Lecture 29-30:

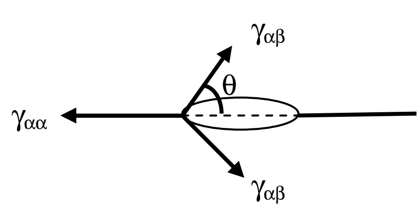
Precipitation from solid solution: Precipitation from super-saturated terminal solid solution: thermodynamics & kinetics of precipitation, precipitation hardening

Question:

1. What types of alloys would respond to precipitation hardening?
2. Why Aluminium alloy rivets are stored in refigerator?
3. For a lens shaped β nucleus formed at αα interface estimate the angle θ if $\gamma_{\alpha\alpha}$ = 500 and $\gamma_{\alpha\beta}$ = 600mJ/m^2 and hence find out the shape factor of the precipitate.
4. Critical radii for both homogeneous and heterogeneous nucleation are the same yet the latter is more likely to occur. Give reason.
5. A batch of age hadrenable alloy has been overagred by mistake. Is there any way to slavage these?
6. Why non-age hardenable aluminium alloys are chosen for beverage can?
7. When can you get more than one peak in the hardness versus aging time plot of a given alloy at a given temperature?
8. If in an alloy 1nm thick disk of θ'' has formed, estimate the critical diameter at which its coherency is likely to be completely lost. Given δ = 10%, γ = 500 mJ/m^2 and E = 70000MPa
9. Ag rich GP zones can form in a dilute Al-Ag alloy. Given that the lattice parameters of Al and Ag are 0.405nm and 4.09nm respectively. What is likely shape of these zones?
10. Under what heat treatment condition an age harden-able alloy can be machined?
11. Show that the shear stress to move a dislocation in a matrix by cutting dispersed spherical particles is proportional to the cube root of f where f represents volume fraction of particles.

Answers:

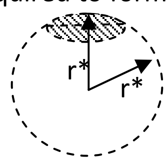
1. Alloys which at room temperture has at least two phases and on heating beyond a temperature attains a single phase structure (solid) can respond to precipitation hardening provided it satisfies the following conditions i) on queching precipitation could be suppressed ii) on heating or aging precipitates that nucleates are cohent with the matrix.
2. Alumunium alloy rivets are first solution treated to get supersaturated solid solution so that they are soft and could be easily deformed durring rivetting. If these are not stored at subzero temperature after solution treatment they would age and become strong and relatively brittle. Therefore it would become unusable.
3. It is seen from the following figure



$$\gamma_{\alpha\alpha} = 2\gamma_{\alpha\beta}Cos\theta \;\therefore\; \theta = \frac{500}{1200} \; or, \theta = 65°$$

$$S(\theta) = 2 + cos^3\theta - 3cos\theta = 0.021$$

4. Although the critical radii for both homogeneous & heterogeneous nucleii are the same their volumes are significantly different. This is clear from the following sketch. Number of atoms required to form a stable nucleus is much less than that for homogeneous nucleus.

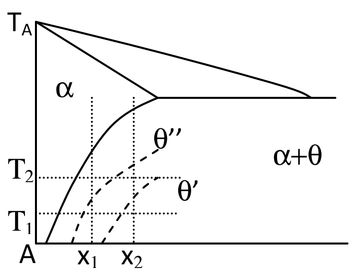


Dotted circle represents homogeneous nucleus. Horizontal dotted line is grain boundary & the hatched region is a lens shaped heterogeneously formed nucleus.

5. Yes. The overaged alloy can be solution treated and quenched before using them as rivets.

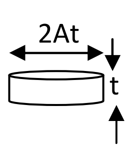
6. Beverage cans are maufactured by cold working. The alloy must have good ductility. Age hardenable alloys have relatively poor ductility. More over these are more expensive.

7. It happens when more than one coherent meta-stable precipitates form during aging. This illustrated in the following sketch where there are two intermediate coherent precipitates θ' & θ'':



Note if x1 is aged at T1 we get one peak for θ' another for θ'' with formation of θ which is incoherent hardness starts dropping. Alloy x2 lies beyond q' solvus here only q'' precipitate could form therefore only one peak is expected. Similar situation would arise for a given alloy when aged at different temperatures.

8. Coherent precipitates have disc shape. Its elastic stored energy is given by: $E_s = \frac{1}{1-\nu}\bar{V}E\delta^2$. Assuming Poisson ratio ν =1/3 and volume of disc shaped precipitate $\bar{V} = \pi(At)^2 t$ where t is thickness of disc and A is its aspect ratio. Therefore radius of disc = At. On substitution of these in the expression for elastic stored energy: $E_s = \frac{3}{2}\pi E A^2 t^3 \delta^2$. Likewise stored surface energy is given by: $S = 2\pi\gamma[(At)^2 + At^2]$ Coherency is lost when E_s exceeds S. By equating the two one gets an expressions for critical thickness: $t_c = \frac{4\gamma}{3E\delta^2}\left(1+\frac{1}{A}\right)$ or; $1 \times 10^{-9} = \frac{4\times 500\times 10^{-3}}{3\times 0.001\times 70\times 10^{9}}\left(1+\frac{1}{A}\right)$ on soling this A = 20. This means critical diameter = 2*20 =40nm



Volume of the disc = $\pi(At)^2 t$

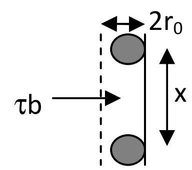
Surface area = $2\pi\gamma[(At)^2 + At^2]$

9. Al & Ag both have face centered close packed structure. Their atomic radii should be proportional to their lattice parameters. Therefore lattice mismatch = 100 x (0.409-0.405)/0.405

= 0.99%. If mismatch is less than 5% shape is determined by its surface energy. Spherical shapes have less surface energy. If it is greater than 5% it is likely to be disc shaped.

10. It is easy to machine a material alloy when it is soft. Age hardenable material can be easily machined either when it is over aged to a low hardness or under solution treated condition. Some solution treated alloy would age harden during machining in those cases the former option is better.

11. Imagine spherical particles of radius r_0 are arranged in a regular fashion with inter particle spacing x. The work done to move a dislocation through a distance $2r_0$ to cut a precipitate is given by $(\tau b x)2r_0$ This is used up in creating new surface having energy = $\pi r_0^2 \gamma$.



Equating these two $\tau = \pi \frac{\gamma r_0}{2bx}$ Volume fraction can be equated to precipitate size and spacing assuming that these are arranged in the form of a cube lattice with spacing x such that $f = \frac{4}{3}\pi \left(\frac{r_0}{x}\right)^3$ On substituting this in the expression for shear stress $\tau = \frac{\pi\gamma}{2b}\left(\frac{3f}{4\pi}\right)^{\frac{1}{3}}$ or $\tau \propto f^{\frac{1}{3}}$