SUPERPAVE PERFORMANCE GRADED BINDER TESTS

PG Specifications

- Fundamental properties related to pavement performance
- Environmental factors
- In-service & construction temperatures
- Short and long term aging

PG Specifications

- Based on rheological testing
  - Rheology: study of flow and deformation
- Asphalt cement is a viscoelastic material
- Behavior depends on:
  - Temperature
  - Time of loading
  - Aging (properties change with time)

High Temperature Behavior

- High in-service temperature
  - Desert climates
  - Summer temperatures
- Sustained loads
  - Slow moving trucks
  - Intersections

→ ***Viscous Liquid***

Pavement Behavior (Warm Temperatures)

- Permanent deformation (rutting)
- Mixture is plastic
- Depends on asphalt source, additives, and aggregate properties

Permanent Deformation

Function of warm weather and traffic

Low Temperature Behavior

- Low temperature
  - Cold climates
  - Winter
- Rapid loads
  - Fast moving trucks

Elastic Solid

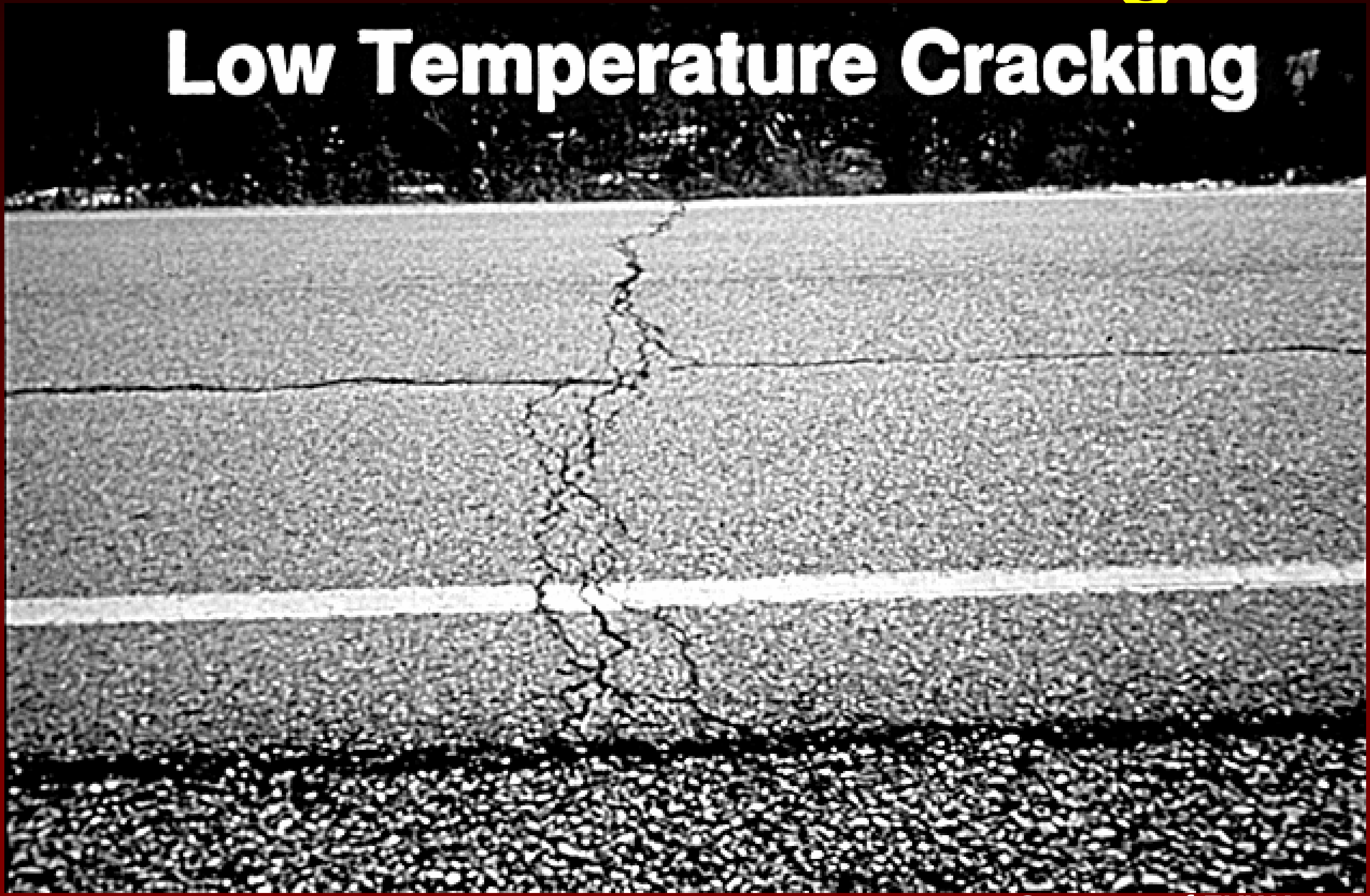
Hooke's Law

$$\sigma = \tau E$$

Pavement Behavior (Low Temperatures)

- Thermal cracks
  - Stress generated by contraction due to drop in temperature
  - Crack forms when thermal stresses exceed ability of material to relieve stress through deformation
    - Material is brittle
- Depends on source of asphalt and aggregate properties

Thermal Cracking



Courtesy of FHWA

Aging

- Asphalt reacts with oxygen
  - “oxidative” or “age hardening”
- Short term
  - Volatilization of specific components
  - During construction process
- Long term
  - Over life of pavement (in-service)

Superpave Asphalt Binder Specification

The grading system is based on climate

PG 64 - 22

Performance Grade

Average 7-day max pavement temperature

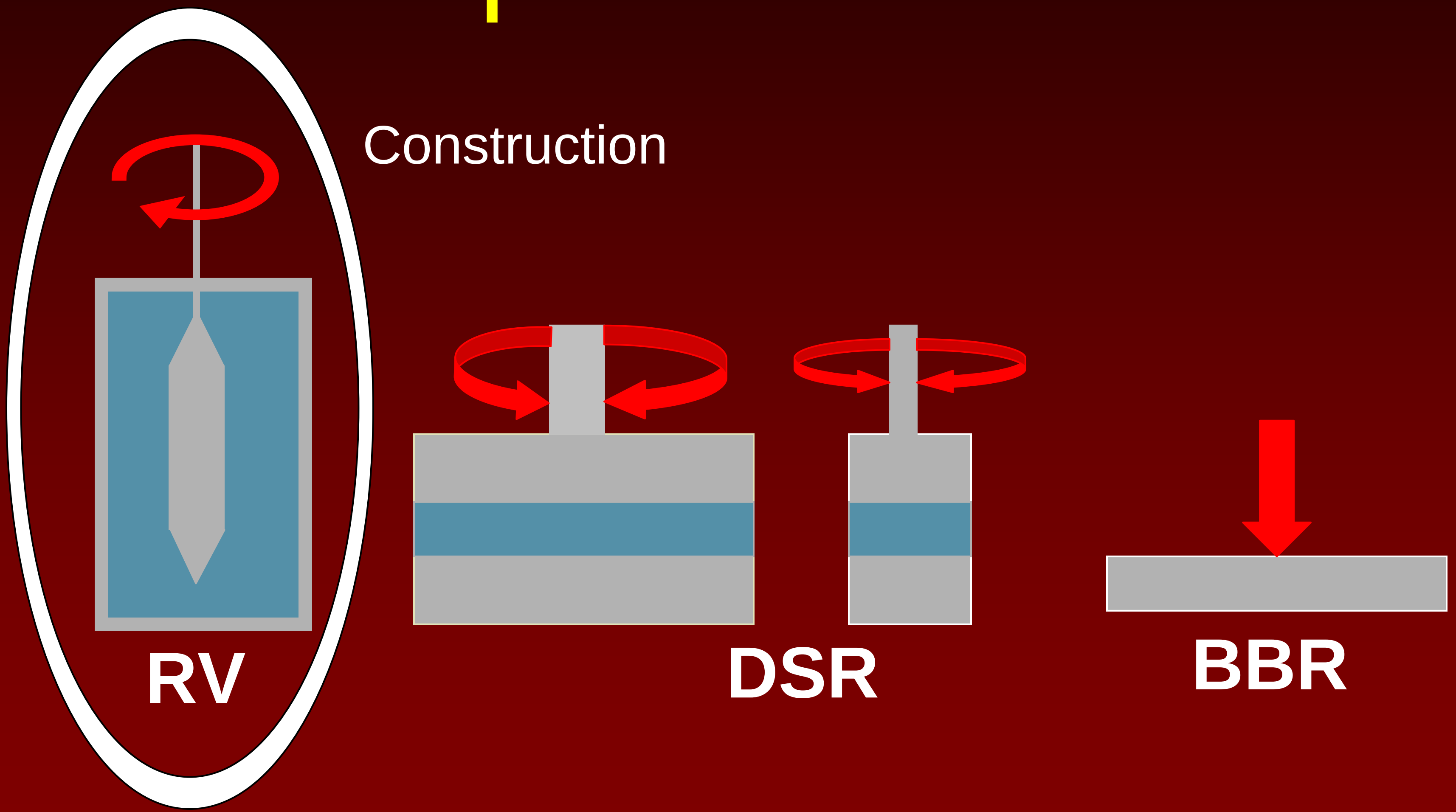
Min pavement temperature

Pavement Temperatures are Calculated

- Calculated by Superpave software
- High temperature
  - 20 mm below the surface of mixture
- Low temperature
  - At surface of mixture

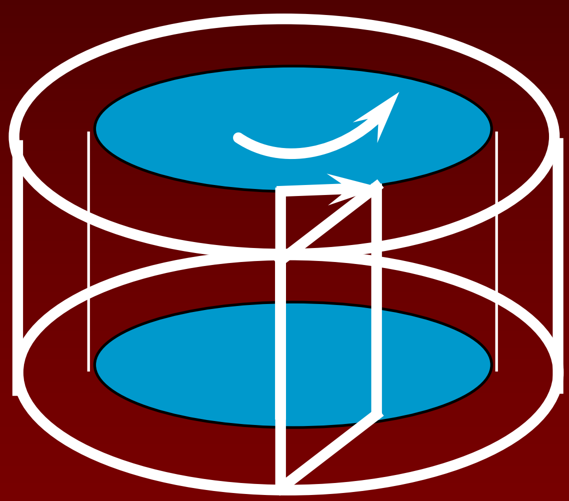
Pave temp = f (air temp, depth, latitude)

Tests Used in PG Specifications



Concentric Cylinder Rheometers

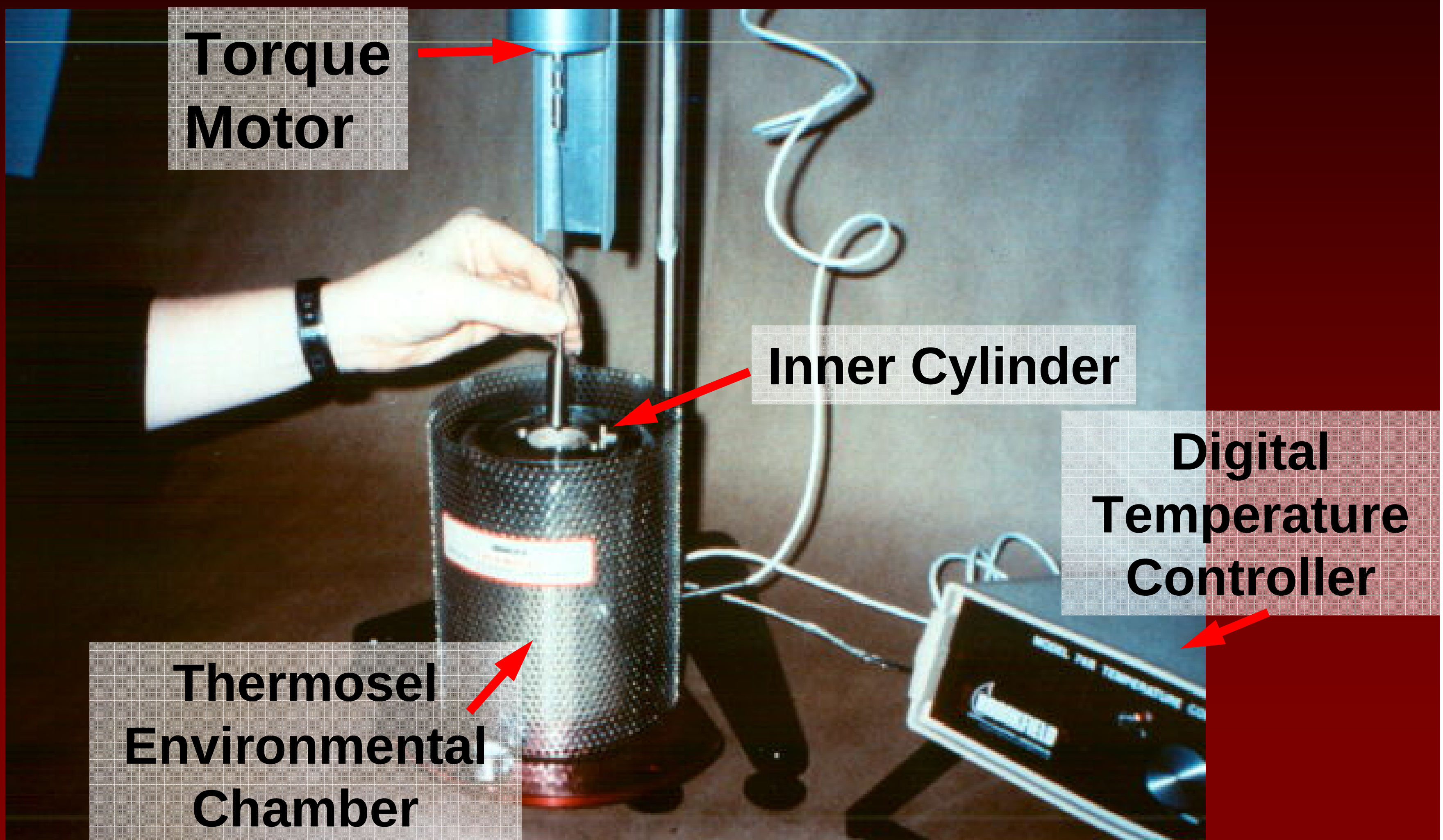
- **Concentric Cylinder**



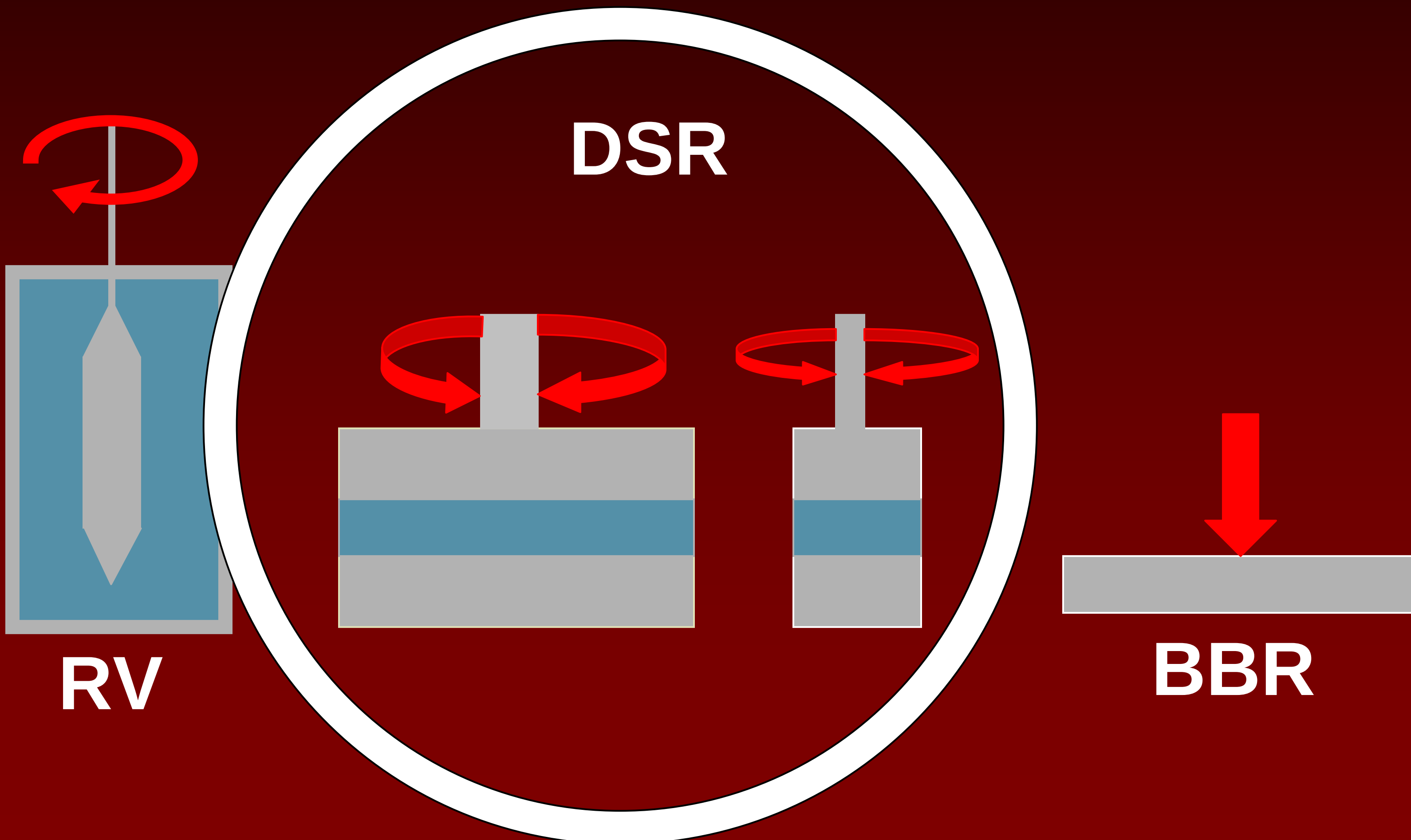
$$\tau_{R\theta} = \frac{M_i}{2\pi R_i^2 L}$$

$$\dot{\gamma} = \frac{\Omega R}{R_o - R_i}$$

Rotational Viscometer

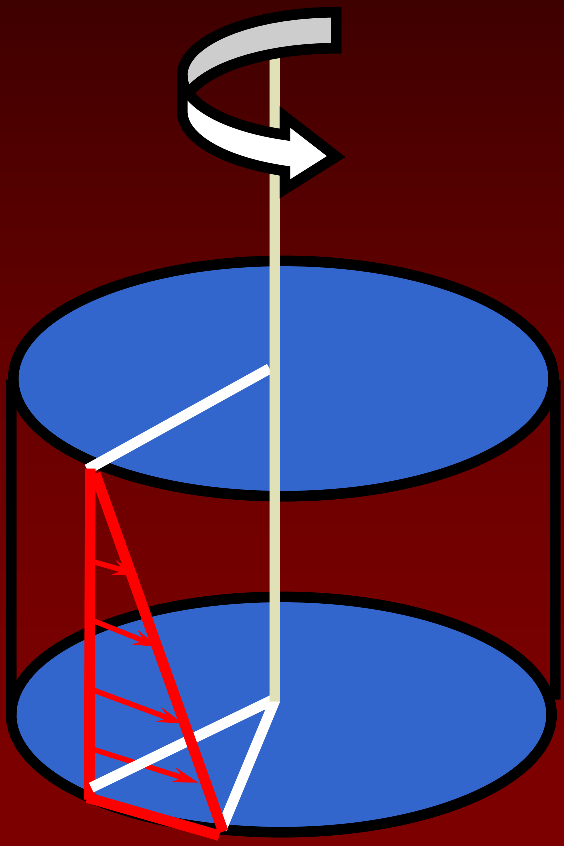


Original Properties, Rutting, and Fatigue



Dynamic Shear Rheometer (DSR)

- Parallel Plate

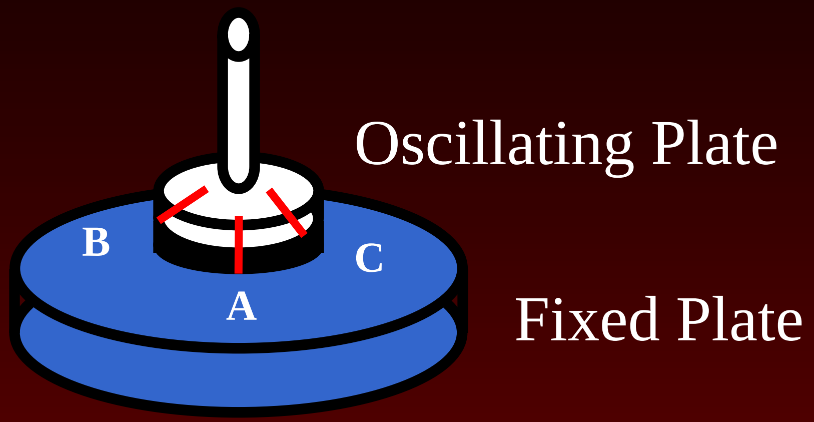


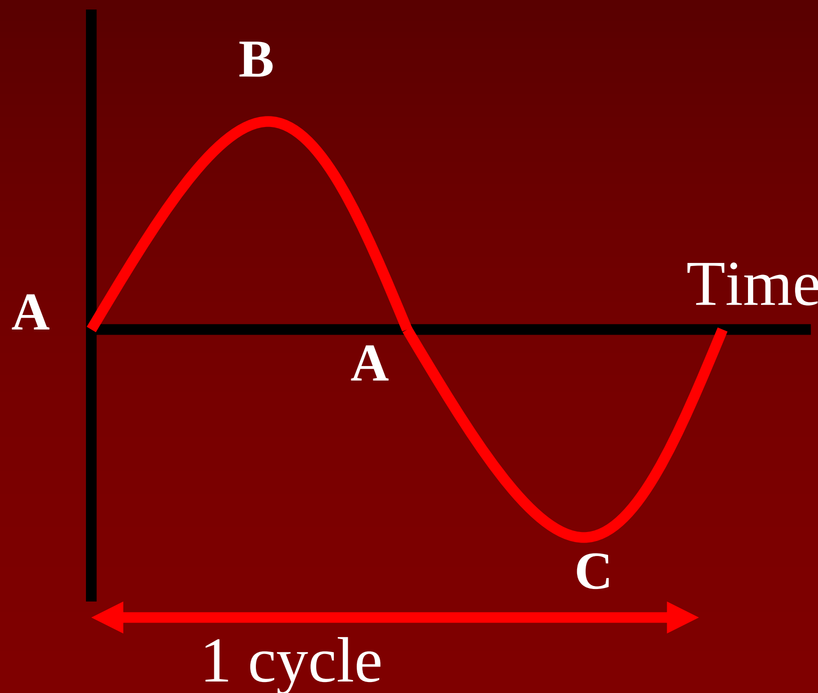
Shear flow varies with gap height and radius

Non-homogeneous flow

$$\tau_R = \frac{2\,M}{\pi\,R^3}$$

$$\gamma_R = \frac{R\,\Theta}{h}$$

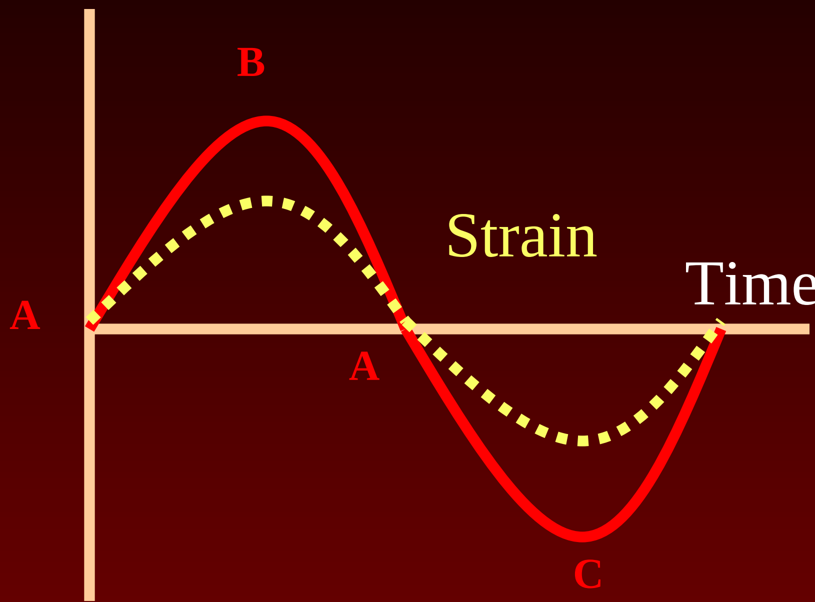




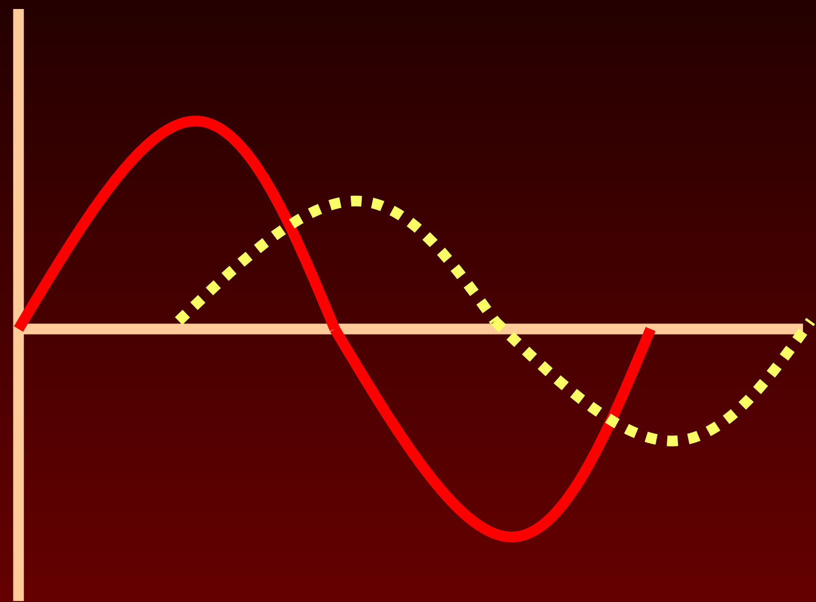
Test operates at 10 rad/sec or 1.59 Hz

$360^o = 2\pi$ radians per circle
1 rad = 57.3^o

Elastic

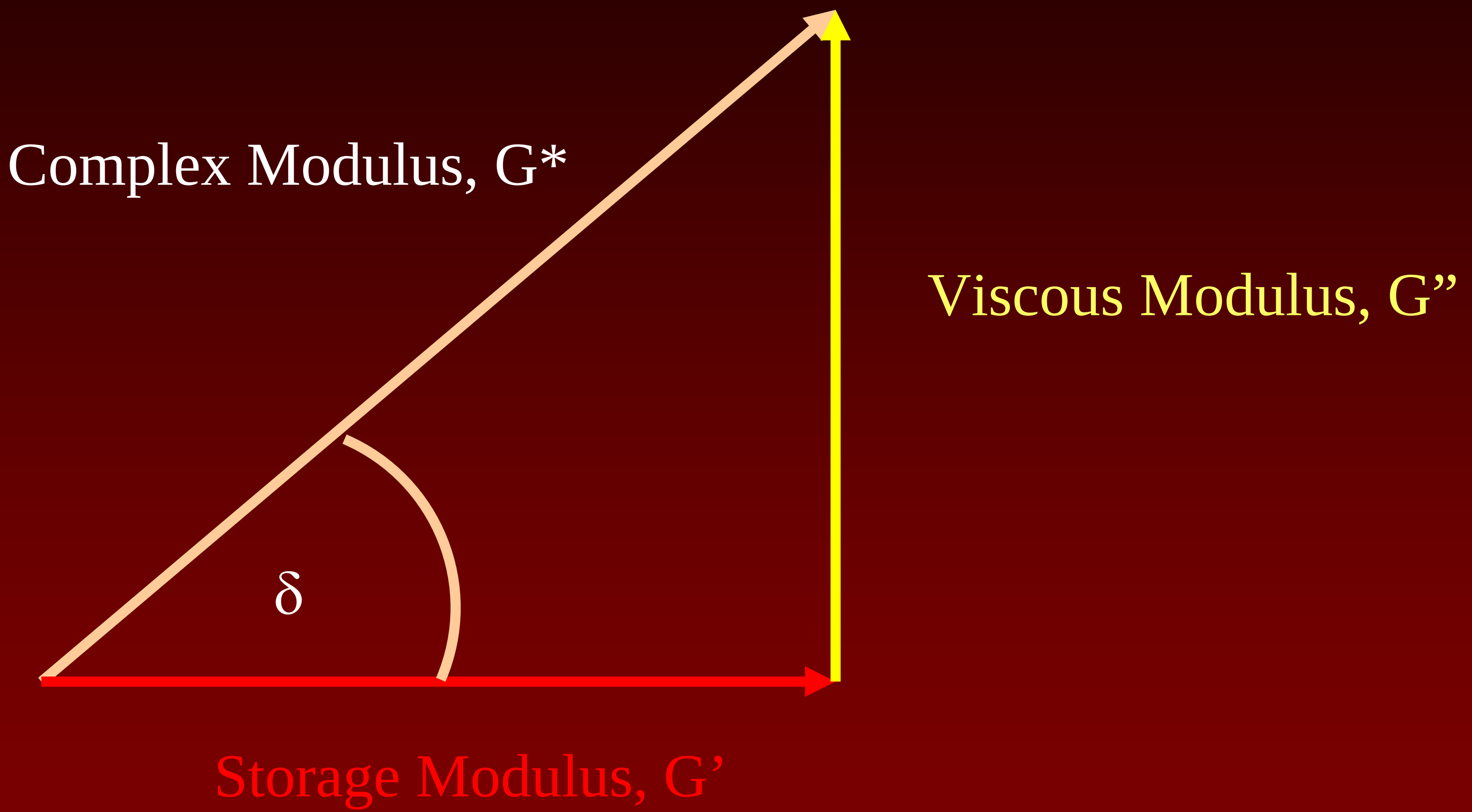


Viscous



Strain in-phase
$\delta = 0^o$

Strain out-of-phase
$\delta = 90^o$

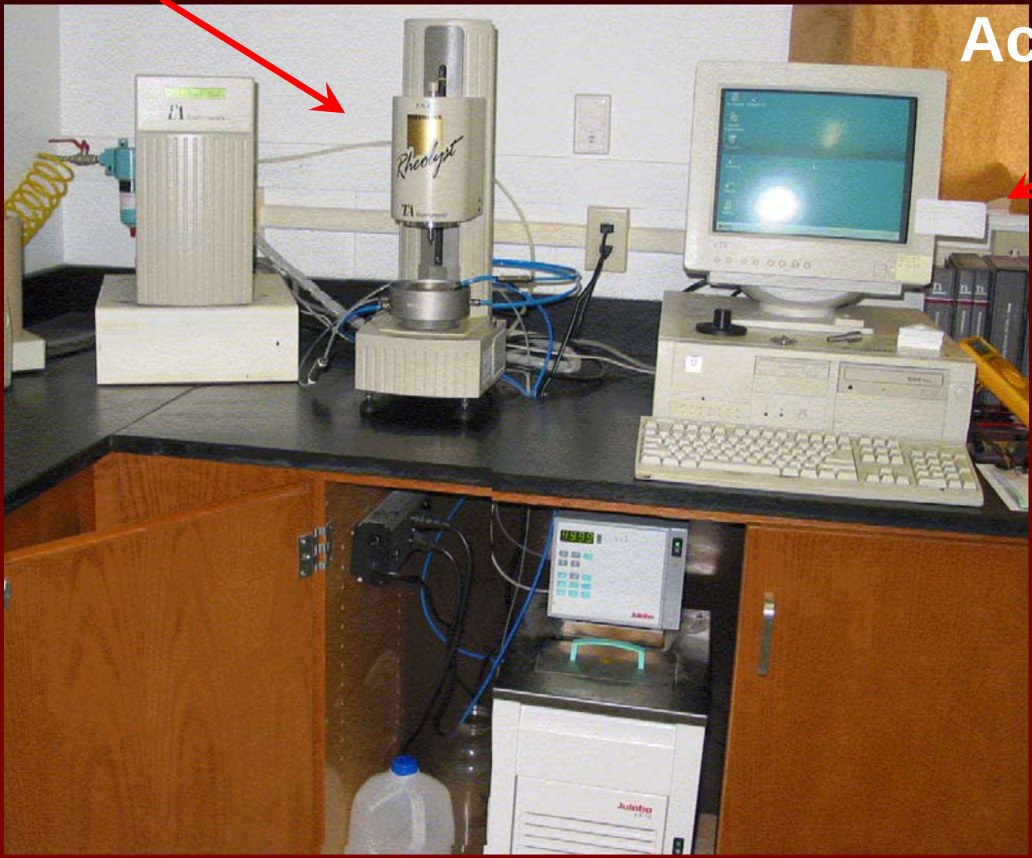


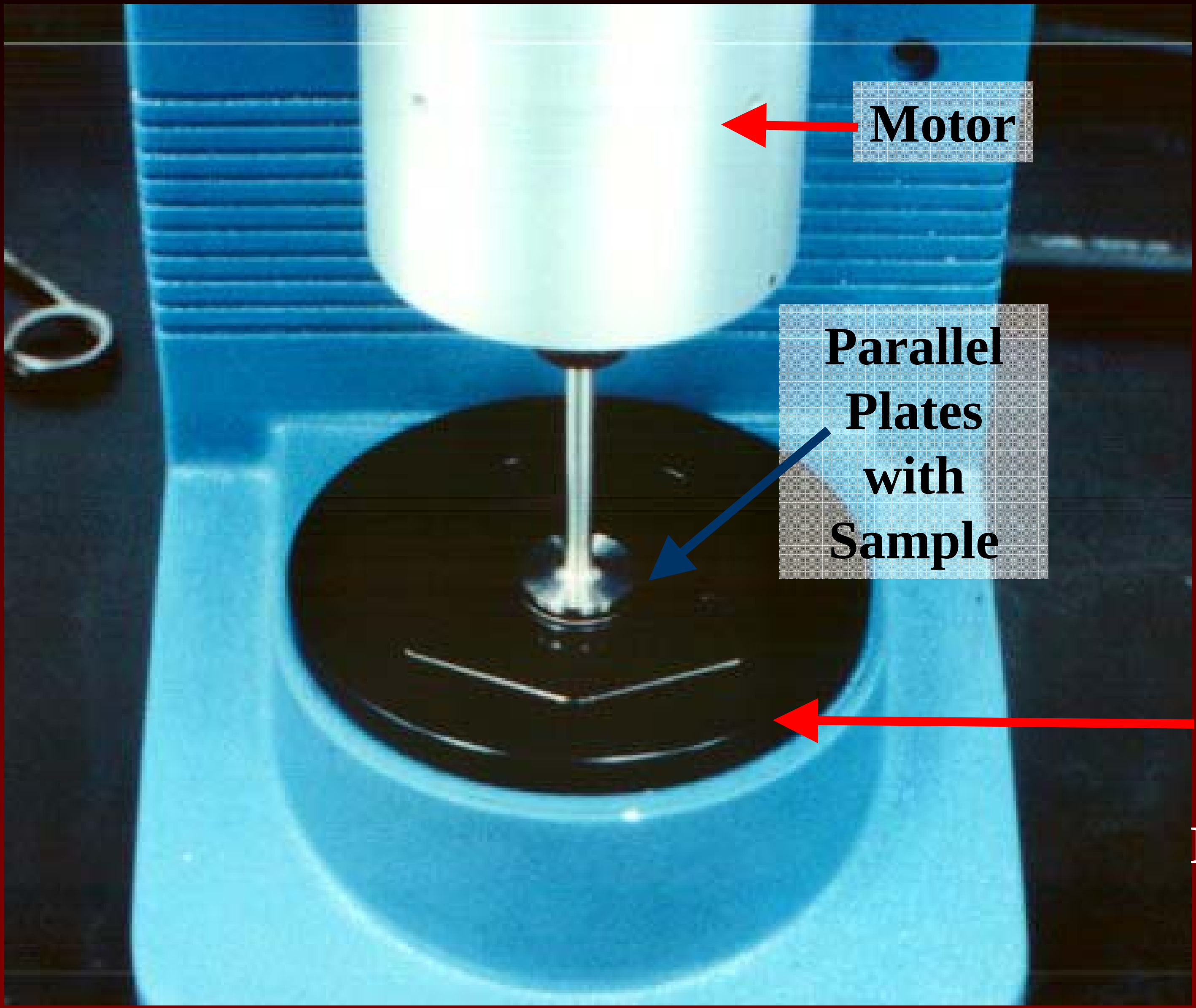
Complex Modulus is the vector sum of the storage and viscous modulus

DSR Equipment

DSR Equipment

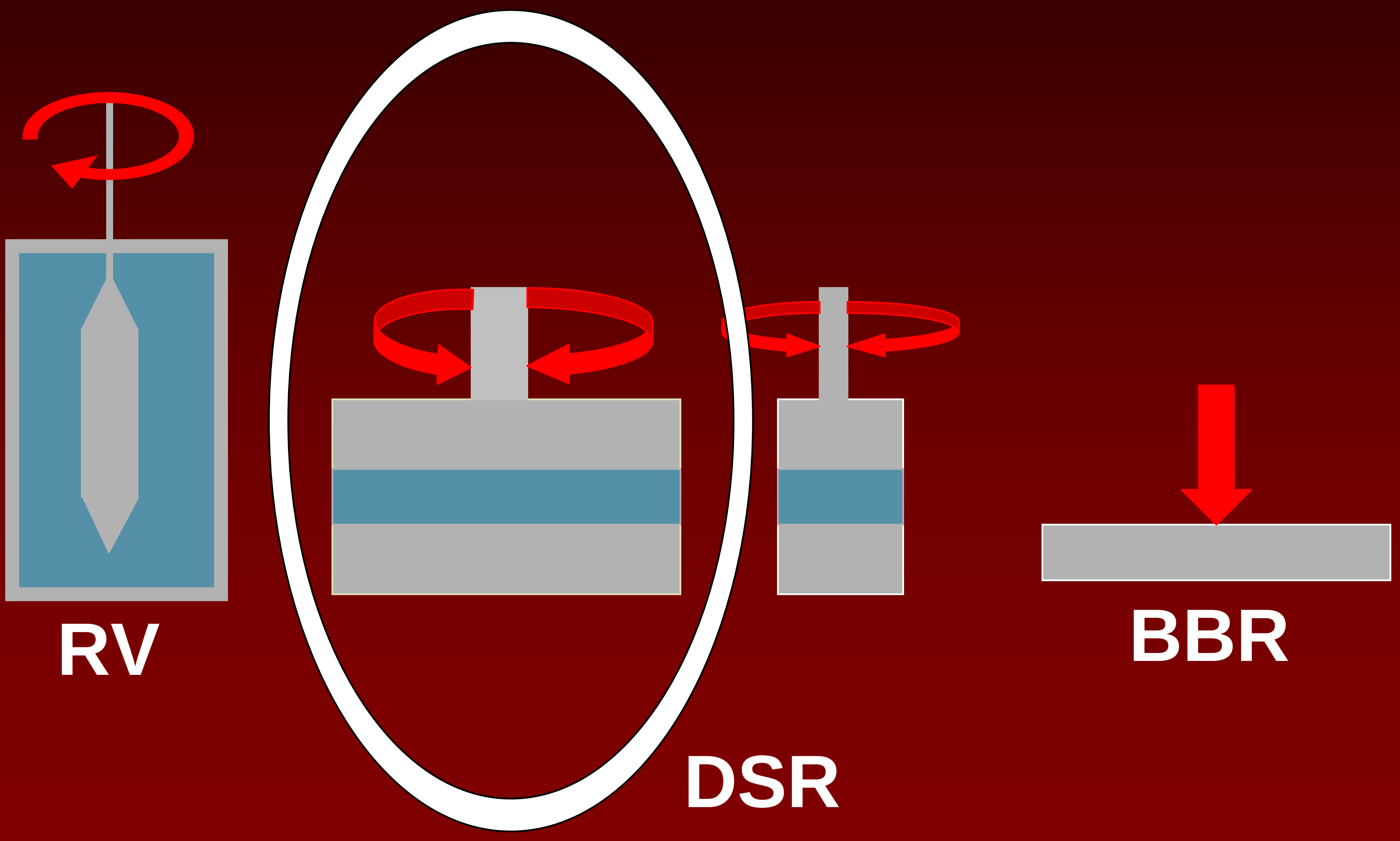
Computer Control and Data Acquisition




Motor
Parallel Plates with Sample
Area for Liquid Bath

25 mm Plate with Sample

Rutting



Permanent Deformation

Addressed by:

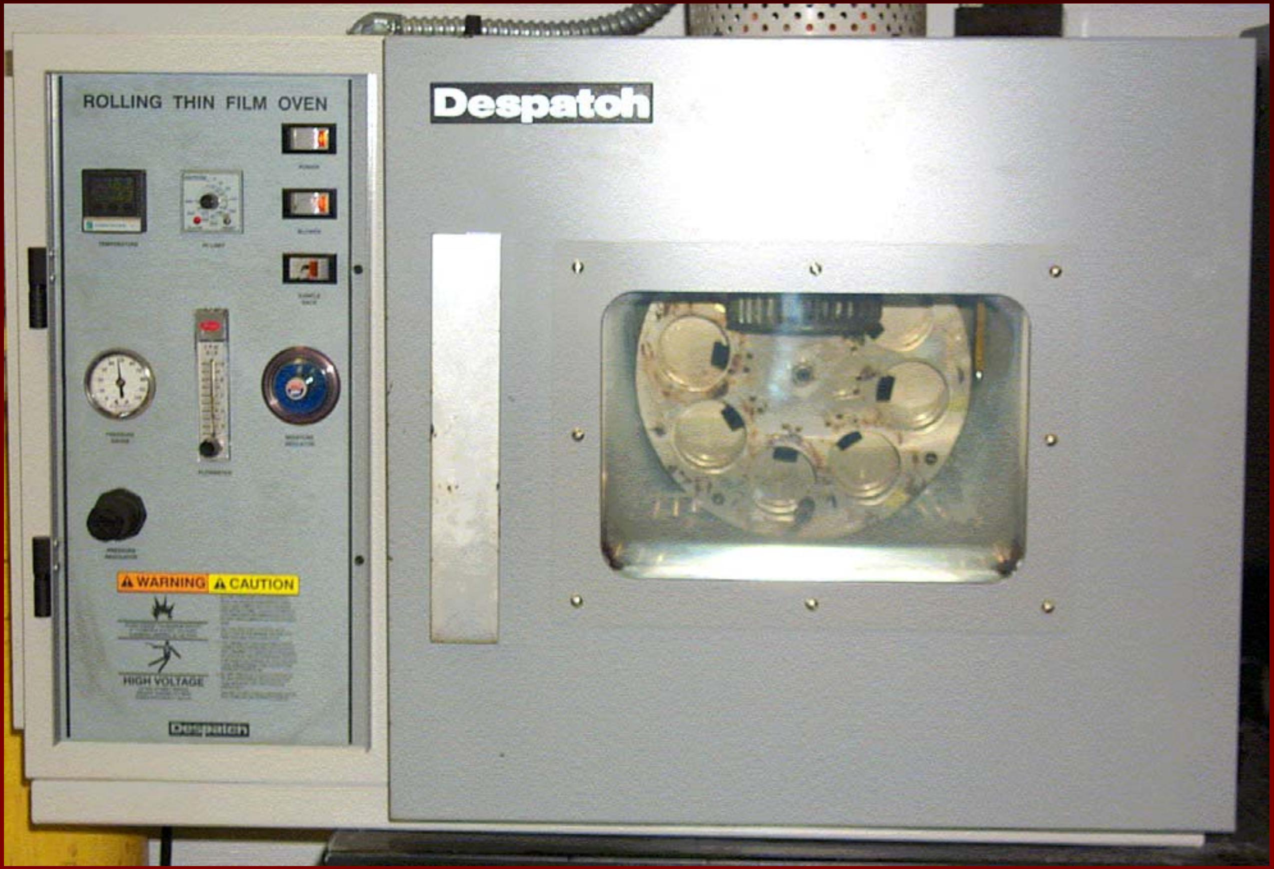
G*/sin δ on unaged binder > 1.00 kPa

G*/sin δ on RTFO aged binder $\geq$ 2.20 kPa

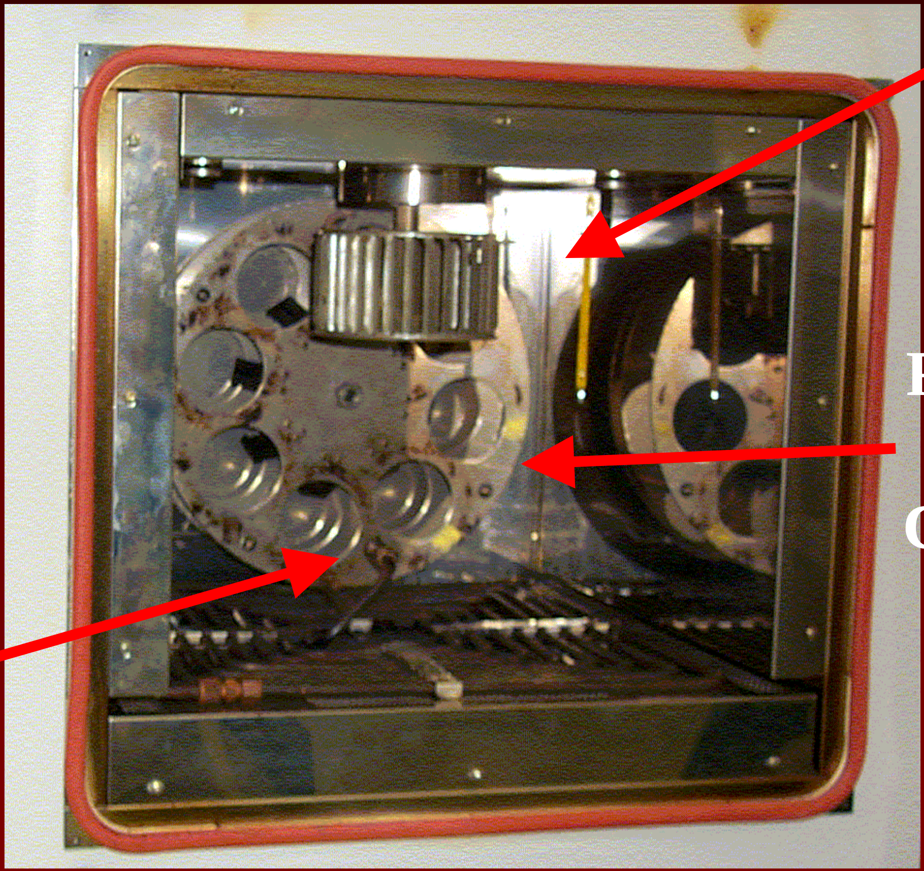
For the early part of the service life

Short Term Binder Aging

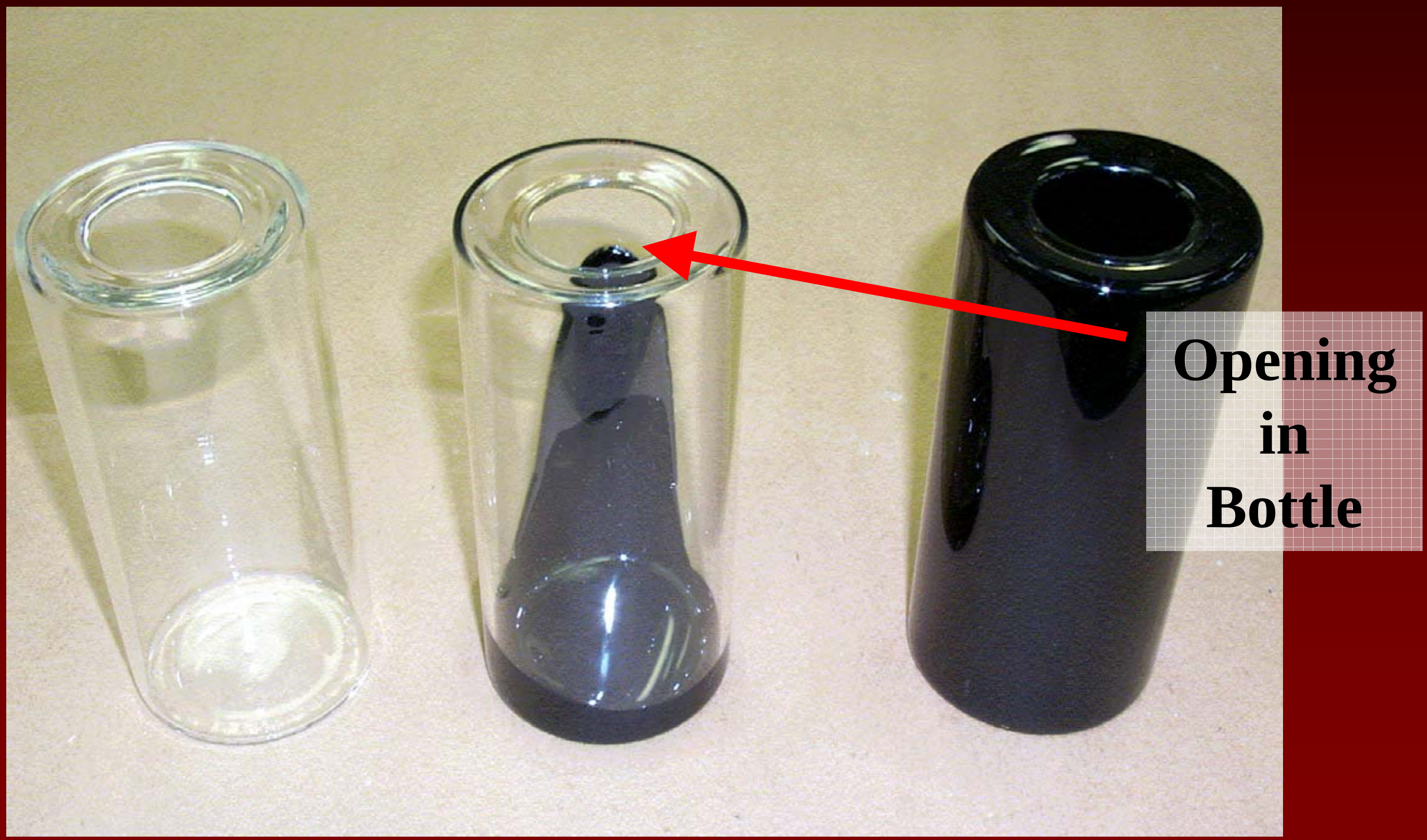
- Rolling Thin Film Oven
  - Simulates aging from hot mixing and construction



Inside of RTFO



Bottles Before and After Testing



Testing

- Calculate mass loss after RTFO

$$\text{Mass loss, \%} = \frac{\text{Original mass - Aged mass}}{\text{Original mass}} \times 100$$

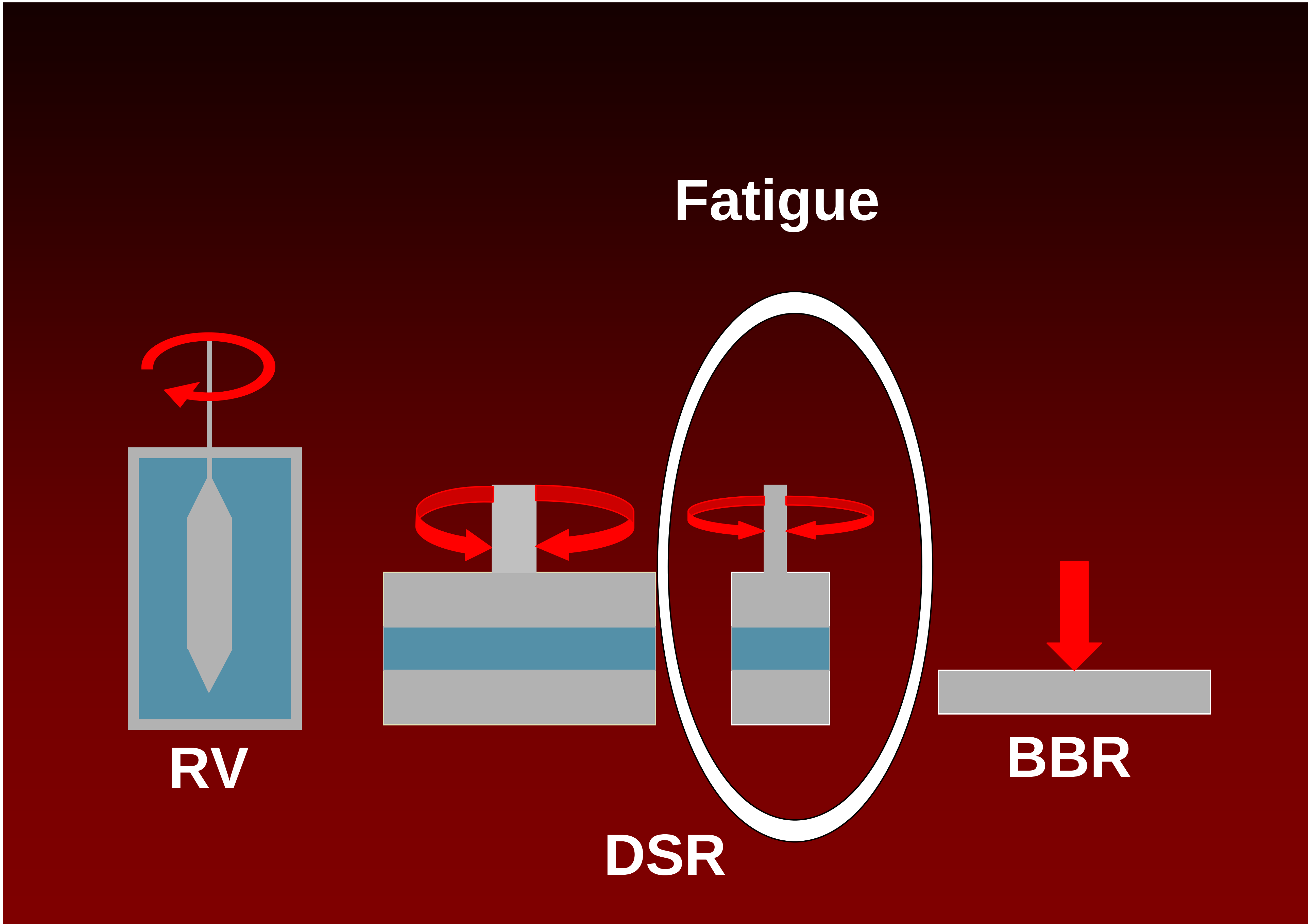
- Determine G*/sin δ for RTFO aged material at same test temp. used for original asphalt cement

Permanent Deformation

<u>Question</u>: Why a minimum G*/sin δ to address rutting?

<u>Answer</u>: We want a *stiff, elastic* binder to contribute to mix rutting resistance

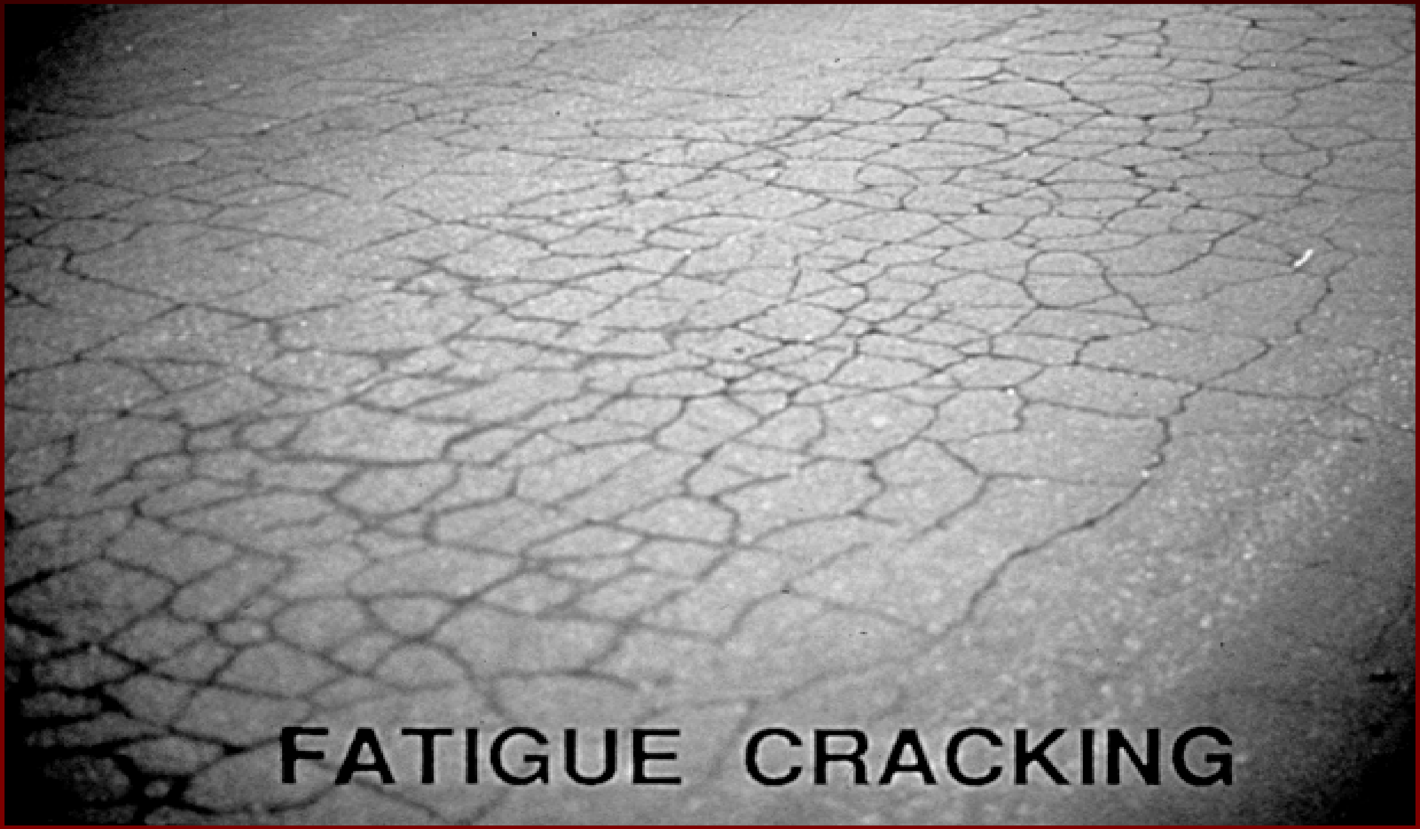
<u>How</u>: By increasing G* or decreasing δ



Fatigue
RV
DSR
BBR

Fatigue Cracking

Function of repeated traffic loads over time
(in wheel paths)



Testing

- Aged binder
  - Since fatigue is a long term performance problem, include:
    - Short term aging
    - Long term aging
- Determine DSR parameters using 8 mm plate and intermediate test temperature

Pressure Aging Vessel (Long Term Aging)

- Simulates aging of an asphalt binder for 7 to 10 years
- 50 gram sample is aged for 20 hours
- Pressure of 2,070 kPa (300 psi)
- At 90, 100 or 110 C

Pressure Aging Vessel

Pressure Aging Vessel

Courtesy of FHWA

Fatigue Cracking

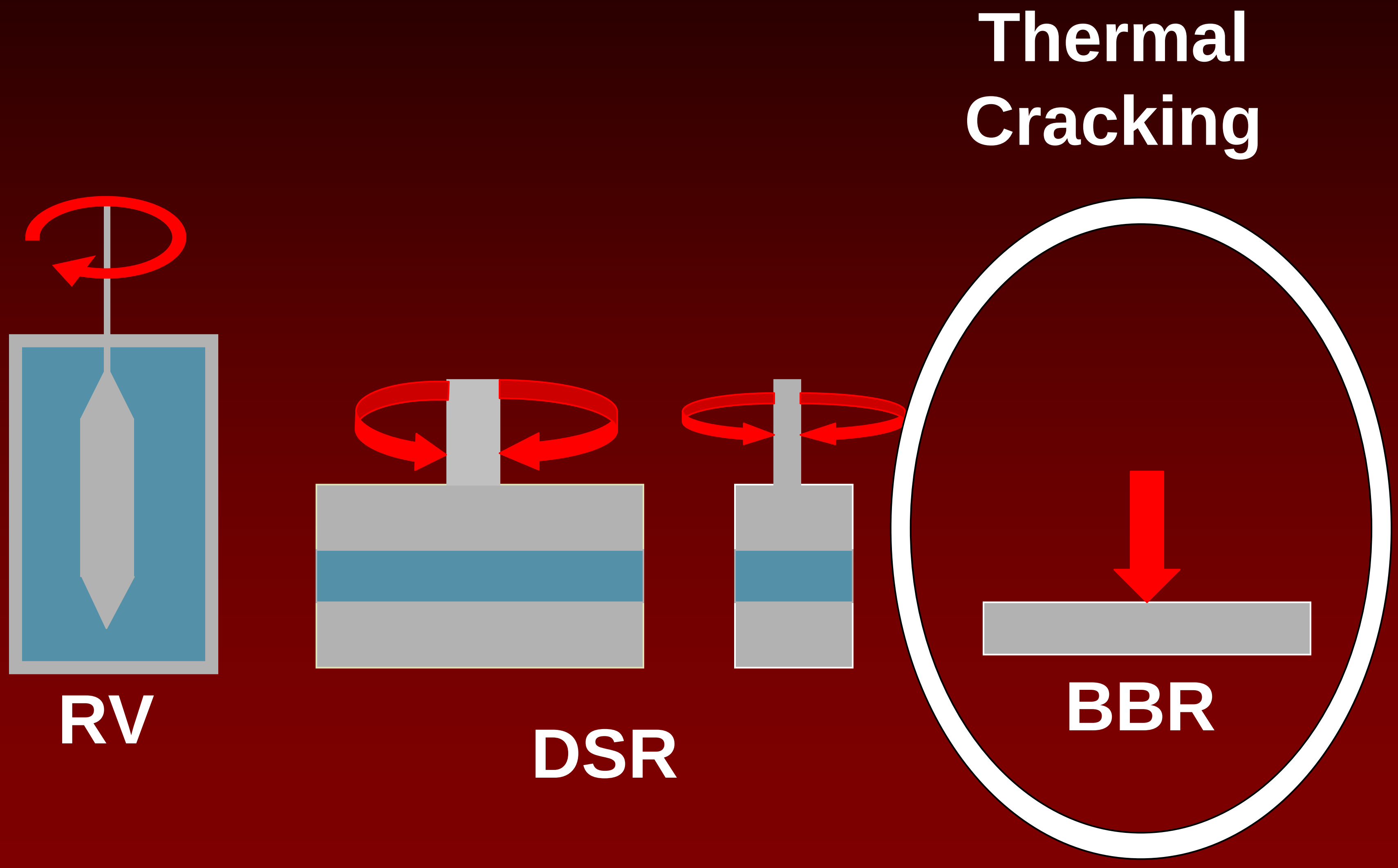
- G* (sin δ) on RTFO and PAV aged binder
- The parameter addresses the later part of the fatigue life
- Value must be $\leq$ 5000 kPa

Fatigue Cracking

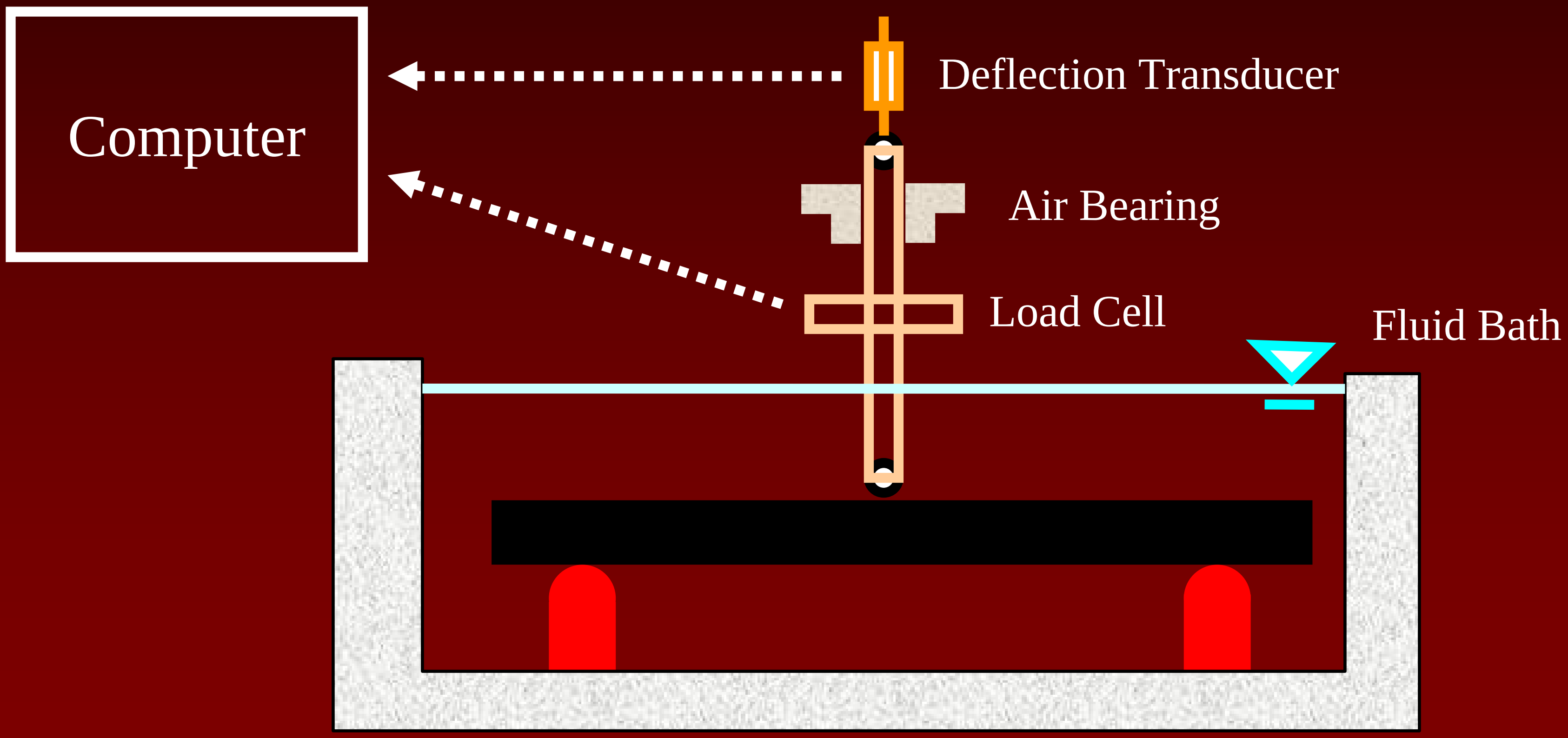
- **Question: Why a maximum G* sin δ to address fatigue?**

Answer: We want a *soft elastic* binder (to sustain many loads without cracking)

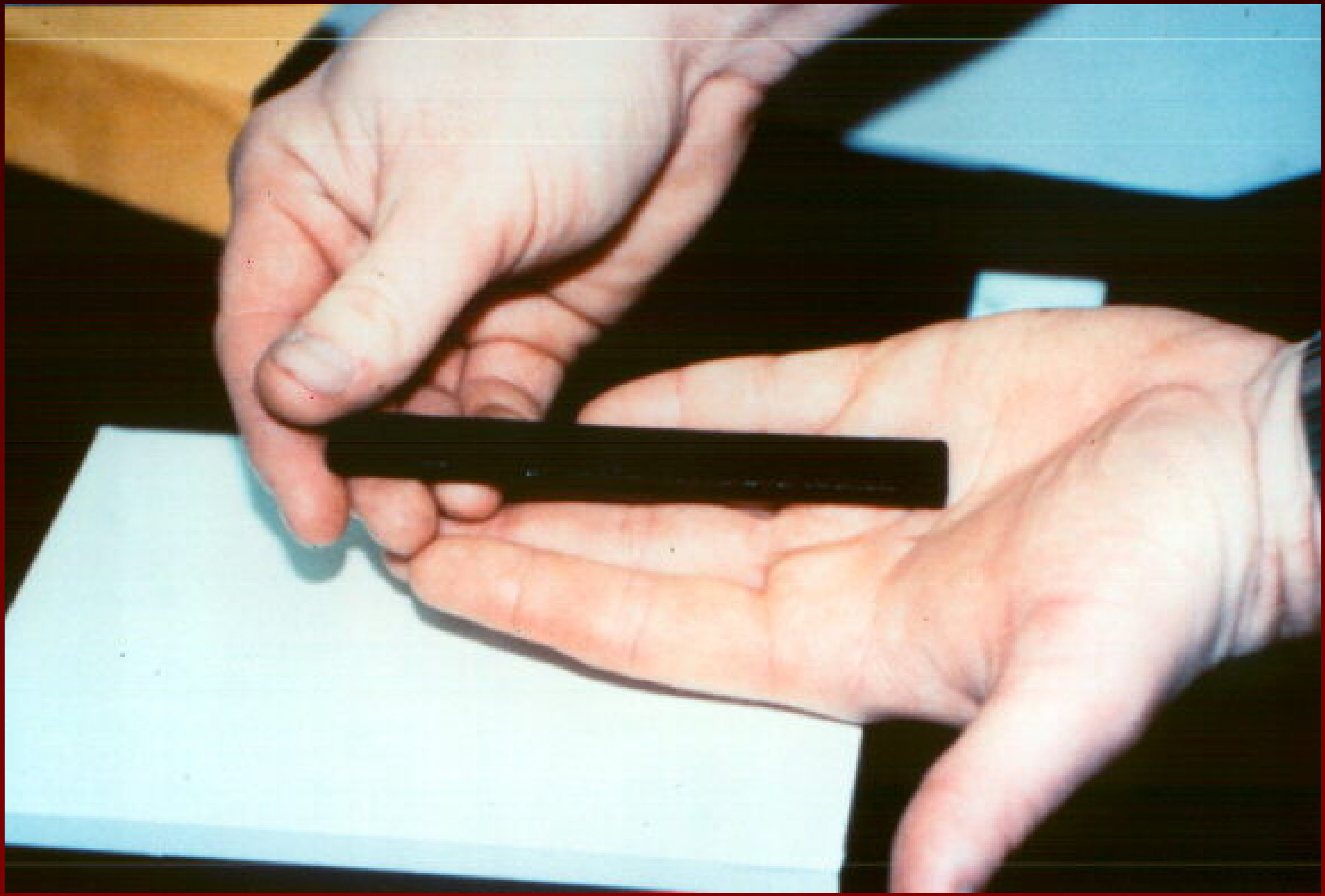
How: By decreasing G* or decreasing δ


Thermal
Cracking
RV
DSR
BBR

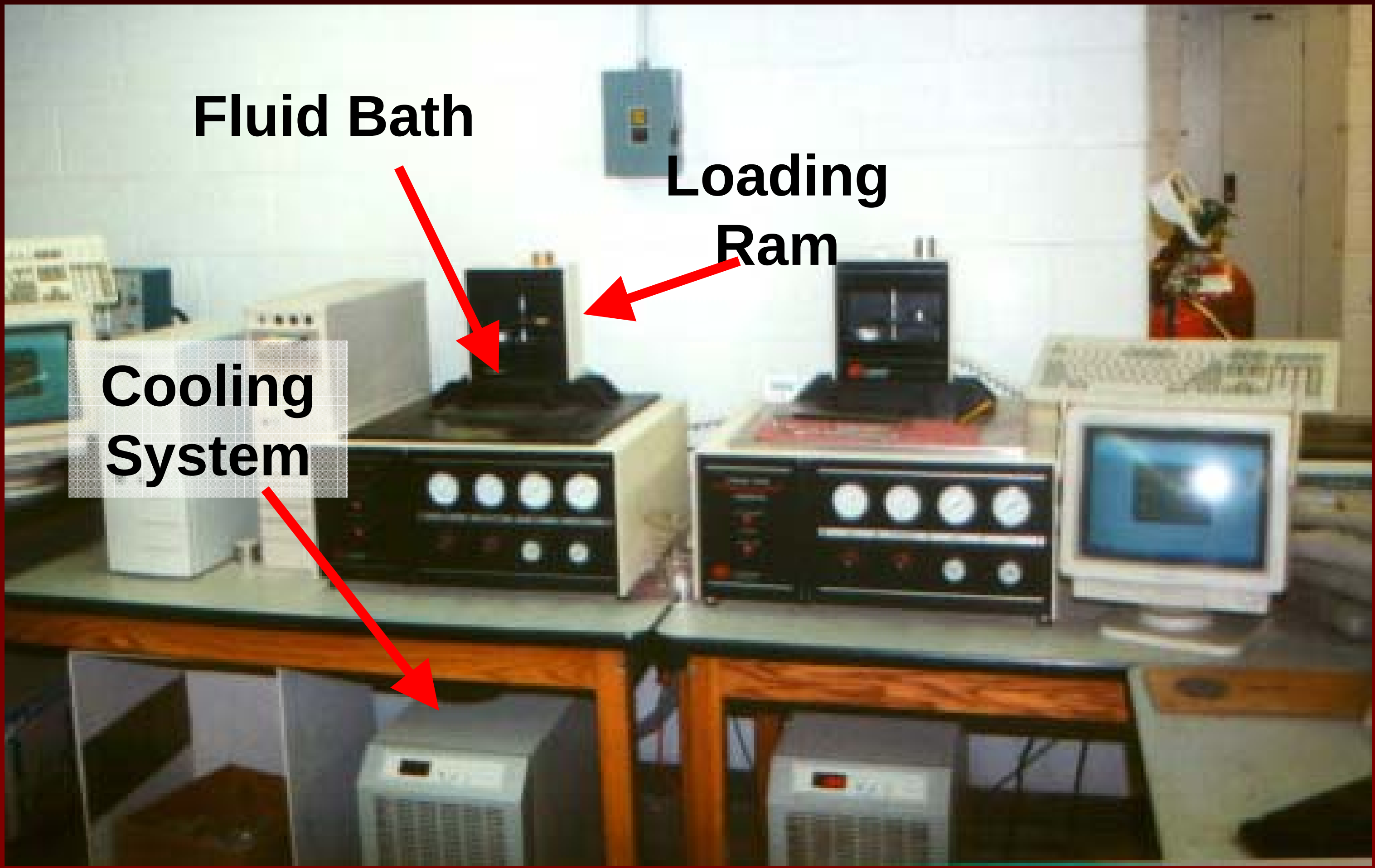
Bending Beam Rheometer

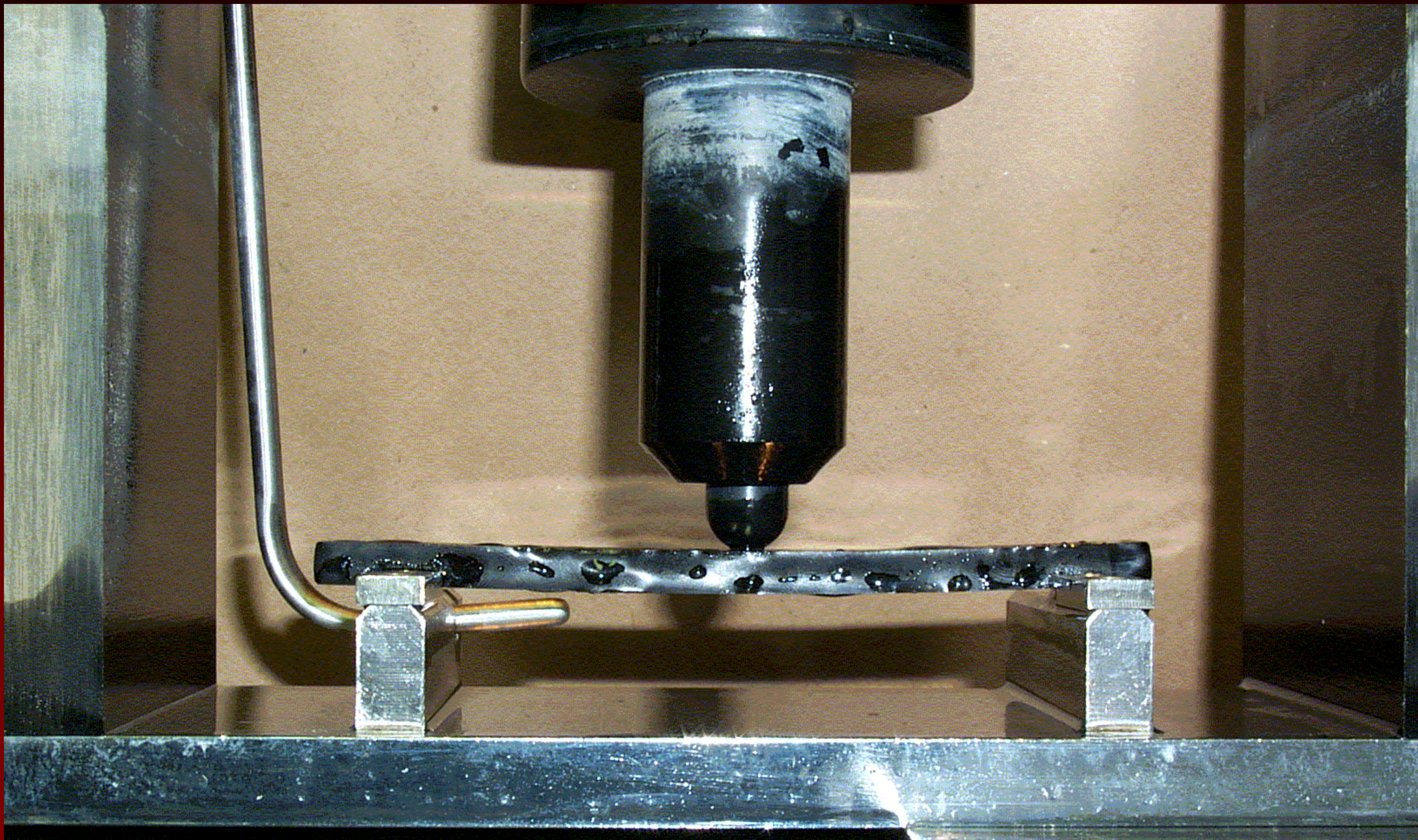


Bending Beam Rheometer Sample



Bending Beam Rheometer Equipment





Bending Beam Rheometer

- $$S(t) = \frac{P\,L^3}{4\,b\,h^3\,\delta(t)}$$

Where:

S(t) = creep stiffness (M Pa) at time, t

P = applied constant load, N

L = distance between beam supports (102 mm)

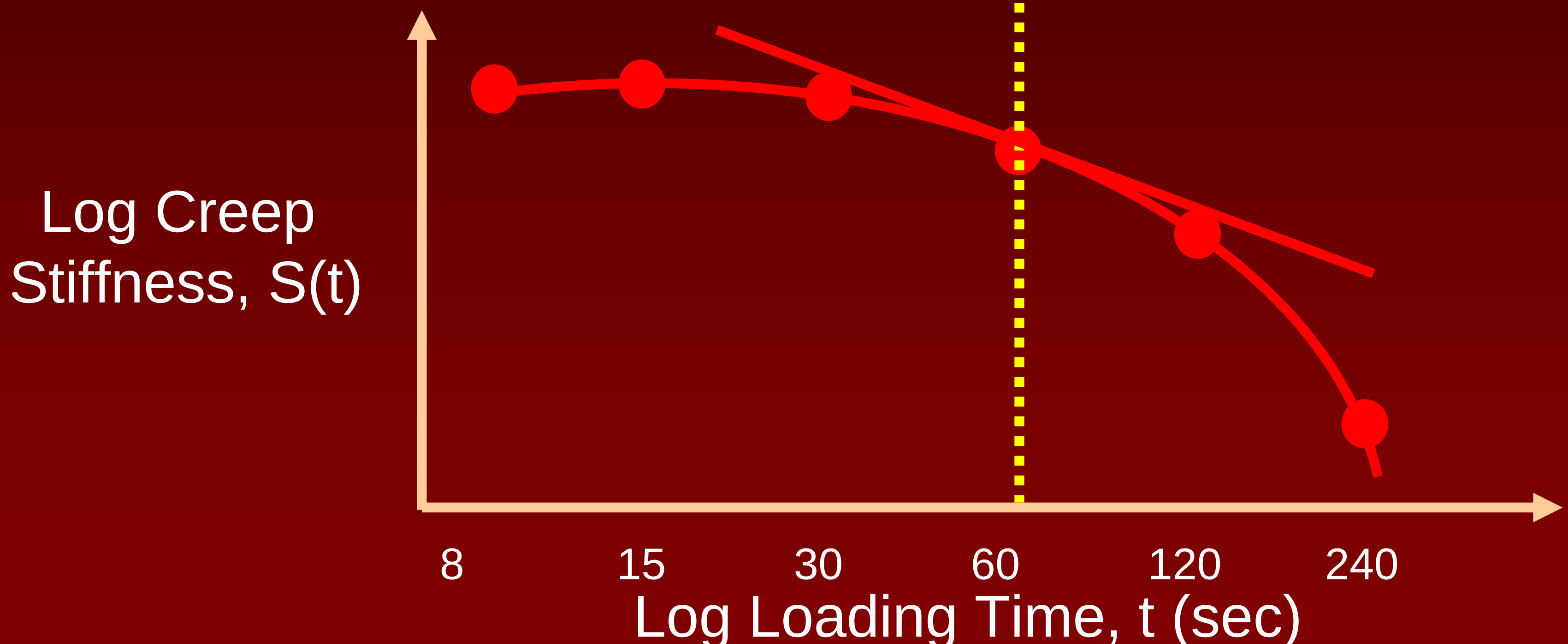
b = beam width, 12.5 mm

h = beam thickness, 6.25 mm

d(t) = deflection (mm) at time, t

Bending Beam Rheometer

- Evaluates low temperature stiffness properties
  - Creep stiffness
  - Slope of response (called m-value)



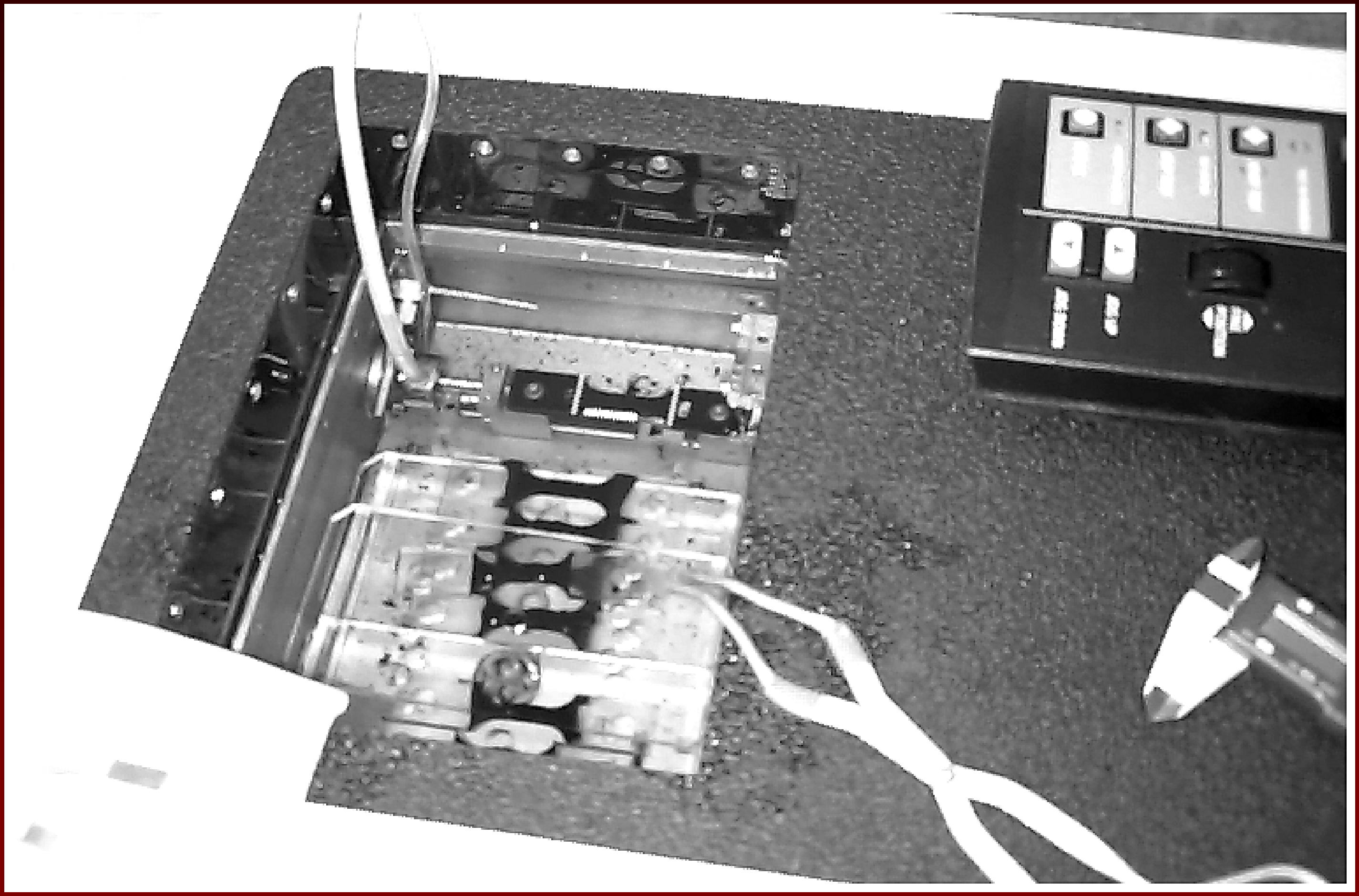
Is Stiffness Enough?

- Need to assess strength at low temperatures
  - Thermal cracking occurs when thermal stress exceeds pavement strength
- Direct tension test
  - Combined with BBR results to calculate critical cracking temperature (t_{crit})
  - States choice to use AASHTO M320 or MP-1a
  - DTT is no longer an option in AASHTO M320

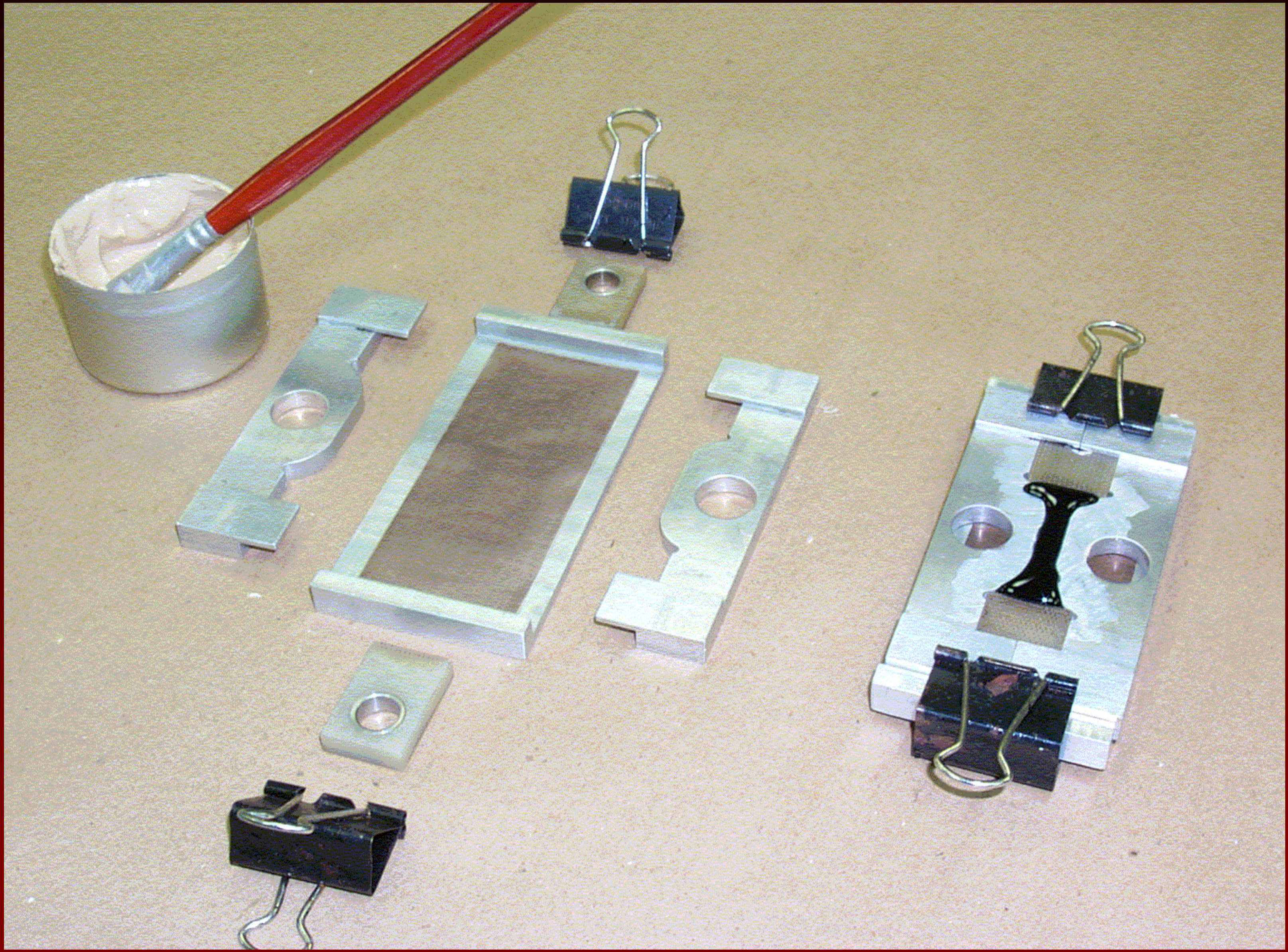
Direct Tension Test

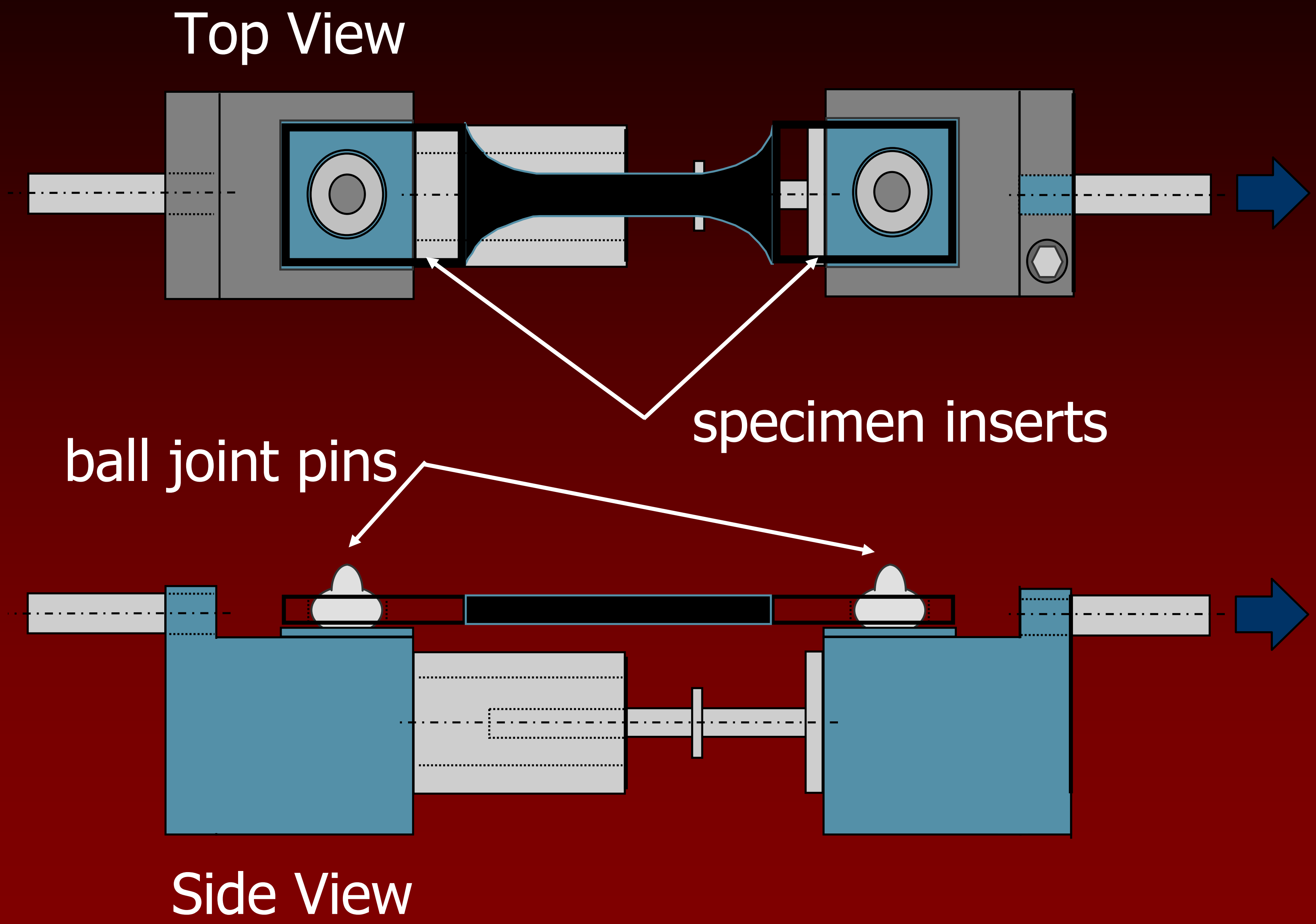
Courtesy of Instron

Direct Tension Test

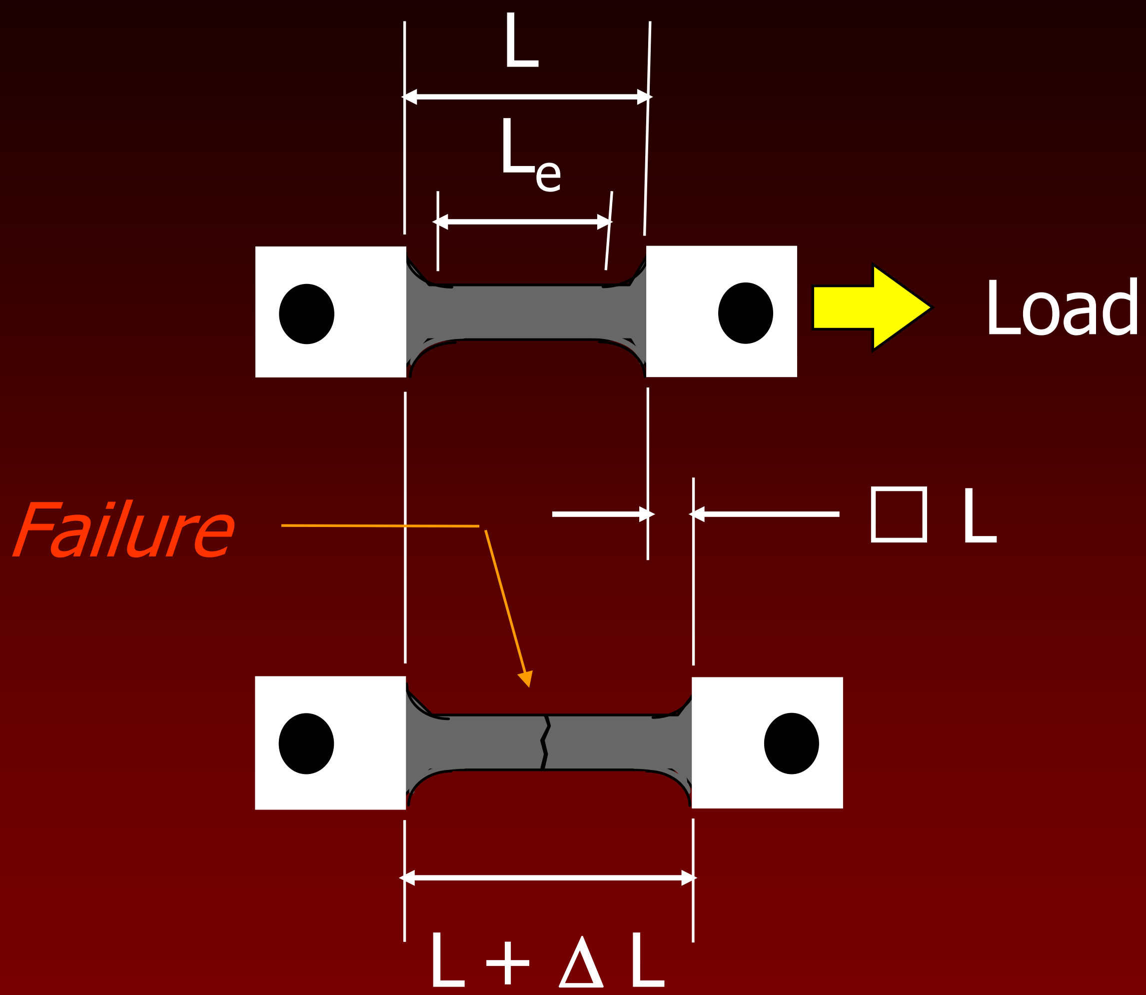


Courtesy of FHWA



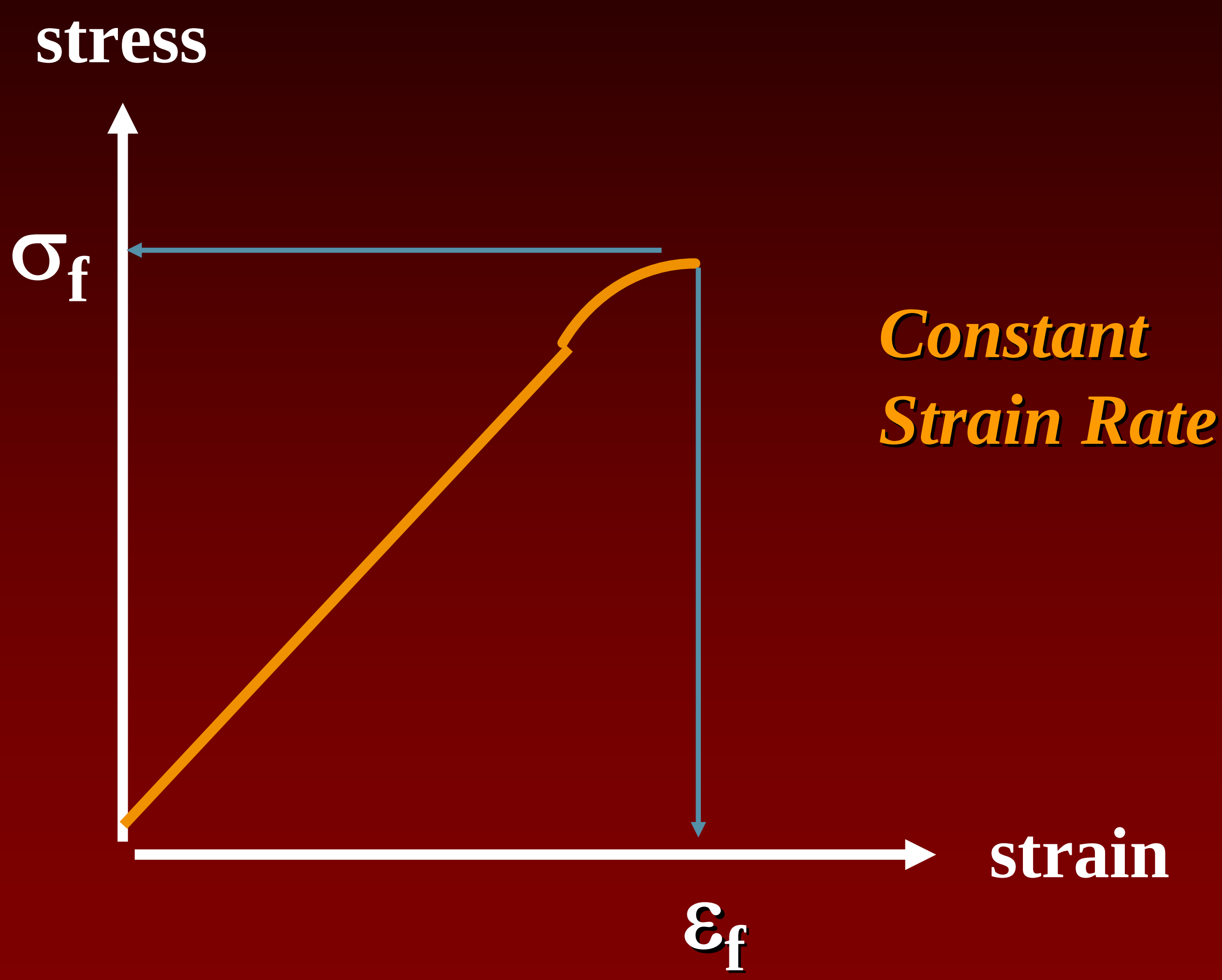


Top View
specimen inserts
ball joint pins
Side View

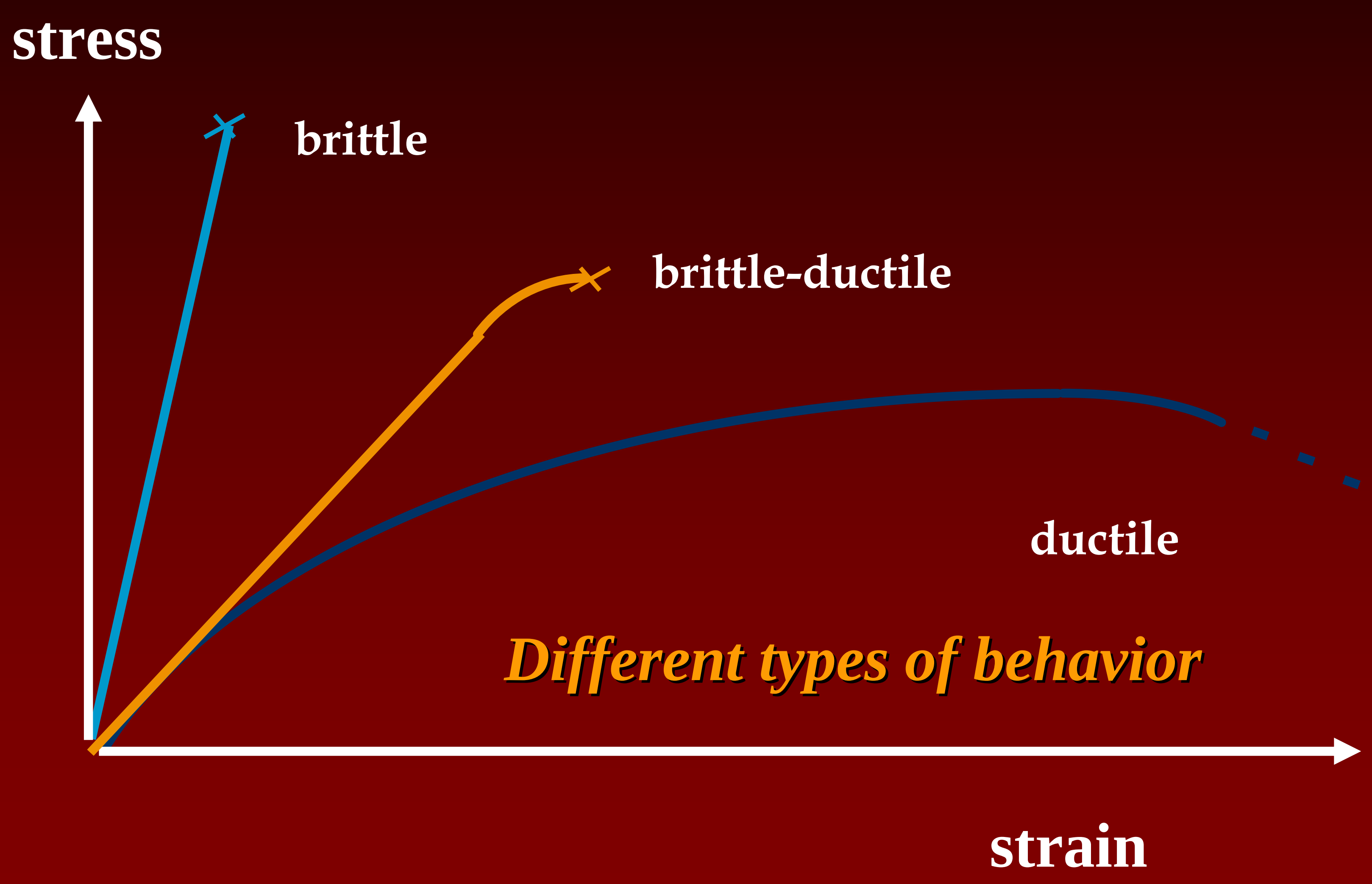


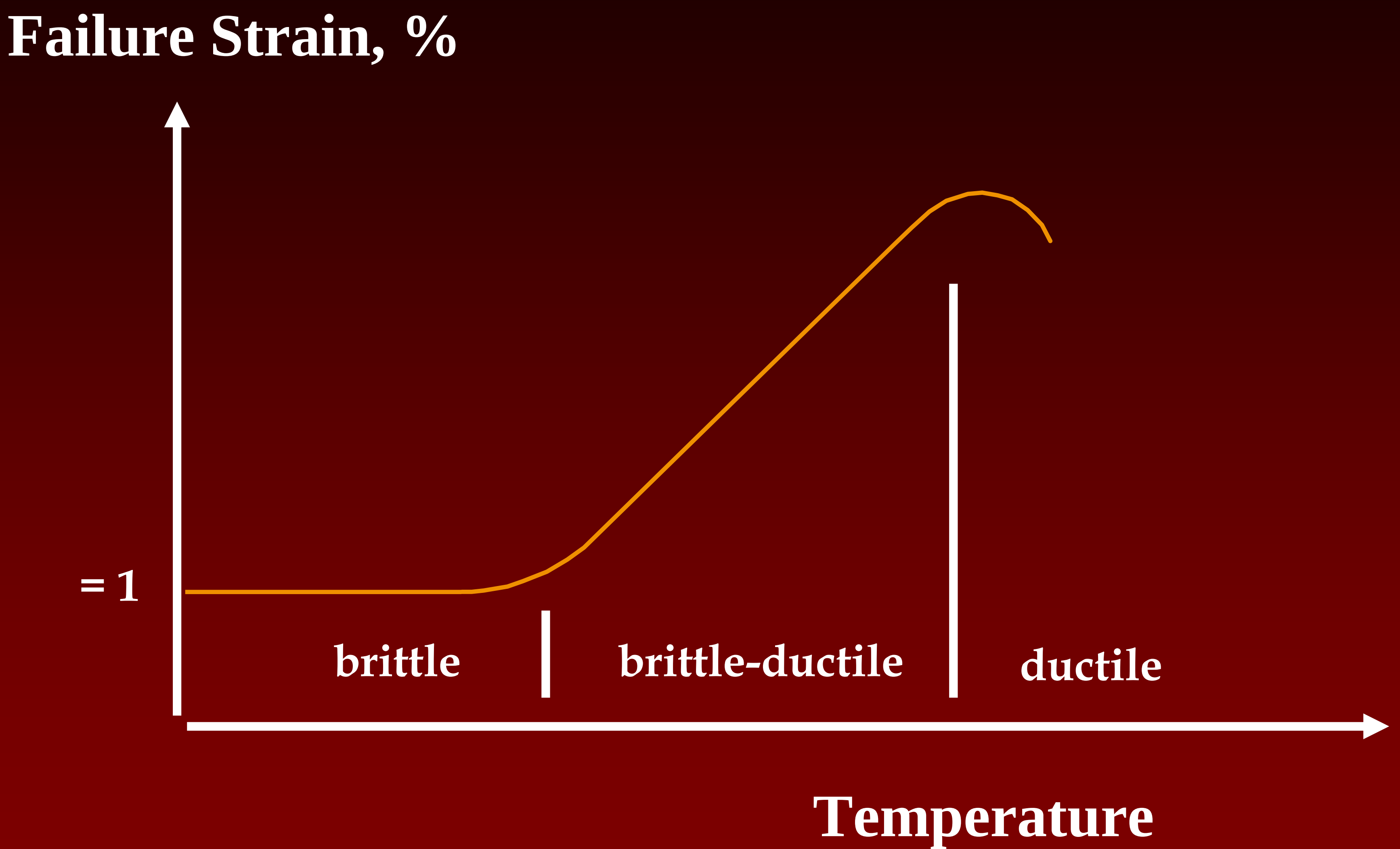
$$\text{failure stress } (\sigma_f) = \frac{\text{Failure load}}{\text{Original cross-section area}}$$

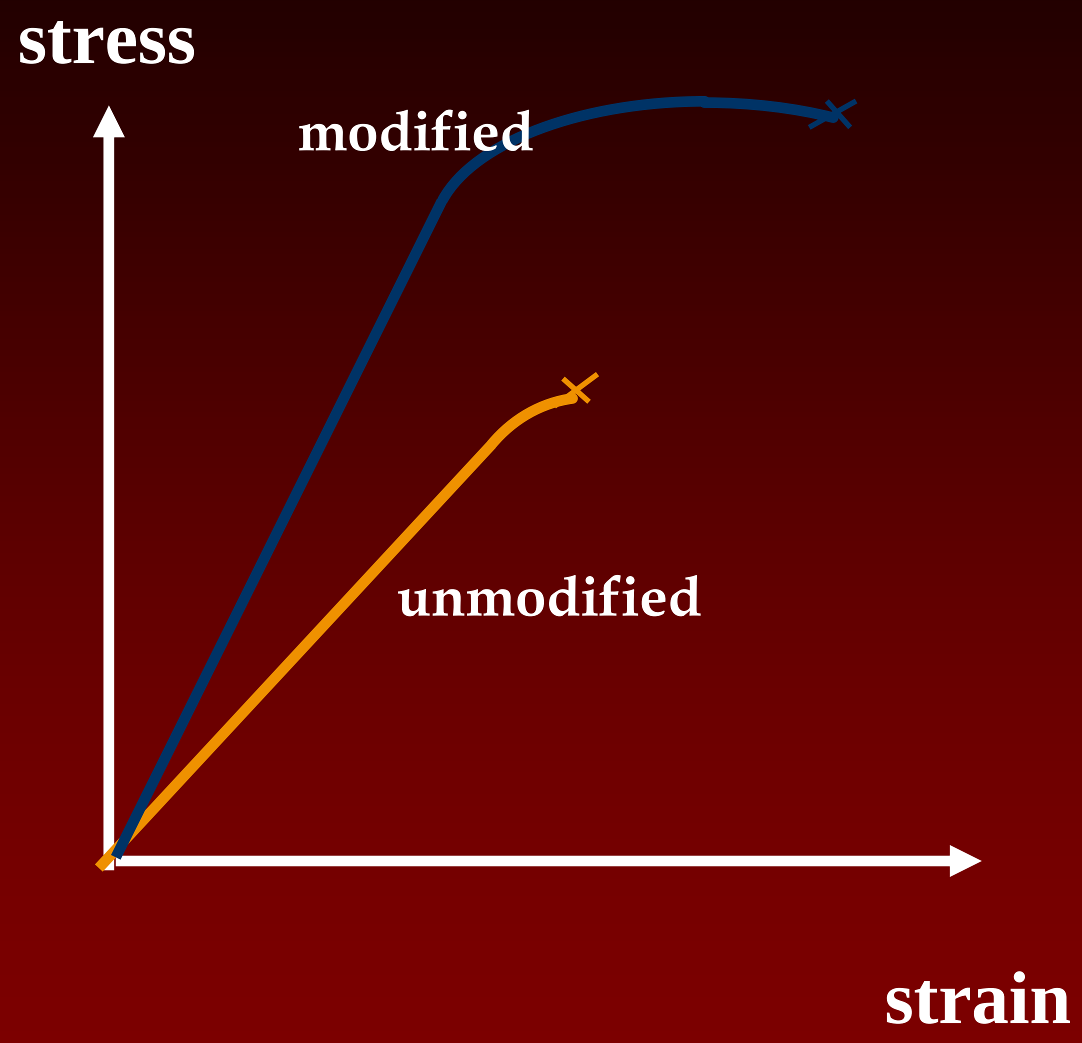
DTT Data



Different Binders or Temps

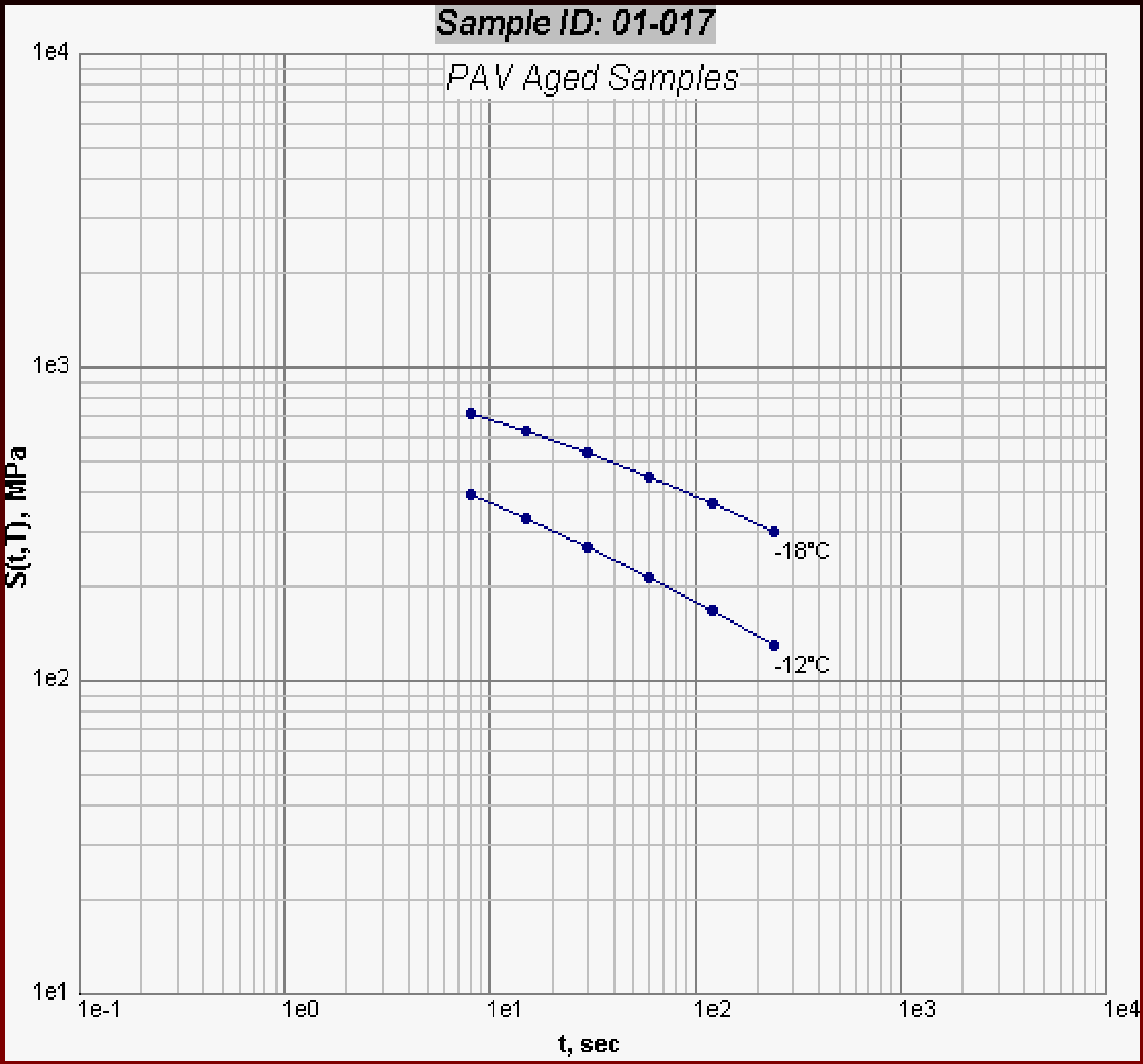



Failure Strain, %
= 1
brittle
brittle-ductile
ductile
Temperature

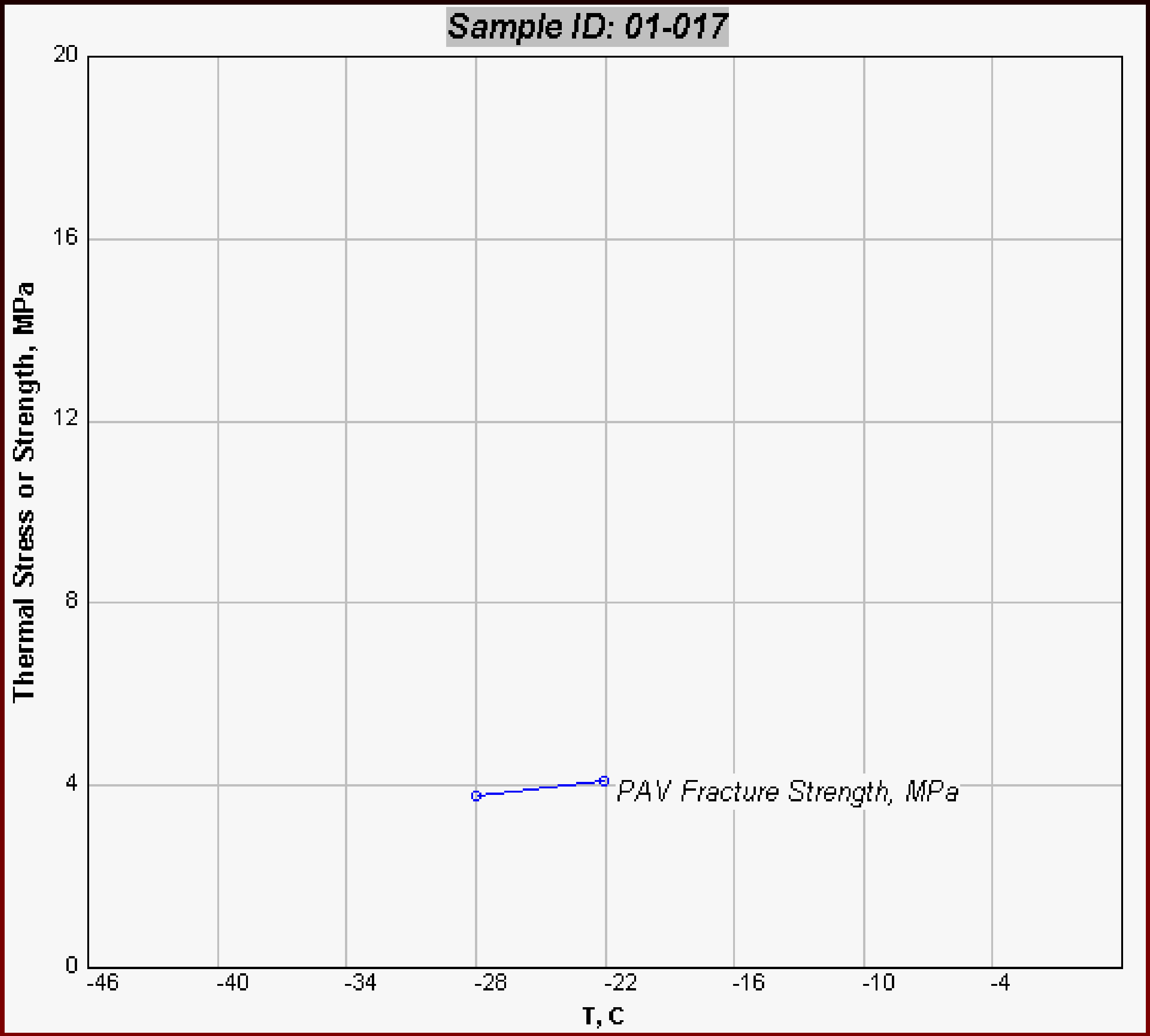

stress
modified
unmodified
strain

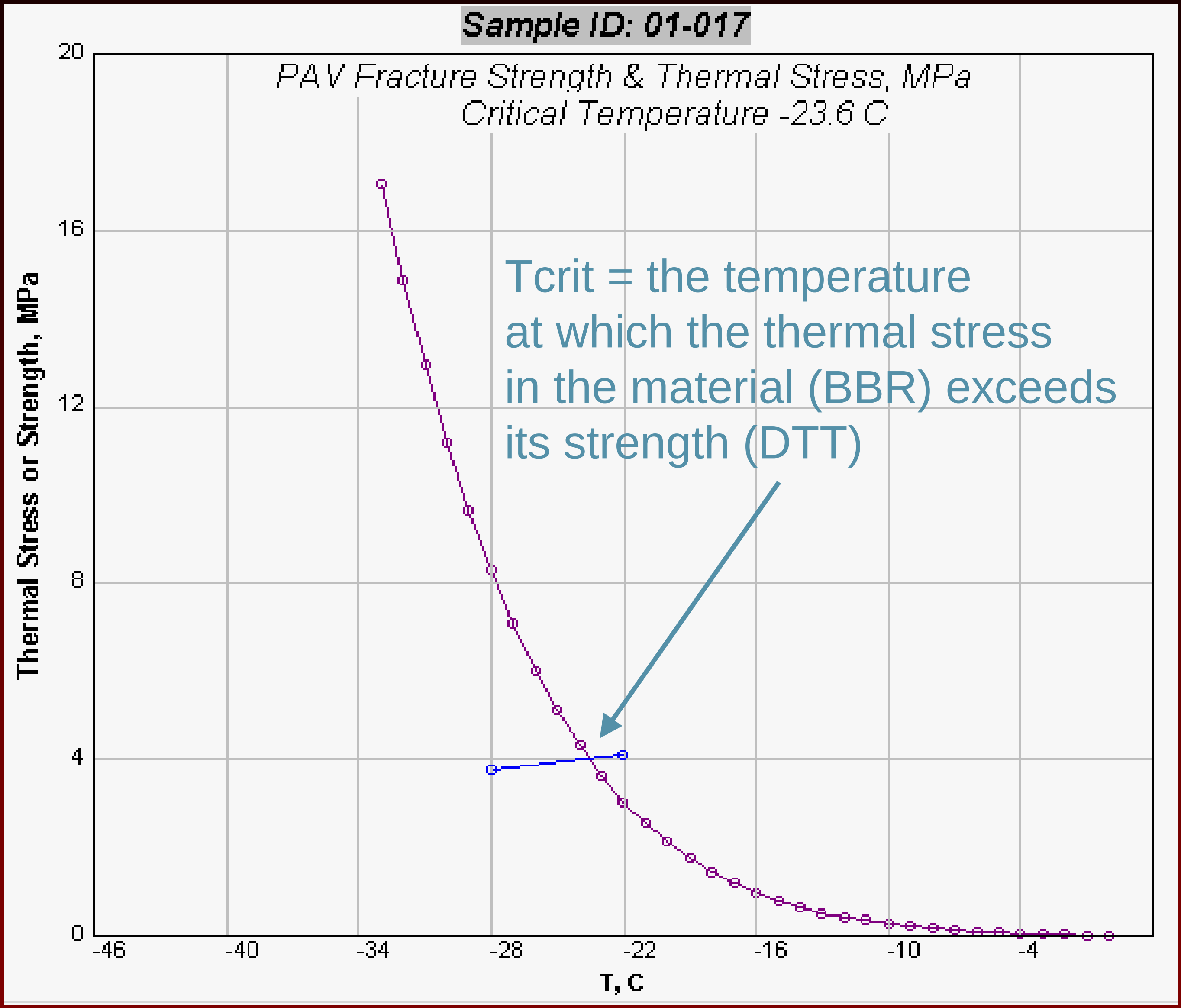
What Do You Need to Calculate T_{crit}?

- BBR Data for at least 2 Temperatures
  - 8, 15, 30, 60, 120, and 240 seconds
  - Stiffness, MPa
- DTT Data for at least 1 Temperature
  - Failure Stress, MPa
- TSAR software

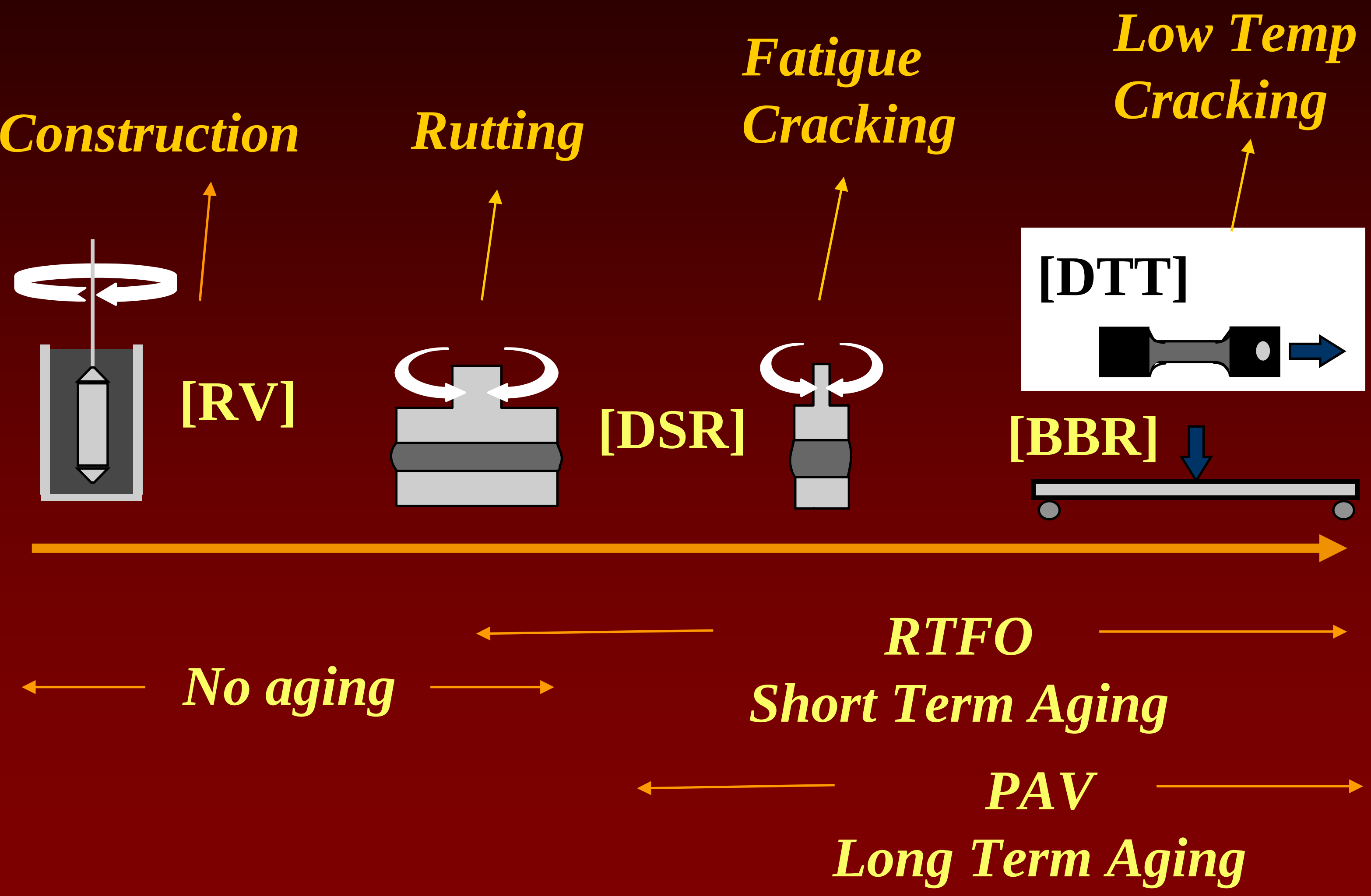


Sample ID: 01-017
PAV Aged Samples
1e4
1e3
1e2
1e1
S(t, T), MPa
-18°C
-12°C
1e-1
1e0
1e1
1e2
1e3
1e4
t, sec


Sample ID: 01-017
Thermal Stress or Strength, MPa
20
16
12
8
4
0
-46
-40
-34
-28
-22
-16
-10
-4
T, C
PAV Fracture Strength, MPa


Sample ID: 01-017
PAV Fracture Strength & Thermal Stress, MPa
Critical Temperature -23.6 C
Tcrit = the temperature
at which the thermal stress
in the material (BBR) exceeds
its strength (DTT)
Thermal Stress or Strength, MPa
20
16
12
8
4
0
-46
-40
-34
-28
-22
-16
-10
-4
T, C

Summary


Construction
Rutting
Fatigue Cracking
Low Temp Cracking
[DTT]
[RV]
[DSR]
[BBR]
RTFO
Short Term Aging
No aging
PAV
Long Term Aging

Questions – does it all make sense?