Mechanical Behavior of Materials-1
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Lecture - 37
Solid Solution Strengthening: Interaction with Dislocations

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Welcome back class to our course Mechanical Behavior of Materials. So in the last class, we started discussing about solid solution strengthening. We discussed about type of solid solution and then we were discussing about also the distortion in the lattice due to the presence of solute atoms, okay. So if you see, this is the last topic we finished talking about. So this is the perfect lattice, okay. So there is no distortion here, okay.

Now if we add interstitial atom, so this is the case of interstitial atom, interstitial solid solution okay. So this is your interstitial atom here. So you can see you added an extra atom which is a black atom here, okay. Again clearly see we discussed about this also in the last class. You can clearly see strain right, distortion in the lattice here. So there is a distortion in the lattice, okay.

And this distortion is non-spherical in nature because the voids are either tetrahedral or octahedral voids and interstitial atoms are going to be sitting there, okay. Now the bottom two are for substitutional solid solution. So both are for substitutional solid solution, okay. So in the first case here, so red is the substitutional atom. So you can see in the interstitial atom we have added an extra atom which is the black color.

In the substitutional case we are not adding any extra atom, right? So the number of atoms remain same as in the first case. So if I say this is the first case, so the number of atoms remain same, okay. Only thing is that we have substituted a red atom, sorry blue atom with red atom. And in the first case here this one, the size of the substitutional atom is smaller than in the second one, okay.

So this is the smaller atom and this is larger one okay, second one. And in both the cases you can again see a very nice distortion, okay. So here you can see a distortion and here also you can see a distortion, okay. So I wanted to show you again with nice schematic. In the last class I drew using my hand, okay. So in both the cases whether it is interstitial or substitutional we are going to see lattice distortion.

And these distortion are going to interact with the dislocation, right. You already know that dislocation also have strain field associated with it, right? So when you have s distribution half plane, you have stress right on the top above the half plane and bottom of the half plane. You have compressive and tensile region, right? So you have a stress field associated with dislocations.

And now you also have a stress field associated with these solute atoms right, around the solute atoms. So now there will be interaction between both the stress field, dislocation stress field and the stress field associated with the presence of solute atoms. And that is how there will be increment in the stress okay, strength of the alloy. That is the whole concept, okay. So let us understand this.

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So the stress field around solute atoms interact with the stress field around the dislocation, okay. So both the stress fields they are going to interact and this will lead to increase in the strength, okay. And why, because there will be restriction in the movement of dislocation, due to restriction in the dislocation motion, okay. That is point number one. Now the next is there are few factors which will play role here, okay.

The factors are number one size of the solute atoms. So more the size difference, so higher the size difference between the solute atoms and the solvent atoms we are going to see more strengthening, okay. So more the size difference higher is the hardening or say strengthening okay. That is point number one.

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Now the second factor is elastic modulus of solute. So higher the elastic modulus okay higher is the strengthening effect, okay. So these are the two factors. One is the size of the solute atom. So higher the size of the solute atoms as compared to the solvent atom there will be more strength right, increment in the strength. And second is the elastic modulus. More the difference more is the strength, okay.

Now there is another point that increasing the solute concentration, so if you have more and more concentration of solute you are going to increase the effect of strengthening, right? So increase in the strength or say magnitude of strengthening, okay. But remember one thing. You know you cannot just continuously increase the solute concentration in the solvent because there is solubility limit of any solute in the solvent, right? Otherwise then you will see formation of second phase, okay.

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Now let us understand how the strength is going to vary with respect to size and concentration. Now we know that if you increase the size as well as concentration of the solute then you are going to see more effect of strengthening, right? So I have some quantitative plot here. So effect of size and concentration, okay. So strengthening scales with two factors, one is the size difference between solute atom and the solvent atom and second one is the concentration of the solute, okay.

And the plot here is for the addition of the solute atoms in proper, okay. So you are adding aluminum in copper, nickel in copper and so on right? Tin, beryllium, silicon etc. And then you have a quantification of increment in strength. So the y axis here is sigma y, yield stress. And the x axis is the solid concentration in atomic percent and it is, the solvent here is solvent is copper, okay.

So you are trying to dissolve all these solute atoms, different type of solute atoms in copper, okay. So the first observation if you look into this plot, one can make is, increase in the solid concentration you are going to see an increment and we are assuming that a linear relation exist. So a linear relation can be assumed, okay. Now the second difference what you see here, let me change the color, okay.

So if you see copper, the radius is 1.28 angstrom and then in the bracket I have listed the radius of other solute atoms, okay. So you can see larger the difference between the radius of copper and the solute atom, higher the magnitude of the yield stress, okay. So the tin which is 1.51 and copper is 1.28 that is the largest difference you can see, right?

So you can see at each solid concentration when we add tin atom in the copper matrix you have the highest yield strength, is it not? Okay. So that is the second criteria that higher the size difference you have more strength, okay. So see here 1.31 and 1.25 both are very near to copper, right? So the increment in strength is much lower. Now another point here is that for the same size difference the smaller atom gives a greater strengthening effect, okay.

So suppose you have two different atoms, one is on the positive side and other one is the negative side but both has the same difference, approximately same difference with respect to the solvent atom, right? So the smaller atom is going to give you more strengthening compared to the larger size atom. That is the another point. So you have size difference and concentration of the solute playing in solid solution strengthening, okay.

So we have understood the concept of distortion in the lattice because of the presence of solute atoms. Now let us talk about distortion in the lattice because of the presence of dislocations and then we will discuss about how these two distortions they are going to interact leading to the increment in the strength, okay.

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So we will now discuss about distortion in the lattice due to dislocations, okay. So this one have been discussed by Professor Shashank Shekhar. So we will move slightly faster, okay. So we have two type of dislocations in general, edge dislocation and screw dislocation. So edge dislocation, okay. So when we have edge dislocation, the stress field around edge dislocation we can write as sigma xx, sigma yy, sigma zz.

Then we have these two components and then rest are 0 okay. So this means that you have both shear and tensile compressive stress field. That is point number one, okay. So if you see the stress matrix associated with edge dislocation, so it has both shear as well as tensile or say compressive component. So components of hydrostatic, right. That is point number one.

Now since you have both the component you are going to have both dilational and distortional component, okay. So you are going to have both, dilational as well as distortional. Now let us talk about screw dislocations. So if I write down matrix associated with screw dislocation is going to be 0 0 0 0 sigma zx, sigma zy, this component will be 0 and then you have xz and yz, okay.

So you do not have any hydrostatic component here, you have only shear component, okay. So point number one only shear stress field, okay. That means no component of hydrostatic, okay. That is point number one. Second, since you do not have any component of hydrostatic you are not going to have dilational component here. You are going to have only distortional component. So only distortional, okay.

So when you have presence of dislocations right, edge or screw, both are going to be associated with stress field around it. In edge you are going to have both components, dilational as well as distortional whereas in screw you are going to have only distortional component, okay. Now we have understood the stress field in both, dislocations as well as solute atoms, right?

Now let us try to correlate both of them and understand the increment in the strength, okay. So let me write down what we have studied.

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So if I have substitutional atoms, then you are going to have spherical, let me change the color. So you have spherical distortion. And if you have interstitial atoms, then you have non-spherical distortion, okay. Both are stress field so stress field, okay. This is number one. Now if you are talking about dislocation, so when we have edge dislocation, so both dilational and distortional field, okay.

And when we have screw dislocation, then distortional field. So we have studied this. So this is the summary, okay. So now let us see how they interact. So let me make a table. So I have let us say edge, then screw, okay. Then on this side I have substitutional and then interstitial, okay. So now interstitial has non-spherical distortion field. So it is going to interact with both, edge dislocation and screw dislocation okay, sorry interstitial.

And substitutional it has only spherical distortional field. So it is going to interact with only edge dislocation, it is not going to interact with screw dislocation, okay because it does not have any shear component, screw dislocation, sorry screw dislocation has only shear component. So substitutional atom is going to interact only with the edge dislocation where interstitial atom can interact with both edge as well as screw dislocation.

And this is one of the reason why interstitial atom, solute atoms will give you a higher hardening effect as compared to substitutional atom, okay because interstitial solute atoms can interact with both edge and screw dislocation, okay.

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So overall if you see interstitial solute atoms give a higher hardening effect as compared to substitutional atoms, okay. And we are talking about per unit concentration, okay. So interstitial atoms are going to interact with both, okay. So one more, let me write down one more summary here.

So if I have solute atoms, interstitial and then substitutional, then you know you can have a effect of this much in terms of increment in strength as compared to substitutional atom, okay. And this is relative strengthening effect per unit concentration, unit concentration okay. So overall we have now studied the effect of both solute atoms interstitial and substitutional solute atoms on the strengthening effect.

And now we know that interstitial solute atom will provide more strengthening as compared to substitutional solute atoms, okay.

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So if I qualitatively draw, you know delta sigma on the y axis and percentage alloying element on the x axis and let me draw, and these are quality. So what I am doing, I am trying to show you the effect of different alloying elements in steel, okay. So this is for say carbon and nitrogen and then we have silicon somewhere here, then manganese okay, then moly and then say nickel, okay.

So you can see here that when I add carbon and nitrogen, the increment is very high as compared to other alloying element, okay. So per unit concentration if you see, the interstitial atom is going to give you more strengthening effect, okay. So this is in iron, addition of alloying elements okay. So in the next class what we are going to discuss is something called yield point phenomena, okay.

So I am going to show you the plots of medium carbon steel in annealed condition where you are going to see the stress strain behavior is completely different than what you have studied till now, okay. Thank you.