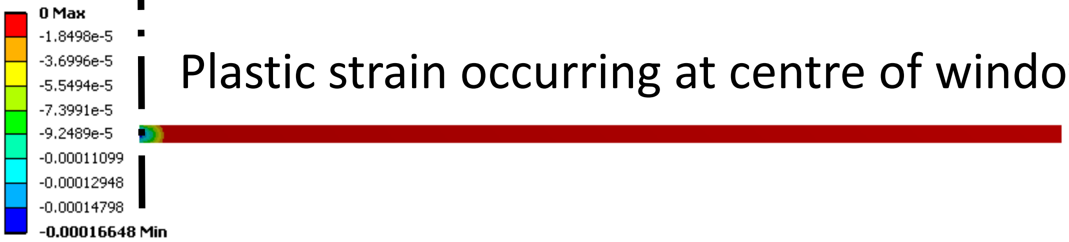
stress exceeds yield point and plastic deformation occurs

Consider the stress and strain near the centre of a window heated by a 'large' beam pulse

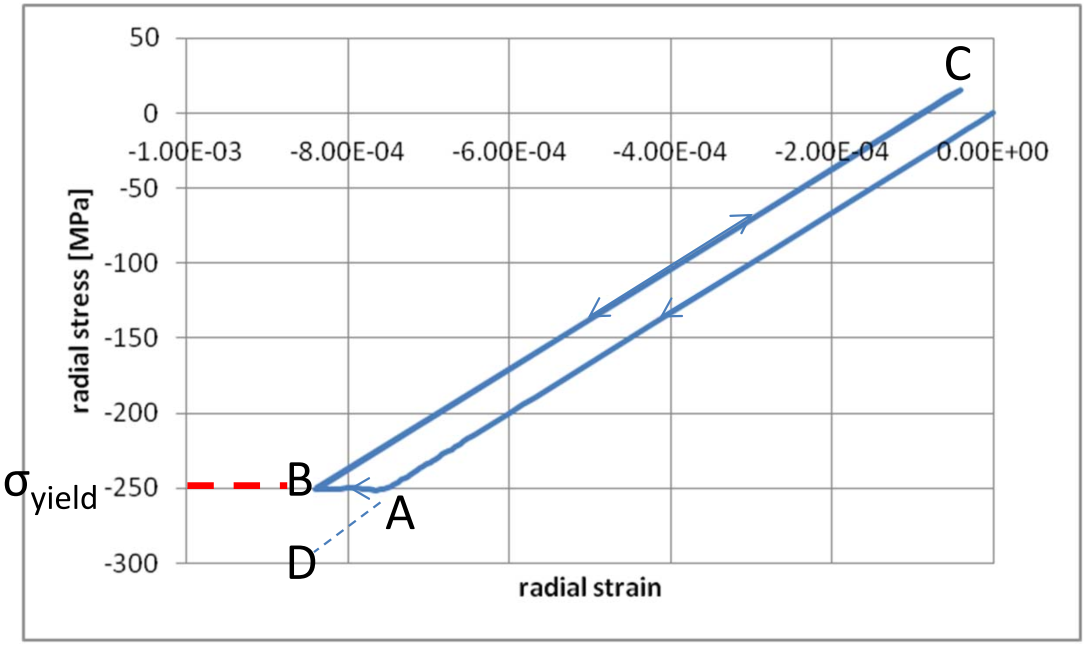
Plastic deformation starts to occur at point A until the point of maximum compressive stress occurs at point B.
If the window is then cooled back to ambient temperature the stress unloads along the line B-C.
Point C has a small amount of tension resulting from the plastic deformation.
If the window is heated again by the same amount the stress will reach point B without any further plastic deformation.



Beam window temperature profile [°C]



Plastic strain occurring at centre of window



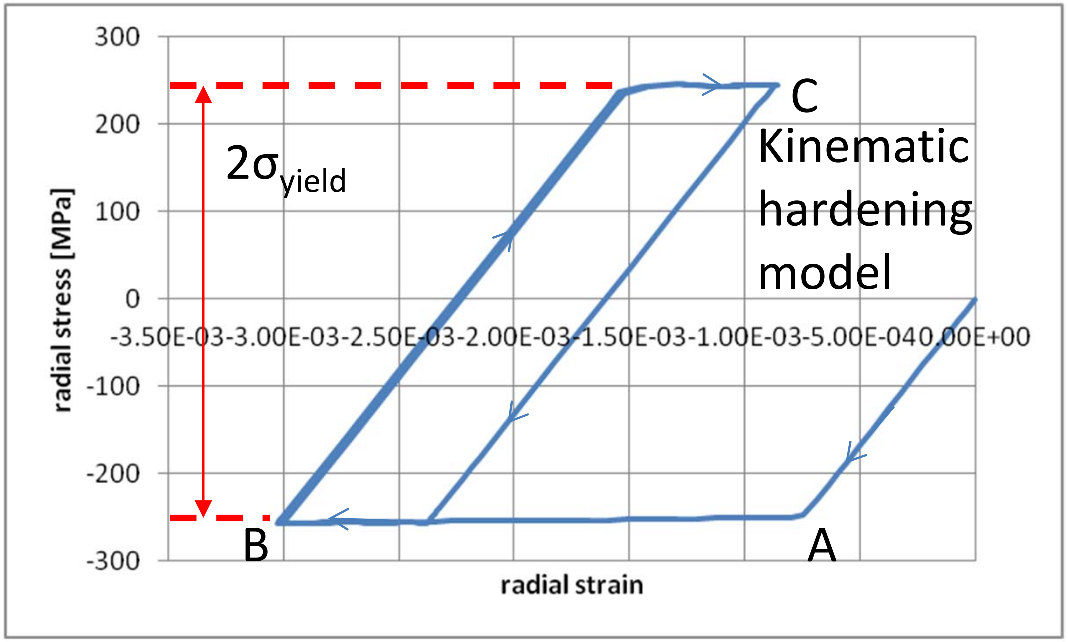
Point D represents stress prediction with a simple linear model

Plastic stress – shake down

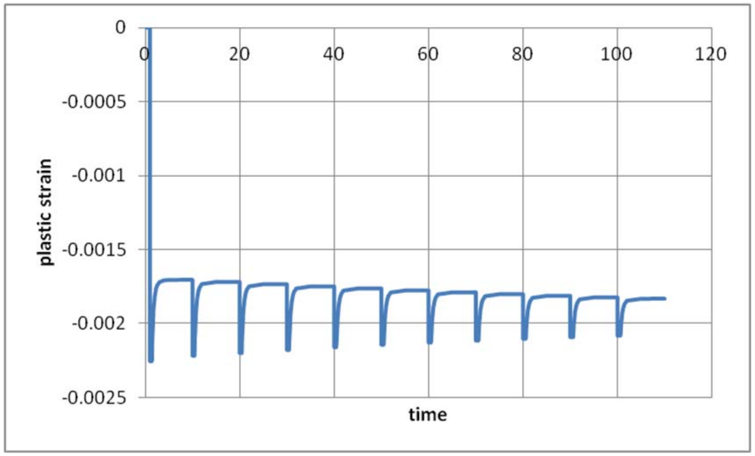
Plastic shakedown behavior is one in which the steady state is a closed elastic-plastic loop, with no net accumulation of plastic deformation

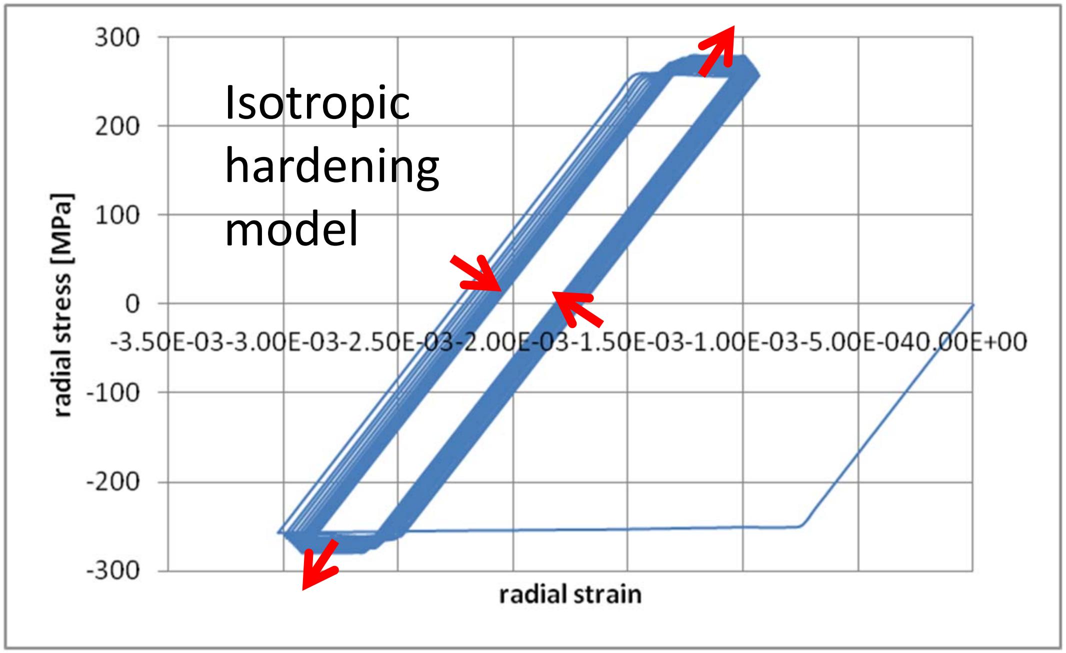
Consider more significant heating to the window resulting in significantly more plastic deformation between A and B.

Unloading now follows line B-C thus setting up a loop of repetitive cycles of plastic deformation



If the yield stress increases following plastic work then the magnitude of the cyclic plastic deformation reduces until return to the elastic regime.

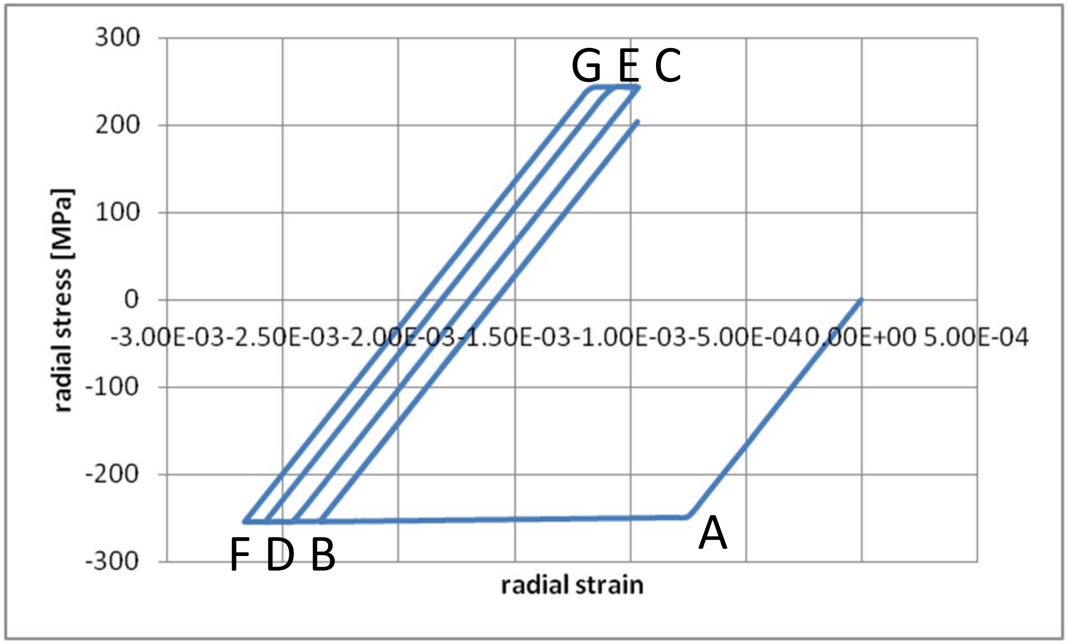


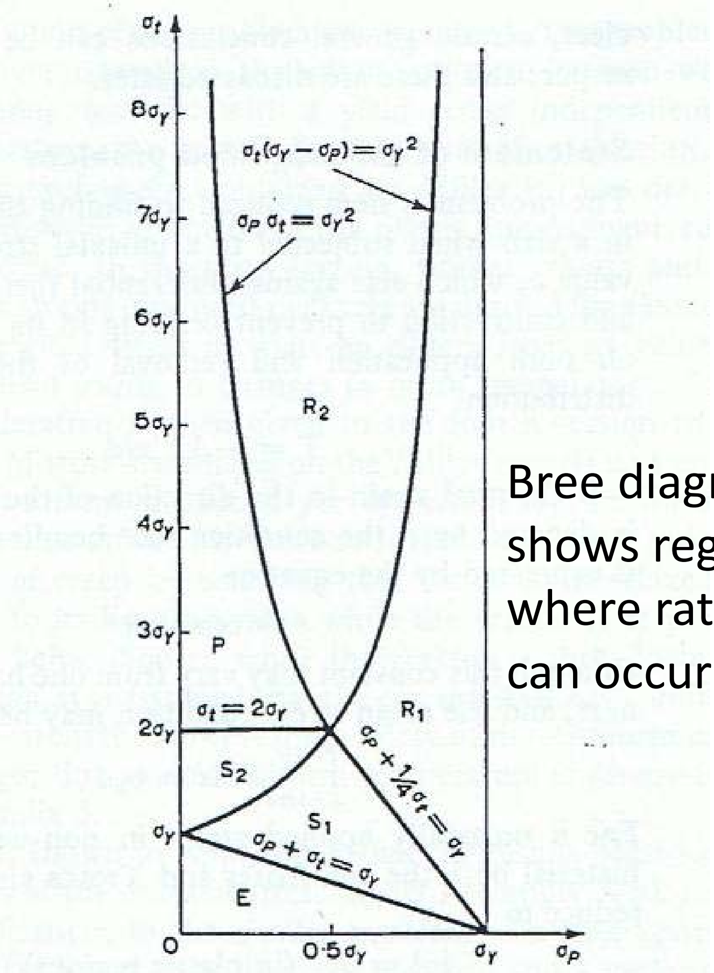


Plastic stress – ratcheting

Ratcheting behavior is one in which the steady state is an open elastic-plastic loop, with the material accumulating a net strain during each cycle

UNSTABLE Ratcheting behaviour observed by increasing window thickness





Stress régime	Can behaviour
R_1 and R_2	Ratchetting
S_1 and S_2	Shakedown after first half-cycle
P	Plastic cycling
E	Elastic

Bree diagram shows regions where ratcheting can occur

Inertial Stress - Elastic Waves

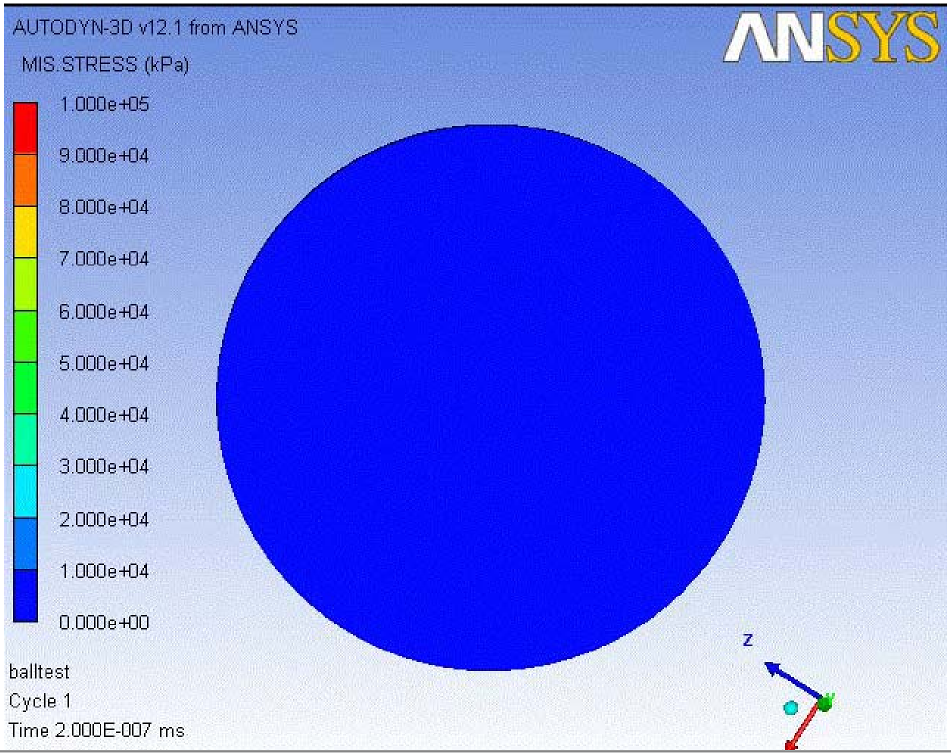
Stress waves with a magnitude below the yield stress propagating with small reversible deflections

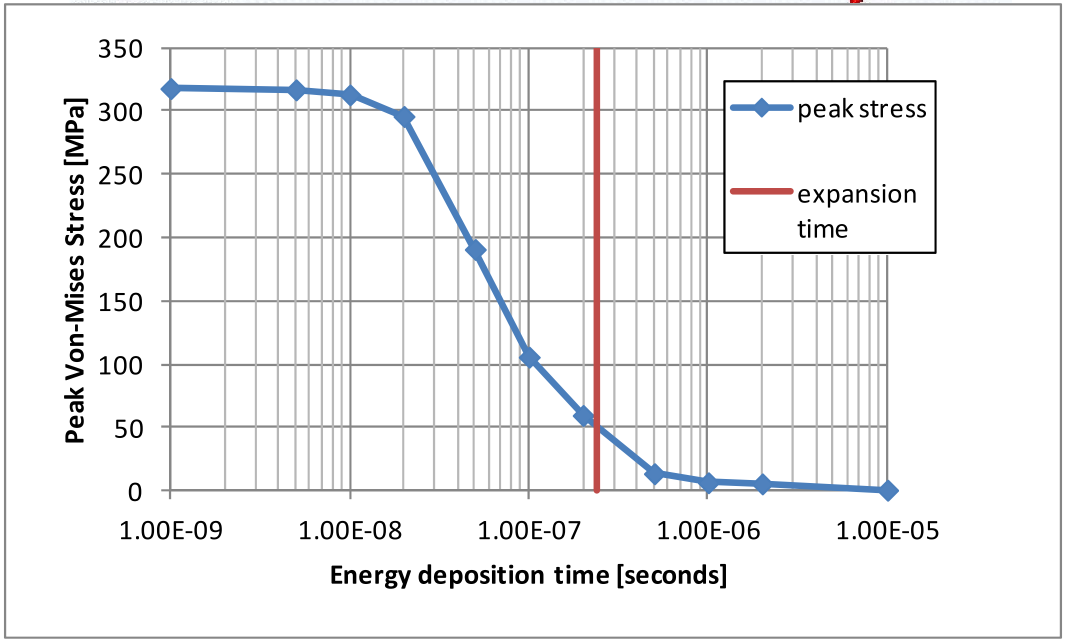
Consider a spherical target being rapidly and uniformly heated by a beam pulse.

If it is heated before it has had time to expand a pressure/stress occurs. This results in oscillating stress waves propagating through the target as it expands, overshoots and contracts again.

The waves travel at the speed of sound in the material. (longitudinal or shear sound speeds)

Stress depends on heating time





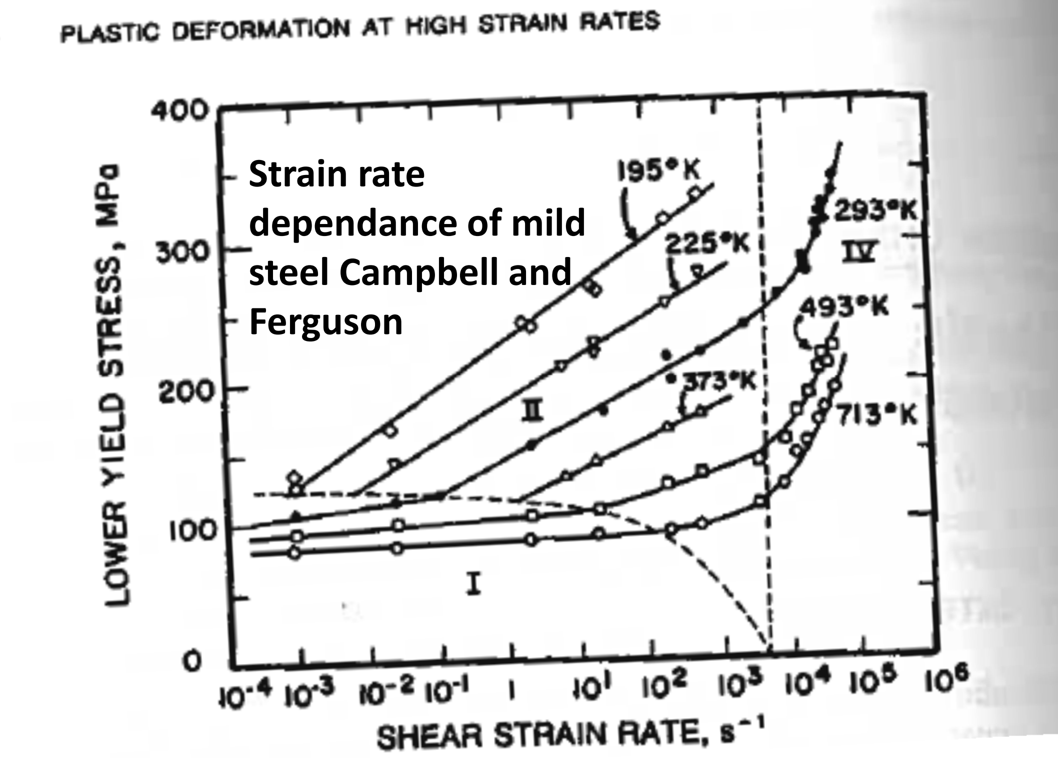
Inertial Stress - Plastic Waves

If a pulse is transmitted to a material that has an amplitude exceeding the elastic limit the pulse will decompose into an elastic and a plastic wave

Plastic waves travel slower than acoustic elastic waves due to the dissipative effect of plastic work

But what is the dynamic yield point?

Material	Hugoniot Elastic Limit [GPa] Meyers	Typical static yield point [Gpa]
2024 Al	0.6	0.25
Ti	1.9	0.225
Ni	1	0.035
Fe	1-1.5	0.1
Sapphire	12-21	
Fused Quartz	9.8	



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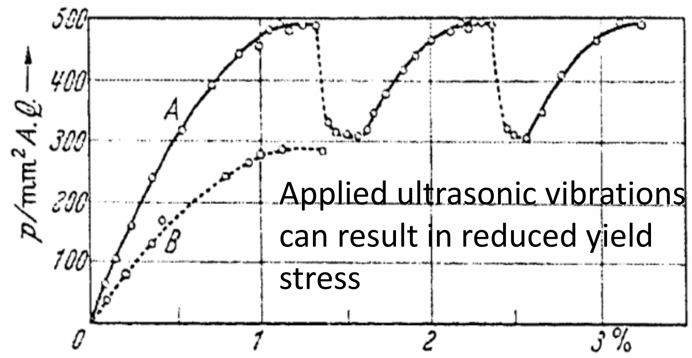
Strain rate dependance of mild steel Campbell and Ferguson



Applied ultrasonic vibrations can result in reduced yield stress

Acousto-plastic-effect

Figure 1.1: Blaha and Langenecker [1] reported the first APE by a compression experiment.

Do we induce vibratory stress relief by bouncing inertial waves through a target?

Research required in this area

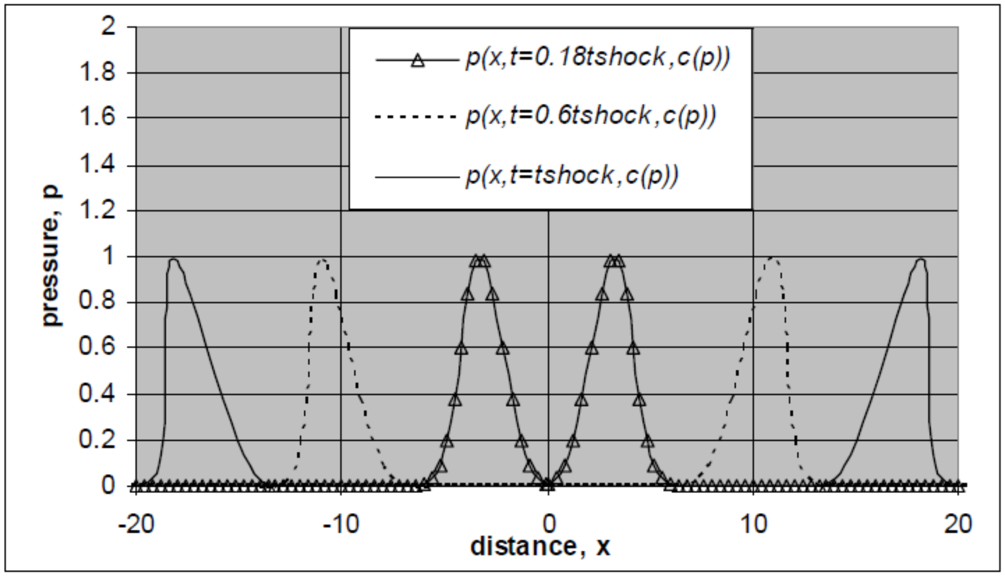
Shock Waves – Inertial

A discontinuity in pressure, temperature and density

Shock waves in solids normally studied using impacts and involve multiple Gpa pressures

Requirement for formation of a shock wave (in a target or window)
Higher amplitude regions of a disturbance front travel faster than lower amplitude regions

Solution of wave equation with c(p)
non linear steepening



Isothermal compression

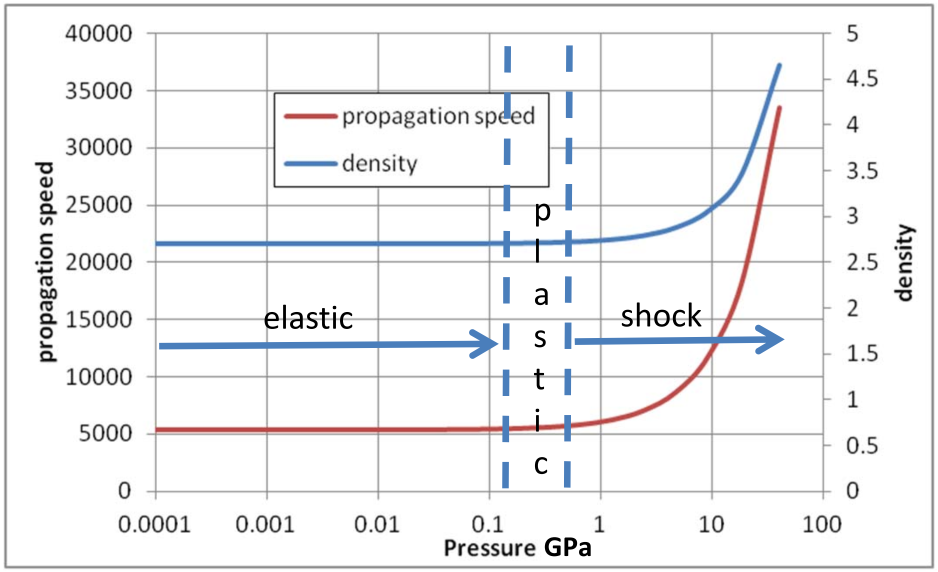
$$\beta_T = -\frac{1}{v}\left(\frac{\partial v}{\partial P}\right)_T$$

$$P = \frac{-ln(v) + \beta_T P_0 + ln(v_0)}{\beta_T}$$

shock compression

$$p = p_r + \frac{\gamma}{v}(e - e_r)$$

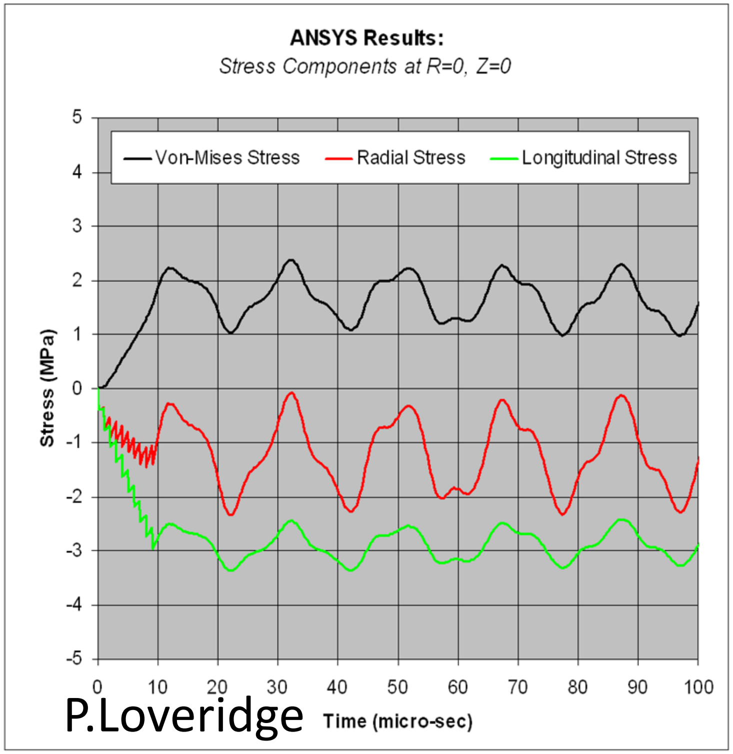
$$P = \frac{c_0^2(v_r - v)}{\left(v_r - s(v_r - v)\right)^2}$$

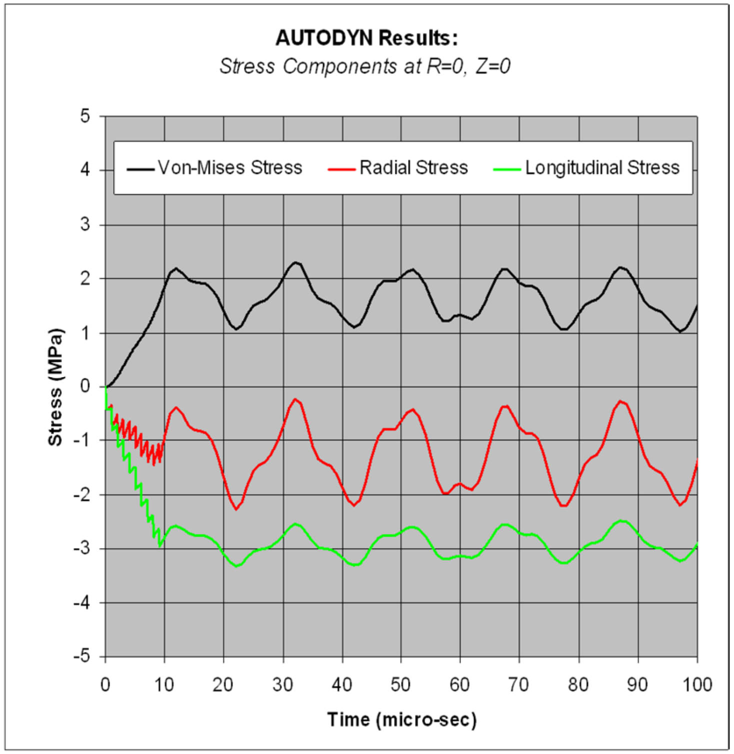


High pressures required for non-linear wave steepening
Geometric spreading of waves in targets results in a reduction in wave amplitude
Acoustic attenuation of wave energy opposes Non-linear steepening (ref Goldberg number)
Formation of a shock wave from a beam induced pressure wave is unlikely

ANSYS Classic vs AUTODYN for inertial stress modelling

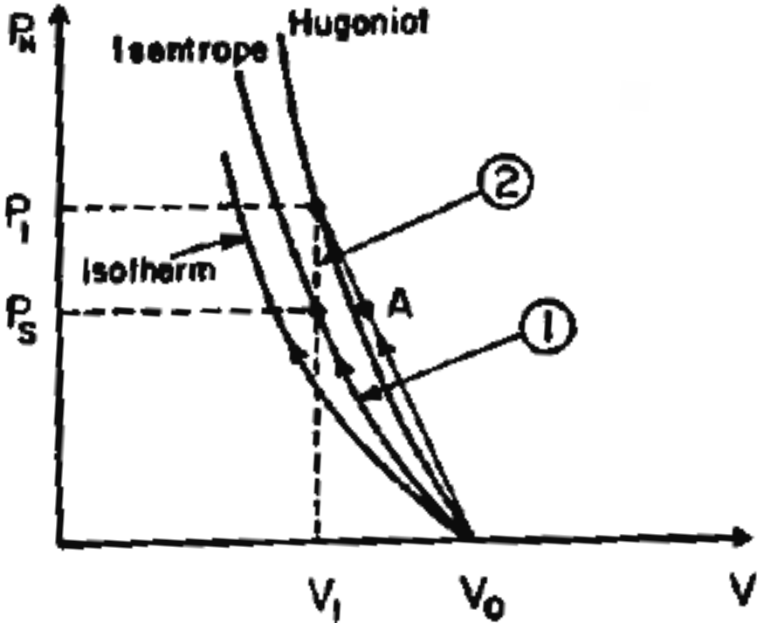
Comparison of implicit and explicit finite element codes in the elastic regime





P.Loveridge

- •Autodyn time step limited by Courant number stability criteria, sometimes may be able to get away with slightly longer timesteps using implicit method, still needs to be short enough to capture physics
- •ANSYS classic has advantages for temperature dependant material modelling in the elastic and plastic regions
- •Autodyn shock equations of state are for high compressions – shock EOS data not employed in this calculation as compression is small
- •No option to enter tangent modulus – inertial plastic wave simulations as yet not attempted
- •Explicit method does offer stability for highly non linear phenomena if you have them
- •Before employing Autodyn or LS-dyna be certain you are in a regime where you need it, are the equations of state and material strength models relevant to your problem?



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