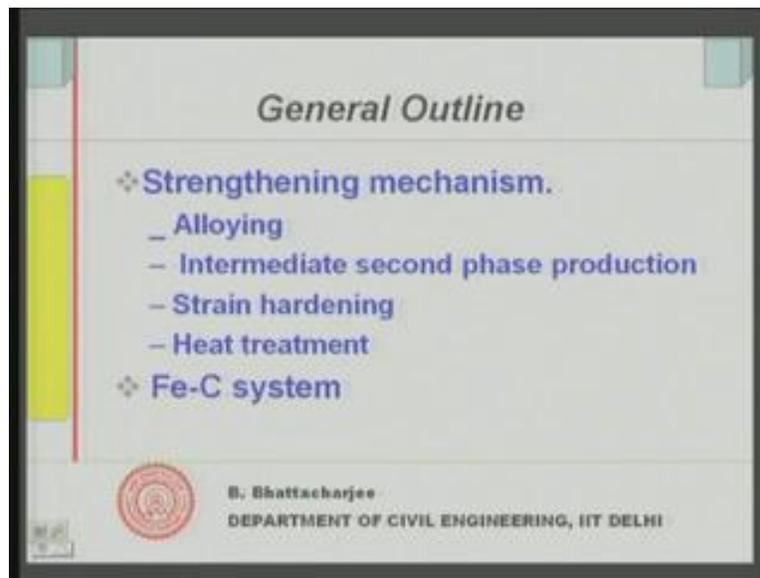


Building Materials and Construction
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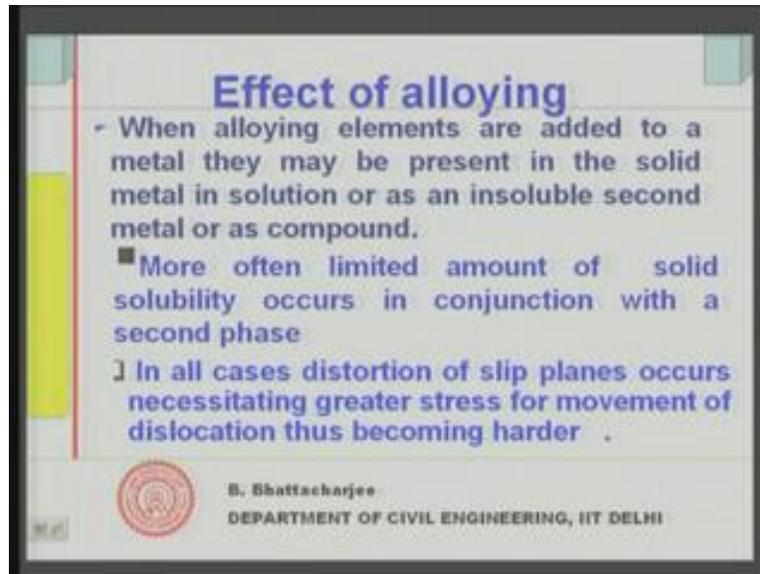
Module - 11
Lecture - 2
Metals and Iron Systems

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Continuing with the metal and iron system, if you recall the last lecture what we have seen is strengthening mechanism. We have seen about, effect of the grain size on strengthening and we said that, the coarse grains are actually fine grain structures are stronger; coarse grain structure is relatively less strong. Then, we have some other strengthening mechanism that we are talking about we just mentioned their names today. So, we shall look into some of them alloying, intermediate second phase productions part of the same thing. And we will talk about, strain hardening and then effect of heat treatment on strain hardening itself. Then we shall look into the Fe C system, so we will introduce this Fe C system today and then 1of the major important product you know of Fe C system is steel which is most commonly used. And of course other one is and so on so you look into that and coming lectures, but today we will just introduce them.

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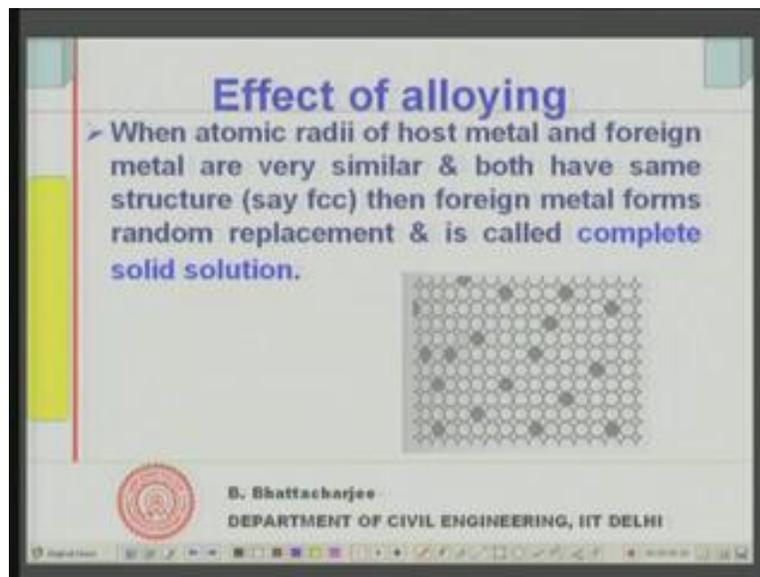
So let us see what is effect of alloying? We have defined what is alloying in the last lecture and we said that, you have another element coming into host element. So, when we add an alloying element to the host metal they may be present, either in what is called a solid solution form or as an insoluble second metal or as a compound right. So, it might either form a compound or might form sort of a insoluble second phase. And then, it might form a solid solution.

Most often limited amount of solid solubility occurs in conjunction with a second phase. This is more common that you have a second phase, but limited amount of solid solubility is also there. Of course, the most important is, in all cases the introduction of the alloying element would actually cause slip planes to be distorted. There is a change in the distortion of the slip plane takes, because something new material as come in and this causes distortion of the slip planes.

So, when you want to know move or deformation as to take place that is dislocations have to move; it as to move through the distorted slip planes. And this creates stresses, this requires higher stresses for movement of dislocation thus greater it becomes difficult to have dislocation.

So, what is it actually happening in all cases distortion of slip planes occurs necessitating greater stress for the movement of the dislocation. So that means, deformation becomes difficult, so thus becoming harder. So, what you need it actually improves the strain, so alloying definitely improves the strain that is the point; alloying improves the strength. Because, dislocation movement of the dislocation becomes now, difficult movements of the dislocation becomes difficult. Because, the slip planes have become distorted so and you need more stresses to ensure that movement of the dislocation therefore, strength increases right.

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Now, as I said they can go into form into solid solution, now this would depend upon the sizes atomic sizes, atomic radii of the 2; the host and the foreign metal which has come into it. So, when you know it will depend upon the dimensions of the 2 if the atomic radii of the 2 are similar right. They are very similar and they have let us say, both have same structure right like you know body centered cubic or face centered cubic structure or whatever structure.

If there are of the similar kind of structure then what will happen? They will just simply replace, randomly so it will be random replacement and is called complete solid solution. So you can see that, when atomic radii the host metal is similar right they are and the

foreign. So when these are similar metal are very similar; this is the point both have same structure.

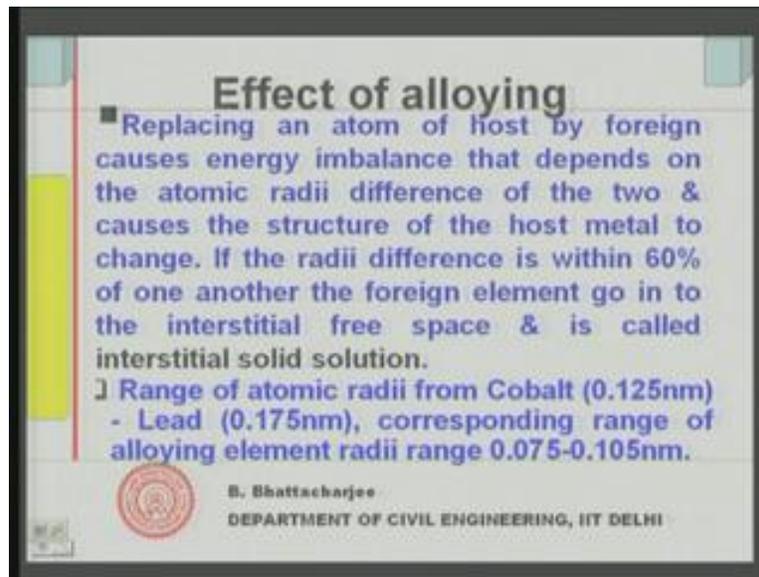
So you remember we discussed about, different structures you know the arrangement in which atoms are present. Because we said that, they are spheres they are in contact with each other and they have a specific arrangement right. In the grains and when they are let us say, all are phase centered cube both the host and as well as the replacing all the you know foreign alloying element, which you have added.

Let us, say there are of the same structure then foreign metal forms random replacement and is called complete solid solution. Because, there are of the same kinds of they will replace randomly, so this random replacement and it will look something like this.

you see it will look something like this, I mean you should look at this, if you look at this diagram what you will see is, say this one's this already this white ones the host metals the white the blank white ones are the host metal it was very much there it was there. And then, you have just the black 1 as come and replaced randomly and there is no pattern, they just replaced randomly.

So, this what is a complete solid solution; a complete solid solution would mean that the foreign metal the second alloying metal which has come in it as just. Because, they are of the same size same arrangement everything is same. So, they can just come and occupy 1 of those 1 of the positions occupied by the host atom. So that's what is called complete solid solution right alright followed from there.

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Now, you know foreign alloying elements are unlikely to be having same structure or the same atomic radii. There can be different atomic radii and different structure as well. So, you see when you are trying to replace host atom by a foreign atom there is some energy in balance. And this in balance depends upon the atomic radii difference of the 2 the host and the foreign element right.

So, when the radii difference is within 6 percent of 1 another you know they are more or less similar they are not same, but they are quite similar within 60 percent of the radii differences are within 60 percent not far too different. They are quite close to each other not very far different they are not same. And it had been same then, there would have been random replacement and it would have been a complete solid solutions.

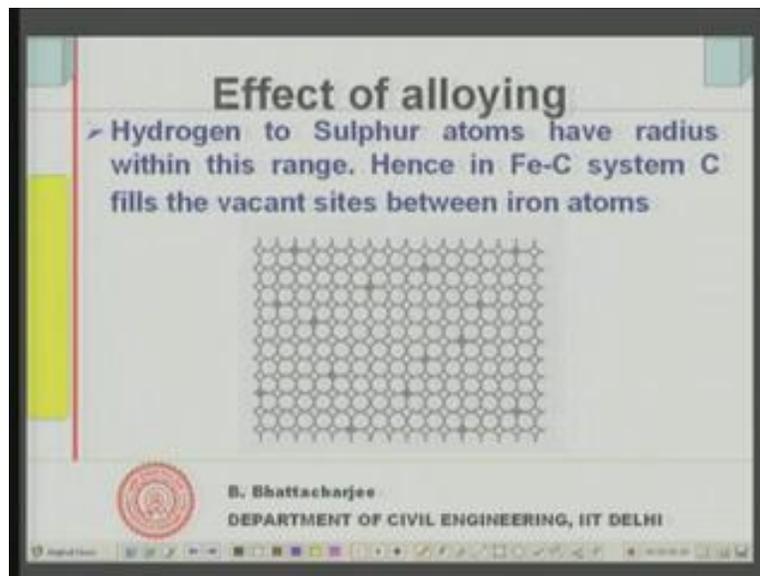
But this is they are not same right, but within 60 percent of each other difference is 60 percent. Then, the foreign element can go into the interstitial free space and is called interstitial solid solution. Then it can go into the interstitial space you see 60 percent difference, it would go into interstitial space.

If it was same they would have just replaced randomly replaced but here, it is difference is somewhat less you know and let us say within 60 percent right. So, it would go interstitials of the host element and it will enter into a free space right. Now, if we look in all metals in the periodic table the larger size metals varying from cobalt to lead. Most of the metal would be you know, either it would be cobalt to lead.

Let us say, if we look at their atomic radii they vary from 0.125 nano meter to 0.175 nano meter cobalt is 0.125 nano meter and lead is 0.175 nano meter. These are the usually the host metal, so if I have to have interstitial solid solution then maximum difference I can have is a 60 percent radii difference. So therefore, this radii difference corresponding to the 60 percent of 125 and 175 these are the 60 percent 0.075 and 0.105.

So, 60 percent radii corresponds to this 1, therefore anything within this size or any element within this size radii would actually can form interstitial solid solution with cobalt to lead right.

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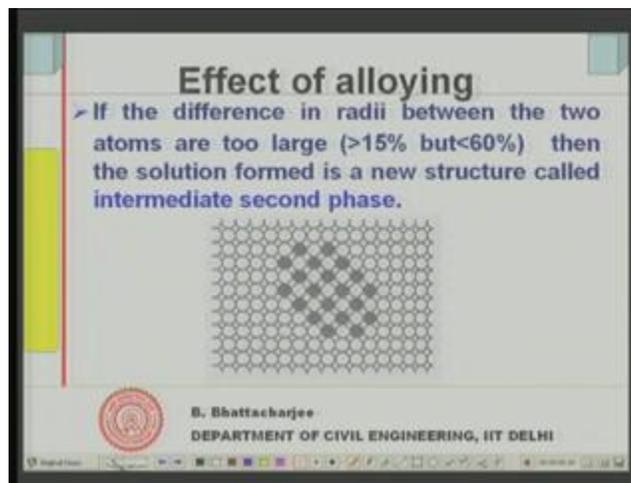
So, that is what it is right and if you look at interestingly we will see that, the size that is we have talked about that is 0.05 nano meter to 0.105 nano meter atomic radii. This you know atomic radius this belongs to this can just have only 6 elements, Hydrogen to Sulphur. So, these 6 elements have atomic radius of each of this individual ones falling between 0.075 to 1.105 nano meter.

Now carbon is included in this, because you know the if you look at carbon will be included in this and that's why carbon can form it can get into the vacant sites between iron atoms. So if you compare the iron to carbon; carbon as a size which is which satisfies this criteria that is size is not different differing by more than 60 percent from the size the atomic radii radius size of iron.

And therefore, it can form interstitial it can go into fields of vacant spaces between iron atoms and form interstitial solid solutions. So, interstitial solid solutions look something like this; these you can see that this white blank ones or the white colored ones are the host element. And this black one which have go into the interstitial spaces they are the foreign alloying element.

So, they have gone into the spaces in between, so they have formed actually interstitial solid solution. So, this is what is interstitial solid solution right ok alright.

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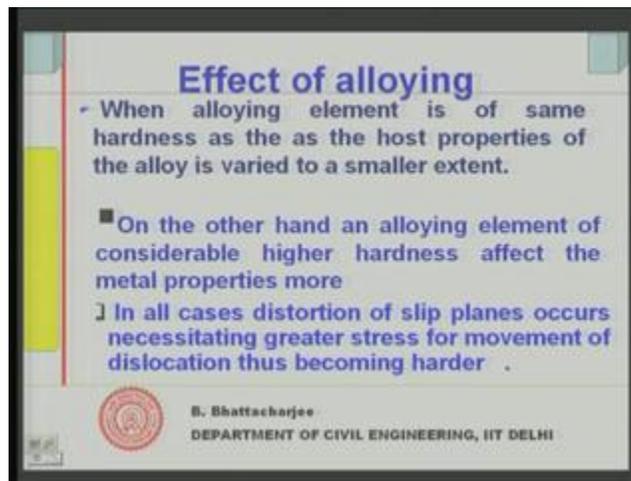
The other variety is of course forming a completely intermediate second phase. Now, in this case the difference of the radii between radii between the 2 atoms if it is too large that is the host atom and the foreign alloying element atom. If radii differences are too large that is greater than 15 percent but of course, less than 60 percent greater than 15 percent. So, they are not similar they are quite similar right the different is greater than of course 15 percent. And less than 60 percent your 60 percent never they will form into spatial solid solution. Now, this forms a new structure they tend to form the solution formed is new structure and it is called intermediate second phase.

Because, now they cannot get into the space between them, no they can replace them. First 1 when they are exactly similar they will replace them form, random replacement and we call them, as a complete solid solution. With the second 1 in that case, if they are within 60 percent the radii difference is within radii difference is within 60 percent.

Then we call it, you know a interstitial solid solution but when it is far more than that, that means they cannot go into the interstitial space. So, they would remain separate and they would form a kind of second phase and that is what the situation when it is large so this second phase formation.

So, they look like this second phase formation would look something like this right. Now, you have the blank ones this ones are the original host atom and here they form a second phase somewhere in between the original atoms are also, here and this 1 forms a kind of second phase formation takes place in this. So, this is third variety of effect of an alloying kind of alloying that we have right.

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Now, all this what do they do 1 thing we have seen that whatever be the case they actually distort the slip planes and therefore, you need more stresses. For dislocation to move in other words deformation so therefore, they would improve the strain ok. Now, if the alloying element as a same hardness as the host properties element then properties of the alloy is varied to a smaller extent. If they have the same hardness, hardness is similar of course properties will be varied relatively less right.

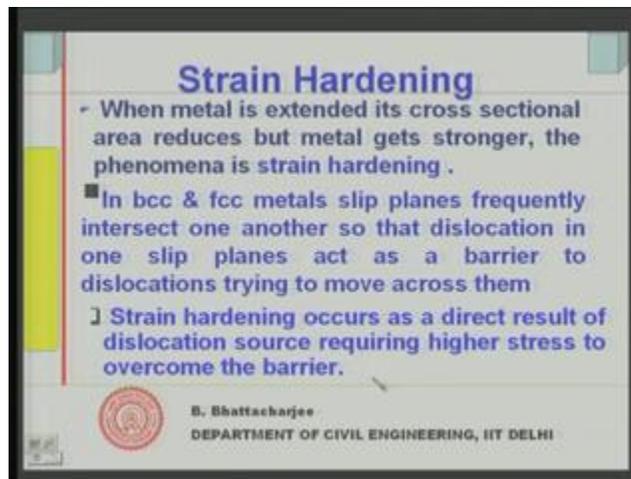
But if you have harder 1 on the other hand, if your alloying element is considerably higher hardness affect the higher properties more. So 1 issue is of course, related to what are the different types of alloying possible that's what we discussed. And we have seen

that, in case of all alloying there will be some improvement in the strength will require more stresses, but the hardness properties it is one thing the atomic radii sizes.

The other issue is of course, related to the hardness of those material and when the properties of the alloying element and the host element if the of the same nature. If the hardness are similar then you won't you are unlikely to find much properties difference of the final alloy. But on the other hand, if you have the hardness of the alloying element higher than the post element then the properties are likely to be differing more.

So, that is we have seen that and this is another issue which we have seen that important thing in all cases distortion of the slip plane takes place and therefore, more strength you are likely to realize in case of alloying.

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So, this is how alloying helps in improving the properties or strength properties, mechanical properties, strengthening of the pure metal right.

Now, the other processes other very important process of improving the strength of the pure metal or alloy system is what we call as strain hardening. So we are quite familiar with this, because we use a product which has strain hardening we shall see that sometime later on.

So, let us see what this process is when you extend a metal its cross sectional area will reduce. This is our common day experience supposing, we take steel and try to pull it you know let us say pull a steel bar, if you pull it so the next stage what that it, as elongated

and there could be some sort of formation of neck, some formation might take place right.

So, its cross sectional area actually as reduced right it elongates and cross sectional area reduces. But it actually becomes stronger and this process we call it strain hardening. So it area reduces, but its strength increases and that's what we call as strain hardening.

You know, in body centered cubic and face centered cubic metals slip planes frequently intersect 1 another. So that, dislocation in one slip plane act as a barrier to the dislocations trying to move across them. So, when you have combinations of body I mean in body centered cubic and face centered cubic metals slip planes frequently intersect 1 another. Such that, dislocation in one slip plane act as a barrier to the dislocations trying to move across them, so that is what it is right.

So dislocations are actually, because they are crossing they intersect with each other. So, they form as a barrier right barrier; barrier since they are crossing slip planes are crossing so there is the- forms a barrier for dislocation movement of dislocation right. Strain hardening therefore, occurs as a direct result of dislocation source requiring higher stress to overcome this barrier.

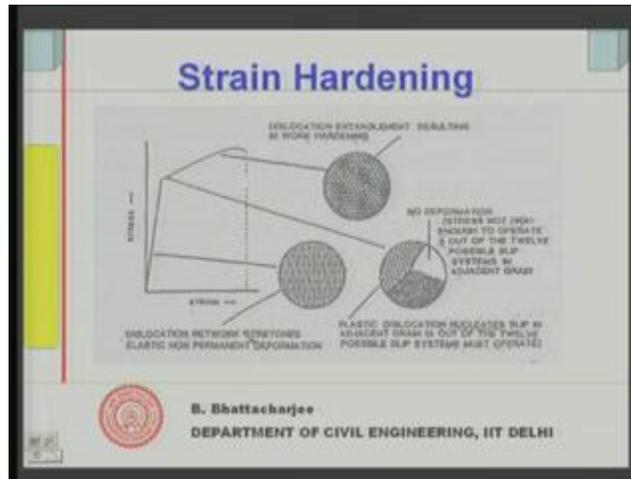
So since there is a barrier, because they are crossing slip planes are crossing and therefore, dislocation cannot move because dislocations move along the slip planes that's what we have seen when another slip plane comes and intersects let us say with it. So, this will act as a barrier for movement of the dislocation and this barrier we have to overcome.

So, when you have actually strain them some dislocation as occurred at some point of time say it will intersect with some slip plane. And further dislocation will have to cross the barrier right; additional stresses will be needed in order to overcome this barrier. And that's why, as the cross sectional area reduces you know its strength actually increases.

Because, now some dislocation as moved, some deformation as taken place, some dislocation as moved; but it has actually now encountered another slip plane right crossing it. And then, when you want to further movement of the dislocation that is more deformation you would need more stresses. And thereby, strength actually effectively

increases after certain amount of movement of the dislocation right. So this is the process of strength strain hardening right ok let us, understand it more.

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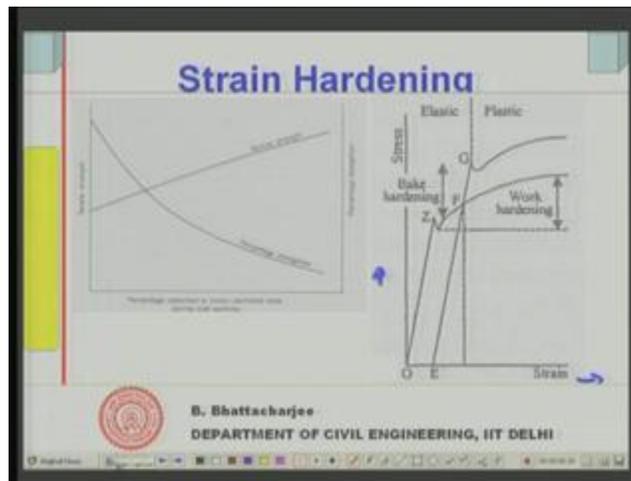


If you look at this diagram, it will make it more clear right you see this is stress and this is strain this is stress and this is strain. Now in this region this is what we have defined earlier, as elastic region where basically stress strain is linear and if you release this will come back. So, what happens during this region dislocation networks stressed just stressed and elastic non permanent deformation.

So, it its though no movement of dislocation is actually taken place it is only stressed and if you release it if you release the load you know what will happen, it will come back to its original position. Because, it is only stressed there is no movement of the dislocation that has taken place. Now, when you go further actually what will happen? Plastic deformation dislocation in the adjacent grains so therefore, dislocation actually starts moving right. And it is specific for a sort of structure.

So, dislocation started moving now as you further move out dislocations are entangled resulting a network you know resulting in of course work hardening. Because, as you move further first this portion it is simply stressed and nothing more. In this zone, it is now dislocation as moved some but as it moves further, there are some position where dislocations will get entangled. Because, the other slip planes will come and intersect with it and therefore, you have to actually overcome that barrier and that's what they say right.

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So that's the idea of strain hardening as we call it, so this is diagrammatically you see as in this axis I have you know percentage reduction in the cross sectional area during working. So, when actually we achieve this strain hardening by working cold state not, in hot state if you have it in hot state then obviously you will not get this effect. So in cold state, as usual see later on, so it is cold world you know this is important.

Because, quite if this is commonly used reinforcement bar 1 of the types are cold war or cold twisted deformed bars we shall discuss about this sometime later on. But supposing somebody gives you hot same thing hot twisted, hot bars, they are not going to give you the same property. So, we do cold twisting that is strain hardening is done by or cold working or you know applying stresses at the cold state no temperature change.

So that's what we are actually working on to it and giving some permanent deformation, so this side gives you permanent you know percentage reduction of cross sectional area during cold working. So, when you cold working trying to pull it or do something or some sort of cold working you are doing the percentage cross sectional area reduces right.

So, this is as you say cross sectional area reduces along this as the cross sectional area reduces more and more what you find is, the strength increases. Because, you have understood what is the phenomena how it is happening we shall see this actually so strength increases. So, that's what we state at first right strength increases but what we see is, the available percentage elongation also reduces we will come back in a minute here this side this exercise strength and this exercise is percentage elongation.

So, we will come back in a minute here; let us look at another diagram you see this would show better idea is side is strain and this side is a stress. Now, this is my original stress diagram and this is you know this is my original before I have done anything; when I let us say, apply stress and reach at this point F. So what will happen, the dislocation have now actually entangled many of the dislocation as got now entangled actually.

So, when dislocation is entangled actually so we will have increase in the stress required to cause further dislocation so that is the idea. So what happens? When I have gone up to this and let us, say I have released it so it this is the is the permanent deformation that i have given. We have gone up to F and i have given permanent deformation.

So, next test our stress it right what will happen? It will actually go somewhere up to G. Because, the dislocations have actually entangled the cross sectional area is reduced and dislocation have actually got many of the dislocations have got entangled. So, you have to cross that barrier and actually you might have an increase in this or you know Z will shift to G. So, this process is simple work hardening in this zone and this is further, if you just wait bake it for some time and then this is what you will get it.

So, what will happen in the process of course your deformation or elongation will reduce original elongation available was this much. Now the elongation will reduce, and therefore percentage elongation and that is why in case of strength strain hardening that you find that your strength increases; useful strength increases. But the available ductility reduces that we have to available ductility reduces right.

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So that's strain hardening supposing I apply heat, on strain harden material now when you have done strain hardening you have actually areas where you have got higher strain. There are regions where there will be higher strain and this will not be thermodynamically stable. Because, you strain something it will like to release you have actually stored some energy there and it would like to release that energy and come to a stable-state.

So this is not thermo-dynamically stable therefore, this dislocation array that you have created after strain hardening this is not stable. So, if you give a little bit of energy you would mean it would come back to its original stable state in an unstable state. So, small amount of heat it can cause redistribution of this dislocation array with heat and that is what happens.

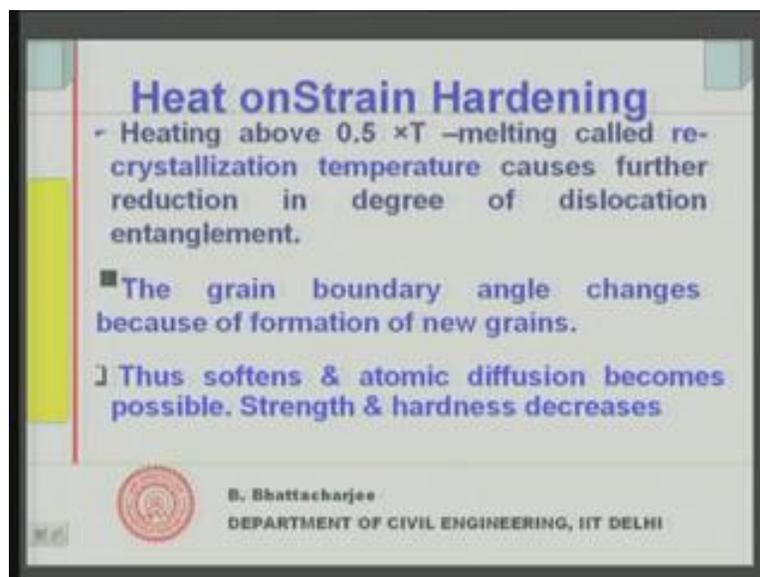
Now, this response to heat of work hardened metals could be 3 kinds: it can be a recovery; a re-crystallization or lastly what you can annealing what is recovery? In case of recovery which takes place up to about 30 percent of the melting point right. So, 0.3 re that is the temperature is 0.3 multiplied by the melting point then what happens is, dislocation entanglement decreases and structure becomes coarser.

But as the dislocation density remain same overall hardness and strength remains almost same. Recovery is little bit what happens is, you just heat it up to 30 percent of the melting temperature such when you know this is happening. Dislocation entanglement

which you have done during the strain hardening, it will get somewhat reduced or decreased and therefore the structure would become coarser.

So, you will have since dislocation density still remains same overall strength would still be nearly same; almost same. And this has got a relevance as we shall see, in case of let us say fire affected strain harden material or strain hardened metal up to certain temperature right you don't see much of an effect on to the structure. Because, this is simply belongs to recovery but beyond the temperature there are changes that take place.

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Let us see, if you go up to 0.5 of the T if you go up to 0.5 that is 50 percent of the melting point we call this temperature as re-crystallization temperature. This causes further reduction in degree of dislocation entanglement, so as obviously the effect of the temperature or heat is to reduce down the effect of dislocation entanglement, which has caused actually strain hardening.

Now, as you go to higher temperature up to 30 percent alright there will be some reduction, but you go further higher and there will be more redistribution of those you know entangled dislocation that is there. Because, the slip planes because the dislocation get entangled so that, entanglement would get further reduced and this will result in what; this will results in grain boundary angles change.

Because, you know dislocation entanglement that as occurred because of slip planes are intersecting with each other. And now you have supplied heat and, because we said that

heat can actually this is an unstable situation the heat can redistribute the whole thing and this causes actually grain boundary changes. So, because of formation of new grains this causes formation of the new grains and grain boundary changes.

So, this grain boundary changes softens the material and now atomic diffusion becomes possible strength and hardness decreases. So, as the re-crystallization takes place strength and hardness would decrease so therefore, the what we see first we have some temperature up to which actually some disturbances in the strain hardening. This is about 30 percent of the melting point.

So, there will be some disturbances in the strain hardening but not much change in the properties takes place, but beyond that as you go on increasing the temperature re-crystallization up to a temperature which you will call re-crystallization temperature right. So beyond 30 percent of the melting if you heat there is no problem; beyond thirty percent of the melting point there will be some little bit disturbances but strength will not reducing frequently.

But beyond 50 percent of the melting temperature, if you heat then there will be re-crystallization and this re-crystallization means new grains structures are formed. So re-crystallization, because now it is almost in the molten state so because you have given heat. So actually new grain formation will take place and this new grains would alter the original grain boundaries altogether.

So, they could be coarse boundaries I mean coarse grain formation and the structure will be now coarse and that will result in actually softening of the metal itself, and therefore there will be some amount of reduction in strength and as well as hardness.

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Let us see what happens beyond that supposing we heat it beyond this temperature what is known as the annealing would take place. So, up to certain temperature there is not much disturbances further beyond this temperature there will be reduction in strain. And still if you go on heating further above this re-crystallization temperature then, much above the re-crystallization temperature.

Then what happens is, there will be redistribution of all the dislocation entanglement. So, new structure formation will take place and this new structure formation would results in actually what you call annealing. And it is complete redistribution of dislocation grains grow become much bigger, because now new formation should take place new grains would form. And this becomes much bigger and therefore, there is a reduction in the strength.

So, there is a strain hardening is an after complete annealing actually total history of annealing is erased. So effect of strain hardening is erased that means, by annealing you can completely bring back I mean not bring back you can all the positive effect that you got due to strain hardening. That would be lost and you will be having now a much coarse grain structure and would actually will be you will have a coarse grain structure and you will have a weak structure actually the strength of the metal will be much less.

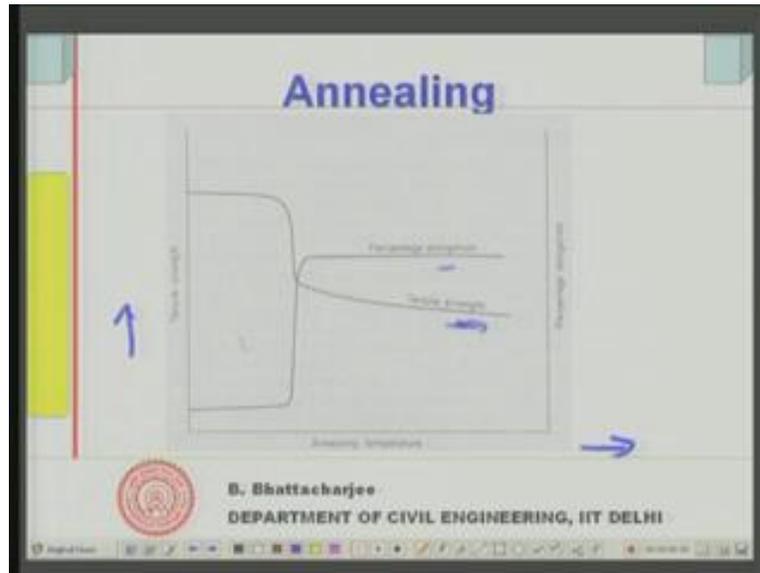
So, that is what is the effect of heat on strain hardening annealing is the process whereby, actually you are removing the effect of the strain hardening completely therefore, if you want to remove the effect of strain hardening completely you just do annealing. And it will be totally removed. Hot working of course you have a re-crystallization temperature in not strain harden otherwise.

So, supposing you have a metal and then you will start working on to it hot working at above re-crystallization temperature both the deformation and re-crystallization will occur simultaneously you are working on to it hot. So, both deformation and because you are applying stress and re-crystallization will take place simultaneously, so it is much easy to work at higher temperature.

Because, since you have given some heat you know the energy has been supplied so the dislocation movement becomes easier I mean the softer it as not much softer. The structure its much softer and therefore, you can work onto it easily and re-crystallization also would take place simultaneously.

Therefore, resulting in similar structure as a annealing, so hot working above re-crystallization temperature deformation and crystallization occurs simultaneously resulting in same sort of structure formation as the annealing structure. But obviously, it is not going to give you the strain hardening so hot working is definitely not going to give you strain hardening. In fact, it will give you huh much lower properties than what is obtained through strain hardening process.

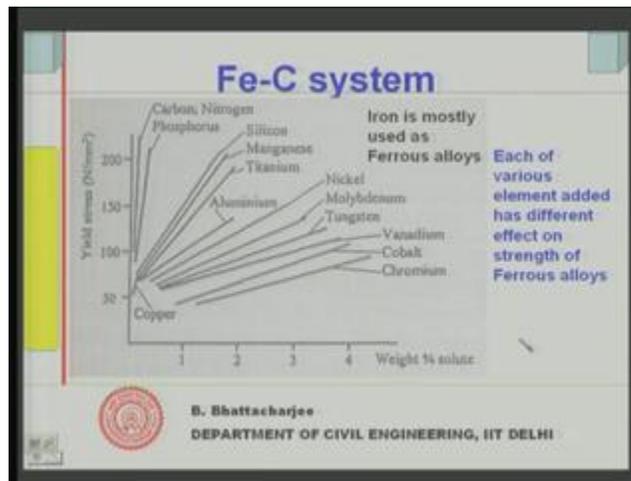
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So, this can be explained easily through this diagram as you can see through this diagram effect of annealing this is the annealing temperature and this is the strength. So, as I this is my re-crystallization temperature actually right, so as I increase my temperature beyond this the annealing temperature beyond this strength reduces say it goes back to a coarse grain structure and therefore the strength reduces.

But percentage elongations of course increase that is the elongation that would be available before failure. So, what has been done actually strength as now reduced strength was much higher before but it had low ductility. So, once you do annealing its actually percentage elongation increases so ductility is recovered ductility is again available. But strength is now reduced percentage elongation of course in this axis so now it is increased as beyond this temperature. So, that is the effect of an annealing; annealing effect is something like this, right.

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So, having seen some of those strengthening mechanism that we have discussed basic strengthening mechanisms now, we can look into our own carbon system.

So, this is the most commonly used alloy in construction or civil engineering industry or even in most of the other industries.

Now, you know iron is not very strong, so we use it mostly as Ferrous alloys. Now you can add various kinds of elements, can be added and they have different effect on the strength right. Because, we have seen so far 1 thing is atomic radii, so atomic depending upon the radii atomic radii some of those elements, which you add in alloying would have one kind of effect some other element will have a different kind of effect.

So each various elements added as different effect on the strength of the Ferrous alloy right so let us, see how what are the effects.

So, if you look at this diagram we can see that what are the different elements, how do they affect how different elements affect. For example, if you chose carbon this is weight of the solute right means, the alloying element that you have added iron is the host supposing 1 percent, 2 percent, 3 percent, 4 percent, weight of the solute that you have added to iron right various solutes and this is the stress.

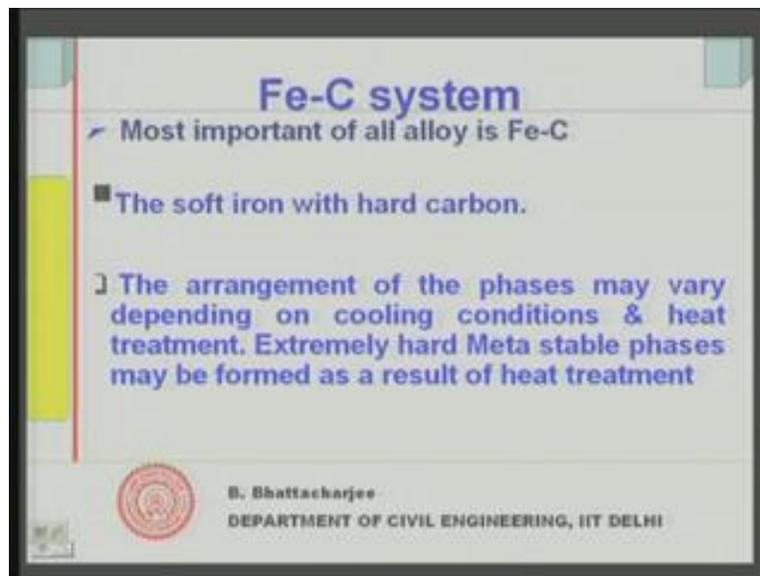
Now, if you see first one is a carbon and nitrogen, so if you add them if you add carbon then it shows a very in you know little bit percentage addition increases the strength significantly whereas, you don't have to do anything it is pretty soft material first for us this does the same thing it also increases the yield strength as we increase silicon does the

same thing, Manganese, Titanium, Aluminum, Nickel, Molybdenum, Tungsten and Vanadium, Cobalt and Chromium.

So, you see out of all this carbon does the trick most basically it actually it increases the yield stress maximum. And among them chromium does least, but phosphorus silicon and manganese all of them go on depending upon the- percentages they go on increasing the yield stress of the alloy right. So therefore, carbon we have also that it forms an interstitial solid solution.

Because, atomic radii of iron and carbon are such that it can form interstitial solid solution and that's what is the background? And that's why carbon iron system is used most often. And you know the steel which is most commonly used or these are all belong to iron Fe C system, right.

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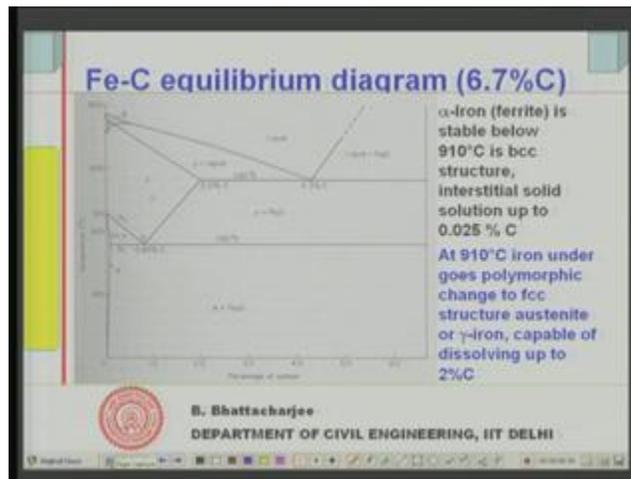


Most important of an alloy is Fe C, and let us look at its behavior a little bit to understand this we will look into it is what is called as equilibrium diagram. Now, in this process of most important of alloy that is Fe C system we add actually soft to the soft iron we actually put a hard carbon. So, we said the sizes atomic radii are within 60 percent and- huh iron is quite soft and we add hard carbon that's why this is, because of the previous diagram that we have seen, carbon is the 1 which gives which improves the yield stress most at a least percentage compared to anything else therefore, we add a carbon. Soft iron

is improved by the addition of carbon and you know that's why we get most benefit right. And this arrangement of the phases may vary, depending upon the cooling condition and heat treatment.

So, you actually in solution form, in liquid form, molten form, you add this and this phases their form it may vary depending upon cooling condition and heat treatment. Some cases extremely hard meta stable phases are formed as a result of heat treatment.

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So, let us see the equilibrium diagram of iron which will give us some idea regarding the same and we will continue to see it more in you know some of these effects in the classes. So that, next lectures so that we can understand it better and see and also see their usage in our construction industry. This is what is an equilibrium diagram of Fe C system with six point seven percent of C 6.7 percent of C.

Now, if you see in this diagram first of all you will see a region where you see alpha this is alpha, this is the region, where you have got alpha iron you know this region this small region where you have got alpha iron. This is stable below 910 degree centigrade, so stable below 910 centigrade and this alpha iron as got a body centered cubic structure.

So, when you have got very low percentages we have 0.25 percentage of carbon very small percentage of carbon. This forms interstitial solid solution as we said the, atomic radii differences are within 60 percent and therefore, carbon can easily form an interstitial solid solution. And when its percentage is low and up to 900 degree centigrade you know it forms this sort of solid solution.

So, well in this diagram of course as you can understand this is all liquid all this equilibrium diagram top form is liquid. This axis is temperature, this axis is the percentage of the alloying element and this axis is temperature. So, become vertically downwards become vertically downwards and as I go the horizontal direction the percentage increase in the alloying element takes place.

For certain elements you can draw the complete diagram from 0 to 100 percent, but our interest is not there in that 1. We are only looking at, iron carbon system which is the most popularly used construction in our or alloy in construction so therefore, that's why we are looking only this 1. And all this are liquid in the beginning as you can it high temperature as you cool it down and we will see this each diagram.

For example, this portion as this you know this is inclined along this direction, because as you increase the percentage of the alloying element there is a depression of the melting point melting point depression of the melting point takes place. This would be possibly pure iron would be melting here, so this as you add carbon that liquid you know it is the liquid pure liquid line if you draw lines.

So, if you draw the cooling curves you will see that at this point with this much percentage this at this temperature it solidifies or rather solidification starts. So, here you will have some solid and liquid, some solid and liquid and at this point of course all are below this are all solids.

So, this line is a line of actually solidification this is the melting starts melting I mean solidification starts here; solidification actually finishes along this line. But depending upon the temperature of cooling, different products are formed. So let us, first look at each of these products and some idea about what kind of structures they are.

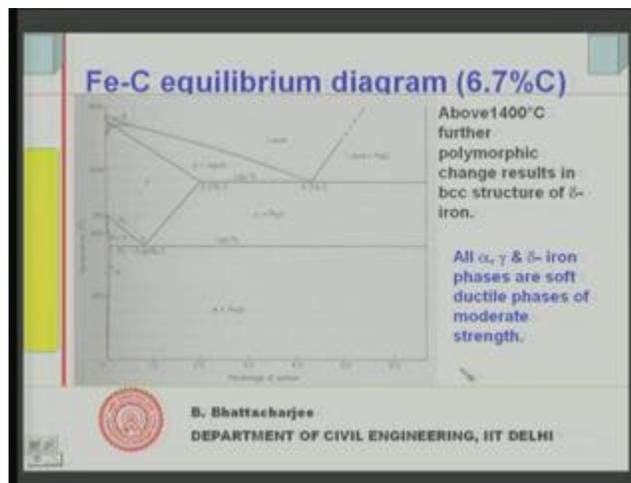
So, first I was talking of is a in this zone below 910 degree centigrade up to a 0.025 you know this would be 0.025 this point will corresponds to 0.025 percentage of carbon. You have a body centered cubic structure known as ferrite or alpha iron alpha iron. It is body centered cubic structure and it forms interstitial solid solution.

Let us, see another one above this 910 degree centigrade you know in this zone you can say in this zone what is formed iron actually in this region when you are cooling from here you will it undergoes a polymorphic change, to face centered cubes. So, it was body

centered cube in this zone here it is all face centered cube and it is called austenite or gamma iron.

Capable of dissolving up to 2 percent carbon so if you see that this point is 2 percent carbon can be dissolved depending upon of course the cooling temperature. So, as you come arrive at like up to 2 percent you know you will have. If you come from this side from here you cool it down, it will reach to this is the maximum 2 percent carbon you can see in austenite or gamma iron.

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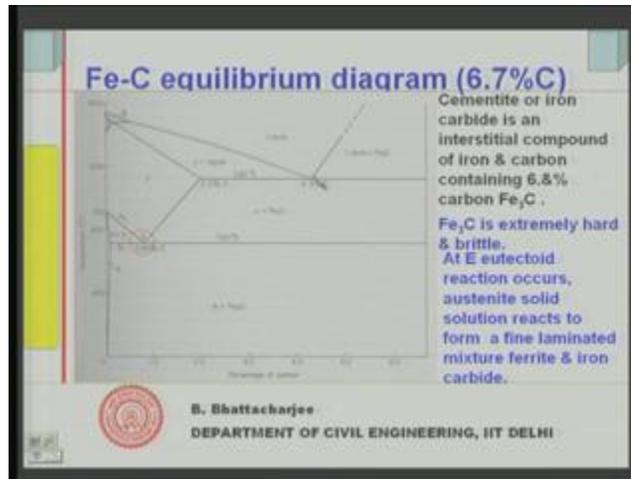
So, these are the 2 faces let us see some more of this faces that forms in case of right. Continue with the same thing above 1400 degree centigrade you know further polymorphic changes taken place and you can see here there is something called delta. So, somewhere around this I mean further polymorphic changes results in structure of delta iron.

So, here it is somewhere 1400 degree centigrade above 1400 degree centigrade you will have delta and this is again as got a body centered cubic structure. So you have alpha, gamma and delta here delta here right. So, above 1400 degree centigrade this delta iron formation takes place. Let us, see what happens on the right hand side ok we will come to that but at the moment lets understand.

So, we have seen 3 phases: alpha, gamma and delta iron these 3 phases are all soft ductile phases they are not very strong; they are quite soft ductile phases. So, this 3 are ductile phases you can see some more zones for example, this zone is alpha plus gamma this is

pure gamma right this is gamma plus liquid. Because, as it is cooling gamma iron plus liquid formation takes place and we will come to this phase now next.

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So, these are all soft phases but ductile, if you look at same diagram again at this ends 6.7 percent or containing 6.7 percent carbon this is not 6 and should be 6.7 percent Fe₃C and this zone in this zone cement cementite or iron carbide compound formation takes place. It is a interstitial compound of iron and carbon containing 6.7 percent of carbon in the - formulized Fe₃C.

So, at this 0.67 percent carbon it can it can contain about 6.7 percent carbon you have a formula Fe₃C compound is formed. So, I said that while alloying that there could be huh intermediate second phase or compound formation, so this is the compound Fe₃C forms at this range. So, you have liquid formation here liquid plus Fe₃C and here gamma plus f e three c and this is alpha plus Fe₃C formation takes place right.

So, let us see what are the properties of this the properties of Fe₃C? Properties of this the properties of Fe₃C is extremely hard and brittle. Now, one important point is this point E you see in at E eutectoid reaction occurs and this austenite solid solution reacts to form fine laminated mixture of ferrite and iron carbon. So, at this point reaction occur I am not define this does not matter, but what we understand is for our purpose that the austenite solid solution reacts to form a fine laminated mixture of ferrite and iron carbon.

So, at this point ferrite and iron carbon so fine laminated structure of ferrite and iron carbon that's what formation take place. So, this is what is a useful phase diagram for our purpose lets relocate it again we said that, carbon is a hard element compared to a soft iron.

So, we can actually an alloying carbon can be used and we have also seen, that its radius is within 60 percent of the iron. So therefore, that's why carbon is used and then second and we have seen that, it gives the stress amongst all the alloying element right.

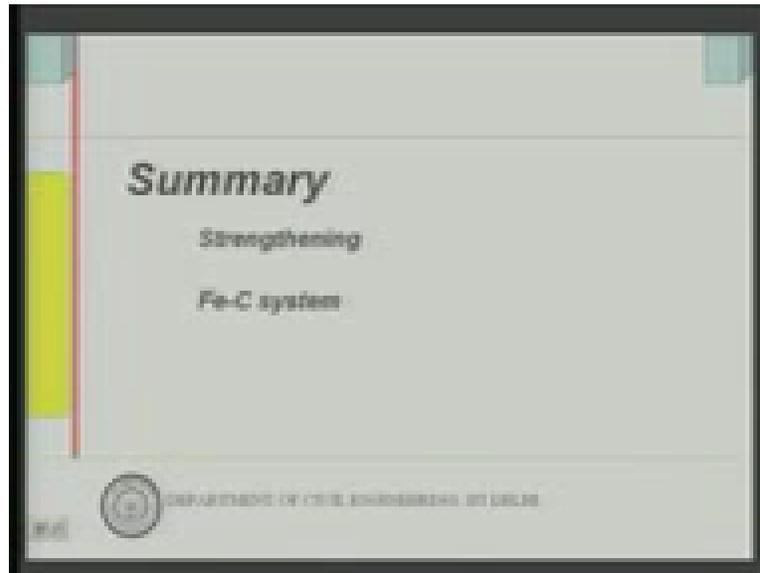
So, coming back to this we when you had very small percentage of the carbon 0.025 percent up to this 910 degree centigrade we have this alpha or ferrite iron above this temperature we have gamma or austenite and above 1400 we have delta iron. So, this has got a body centered cubic structure, this has got a face centered cubic structure and this as again got a body centered cubic structure.

At when we add 6.7 percent on the higher side no this percentage of 6.7 percent of the carbon you have Fe C₃ and in this zone you have got liquid Fe C₃, in this zone you have got gamma Fe C. And then, here the reaction at 0.85 C at E the reaction eutectoid reaction takes place and which gives us a fine laminated mixture of ferrite and iron carbon carbide and that's what we have seen here.

So, its gamma plus Fe C₃ and that's what is the phase diagram of or equilibrium diagram of the Fe C equilibrium diagram of Fe C system. Now, this will help us in understanding the behavior of iron and the types of iron that we use or behavior of system that is steel etcetera. So, it is quite often it is asked for some of the code specified certain maximum amount of carbon for let us say, steel or steel to be used in particular usage.

Now, if you know why this sort of equilibrium diagram will give us understanding of- why such restrictions are imposed by various practices for various kinds of steel that we use in certain construction practice.

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So, with this I think we can now summarize today's discussion, so what we have done we have looked into various strengthening mechanisms right. If we go back a little bit further first we have looked into, the grain size its effect on strengthening. We have seen that, coarse grain tends to give us lower strength and compared to fine grain.

Then we have looked into, the effect of alloying normally alloying would give us higher strength, and then we have looked into effect of strain hardening which you have said that it can give us higher strength. But on the other hand, if you heat it up to certain temperature of course there is no problem there is not much reduction in the properties, but if you heat it up further then there will be reduction in the properties.

Then, if you further much beyond I mean if you further above beyond re-crystallization temperature the crystallization will start, and therefore the whole effect of strain hardening will be lost. So, quite often we use strain hardened steel, in construction practice but as you can understand when you subject them to fire or heat their properties would be their lost properties and that as got the relevance.

Because, steel is normally it is supposed to have poor fire resistance compared to many other material namely the other construction material I mean with other construction material such as, structural construction material. Let us say, concrete or even reinforced

right, so that is what we have seen. Then, we have looked the structure of the structure of the Fe C system what we said is, this is the different types of phases that form.

So, we have seen in small percentage of carbon up to 0.8 percent alpha or ferrite and above this up to 2 percent carbon we have that gamma or austenite and we have delta around 400. But on the right hand side, with 6.7 percent of carbon we have Fe₃C formation and at lower you know in bulk of the higher percentage of carbon we have seen Fe₃C with alpha ferrite combination etcetera. So, I think with this we can now going to look into various properties of the steel and iron etcetera types of steel and their usage, in civil engineering construction practices and performance in services in the next lecture.

Thank you to conclude this lecture.