Lecture 38-39: Application of physical metallurgy: Structural steel, Micro-alloying, thermo-mechanical processing

Questions:

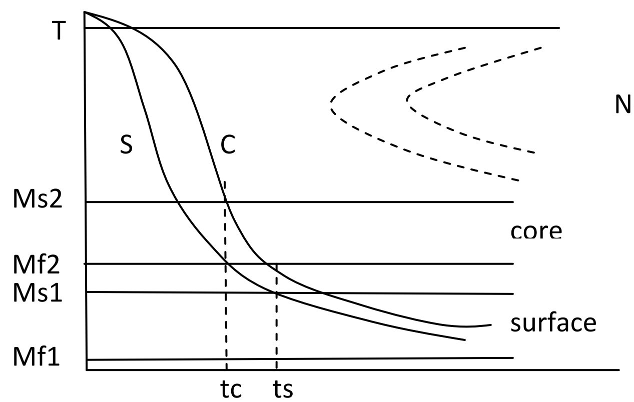
1. Microstructure of a cold rolled annealed mild steel sheet shows elongated pearlitic region in equiaxed ferritic matrix. Comment on the processing route that will give this type of microstructure.
2. Name three common grades of steel produced by ingot route. Which of these has higher yield?
3. Why does compressive stress develops at the surface in a case carburized and subsequently case hardened steel?
4. Why low carbon content is preferred in most structural application? Is high strength not a major criterion?
5. What is the composition of the steel designated as 25Mn1S14? What is the role of sulfur in this steel?
6. Why is it possible to get much finer grain structure in steel than in aluminum?
7. Estimate the amount of martensite that can be obtained in 0.2% carbon steel by quenching from inter-critical temperature regime (between A1 & A3) as a function of temperature. Which of these is likely to give maximum strength?
8. The concept of solubility product is used to estimate the amount of MX precipitate in micro-alloyed steel (Fe-M-X) in terms of its composition in wt%. If solubility product of VN is given by $\log k_{VN} = -\frac{8330}{T} + 3.46$ estimate the amount of V present as VN precipitates in alloy having 0.15 wt% V and 0.015wt% N at 1273^{o}K.
9. How is ausforming different from austempering? Is this a hot working process?
10. What is the effect of micro-alloy addition on rolling load?

Answers:

1. Elongated pearlite is a sign of cold work whereas equiaxed ferrite means annealed structure. It looks that the steel was cold worked when both pearlite and ferrite got elongated. Later on annealing just below eutectoid temperature ferrite has re-crystallize but pearlite remains untransformed. To modify pearlite shape it must be heated above eutectoid temperature.

2. Steel produced by ingot route is classified as killed, semi-killed and rimming steel. This is based on the way the dissolved oxygen in molten steel is removed. Rimming steel has the highest yield. Here the oxygen gets removed by the reaction between dissolved carbon and oxygen with evolution of CO bubbles as the steel cools in mold. This gives the rimming action. Formation of solid crust at the top of the ingot does not allow the gas to go out. It remains entrapped as porosity and balance the shrinkage associated with solidification. There is no shrinkage pipe. Therefore the entire ingot without cropping can go for hot rolling. The pores get welded during hot working.

3. This is illustrated with the help of following diagram. Here we have high carbon steel with lower Ms & Mf temperature at the surface whereas core is a low carbon steel with higher transformation temperatures (Ms & Mf). Therefore transformation occurs first in core with expected expansion when surface is still soft austenite and therefore it can allow the core to expand (due to transformation) by plastic deformation. When martensite starts forming at the surface accompanied by volume expansion the core which is now strong will inhibit this. This is why there is a residual compressive stress at the surface.



Note that transformation would start at tc within core although it is at a higher temperature whereas when transformation starts at surface at ts transformation at core is complete.

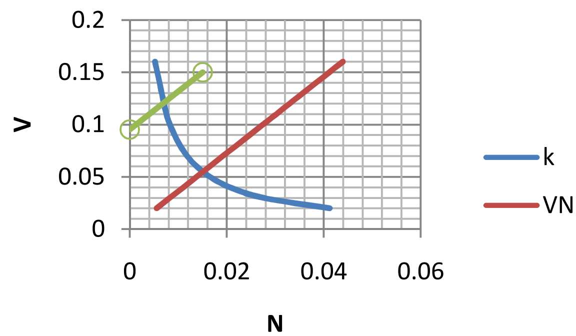
4. Often structural steel is supposed to have additional properties like weldability & formability apart from high strength. Low carbon content gives better formability & weldability. Loss in strength due to lower carbon is made up by grain refinement through controlled thermo-mechanical processing with addition of micro-alloy elements like Nb, V, & Ti. They prevent grain growth during hot rolling.

5. This is a free cutting steel having 0.25% carbon, 1% Mn and 0.14% S. In presence of Mn, S is present as MnS inclusion. This improves machinability. It is mostly used for making nuts & bolts. If Mn is not present then S forms a low melting eutectic between Fe & FeS. This segregates along austenite grain boundary leading to hot shortness. This is undesirable. This is why in most steel S is less than 0.05%.

6. Steel unlike aluminum offers additional opportunity for grain refinement because of austenite to ferrite transformation. In addition to grain refinement during solidification there is further refinement because of nucleation & growth of new ferrite grains at prior austenite boundaries.

7. Apply lever rule to estimate % γ as a function of inter-critical temperature. Amount of γ will be minimum near A1 and maximum (100%) at A3. On quenching this gets converted to martensite. Hardness of martensite depends on carbon content. Therefore Martensite formed on quenching from A1 will have maximum hardness where as that formed on quenching from A3 will have minimum hardness. Hardness of ferrite remains constant. Apply rule of mixture to get the hardness of ferrite martensite aggregate. Assume hardness of martensite change linearly from 200VHN at 0% C to 950VHN at 0.8% C. Assumption: there is no retained austenite in final structure.

8. Since $\log k_s = -\frac{8330}{1273} + 3.46 \; or \; k_s = 0.000825$Use this to generate solubility plot at 1273K. This is shown by line k in the graph. Atomic weights of V & N are 51 & 14 respectively. Plot line VN passing through origin with slope = 51/14. This represents amount of V needed to form VN (Stoichiometry).



Mark the composition of the steel by a point (0.15V, 0.015N). Draw a line parallel to VN through this point. The point of intersection with k represents amount of V that is present in solution. Thus soluble V = 0.12wt% Balance 0.03 is present as VN.

9. In austempering the steel is austenitized and then quenched in a bath kept at a little above Ms temperature for sufficiently long time to get 100% Bainitic structure. Whereas in ausforming the steel is taken to austenitic state followed by quenching in a bath kept at a temperature a little above Md and subjected to plastic deformation before quenching to get martensitic structure. Md temperature corresponds to a temperature above which martensite does not form even if austenite is being deformed. Since plastic deformation during ausforming takes place below re-crystallization temperature of austenite it is a cold working process.

10. In the case of Nb containing steel grain boundaries get pinned by nano sized NbCN precipitates formed soon after rolling at high temperature. Finish rolling is done below its re-crystallization temperature. This gives rise to elongated austenitic grains which ultimately transform to ferrite pearlite structure. This process would need higher rolling load. Whereas steels having V as micro alloy addition precipitation occurs during finish rolling stage to inhibit grain growth. Therefore rolling load here is low.