Engineering strain, $e = \frac{l - l_o}{l_o}$

Engineering strain rate, $\dot{e} = \frac{v}{l_o}$

Engineering stress, $\sigma = \frac{P}{A_o}$

True strain, $\epsilon = \ln\left(\frac{l}{l_o}\right)$

True strain rate, $\dot{\epsilon} = \frac{v}{l}$

True stress, $\sigma = \frac{P}{A}$

Modulus of elasticity, $E = \frac{\sigma}{e}$

Shear modulus, $G = \frac{E}{2(1+\nu)}$

Modulus of resilience $= \frac{S_y^2}{2E}$

Elongation $= \frac{l_f - l_o}{l_o} \times 100\%$

Reduction of area $= \frac{A_o - A_f}{A_o} \times 100\%$

79 Shear strain in torsion, $\gamma = \frac{r\phi}{l}$

Hooke's law, $\epsilon_1 = \frac{1}{E}\left[\sigma_1 - \nu\left(\sigma_2 + \sigma_3\right)\right]$, etc.

Effective strain (Tresca), $\bar{\epsilon} = \frac{2}{3}\left(\epsilon_1 - \epsilon_3\right)$

Effective strain (von Mises), $\bar{\epsilon} = \frac{\sqrt{2}}{3}\left[\left(\epsilon_1 - \epsilon_2\right)^2 + \left(\epsilon_2 - \epsilon_3\right)^2 + \left(\epsilon_3 - \epsilon_1\right)^2\right]^{1/2}$

Effective stress (Tresca), $\bar{\sigma} = \sigma_1 - \sigma_3$

Effective stress (von Mises), $\bar{\sigma} = \frac{1}{\sqrt{2}}\left[\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2\right]^{1/2}$

True stress–true strain relationship (power law), $\sigma = K\epsilon^n$

True stress–true strain rate relationship, $\sigma = C\dot{\epsilon}^m$

Flow rules, $d\epsilon_1 = \frac{d\bar{\epsilon}}{\bar{\sigma}}\left[\sigma_1 - \frac{1}{2}\left(\sigma_2 + \sigma_3\right)\right]$, etc.

Maximum-shear-stress criterion (Tresca), $\sigma_{\max} - \sigma_{\min} = S_y$

Distortion-energy criterion (von Mises), $\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2 = 2S_y^2$

Shear yield strength, $k = S_y/2$ for Tresca and $k = S_y/\sqrt{3}$ for von Mises (plane strain)

Volume strain (dilatation), $\Delta = \frac{1-2\nu}{E}\left(\sigma_1 + \sigma_2 + \sigma_3\right)$

Bulk modulus $= \frac{E}{3(1-2\nu)}$

Brinell hardness number, $HB = \frac{2P}{(\pi D)(D - \sqrt{D^2 - d^2})}$ kg/mm^2

D - diameter of the ball

d - diameter of the impression in mm

P - Load

$$\text{Hardness} = c\, S_y$$

c - proportionality constant. typically $c \approx 3$

S_y - Yield Strength

Strain hardening exponent n

@ necking $\epsilon = n$

Theoretical shear strength of metals, $\tau_{max} = \frac{G}{2}\pi$

Theoretical tensile strength of metals, $\sigma_{max} = \sqrt{\frac{E\gamma}{a}} \simeq \frac{E}{10}$

Hall—Petch equation, $S_Y = S_{Y_i} + kd^{-1/2}$

ASTM grain-size number, $N = 2^{n-1}$

Fracture strength vs. crack length, $S_f \propto \frac{1}{\sqrt{\text{Crack length}}}$

1. A minimum amount of deformation is needed to cause recrystallization.
2. The smaller the degree of deformation, the higher the temperature required to cause recrystallization.
3. Increasing the annealing time decreases the recrystallization temperature. However, temperature is far more important than time. Doubling the annealing time is approximately equivalent to increasing the annealing temperature 10°C.
4. The final grain size depends chiefly on the degree of deformation and to a lesser extent on the annealing temperature. The greater the degree of deformation and the lower the annealing temperature, the smaller the recrystallized grain size.
5. The larger the original grain size, the greater the amount of cold work required to produce an equivalent recrystallization temperature.
6. The recrystallization temperature decreases with increasing purity of the metal. Solid-solution alloying additions always raise the recrystallization temperature.
7. The amount of deformation required to produce equivalent recrystallization behavior increases with increased temperature of working.
8. For a given reduction in cross section, different metalworking processes, such as rolling, drawing, etc., produce somewhat different effective deformations. Therefore, Identical recrystallization behavior may not be obtained.

- Large grain size is generally associated with low strenght low hardness, high ductility.

Six main variables influence recrystallization behavior. Amount of prior deformation ② temperature ③ time ④ initial grain size ⑤ composition ⑥ amount of recovery or polygonization prior to the start of recrystallization.

What effects does recrystallization have on the properties of metal?

By recrystallizing, the density of crystal deformations, called dislocation, is decreased. This is due to the recrystallization process "repairing the defects in the crystal structure.

A metal undergoing recrystallization will also typically have a lower strength and higher ductility characteristics than its original form.

3.16 Explain why the strength of a polycrystalline metal at room temperature decreases as its grain size increases

Since strength is directly proportional to the entanglements of dislocations that take place with each other and with grain boundaries. Also, more is the grain size less will be the grainboundary area per unit volume. Therefore, for metals with large grains fewer entanglements are generated at grain boundaries and thus have lower strength. Hence, we can say that the strength of a polycrystalline metal at room temperature decreases as its grain size increases

3.9 Describe why different crystal structures exhibit different strengths and ductilities.

Ductility of the material is directly proportional to the number of the slip systems. Along with it, plastic behaviour of the material can be estimated with the help of number of active slip systems. As an example, a hcp material has few grains oriented in reference to a slip system and thus to start plastic deformation high stresses are required because of having few slip systems and are brittle whereas because of having many slip system a fcc material requires lower stresses for the same and thus have moderate strength and good ductility.

What is the relationship between nucleation rate and the number of grains per unit volume of a metal?

There is a very close relationship between nucleation rate and the number of grains per unit volume. Grain size depends upon the number of sites in which crystal form and the rate at which there grow. Commonly, small grains are formed due to rapid cooling whereas slow cooling gives larger crystals.

avg grain diameter $\rightarrow d = \frac{0.254}{\sqrt{N}}$ $N = 2^{n-1}$

N = # of grains @ 100x

$d = \frac{L}{N}$ — length of line

grain diameter

Number of Intersection