Project of Materials (Nature and Properties of Materials: III)
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Lecture 32
Solid Solution Strengthening

So, welcome again to the new lecture of the course Properties of Materials. Let just briefly recap the contents of last lecture.

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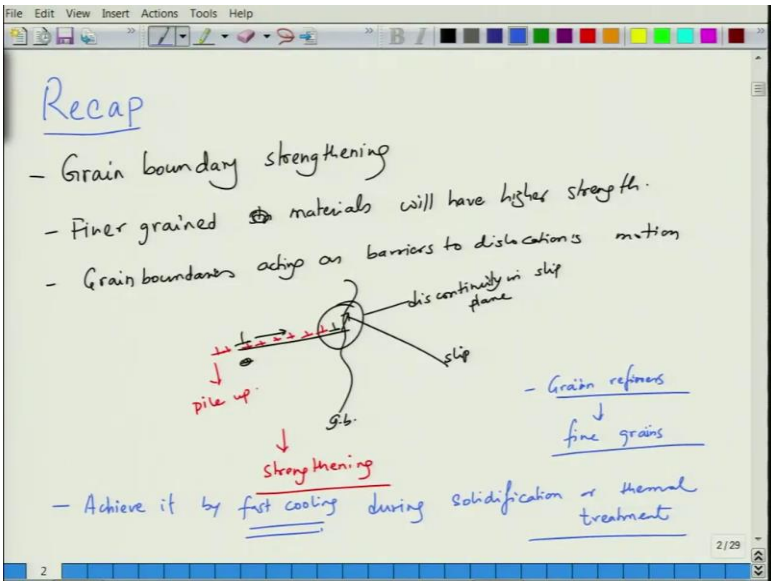

So, in the last lecture we talked about Grain Boundary Straightening, in which we said that finer grain structures, finer grain materials or metals will have higher strength and this is because of grain boundaries acting as barriers to dislocations motion and this is because when you have a grain boundary let us say and if you have a dislocation moving on this slip plane, let us say, the dislocation does not find a slip plane.

So, slip plane, in this case could be you know like this. So, this could be the slip plane. So, to to, so dislocation does not find a slip plane. It has to go from there to there and is it not, it does not happen because they are not continues. As a result there is discontinuity in slip plane. Also even though it was continuous, it could have been a different angle, so that the resolved shear stress could have been different. So, basically this leads to you can say, if you keep doing it, then this will lead to piling up of dislocations here like this.

So, this would be pile up and this pile up again leads to increase in the stress because you are piling up similar dislocations. So, as a result there will be repulsion between the dislocations as well and this leads to strengthening. So, this is a simple way of carrying out strengthening in metals and the way you do it is, you achieve it by fast cooling the materials. So, fast cooling during heat treatment or solidification can lead to. So, during solidification or thermal treatment can lead to finer grain structure.

So, this is a very effective way of strengthening the materials which is and you can also add things like grain refiners. So, that we did not discuss. So, grain refiners are basically, second extra elements which are added to a molten material and they basically increase the nucleation rate and decrease the growth rate and they can also lead to finer grains. So, and there are different kinds of grain, grain refiners for different materials that you can find in literature.

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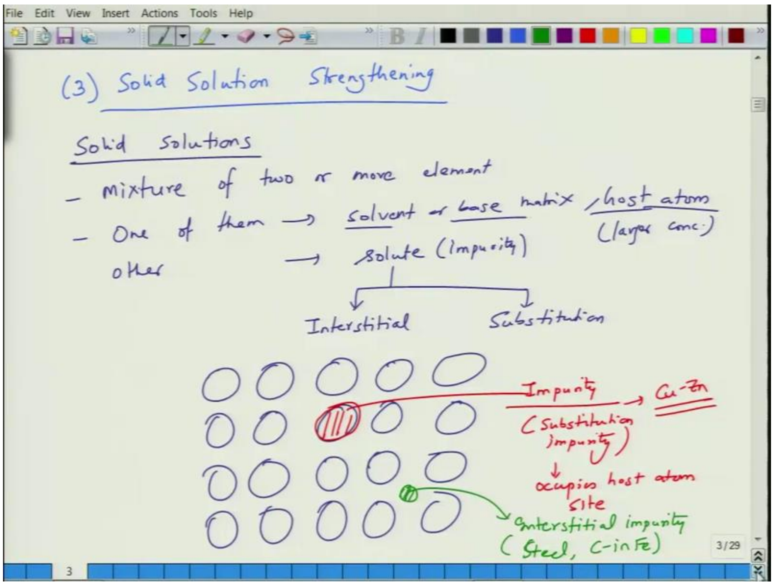

Now, the third method of strengthening is called as Solid Solution Strengthening. So, basically here what we do is that. So, we know what solid solutions are? Solid solutions are solid solutions are mixture of two or more elements and generally one would be the base, one would be in larger concentration than the other. So, basically you can say one of them is solvent or base, it is not liquid form.

So, you cannot say solvent is not a very good term but let us say, base matrix and the other one could be solute and the solute atom could be present in the form of depending upon the size of interstitial, so basically this is an impurity or it could be substitutional. So, let us say, if you have this kind of, these are the host atoms. So, instead of, we can host atom. It is in larger concentration generally, larger concentration. Now, let us say, in this host, so these are blue ones are host atoms.

Let us say we have a red atom here which is a impurity and if the size of impurity is such that it cannot go into the interstitial sites, then what it makes is a substitutional impurity if it occupies the, the host site. So, basically it occupies host atom site. On the other hand, we can have this other type. So, if the impurity is a small, it can go and sit in the interstitial sites. So, this could be interstitial impurity.

So, these two kinds of impurities will give you or solutes will give you substitutional solid solution, if the impurity atom occupies the host sites all of the interstitial or it is interstitial if it is in one of the interstisis. So, what are the examples of substitutional solid solutions are, so substitutional is for example cooper, zinc. Roughly similar sizes and they make a substitutional solid solution. Interstitial solutions could be steel. So, basically you have carbon in iron. Carbon is smaller atom. It goes to interstitial sites in iron. So, these are two examples of solid solutions.

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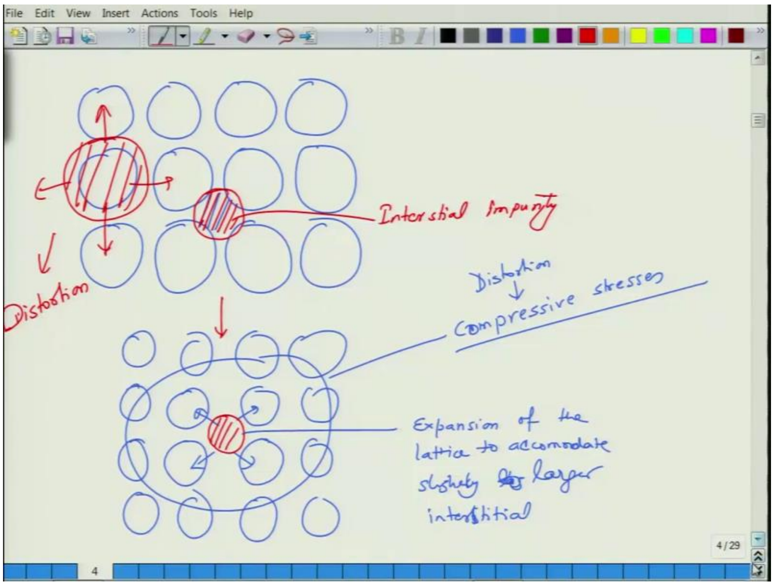

Now, what the, what this does is basically when you have let us say a structure like this. So, these are host atoms. So, if I put a interstitial impurity which is slightly bigger than the size of the interstisis. So, the my interstitial impurity is like this, it is slightly bigger. So, what it is going to do is that, it is going to displace these host atom.

So, this is the interstitial impurity. What it does is, it displaces the atoms around it in order to be accommodated. So, this is the impurity and it sought of displaces these host atoms around it. So, basically you can say, the matrix was like this. So, if just make it a little smaller that will make it better. So, this basically leads to expansion of the lattice here.

So, expansion of the lattice to accommodate slightly larger interstitial which leads to local dilatation. So, as a result it is going to stretch. So, what it, what it does is that, it creates within this region you will create compressive stresses. Compressive stresses to compensate for that as a, as a counter balanced force. So, basically it creates a distortion in the lattice.

The distortion gives rise to let us say, distortion and this dislocation leads to compressive stresses. Similarly it can happen in solid solutions also. So, if you have a bigger atom here, let us say, this is a substitutional atom, this is a bigger atom. It again pushes the neighbouring atoms away and again it creates what we call as distortion. So, it could be a bigger atom, it could be a smaller atom depending upon the type of atom it can basically lead to distortion of the lattice.

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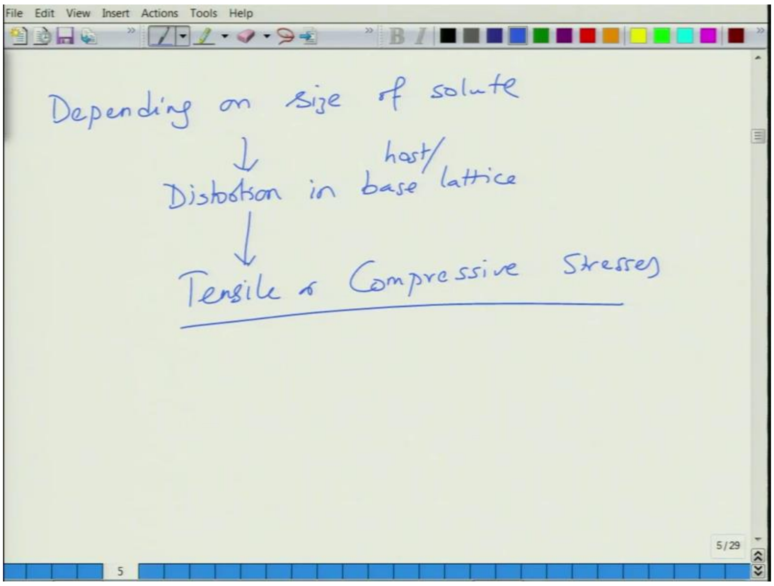

So, depending upon the size of the, so size of solute, you will have distortion in base lattice or host lattice and this gives rise to tensile or compressive stresses. So, basically you strain the, the crystal. Now, how does it help with the strengthening? It helps with the strengthening is.

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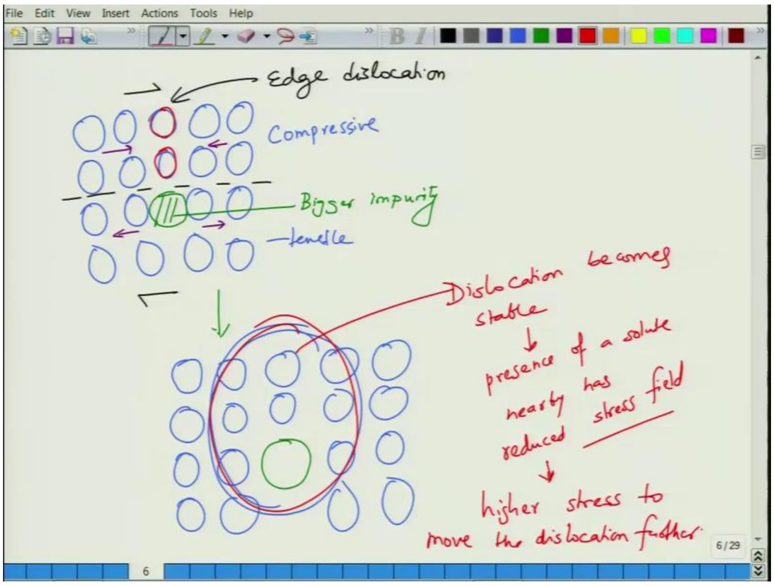

Suppose you have a, you have a situation like this in which you had an extra row of atom. So, this is the extra row of atoms. So, this is let us say, we can say, this is edge dislocation and this is the slip plane. So, when you apply stress, it will try to move to right to relieve the stress to get out of the crystal.

Now, let us say, in the vicinity of this crystal, in the vicinity of. So, when this dislocation moves, let us say, I put an impurity atom which is slightly. So, we can see that this part of the crystal is under compressive stress and this part, this crystal is under tensile stress.

So, what I do is that now, if I put an impurity here, which is bigger. So, this is the impurity, bigger impurity and the bigger impurity will dilate the lattice. So, if I do that, then what situation might emerge is, you have a situation like this and this is the bigger atom. So, you can see now the earlier in the top portion was under compressive stresses, the bottom was in the tensile stresses. So, this is compressive and this is tensile.

Now, you have put this bigger atom, you have expanded the bottom part. So, the stress is in the top end part counter balance each other. So, basically you can see the dislocation has now become attached to the impurity. So, basically you can see, this dislocation becomes more stable. So, dislocation becomes stable, because now it has become attached to this impurity because the stress field is reduced.

So, because presence of a solute nearby has reduced stress field. So, as a result you require more stress to move it because it has become attached to, it has been stabilized with the presence of impurity. So, this is basically what we call as solid solution strengthening.

Where, where we can see that, stress required to move the dislocation is increased because impurity reduces the stress field around the dislocation by compensating the stresses. So, earlier you had tensile stresses.

When you put in this bigger impurity, it introduces complexive stresses. As a result the stresses become lower and hence there is dislocation does not feel to move out of the crystal. So, basically you require we can say higher stress to move the dislocation further. So, this is called as solid solution strengthening. It can happen by the way of both impurity atoms as well as, it can happen with the, by the virtue of putting substitutional impurity atoms, as well as interstitial impurity atoms. So, basically this impurity at, so not only it does this.

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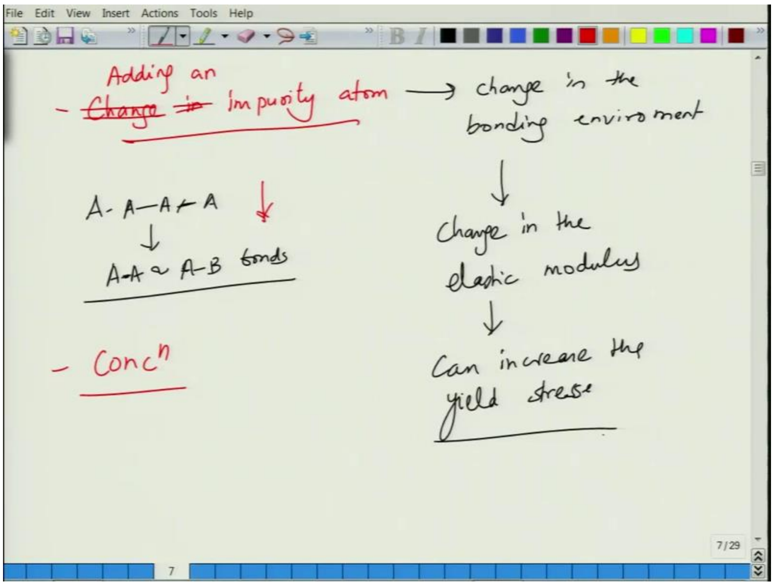

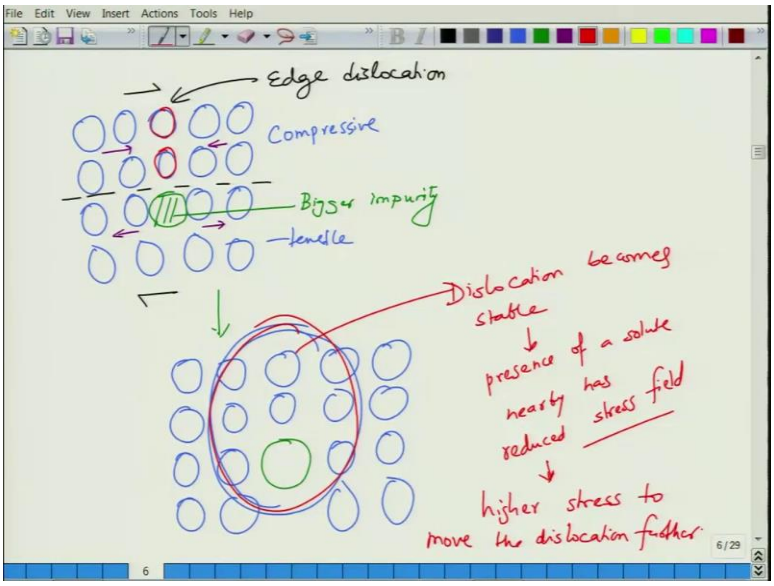

But it also brings another change that is the change in the impurity atom, so, adding an impurity atom also causes a change in the bonding environment because earlier you had A-A kind of bonds and this now leads to A-A and A-B kind of bonds and if A-B bonds are stronger than A-A bonds, then you will have change in the elastic modulus and this again can increase the yield stress.

So, impurity atoms what we also. So, another factor is the concentration. So, when you, not all the concentration will work. It may happen the effect is valid only up to certain concentration. So, there is a critical concentration up to which the effect will be valid. So, basically what we are saying is that additional impurity atoms substitution or interstitial impurity, it can stabilize a dislocation by compensating the stress fields, making dislocation more stable and hence, you will require larger stress to move, depending upon the size of course.

Then adding an impurity atom also causes a change in the bonding environment from A-A to A-B kind of bonds and if the A-B bonds are stronger than A-A bonds, then elastic modulus will change, then you can change the yield stress and of course, it depends how much you add to everything. So, how much you add the solute atom to the, to the host.

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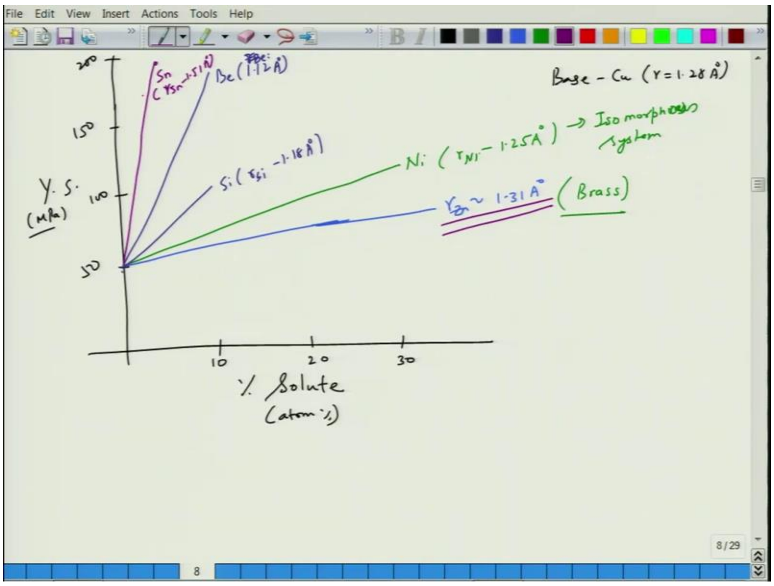

So, basically there is, there are people who have studied this. So, if you plot for example, yield strength as a function of solute, percentage solute addition, let us say, then what we see is that, let us say this is 10, 20 and 30 and this is atom present. So, let us say this is 50, 100, 150 and 250, 100, 150 and 200. This is in MPa, mega Pascal. So, this is here, the base matrix is copper and copper has a radius of 1.28 Angstroms.

So, copper in case of copper, if you look at zinc, zinc creates some strengthening up to about 30 percent and zinc has a r zinc is about 1.31 Angstroms. So, zinc has certain solid solution strengthening effect. If you look at nickel to cooper, then nickel to copper is a very good example. Nickel to copper can lead to higher effects. So, it can increase the values up to about, nickel to copper will be somewhere here. So, this is nickel and nickel size is r nickel is 1.25 Angstroms, very similar to copper.

In fact, they may a nice substitution solid solution which has, which is isomorphous systems. So, it makes a isomorphous system. So, it remains FCC all the way whereas, copper with zinc makes brass. So, it has limited solid solubility. After this it forms second phases and so on and so forth and then we have silicon. You can also add silicon to copper and silicon to copper will have certain solid solubility.

Silicon is about, r silicon is about 1.18 Angstrom. Then we have beryllium, beryllium has a, so you have beryllium bronze where you add beryllium to it. So, beryllium is about 1.12 Angstroms and you can also add tin and this makes basically tin has limited solid solubility. So, tin can increase the strength quite substantially. This is tin, this is about 1 point. So, r tin is about 1.51 Armstrong. So, you can see that the predominant effect.

So, you can add a little bit of tin to copper and you can increase the strength from 50 to nearly 200 mega Pascal, 4 times increase in the strength. You do not have to add a lot of tin to it and tin however has a larger size as compared to copper. So, you cannot add a lot of tin. Zinc on the other hand is solid. It gives you stability of about 20-30 percent. You look at the phase diagram, what is the range, but it does fair bit of strengthening from 50 to let say about 70 MPa.

Nickel does a strengthening all the way and the nickel can increase the strength about 100 mega Pascal or so when you add nickel. Silicon again, silicon has smaller size than copper. So, silicon increases the strength to about 100 mega Pascal up to about 10 percent. You can add beryllium which can increase the strength again to more than 150 mega Pascals. For small amounts about 10 percent and then tin you do not have to add even 10 percent, tin goes all the way up to about 170-180 may be 200 mega Pascals.

So, these are the effect of adding solute atoms to, for example copper which leads to substantial amount of strengthening in copper. So, this is a fantastic way of strengthen again and that is how most materials lot of these materials, so you can strengthen by grain boundary strengthening, you can strengthen by work hardening but you can also strengthen them by adding these foreign atoms.

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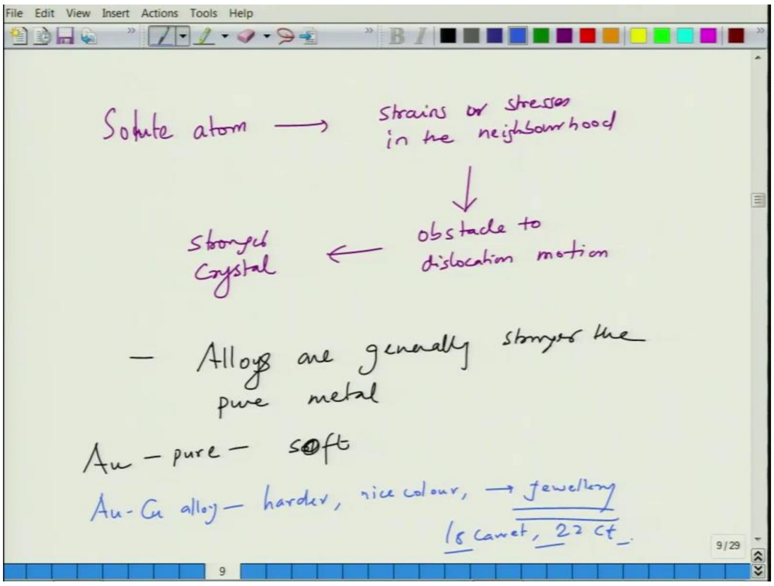

So, basically you add solute atoms. In summary, solute atom create strains or you can say stresses in the neighbourhood and this creates basically you can say, this can either recreate as a obstacle to dislocation motion, because dislocation may get stabilized by coming there and then as a result you make a stronger crystal.

So, this is why generally you can say, alloys are generally stronger than pure metals. So, for example, gold, pure gold is very soft that is why you cannot have jewellery made of pure gold. It is not, it is never 24 carat. If gold is very soft, all the all the jewellery will deform itself very softly.

So, you add a bit of copper, so Au Cu alloy is harder. It also provides nice colour to it and this is what is used for jewelleries. So, you have 18 carat, you can 22 carat and so on and so forth. So, this is because of addition, addition of copper to gold and this is true for every alloys.

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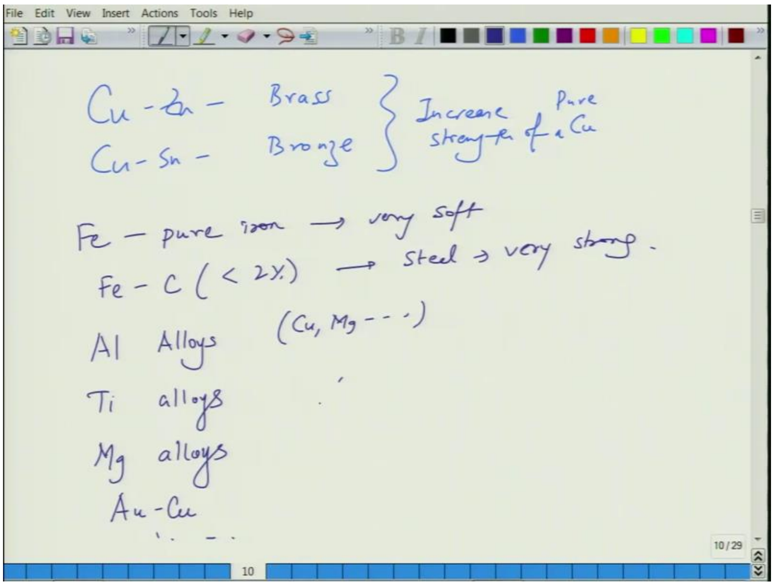

So, you have copper zinc which is brass, copper tin which is bronze. So, these are basically increase strength of pure copper. Similarly, iron, pure iron is very soft. But that is why if you add iron to carbon, so less than 2 percent of carbon makes steel which is very strong. This is also true for let us say, aluminium alloys. So, aluminium has lot of elements. So, aluminium can have copper, it can magnesium, other elements as well.

Similarly, you can have titanium alloys, magnesium alloys. These are all engineering alloys. We saw gold, Au-Cu and so on and so forth. So, essentially addition of smaller amount have impurity atoms to metals and alloys. Metals, leads to increase in the strength of these metals making them stronger and useful for engineering applications because things like aluminium and magnesium in the pure form, they are very soft. So, they not they not extremely useful for lot of these engineering applications. However, when you add these impurity atoms, they becomes they become harder.

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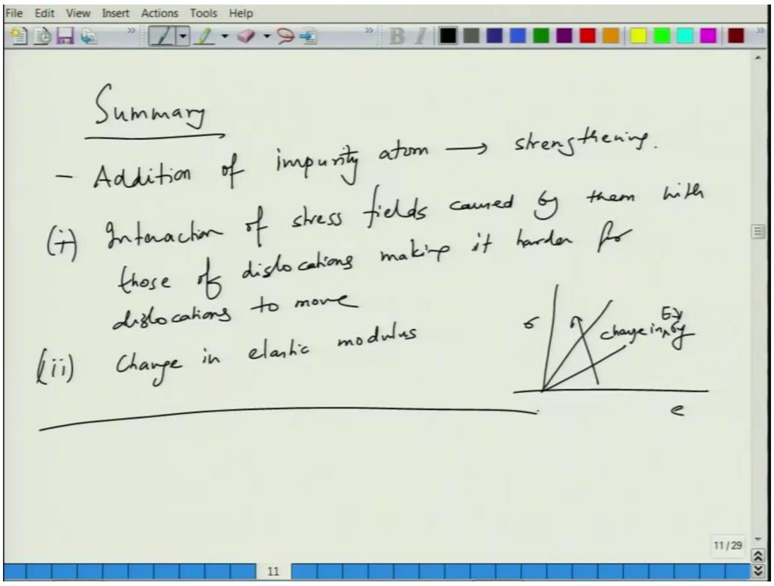

So, what we have said is, so if you just summarise it now, addition of impurity atoms causes strengthening. This could be because of interaction of stress field caused by them with those of dislocations. So, this is the first mechanism, making it harder for a dislocations to move. Second mechanism is, as we said is a change in elastic modulus.

So, in the first case, the modulus could be like this in the other case, the modulus could be like this. So, this is sigma e. So, this is change in sigma y. So, change in e causes the change in sigma y. So, this is another way of increasing the strength of these materials. So, and this is something which we which is done in engineering industry on a routine basis. Where, we add these alloying elements to make the materials stronger. Now, the next thing that we are going to study now is.

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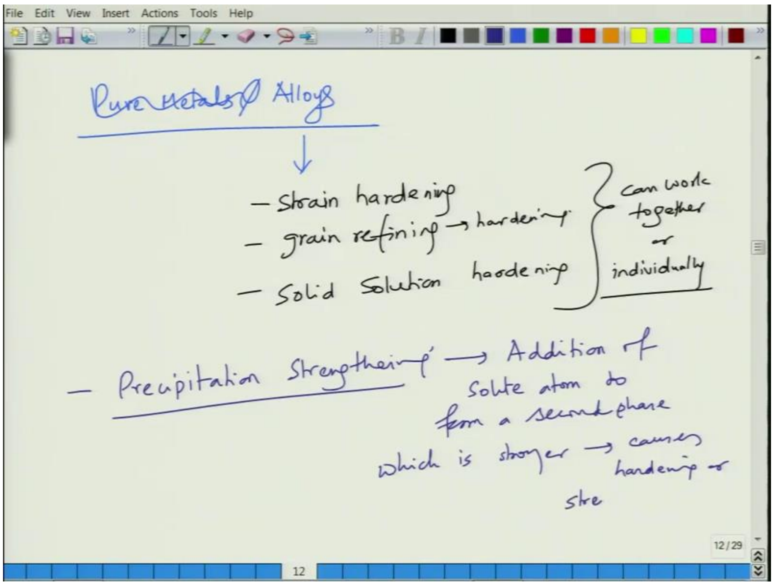

However, let me just, so if you do not form second phases. So, let us say, so pure metals and so let us say, we talk about alloys. In alloys, we can do strain hardening, we can do grain refining and we can do solid solution hardening and all these three mechanisms can work together or you can make them work. So, can work together or individually.

So, depending up on what, how much you want improvement in terms of, you can make all three of them, employ all three of them and make the materials stronger and or you can use either one of them to make the materials stronger without forming a second phase. Now, the next last category that we will look at is precipitation strengthening.

So, precipitation strengthening is basically addition of impurity, addition of solute atoms to form a second phase which is stronger and this causes a hardening or strengthening and this is what we will look at in the next lecture.

In the next lecture, that is going to be the last lecture on mechanical behaviour of materials. We will look at the precipitation strengthening where addition of solute atoms to the base lattice to the base material will form the second phase and the second phase depending up on how you form the second phase.

If the second phase is harder, it can cause strengthening of materials. We will, so that is the last part. We will see hat in the next lecture. This is very common for aluminium copper alloy, aluminium magnesium alloys, steel even. So, we will see that in the next class. Thank you very much.