Introduction to Materials Science and Engineering
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Lecture – 121
Solid solution hardening

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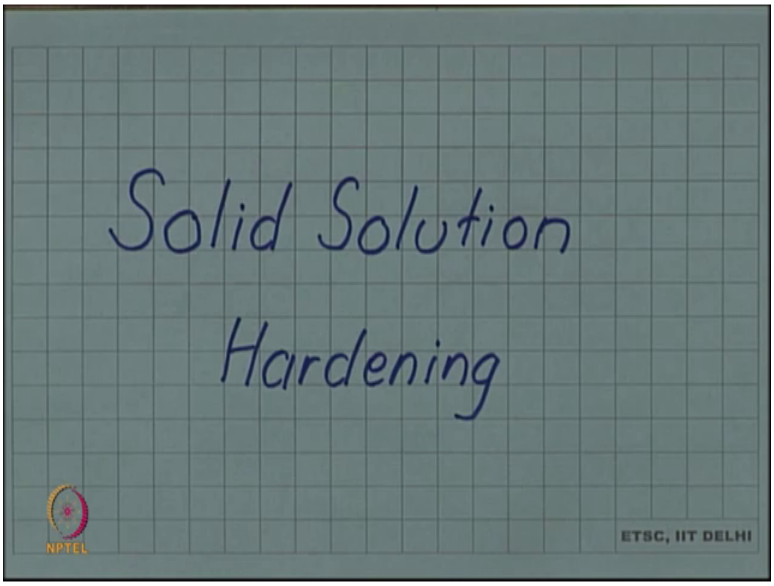

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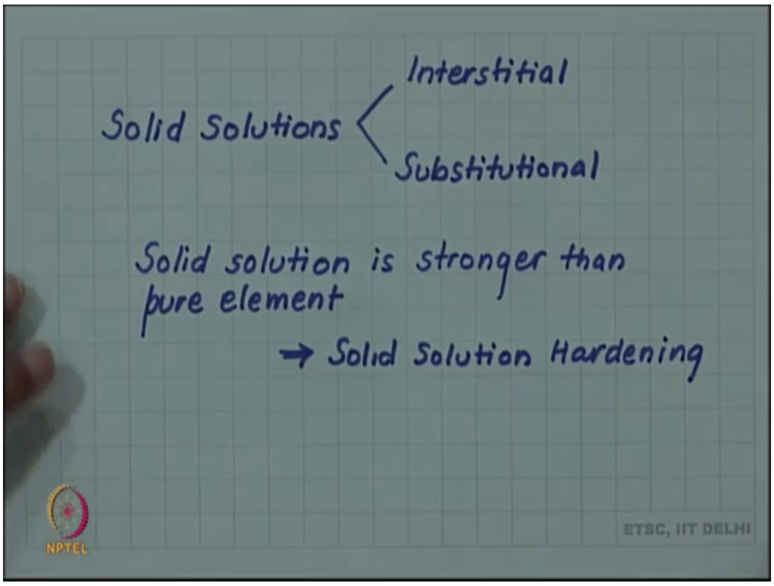

Let us discuss another strengthening mechanism called Solid Solution Hardening. You have met with solid solution and we have discussed two kinds of solid solution; Interstitial solid solutions, we discussed two kinds interstitial and Substitutional.

In both kinds, the solid solution is always a stronger or has higher yield stress than the pure element. Solid solution, pure element; this is what is called solid solution hardening.

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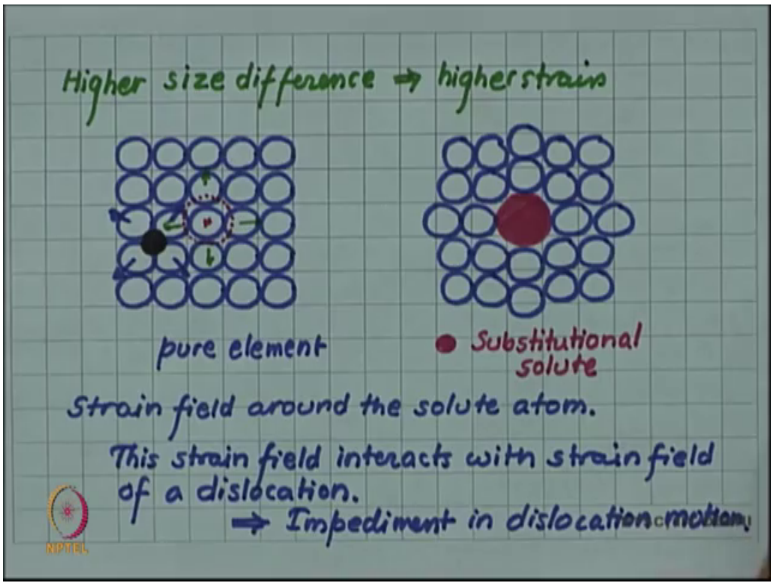

Let us look at; why is this? So, let us look at this schematic of a solid solution. So, we have this pure element where all atoms are equisized and suppose, we now substitute this atom, the central atom here by a larger atom. So, this is a substitutional solute, the red element here is substitutional solute and the way I have drawn it, you can see that I have substituted a larger substitutional solute atom.

So, because this atom is larger, it is it will displace the atoms around it to make room for itself. Since, this was a smaller atom and now we are replacing a larger atom for it; so, it has to displace these surrounding atoms to make room for itself. So, because of the displacement, these displacements caused a deformation or a strain field around the solute atom. So, solute atoms are a companying.

So, there is a strain field. I have shown here a larger solute atom, larger substitutional solute atom but whether the substitutional solute atom is large or small or whether it is substitutional solute or interstitial solute. Imagine an interstitial solute and let me show it in this diagram itself. So, suppose, I try to introduce an interstitial solute here and again if the interstitial solute happens to be larger than the void size, we have seen that but every void can accommodate tetrahedral void or octahedral void can accommodate a certain maximum size of atom.

So, if the size is larger than that; then to accommodate that interstitial solute again these atoms have to move out to create room for it and there will be strain field around it. So, there is always a strain field around the solute atom; this strain field interacts with a strain field of a dislocation. Recall in the case of edge dislocation, we said that there are tensile stresses below the slip plane and compressive stresses above the slip plane. So, if there is a half plane of the edge dislocation. So, above the slip plane, there is compressive stress below the slip plane there is tensile stress.

Now, if this interacts, the solute atom stress field interacts with this and suppose the tensile and tensile overlap, this will cause increase in the strain energy of the material and there will be a repulsion. So, the dislocation line will be repelled by the solute atom. So, if the dislocation line is being repelled by the solute atom, the motion will be impeded but suppose the tensile of solute atom overlaps with compressive of the dislocation line, then there will be an attraction and the edge dislocation will like to come close to the solute atom.

But in this case also, if it wants to continue to move to create further plastic deformation, it will not like to move away because there is an attraction with the solute atom. So, in either case, the strain field interaction with the dislocation strain field causes impediment in the motion of the dislocation; in dislocation motion. Also note that an important point here or important factor here will be the size difference; larger is the size difference. If the substitutional solute atom happen to be exactly of the same size as the solute as the pure element or as the matrix element, then there would have been no strain. So, the strain is caused because of the size difference. So, higher will be the size difference higher will be the strain; higher strain and so there will be more effective hardening due to the solute atom.

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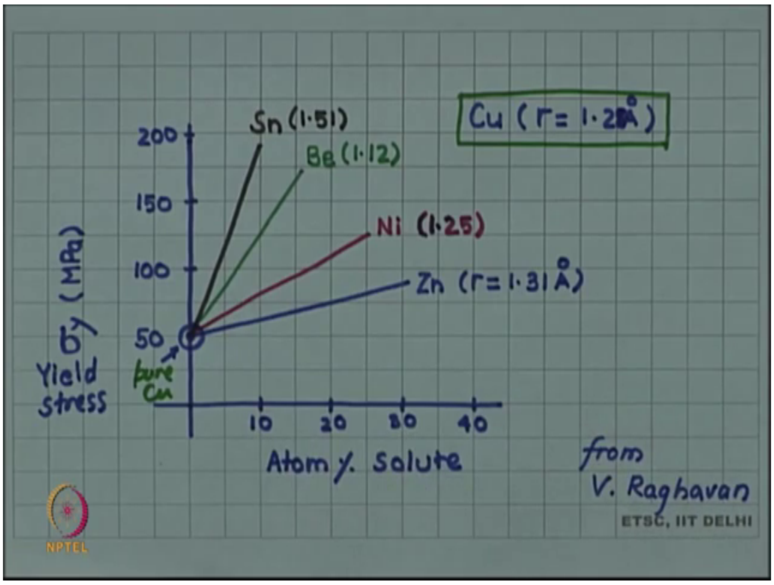

So, let us look at this example. We have the base element copper, the base element is copper and the radius of copper atom is 1.28 angstrom, this is 8; 1.28 angstrom and in that we use a substitutional solute different elements; zinc, nickel, beryllium and tin and they have their own radii. You can see nickel and zinc; both have radii close to the radius of copper. So, since there may the radii are matching, the strain created by them is a small. So, the straining or effective straining is less. In this plot, we are plotting the yield stress sigma y as the y axis and atom percent solute as the x axis.

So, for any given solute let us say zinc, if I am adding zinc to copper as I increase the solute concentration, yield stress is increasing. This 50 mega Pascal is for the pure copper because 0 percent solute. So, this is for pure copper and as you add the solute its strengthening is taking place. So, whatever solute you add with the increasing amount of solute its strengthening increases strength increases.

However, if the radius ratio is small the effect is small, the slope is small; whereas, if radius difference is large as in the case of tin and beryllium the difference is more with the base element copper. So, for a small amount of solute, the hardening is much more. So, you can see that how the solid solution hardening depend both on the size difference as well as the amount of solute.