Lecture 5 - 6

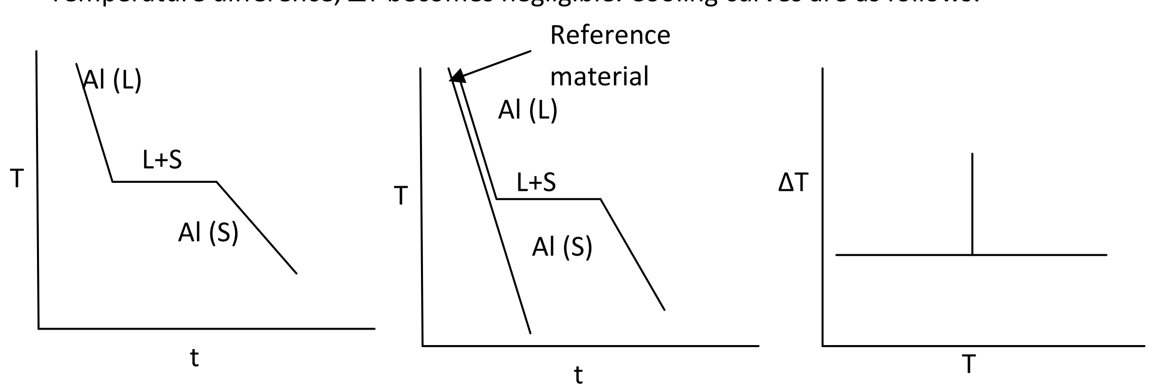
Experimental tools & techniques: Metallography (Optical TEM, SEM), X Ray Diffraction, Mechanical Properties, Thermal analysis

Questions:

1. Sketch the cooling curve of pure aluminium as it is cooled from 750^{0} C. Given mp = 660. How would the DTA plot look like?
2. Suggest two simple methods for increasing the resolving power of an optical microscope.
3. Use Bragg law to find out the indices of the first three reflections in a powder diffraction pattern taken from a simple cubic crystal.
4. Use Bragg law to find out the indices of the first reflection in a powder diffraction pattern from fcc structure.
5. Explain why reflection from 100 is absent in diffraction patterns from bcc crystal.
6. Derive a relation between wave length & accelerating voltage in an electron microscope. What is the wave length of electron beam if voltage is 200KV?
7. If tensile stress strain plot beyond elastic limit is given by $\sigma = k\varepsilon^{n}$ show that necking (plastic instability) sets in when true strain exceeds n.
8. Derive a relation between true strain and engineering strain.
9. The size of Brinell indentation taken on a steel specimen was found to be 5mm. Diameter of the ball indenter is 10mm. Estimate its hardness.
10. Does necking take place during compressive loading?
11. Estimate the size of Vickers indentation on a specimen taken with 10kg load if its hardness is 200VHN. What will be the size of indent if load used were 30kg?
12. At what temperature does time dependent deformation become measurable?
13. What problem do you anticipate in measuring hardness of lead?
14. A specimen having initial length l_o is deformed under tension in two stages. In stage I it is deformed to a length of l_1 and subsequently it is deformed to a length l_2. Find out engineering and true stain in each of these stages. Which of these follows additive rule if you have to estimate final strain? Assume that deformation is uniform.

Answer:

1. In DTA the temperature of reference material keeps going down where as that of Al at its melting point remains constant until solidification is complete. This is due to latent heat liberation during solidification. Once it is complete the temperature starts dropping. Temperature difference, ΔT becomes negligible. Cooling curves are as follows:

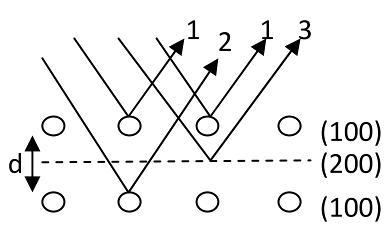


2. Resolving power of an optical microscope is given by $\frac{\lambda}{2\,\mu\, sin\alpha}$ where λ is wave length, μ is the refractive index of the medium between the objective and the sample and 2α is the apex angle of the cone light that gets reflected from a point on the specimen. Clearly the resolving power could be increased by reducing the wave length of the light (use blue) & using oil immersion objective where a drop of oil having high refractive index replaces air between lens & specimen.

3. Powder diffraction pattern are recorded with the help of monochromatic beam of X-Rays where as the samples consists of a large number of tiny crystals of random orientation. The condition of diffraction is given by Bragg's law: $2\,d\sin\theta = \lambda$ where 2θ is the angle between incident beam and the diffracted beam. The angle (sin θ) of diffraction is inversely proportional to inter planar spacing (d). The first three reflections therefore must come from the three most widely spaced crystal planes. The d spacing of a simple cubic crystal is given by $d = \frac{a}{\sqrt{h^2+k^2+l^2}}$ where (h,k,l) are the Miller indices of the crystal planes. Clearly the lowest sum square value of (hkl) would have the highest d spacing. The first 3 values of $h^2 + k^2 + l^2$ are 1, 2 & 3 respectively. Therefore the indices of the first 3 reflections are (100), (110) & (111).

4. The most widely spaced plane in fcc crystal is (111). The angle at which the reflection is likely to occur is given by $\theta = sin^{-1}\left(\frac{\lambda}{d}\right)$. Clearly d, the inter-planar spacing for (111) reflection is the lowest. Therefore this is the indices of the first reflecting plane.

5. Diffraction occurs if the path difference between two reflected beams from two parallel planes is equal to the wave length of the beam. In bcc lattice there is a plane having atoms half way between two (100) plane. Therefore this too will reflect the incident beam. The path difference will therefore be λ/2. This would result in destructive interference. This is why there is no reflections from (100) plane in bcc crystal.



Beam 1 represents reflections from the first (100) plane. & beam 2 is the reflection from the next (100) plane satisfying Bragg condition. Let path difference between 1 & 2 = λ If there is a plane halfway between the two having atoms there will be a reflected beam from it. This is shown by path 3. Path diff between 1&3 = λ/2.

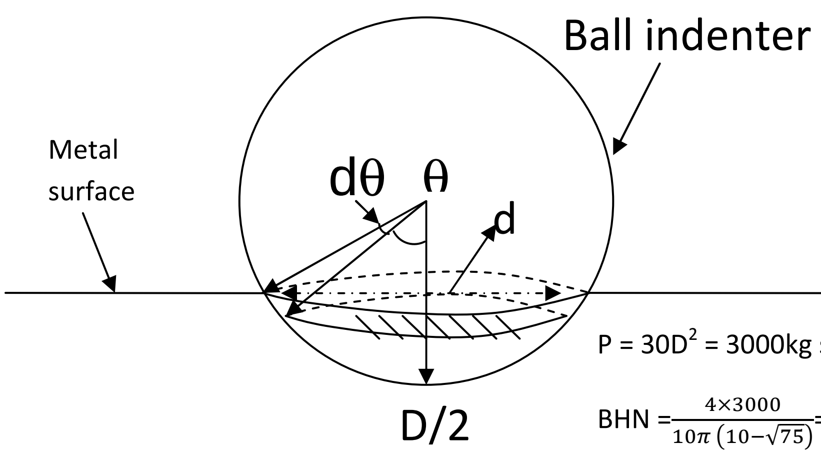
6. If V the accelerating voltage energy of electrons = eV = kinetic energy = $\frac{1}{2}mv^2$ therefore $v = \sqrt{\frac{2eV}{m}}$. The particles moving at high speed also have wave nature. The wave length is given by:

$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2meV}}$. Where h (6.63x$10^{-34}$ Js) is Plank's constant, v is the velocity of electron, e (1.6x10^{-19}Coulomb) is the charge of an electron & m (9.11x10^{-31} kg) is its mass. If V=100kV, $\lambda = \frac{1.23}{\sqrt{V}}$ = 0.0039nm. This off course is an approximate relation ignoring relativistic correction for mass of electron moving at high speed.

7. Necking sets in during tensile test when the load (P) reaches its peak value. This is given by P = σ A where σ is the stress and A is the cross sectional area. Take log & differentiate to get $\frac{dP}{P} = \frac{d\sigma}{\sigma} + \frac{dA}{A}$. This becomes zero when P is maximum. Since reduction in area (-dA/A) is equal to true strain increment (dε) it gives: $\frac{d\sigma}{d\varepsilon} = \sigma$. Since σ = k$\varepsilon^n$ it can be shown: $\frac{d\sigma}{d\varepsilon} = k\,n\,\varepsilon^{n-1} = k\varepsilon^n\, n/\varepsilon = \sigma$ Therefore: strain at which necking sets in is given by ε= n.

8. True strain (dε) is defined as change in length (dl) over instantaneous length (l). Let initial length be l_o and final length l so that engineering strain (e) is = $(l-l_0)/l_0$. Therefore to obtain true strain one has to integrate the following equation between limits l_o & l. $\varepsilon = \int_{l_0}^{l} \frac{dl}{l} = \ln\frac{l}{l_0} = \ln\left(\frac{l+dl}{l}\right) = \ln(1+e)$

9. Relation between indenter & indentation mark is shown in the following figure. Area of the annular strip on the surface of the indenter = dA



$$A = \int_0^{\theta} \frac{\pi D^2}{4} \sin\theta \, d\theta$$

$$= \frac{\pi D^2}{4}(1 - \cos\theta)$$

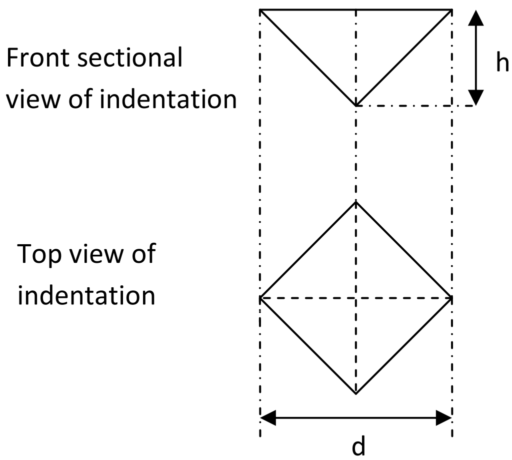
$$= \frac{\pi D}{2}\left(\frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}\right)$$

P = $30D^2$ = 3000kg since D=10mm & d=5mm

BHN $= \frac{4\times 3000}{10\pi\,(10 - \sqrt{75})}$ = 285

10. Necking does not occur under compressive load because stress decreases with strain (note that in this case cross section area increases with deformation). There may be instability of another kind. This is known as buckling. It is determined by length to diameter ratio. Cylindrical test piece with higher height to diameter ratio is prone to such instability.

11. Vickers hardness VHN = P/A where P is load and A in area of indentation mark. The indenter is a square based pyramid with apex angle =136°. If the diagonal of the indentation is d the area of indentation can be obtained as follows:



Length of one side of indentation = d/√2 if the apex angle = θ using simple trigonometric relation the area of one of the triangular faces of the indentation can be shown to be = $\left(\frac{d}{2\sqrt{2}}\right)^2 \frac{1}{\sin\frac{\theta}{2}}$. There are 4 such faces. Therefore VHN defined as P/A is given by: $\left(2\sin\frac{\theta}{2}\right)\frac{P}{d^2} = \frac{1.854P}{d^2}$. If P =10kg d = 0.304mm & if P=30kg d=0.527mm

12. Creep is a time dependent deformation. It is a strong function of temperature. It becomes measurable when test temperature is greater than 0.5 times the melting point of the metal in degree Kelvin.

13. Melting point of lead is low (~327°C). Tm = 600°K. Room temperature (~300°K) = $0.5T_m$. Therefore it would creep and the size of indentation will increase with time. A more precise control of time is required to get reproducible result.

14. Engineering strain in stage I = $e_1 = \frac{l_1-l_0}{l_0}$ and that in stage II = $e_2 = \frac{l_2-l_1}{l_1}$ whereas total strain = $e_t = \frac{l_2-l_0}{l_0}$ However true strain in stage I = $\varepsilon_1 = ln\left(\frac{l_1}{l_0}\right)$ and that in stage II = $\varepsilon_2 = ln\left(\frac{l_2}{l_1}\right)$ and total strain = $\varepsilon_t = ln\left(\frac{l_2}{l_0}\right)$ It is easily noted that in case of true strain $\varepsilon_t = \varepsilon_1 + \varepsilon_2 = ln\left(\frac{l_1}{l_0}\right) + ln\left(\frac{l_2}{l_1}\right) = ln\left(\frac{l_2}{l_0}\right)$. This is not true for engineering strain.