

# CHAPTER 12 - Rate and Temperature-Dependent Mechanical Properties

\* Mechanical properties of materials can become very sensitive to loading rate and temperature, if temperature in question is near the material's melting point



$$\text{strength, ductility, etc.} = f(\dot{\epsilon}, T)$$

creep

stress relaxation

(viscoelasticity)

$$\text{homologous temperature (}^\circ\text{K)} = \frac{\text{temperature (}^\circ\text{K) of interest}}{\text{materials melt temperature (}^\circ\text{K)}}$$

## Stress - Strain Relation (Holloman)

\* The portion of the true stress-strain curve (from the onset of yielding to the maximum load) may be described empirically by:

$$\sigma = K \epsilon^n$$

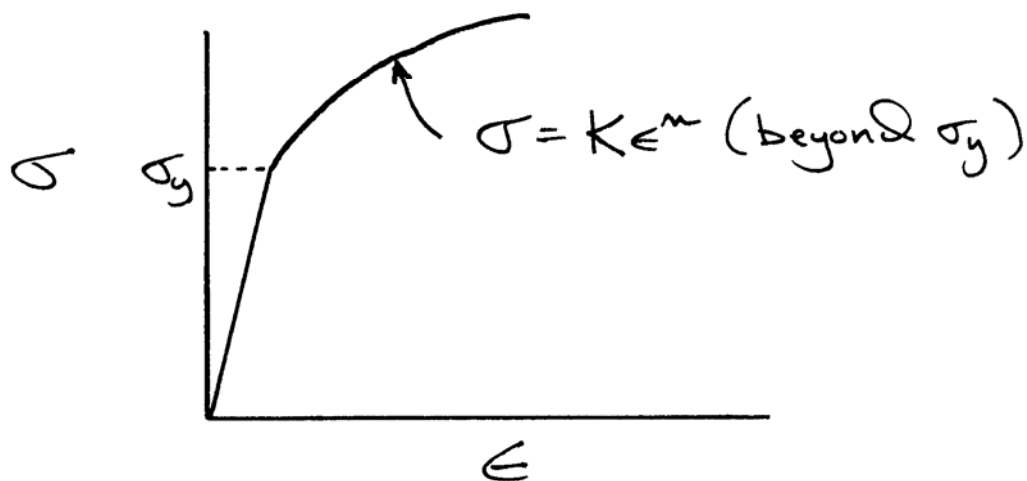
where:

$\sigma$  - true stress

$\epsilon$  - true strain

$n$  - strain hardening coefficient  
(work-hardening index)

$K$  - material constant  $\rightarrow$  the true stress at a true strain of 1.0



Name \_\_\_\_\_

Subject \_\_\_\_\_

Date \_\_\_\_\_

Sheet 3

Of \_\_\_\_\_

\* Ideally when plotted  $\log \sigma$  vs.  $\log \epsilon$ , straight line relation obtained  $\Rightarrow$   
 $\therefore \sigma = K \epsilon^n$ , with  $n$  being the slope

$\sigma$  - referred to as the flow stress

$n$  - its magnitude reflects the ability of the material to resist further deformation

$$0 \leq n \leq 1$$

$n = 0$  ideally plastic

$n = 1$  ideally elastic

\*  $n$  values for metals are sensitive to thermomechanical treatment:

- generally larger for materials in the annealed condition and smaller in the cold-worked state



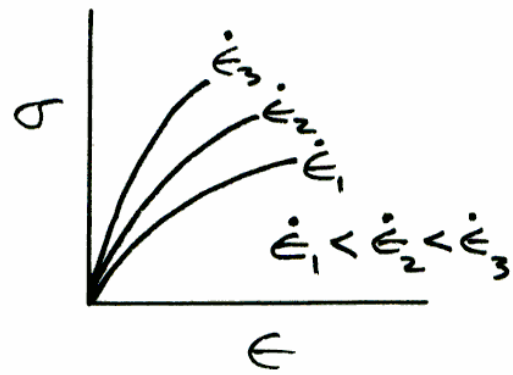
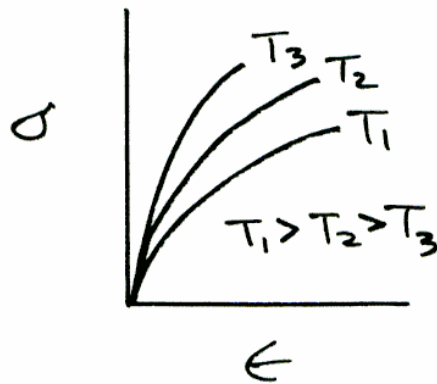
\* initially soft materials tend to work harden faster

## Selected Strain Hardening Coefficients :

<u>Material</u>	<u>n</u>
1015 steel, normalized, 80 Bhn	0.26
1045 steel, Q+T (650°C), 225 Bhn	0.13
1045 steel, Q+T (180°C), 595 Bhn	0.07
ferritic stainless steel	0.16-0.23
austenitic stainless steel	0.40-0.55
copper	0.35-0.50
brass (70-30)	0.45-0.60
aluminum alloys	0.20-0.30

## Strain Rate Sensitivity

\* If materials are tested @ various  $\dot{\epsilon}$  and  $T$ , their  $\sigma$  vs.  $\epsilon$  curves change. For example:



Thus, modifying the Holloman relation:

$$\sigma = K \epsilon^m$$

letting:

$$K = C \dot{\epsilon}^m$$

where:

$m$  - strain rate sensitivity

$C$  - material constant  $\rightarrow$  value of  $K$  @  $\dot{\epsilon} = 1.0$

substituting:

$$\sigma = C \dot{\epsilon}^m \epsilon^m$$

strain rate -  $f(T)$

sensitivity,  $m$  - low @ low  $T$ ,  $m \uparrow T \uparrow$   
 ( $m \downarrow T \uparrow$ )

- low for worked, high strength metals (@ low  $T$ )

$$C = f(T)$$

-  $C \downarrow T \uparrow$

- varies with  $\exp\left\{\frac{1}{T}\right\}$

Thus, general form of flow stress/  
strain relation:

$$\sigma = K_0 \exp\left\{\frac{1}{T}\right\} \dot{\epsilon}^m \epsilon^n$$

## Creep in Metals

Creep - the time-dependent permanent deformation that occurs under stress at elevated temperatures

$\epsilon$  vs.  $t$  plotted @ test temperature

Three stages of creep identified  
(Fig. 8.36, 8.37)

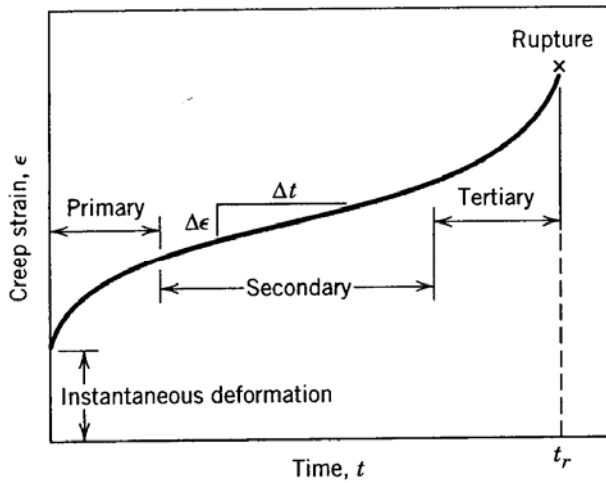


FIGURE 8.36 Typical creep curve of strain versus time at constant stress and constant elevated temperature. The minimum creep rate  $\Delta\epsilon/\Delta t$  is the slope of the linear segment in the secondary region. Rupture lifetime  $t_r$  is the total time to rupture.

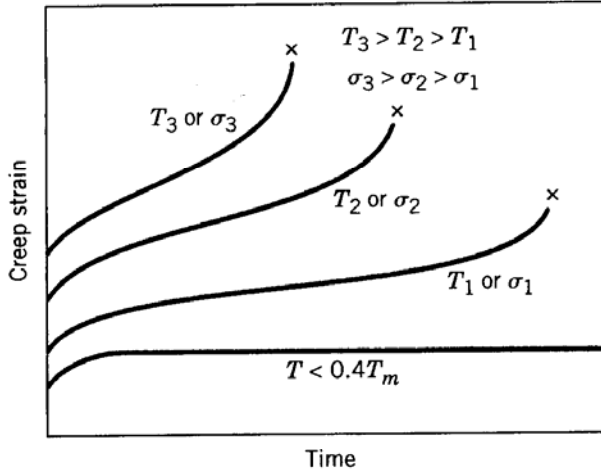


FIGURE 8.37 Influence of stress  $\sigma$  and temperature  $T$  on creep behavior.

## Mechanisms of High Temperature Deformation in Metals :

- vacancy motion (particularly along grain boundaries)
- dislocation climb (assisted by vacancies)
- grain rotation
- void formation
- metallurgical changes

## Alloy Selection for High Temperature Application :

- high melting point metal
- metal with large Young's modulus
- metal with large grain size
- metal that is metallurgically stable and oxidation resistant