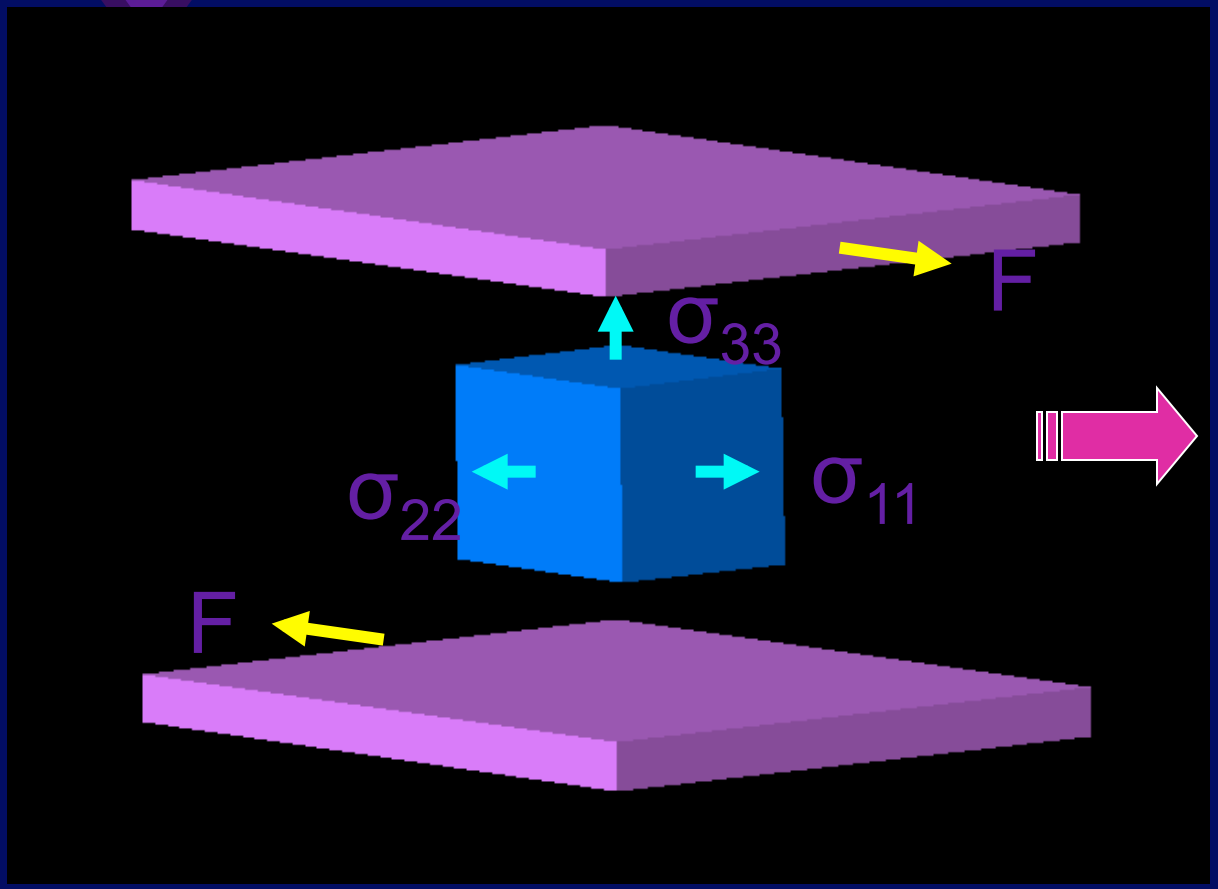
Normal Stress Difference



Δ N = N1-N2

N1 = σ11- σ22

N2 = σ22- σ33

Normal Stress Difference and Extrudate Swell

$$N_1 = \tau_w (B^4 - 1)^{1/2}$$

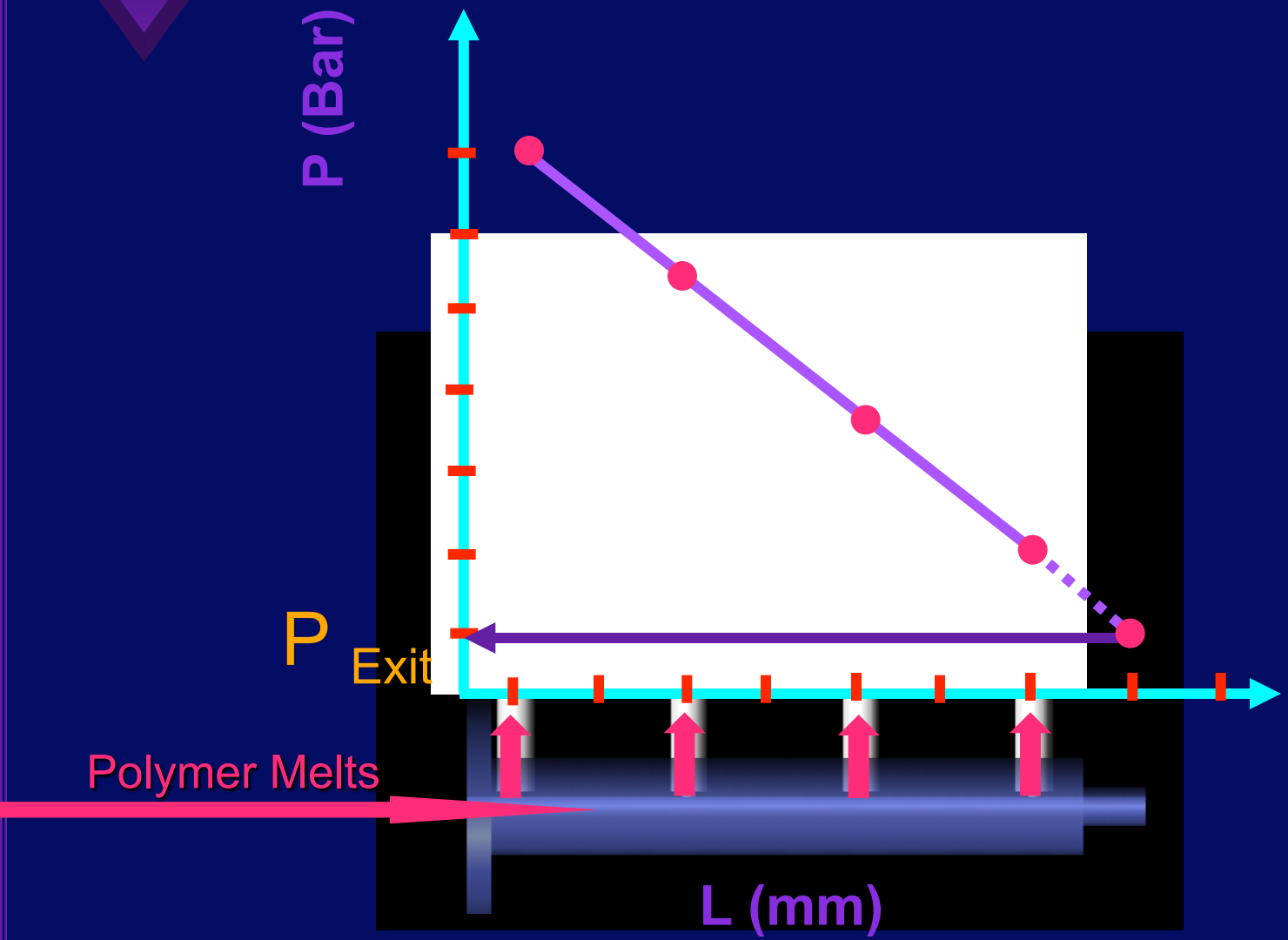
Normal Stress Difference and Pressure Exit

$$N_1 = P_{exit}[1 + d(\ln P_{exit})/d(\ln \tau_w)]$$

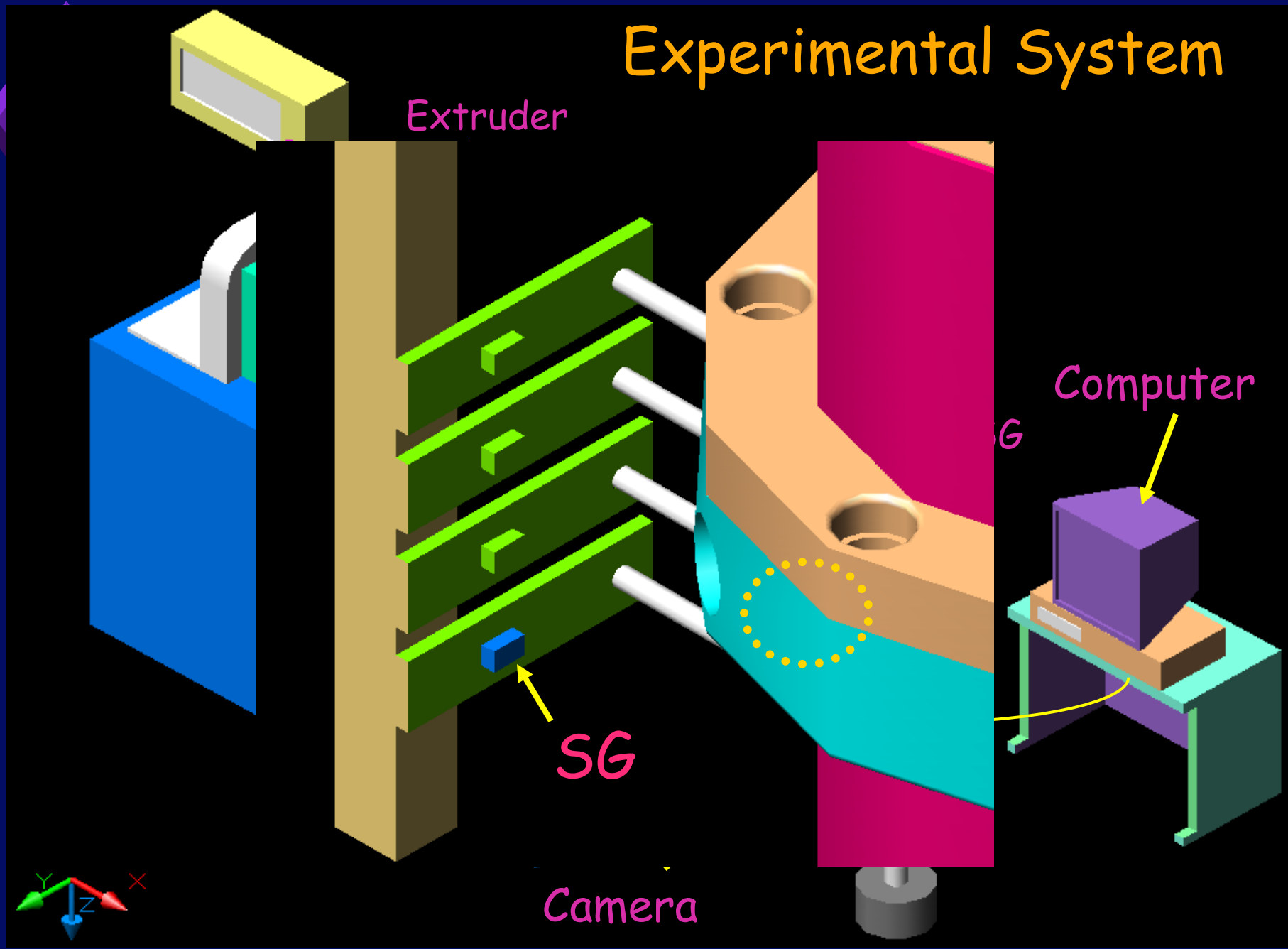
ความสัมพันธ์ระหว่าง Normal Stress Difference กับ Pressure Exit

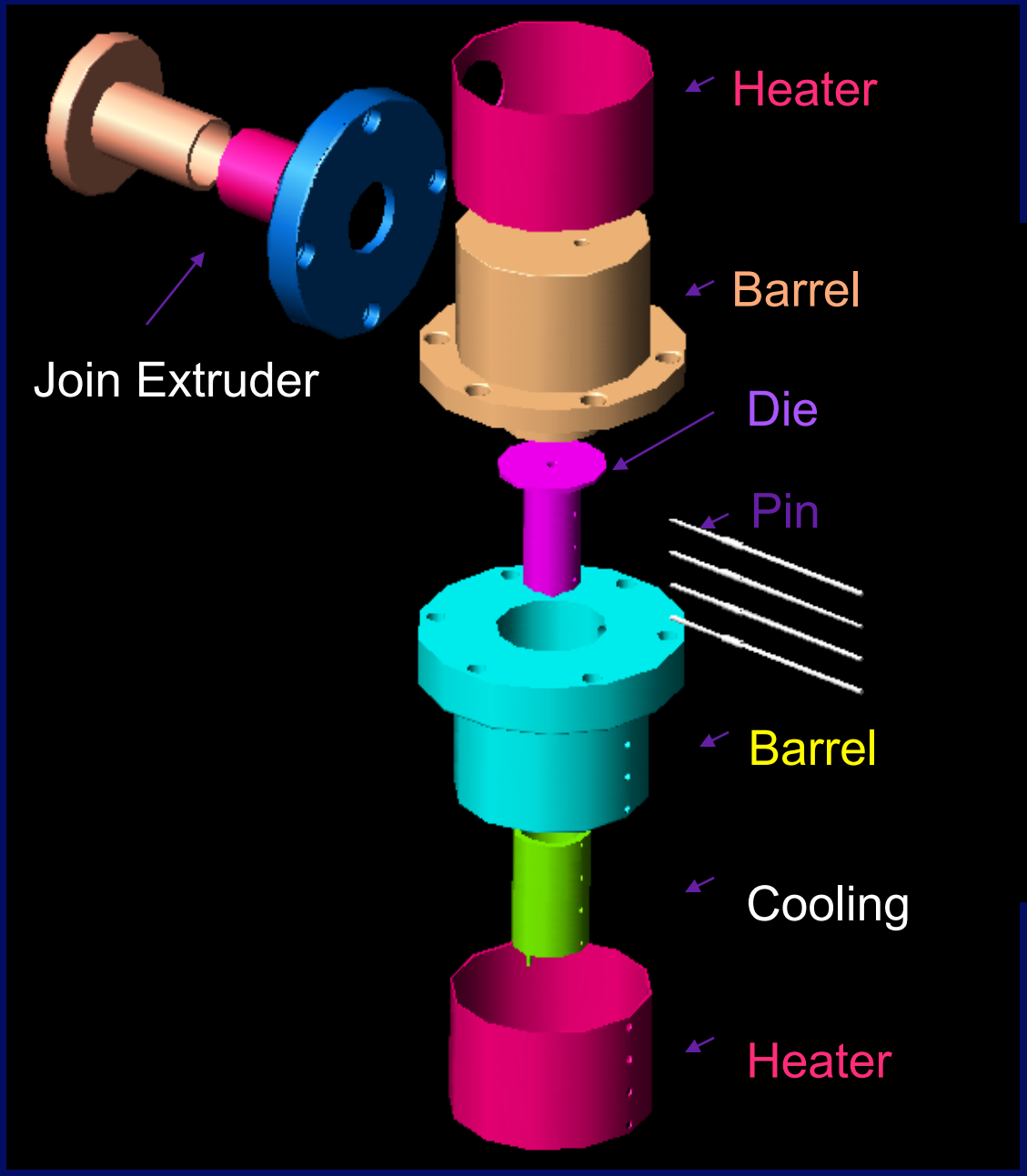
$$N_1 = 3DP_{exit}$$

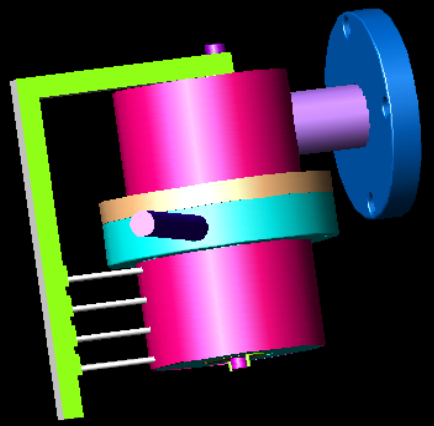
Pressure Exit By Extrapolation



Experimental System

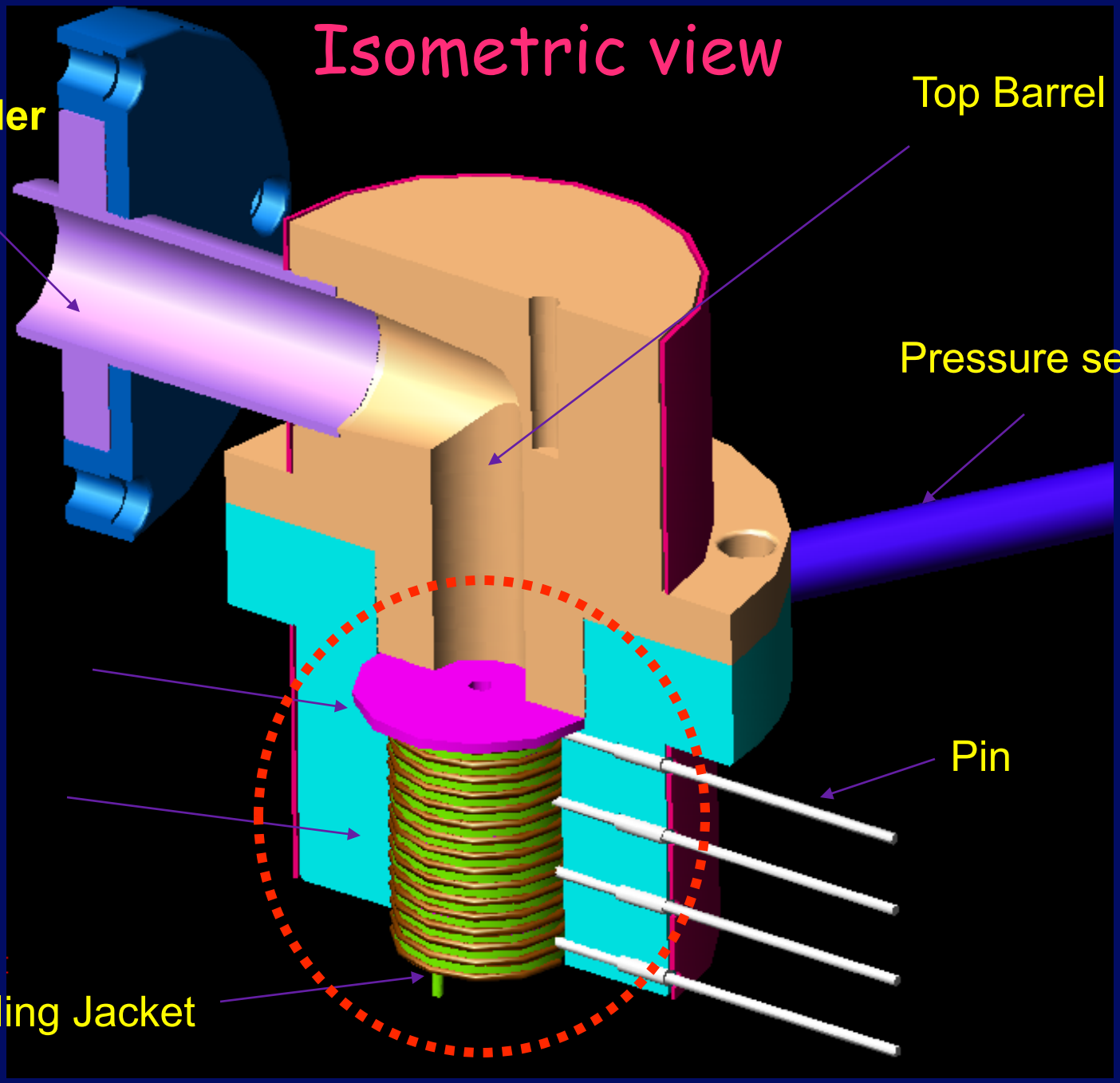






Assembly View

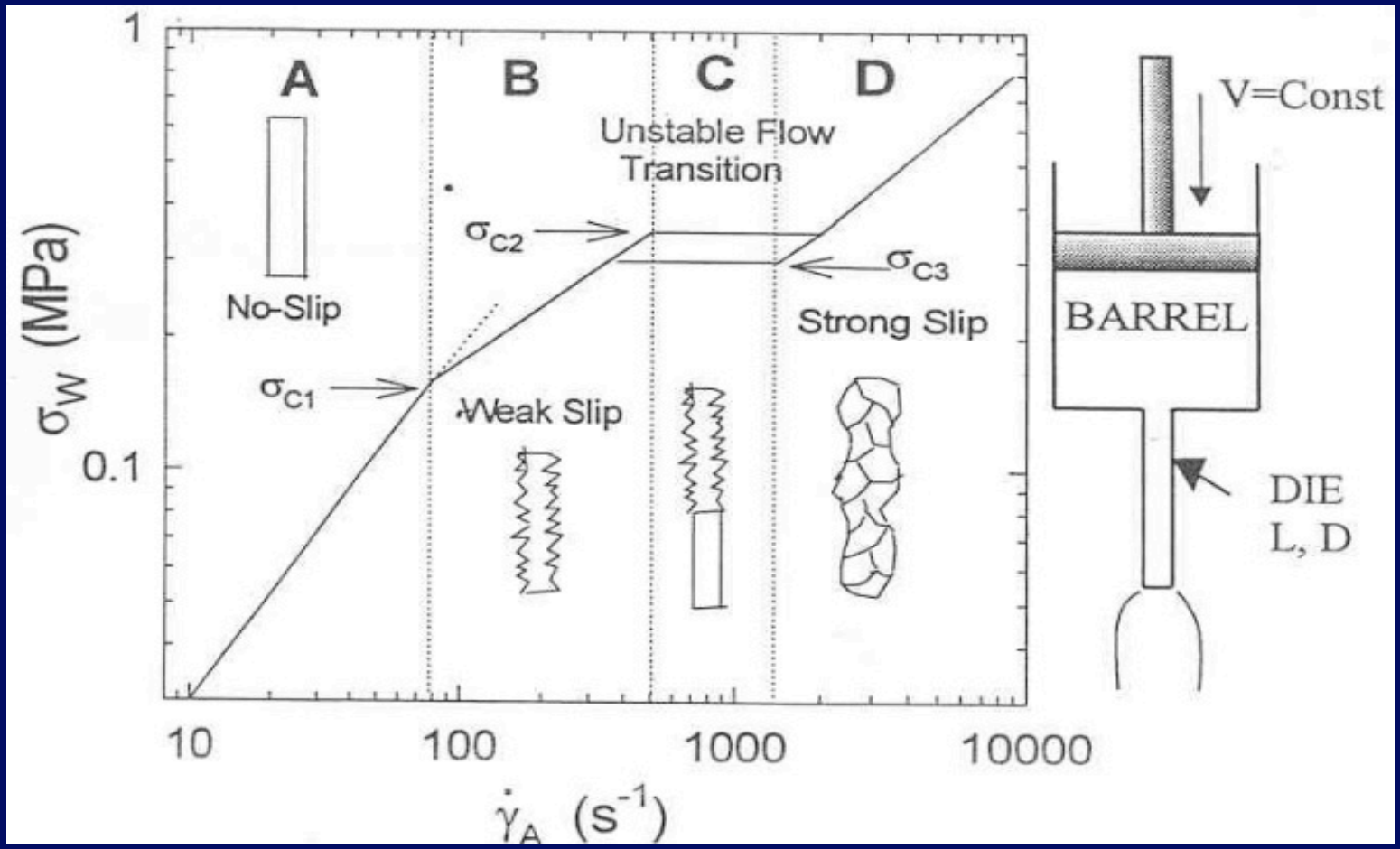
Isometric view



Sharkskin

- Defined as a fine surface distortion which runs perpendicular to the direction of polymer extrusion.
- As a melt flows in the die, a force required for the acceleration of the outer layer of the melt increases in order to equalise the melt velocity at the exit. If the force exceeds tensile strength of the melt, the melt will rupture and generate sharkskin.
- Mechanism of sharkskin is related to two possibilities that are (a) arrangement of velocity profiles in the die land through the die exit and (b) the balance of elastic to viscous properties. The latter one appears to be strongly affected by the temperature.

Polymer Melt Flow in an Extrusion Process



Fyrillas et al: Polym. Eng. Sci. (1999)

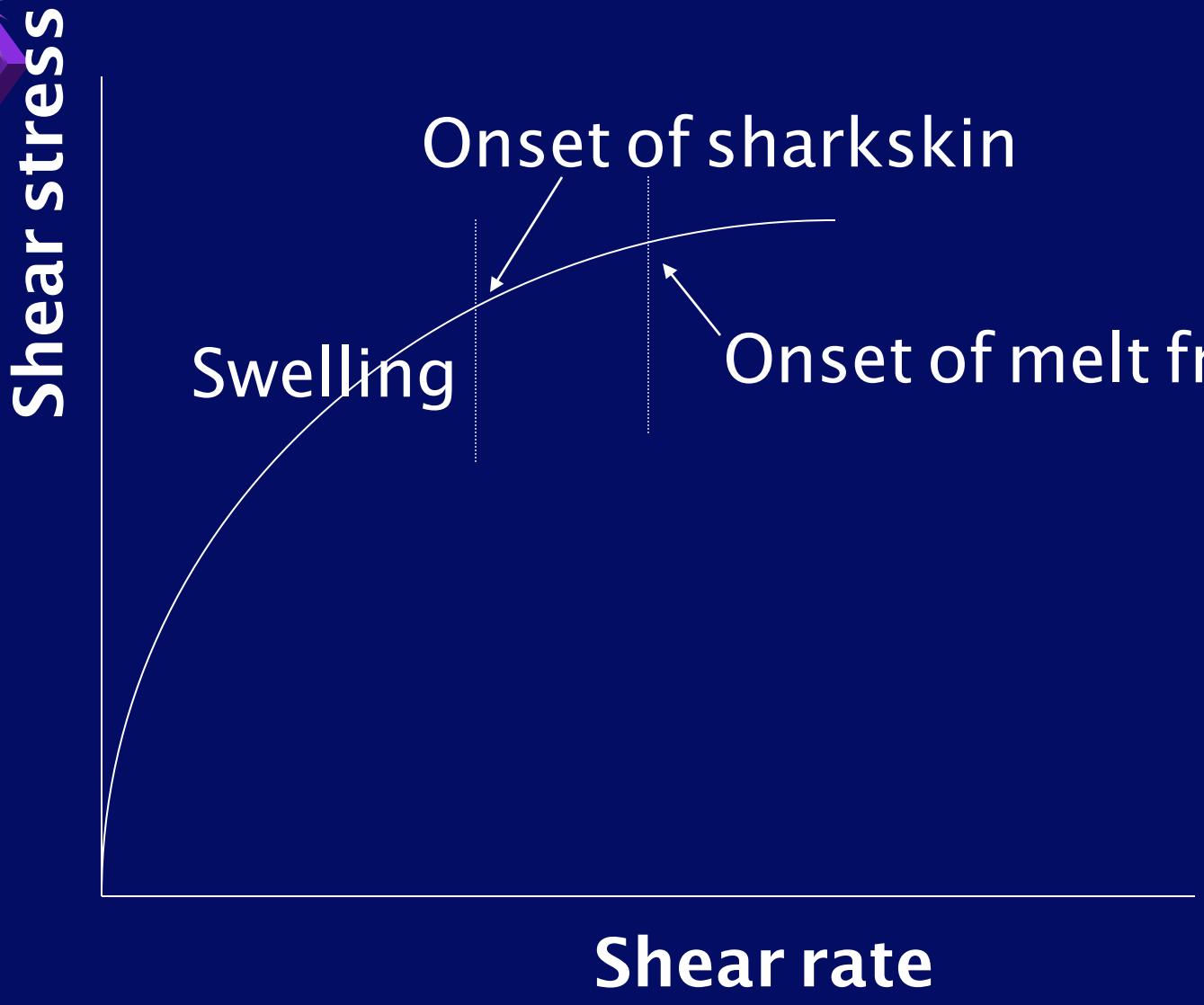
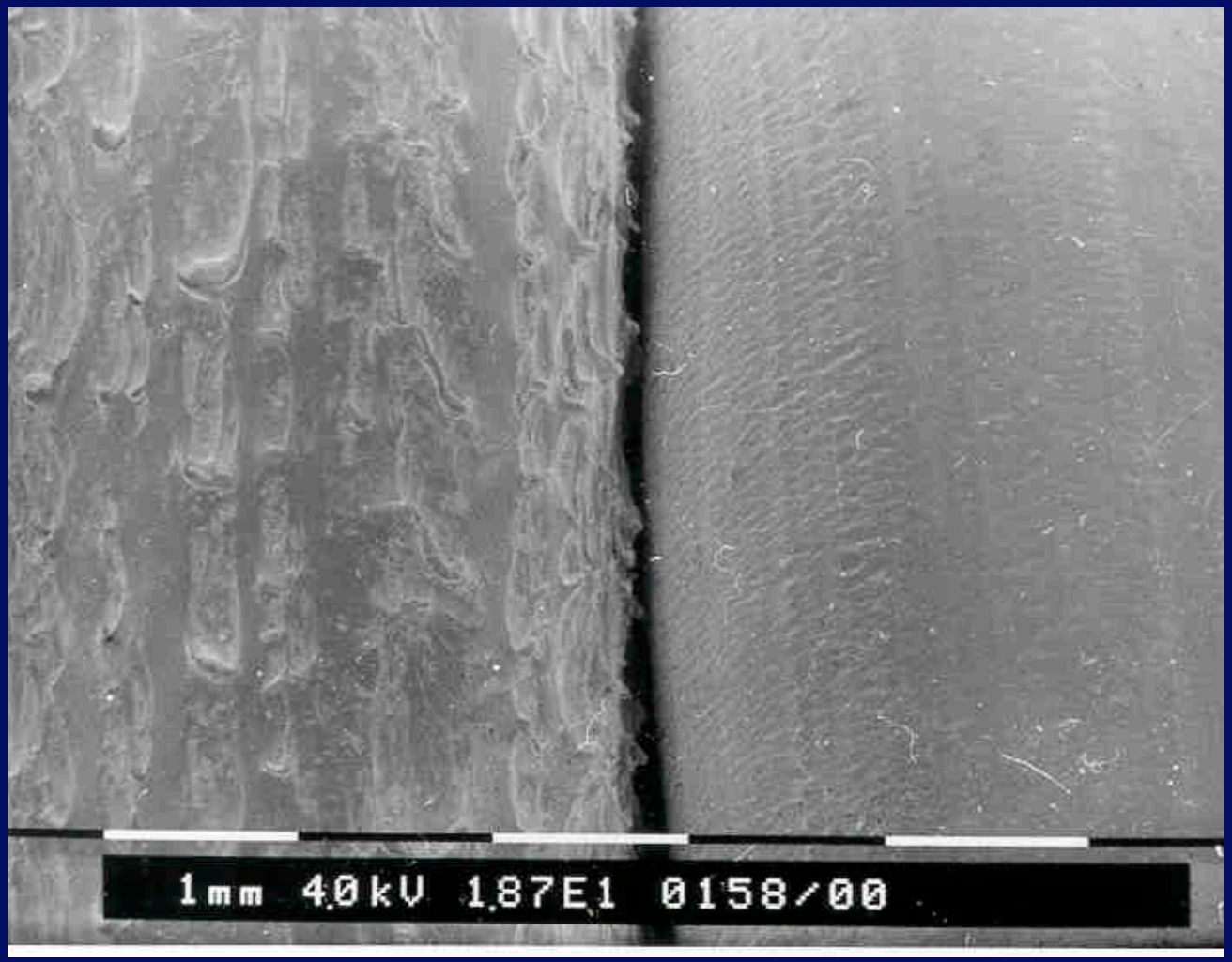
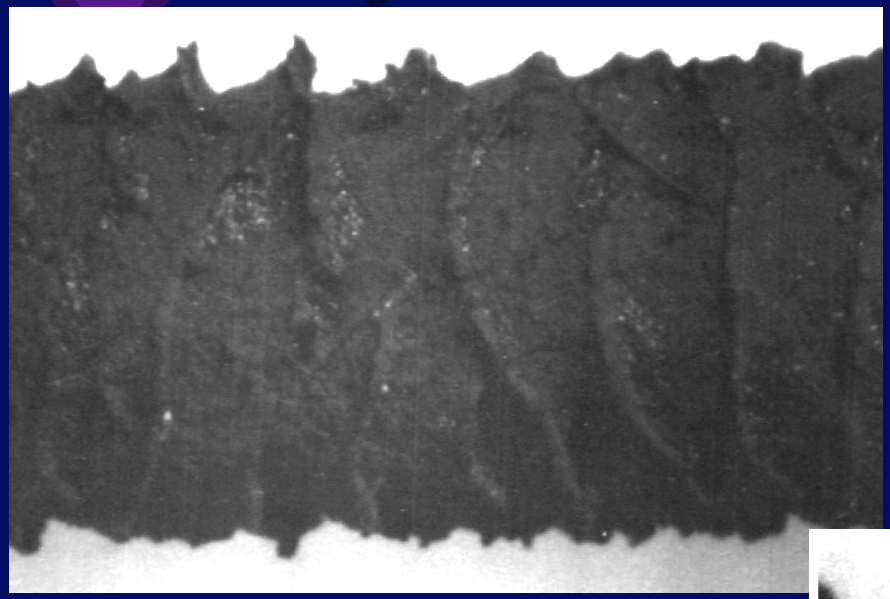

Shear stress
Onset of sharkskin
Swelling
Onset of melt fracture
Shear rate

Fig 5

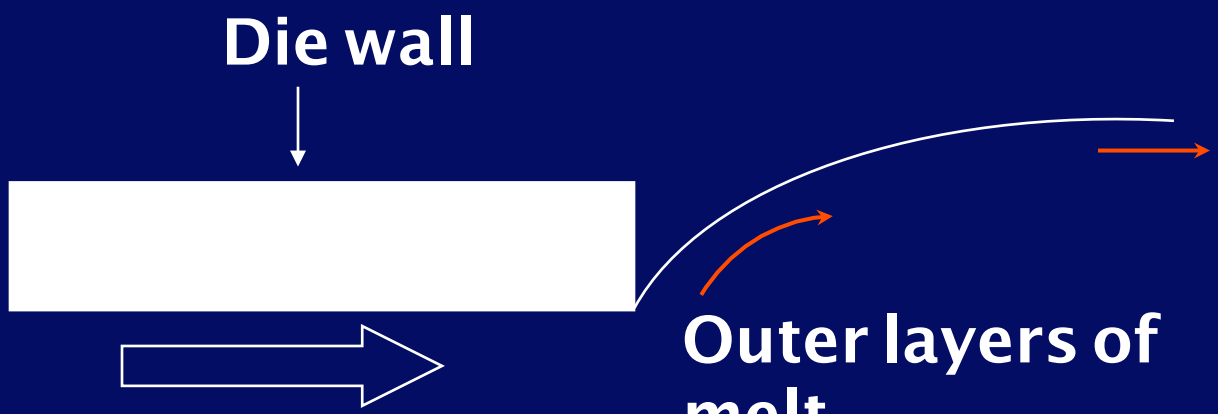
Minor sharkskin (PP)



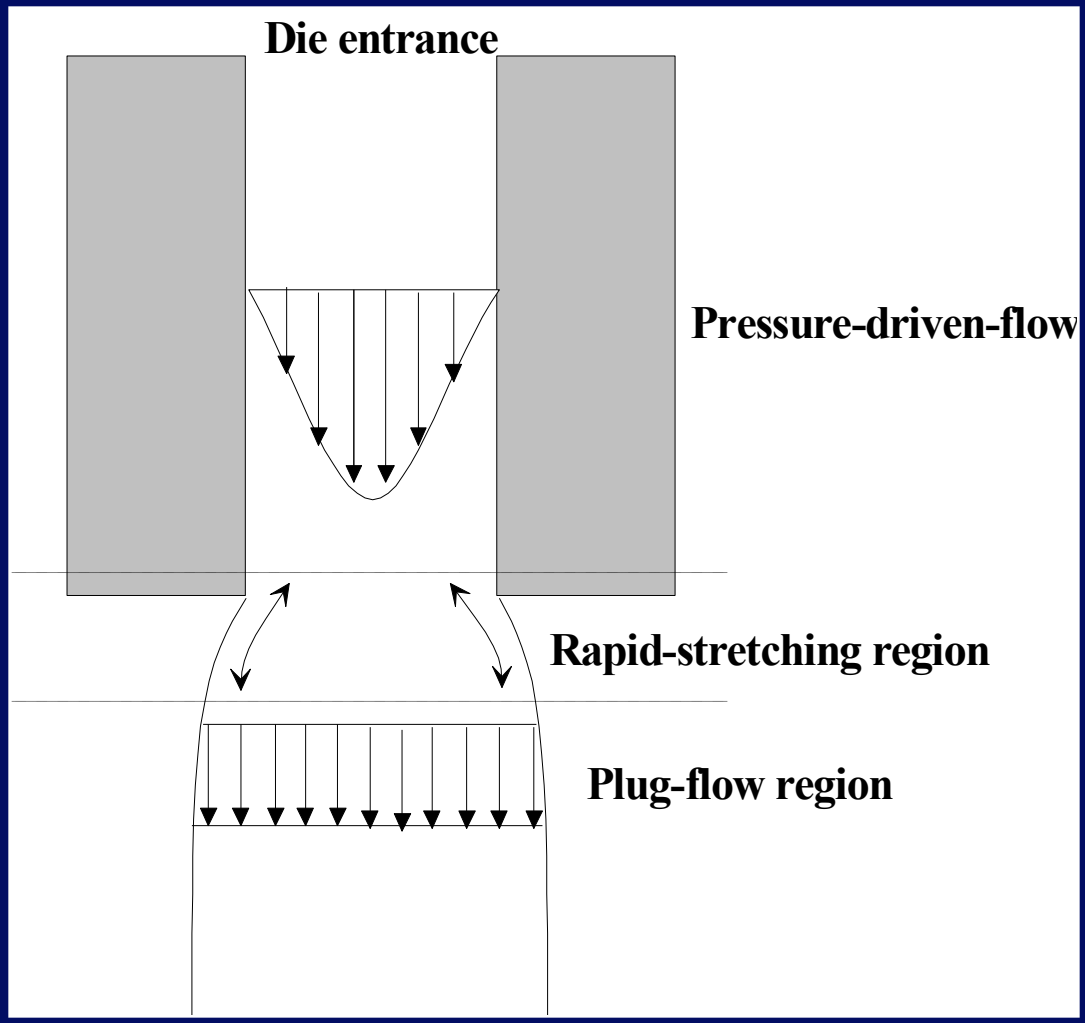
Major sharkskin (SBR rubber)



Sharkskin mechanism



Velocity profiles and die swell relationship



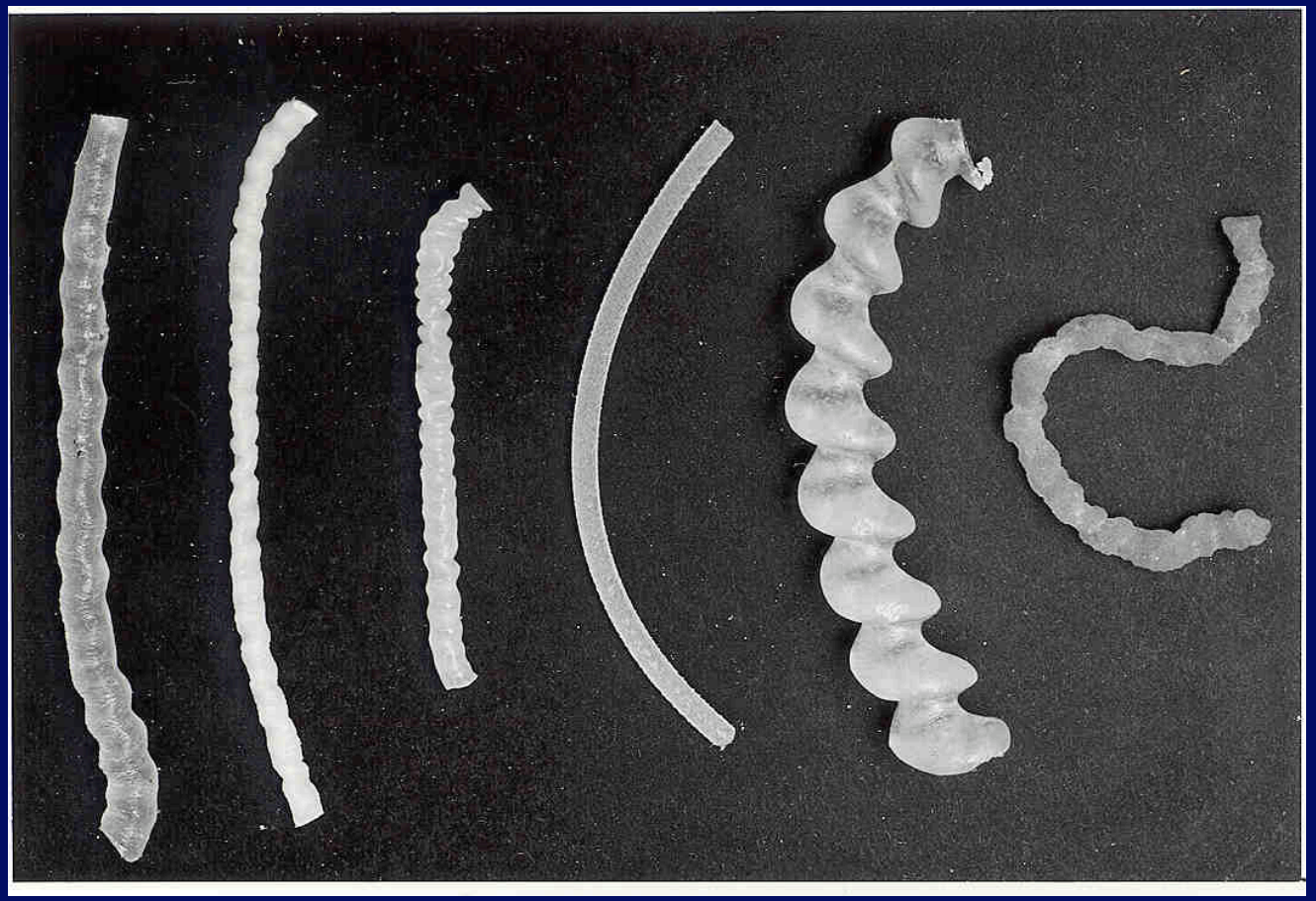
Sharkskin (cont.)

- Increasing the die temperature is the usual way to minimise the sharkskin.
- Suitable lubricants (both internal and external) are helpful.

Melt Fracture

- As the shear rate and shear stress are associated with a flowing polymer melt, there is a stage reached where the structure of the extrudate breaks down. This rupture is well known as “melt fracture or elastic turbulence”.
- The nature of the extrudate varies depending on the polymer and can be totally irregular, spiral or consists of smooth and irregular sequences.
- So far *no absolute explanation* for the site of melt fracture initiation is found.

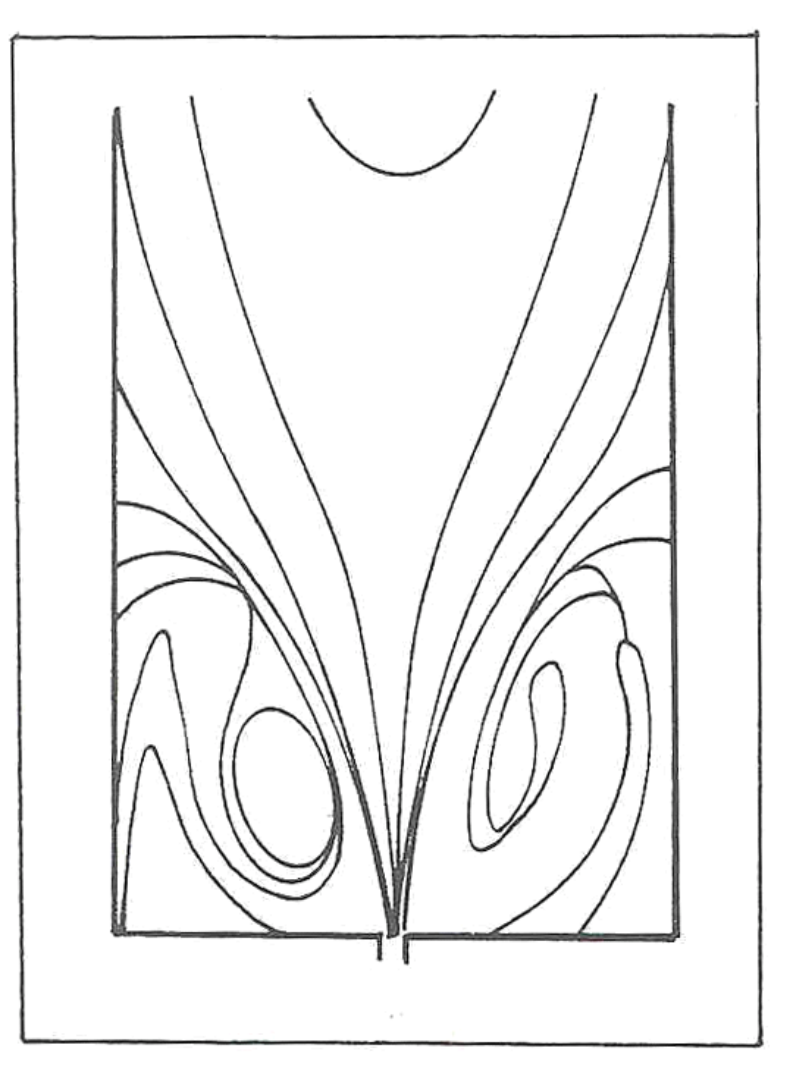
Melt fractures of various polymer melts



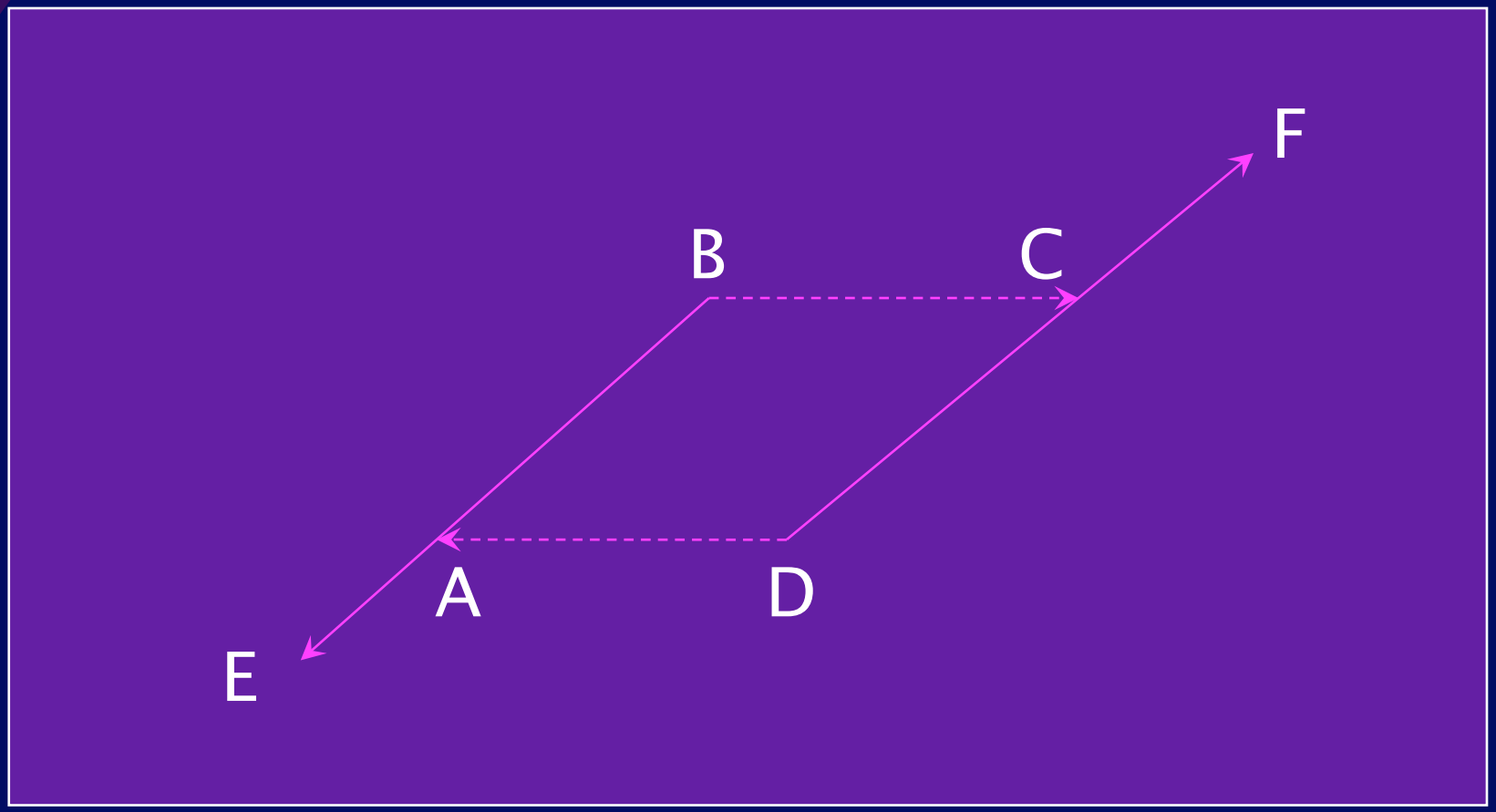
Possible explanations for melt fracture

- Conventional turbulence effect: This effect involves the determination of the Reynold number of fluids.
- Elastic effect: This involves the fracture/ tearing of molecular structure of polymer melts at die entrance.
- Melt strength: This is related to the shear rate or shear stress of the extrudate as it comes out of the die exceeding the tensile strength of the melt.
- Wall slip: This is related to slip-stick theory.

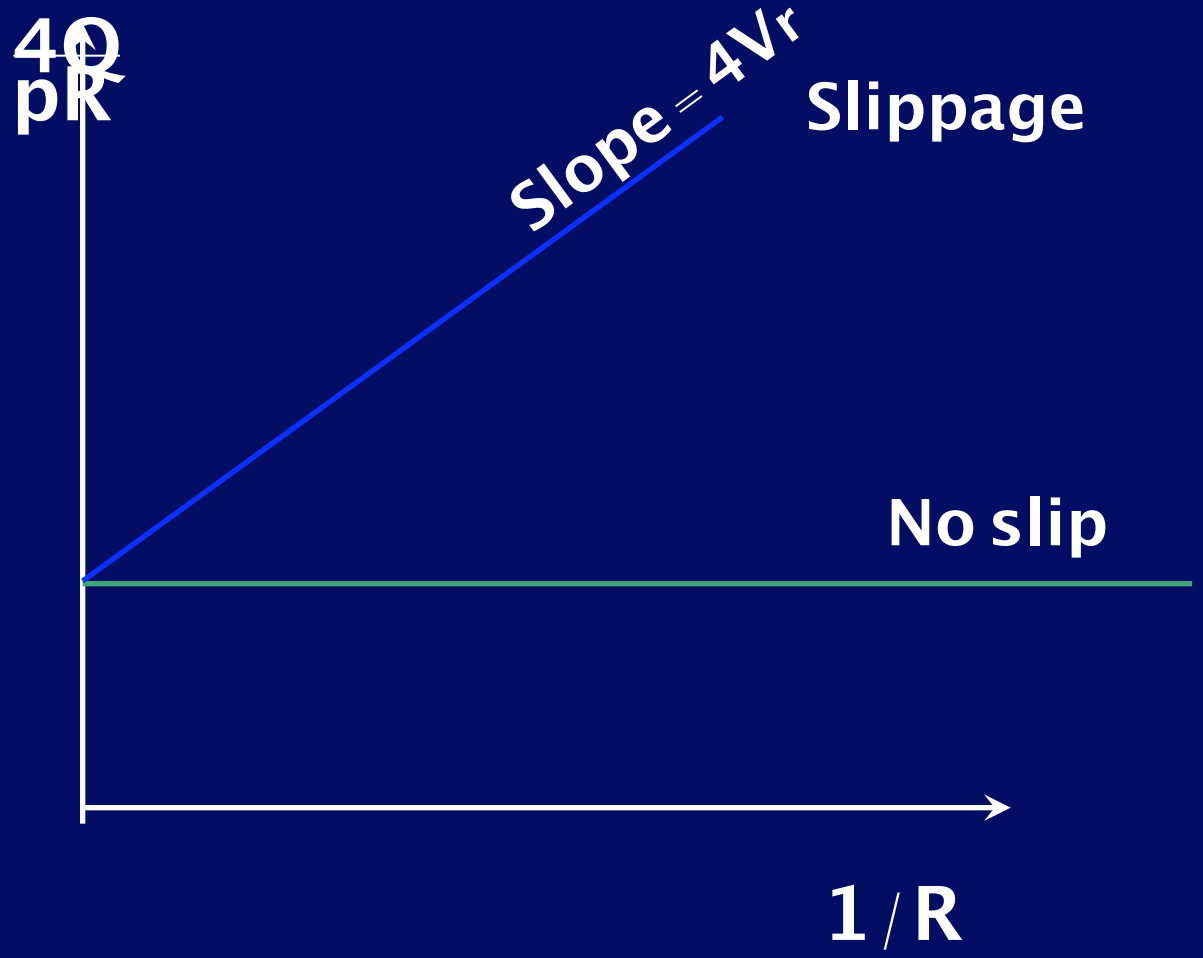
Secondary flow (dead flow) at die entrance

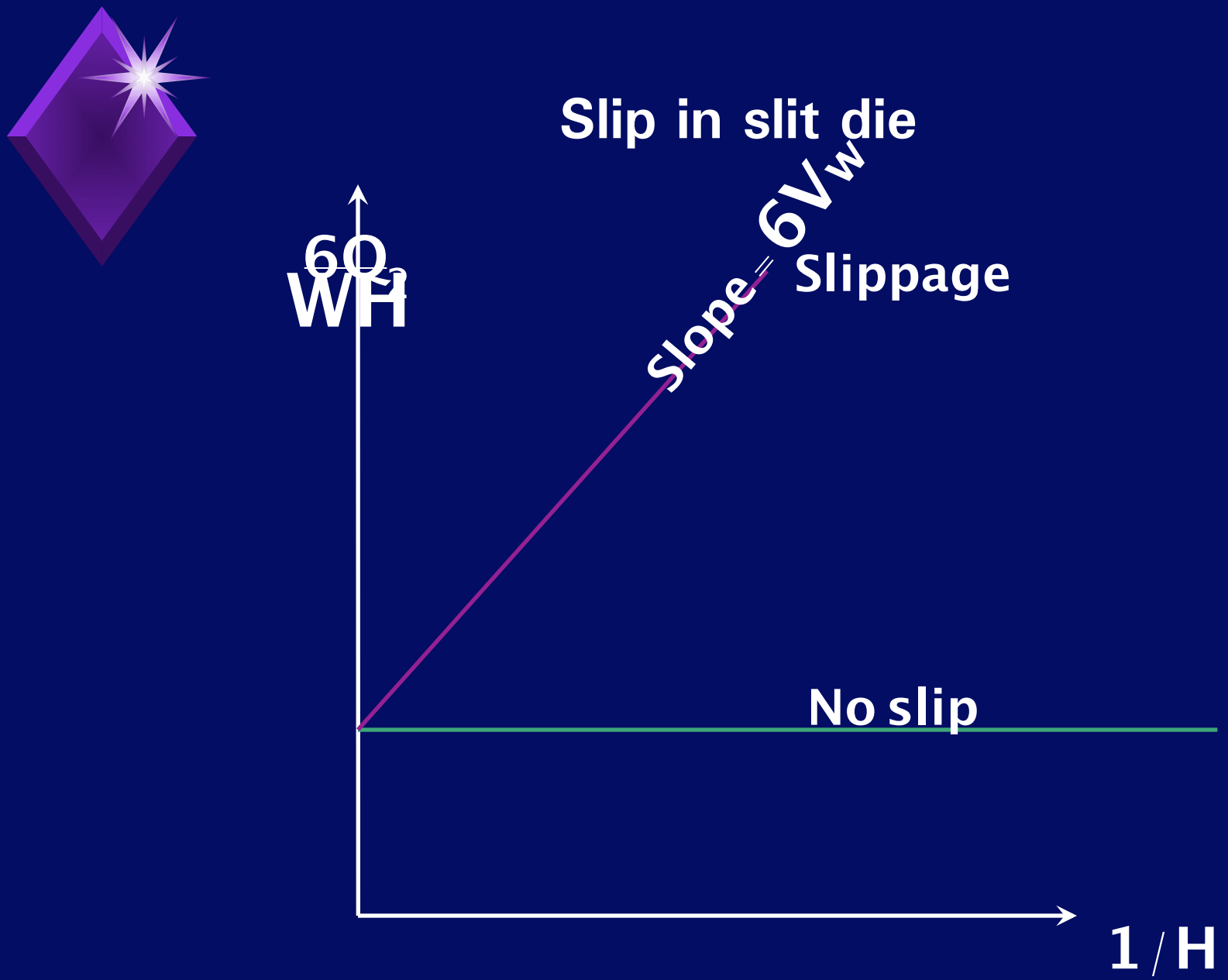


Slip-Stick Theory



Slip in circular die




Slip in slit die
$\frac{6Q}{WH}$
Slope = $6V_w$
Slippage
No slip
1 / H