

Basic Construction Materials
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Lecture - 16
Nature of Materials – Part 6

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Flaws, slip planes, and grain structure

• Recap

The slide contains several diagrams. On the left, two diagrams illustrate dislocations: 'Edge dislocation' and 'Screw dislocation'. Each shows a 3D block of material with a dislocation line and arrows indicating the direction of motion. The edge dislocation diagram shows a half-plane of atoms, and the screw dislocation diagram shows a helical arrangement of atoms. On the right, a 2D diagram shows a polycrystalline structure with 'Grain Boundaries' and 'Grains (Differently Oriented Crystals)'. The BICM and NPTEL logos are in the top right. A small video inset shows a man speaking.

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Now let us recap what we talked about in the last lecture. We talked about flaws or slip planes or line dislocations with edge and screw dislocation and earlier we talked about grain structure also. So, just to recap, you have dislocations, you think about this plane here which is actually, the slip plane or the plane along which the deformation is happening or slipping is happening.

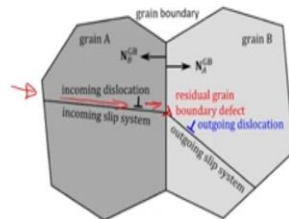
And just wanted to tell you about the slip plane because the next discussion is generally associated with this and in the other drawings we used to notate this using a perpendicular sign and then here you have a rotation sign there.

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Influence of flaws, slip planes, & grain structure on mechanical properties



- Flaws & defects can be weak locations
 - Decreasing strength and toughness of the grains
 - Associated with the energy required to propagate crack
- Grain boundaries can act as crack inhibitors
 - Increasing toughness (more energy required)



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Now how these slip planes flaws and grain structure influence the mechanical properties, they do have an influence on mechanical properties and flaws and these defects, line defect or like edge dislocation or screw dislocation etc. can be the weak locations within the bulk material. Now because they tend to be weak, they actually tend to decrease the strength of the material, if there is a lot of defects in the material or flaws in the material - voids, cracks etc. present in the material then the material general will have no lower strength and also it might reduce the toughness.

Now this is all associated with the energy required to propagate a crack. If there is a flaw, we can think of it as a crack, micro crack maybe but then there is some energy which is required to propagate that crack. So that energy is what is most important thing, when we talk about toughness or even in strength case also that matters a lot, because you know it has to lead to the fracture behavior. I mean here we are talking about the true stress at which the material fails etc.

Now grain boundaries can act as crack inhibitors. So, let us look at this drawing here at the bottom, this again I got it from the internet but you can see here, there is an incoming dislocation, see this perpendicular sign here. Now if the force is applied like this, there is an incoming dislocation. So, this dislocation will keep moving towards the right.

And at the grain boundary there will be some stress release or because the alignment is not same as on the left side and on the right side. Right side, the alignment is slightly different. So, because of this change in the alignment there are direction changes, direction of

movement of this slip of this dislocation changes. So, dislocations, first they try to accumulate over at the grain boundary and then they start moving in this direction along this slip plane.

So, you have 2 things here, incoming dislocation and outgoing dislocations. So, if it was going in the same direction probably you would need less energy, if it is in the same direction then the energy requirement to move that dislocation would be relatively less. But this is what is kind of a useful thing about the grain boundary, because, it helps in enhancing the toughness and probably strength also of the material.

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Effects of slips and grain boundaries (GBs) on toughness/ductility

- Atoms at the GBs are at higher energy state than the bulk atoms
- Slips are blocked at GBs
 - increasing the length of slip path
 - requires more energy to deform the material

http://nptel.srujanika.org/nptel/slides/slip_transmission.html
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Now effects of slips and grain boundaries or I am going to call grain boundary as GB here on toughness and ductility. Now atoms at the grain boundaries are at higher energy state, when we talk about atoms which are at the grain boundaries, they are at higher energy state than a particular atom within the grain boundary. Now slips are blocked at grain boundaries, so we just to show that drawing earlier, same drawing I have repeated here.



So, the slips are blocked, because the grain boundary acts as a crack inhibitor or it stops the crack from progressing. So, they are blocked at grain boundary but then as you apply more stress, there will be a point at which it starts moving in a best possible direction through the next grain or adjacent grain available. Anyway this process requires more energy because you have to cross through that grain boundary, you need more energy to deform the material.

Now look at the drawings here, you can see this is an incoming slip plane (ISP) and outgoing slip plane (OSP). So, you can see here, look at the direction of these arrows. So, these perpendicular symbols are actually the edge dislocations. Now in this sketch b you can see that there are multiple movements possible, this is one outgoing slip plane and this is another one and here it is happening along the grain boundary also.

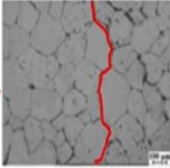
Now there is a third one where this point, so in the second one this point was swaying and the third one there is a slight movement, so this move like a zigzag frame. It goes, comes this way and then goes like this. So, again that might need more energy than in case b, so c might need more energy and again another case which is d here also you have movements in multiple directions. So, these all are associated with different levels of energy requirements to continue to deform the material.

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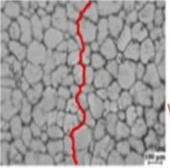
Effect of grain size on toughness/ductility

- For the same material
 - the smaller the grain size, the more will be the length of GBs → more toughness




Due to slow cooling, the total length of GB is less



Due to rapid cooling, the total length of GB is more

- These are for hot-rolled metals



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So, because of this, the size of the grain boundary has an influence on the toughness, we can say that. Now here when you look at the left side micrograph, it is like you know this is 100 micron, the length of this little draw straight line is about 100 microns. So, you can say the size of this, let us say 0.8 millimeter is the distance from this point to this. So, you are looking at within a millimeter in size.

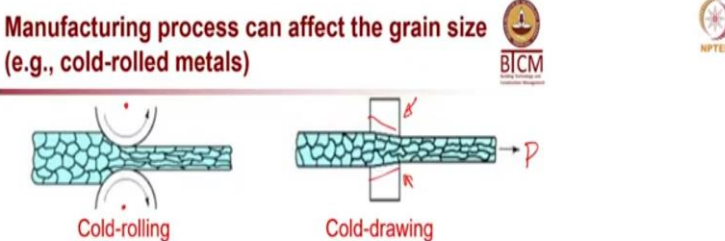
Now on the left side you have larger grains as compared to the image on the right side. Now when you have larger grains, if you have a crack along the grain boundaries or this is the inter granular crack, if I measure the length of this red line or this red crack, the red line indicates the crack, the one on the left side will be shorter than the one on the right side.

This is less and this is more. Because when you have larger grain size the actual length, if you just follow the grain boundary the actual length, not the displacement from one point to the other but the actual length from one point to the other, it will be more in the case of a smaller grain size that is this, than in this case. So larger the grain size, shorter will be the length of the grain boundary. Now when you have shorter length that means the energy required to move a dislocation along that would be also relatively less.

So, message here is, smaller the grain size the more will be the length of the grain boundary and hence more toughness. So, these are mainly for hot rolled metals. If you actually do cold rolling,

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Manufacturing process can affect the grain size (e.g., cold-rolled metals)



- In general, with increasing cold-work, the hardness and strength increase and the ductility decrease
- To restore ductility, heat treatments are done during the manufacturing itself

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Or cold drawing also, this is the 2 difference in a major way by which we do cold working, there is a common term, cold working or strain hardening etc. So, cold rolling where you have 2 rollers here and the material is coming out in a through these rollers, whereas in case of cold drawing, you are actually pulling the metal through a die which is probably, this is a die and then you can see the change in the dimension or reduction in the dimension as the material is pulled through that.

So, cold rolling and cold drawing, these are 2 different processes but the objective is kind of similar and mainly to increase the yield strength that is typically what we do this for. So, this process changes the way in which the microstructure is and in general what happens is with increasing cold work, the hardness and strength increases and the ductility decreases. So,

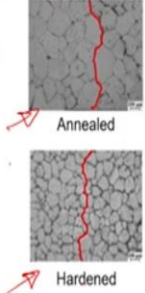
hardness and strength increase, it is probably a good property which you want depending on the case.

But decreasing ductility is usually not a good idea because then it becomes a brittle material and brittle material will have catastrophic failure in nature, so which we do not want. So, we want to maintain the ductility or increase the lost ductility. How do we do that? So, to restore ductility, we do heat treatment during the manufacturing itself. So, cold drawing is done to increase the strength or yield strength or even hardness of the material, but in that process the material loses ductility. So, to regain that or restore the lost ductility, there is some heat treatments which are done.

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Heat treatments can be done to control the grain size

- Annealing
 - Heating and then slow cooling
 - Breakdown of existing large grains
 - Grain growth upon slow cooling
- Hardening
 - Heating and then rapid cooling
 - Breakdown of existing large grains
 - Rapid cooling limits the time for grain growth
 - Smaller grains than in the case of annealing



Logos: BICM, NPTEL

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Now heat treatment, what is the idea? When you do this heat treatment, it changes the grain size to a desired level as you want. So, 2 major way of heat treatment which I am going to discuss here briefly are annealing and hardening. So, in case of annealing, what we do is we heat the material and then allow it to cool in a slow manner, heating and then slow cooling and in case of hardening, it is heating but cooling is very rapid.

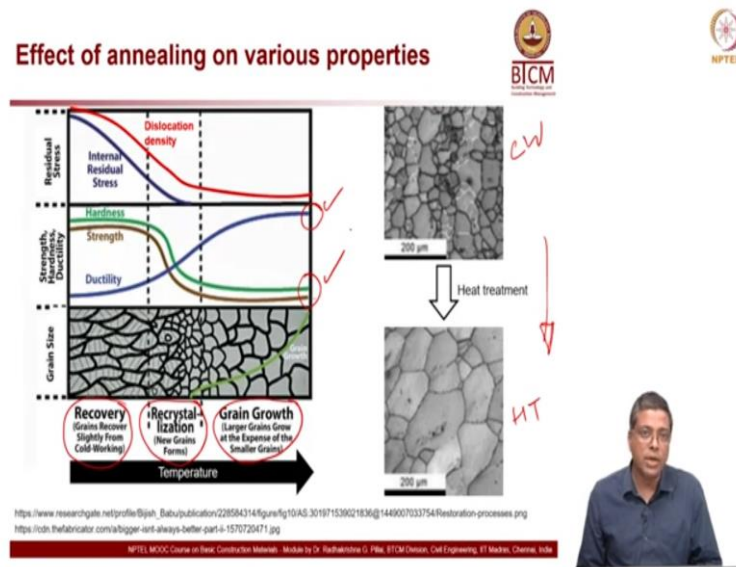
So, heating and then slow cooling here, heating and then very rapid cooling. So, you can see the slope in the second phase is relatively less. Now because of this slow cooling and rapid cooling, the final grain size is going to be different. Now anyway let us look at the annealing first, you have heating and then slow cooling, then what happens in this process is, when you heat the material, the large grains which are present, they tend to break down and then as it progresses it allows a little bit of grain growth.

Means a new set of grains are formed and which could be larger in size that depends on the rate of cooling. So, you are basically rearranging and this happens not in a molten state, this happens after the solidification, after the material solidifies. So, grain growth, so you kind of rearrange the grains to a desired level of grain size. Now in case of hardening, it is heating and then rapid cooling and this also breaks down in the heating process, it breaks down the existing large grains.

And then because of rapid cooling what happens is the new, the final grain size is going to be relatively smaller as compared to the annealing case. Now when you have smaller grains than in the annealing case, you might expect it to behave in a different way. Why? When you have smaller grains? That is this case, here you have larger grains finally, now this hardened one will need probably more energy to deform or crack etc. because of the length of the grains.

But again these comparisons when you look at, you know more ductility and less ductility etc., you should look at the grain size for the same material, not for different materials you cannot compare like that. For the same material, if the grain size is more then you will have lower toughness, if the grain size is smaller you might have higher toughness.

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Now generally when we look at this, you can see that heat treatment generally tends to increase the grain size from the cold work stage. So, this is cold working stage and then this is after the heat treatment. Now look at the graph on the left side you can see recover, so this

is the temperature increase in temperature, then there is a recovery happening here and then re crystallization and then the grain growth.

Now grains recover slightly from cold working that is the recovery stage and then the re-crystallization temperature when it gains and then you cool it down. So that is what is happening, so the grain growth is allowed. So, here you can see, look at the dislocation density first thing to look at, you can see here there is all these light grey lines, they are the dislocation present in the material.

Now you have these dark lines here, these are all dark lines which kind of indicate the grain boundaries. So, you can see several grains over there. Now what will happen? So the dislocation density decreases as you move to the right and then as you keep heating the material and then internal residual stress you can see here, this decreases as you go in through this 3 phases.

Now look at the major properties which is hardness in the beginning, the cold work stage, so for some time there is no change but when the re-crystallization happens, definitely the hardness is decreasing. You can see here the hardness in this region is decreasing the green graph is going down and then it remains kind of stable after that. See most of these things if you are taking a graduate level course, we will go deeper into this but here my idea is to just to give you a flavor in very superficial way.

But of what happens, when we talk about heat treatment. You should know what heat treatment is and why it is done and what really is achieved because of heat treatment. Now looking at the strength this brown graph here, in the recovery stage, not much difference but again in the re-crystallization stage, you lose the strength. Now after the re-crystallization, in the third stage grain growth you have again similar strength.

Now you can say that you do not want to reduce the strength but that is the metallurgist job of finding a material combination where strength loss need not be very high or see at the end what do you want is at this point, you need sufficient strength, sufficient hardness and sufficient ductility that is the objective let us say. So, as long as all these properties are sufficient in nature, then it is okay to use that material.

So, you do not just because one graph is going downward you do not need to get worried about it. So, the point is, so over here these 2 are the strength and hardness, if they are sufficient that is fine. Now here ductility, if they are sufficient that is fine. So, you always have you know, this requirement of these parameters, hardness how much it should be, ductility how much it should be or minimum, strength-minimum how much it should be.


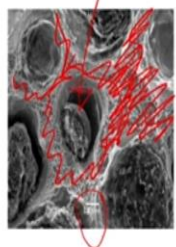
All that are the target properties or target values for these properties will be given at the time of design and then the steel manufacturer has to adjust the material combination or the composition of the material. I mean the raw materials which is put in the molten material and then all this manufacturing process or the cooling rate or you know how many times you do this heating, cooling treatments etc. All that are have to be fine tuned so that you get these target properties.

So, change in the grain size can change various properties of the material that is a big message. And grain size can be changed or controlled by having a heat treatment even after the cold working process or cold drawing or cold rolling process. We can make the material to go through some heat treatment, so that you get desired grain size and then because of that the properties can be engineered.

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Volume Defects in Crystal Structures

- Voids and inclusions
 - 3-D regions of defects
 - Considered to be external to the crystal structure
- Voids ✓
 - Small pores left by incomplete filling of the available space
- Inclusions
 - Regions of a second phase contained wholly within a single grain.



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Now let us go into the fourth type of defect which is volume defect. We started with point defect, then we talked about line defect, then we talked about you know the surface or plane defect, that is a grain boundaries and then we are now going to talk about volume defect which are mainly voids and inclusions. Void means air void, there is no material present.

Inclusion means there is a foreign material which is present inside the parent or inside the bulk material.

So, you can see this micrograph on the right side, you can see the size over here, there is a white line and that is 10 micron, that is 0.01 millimeters, so small. Now this is one you know, we can say an inclusion inside a material. So, this region here is the bulk material and this region and this I can say as the enclosure, the center one. So, like this, this is a very close up view, to make you understand.

And then these materials are considered to be external to the typical phase of the material, that is this region here, they are not really interacting with them. And if you say void, there are small pores left incomplete or just some spaces available, inclusion is regions of a second phase contained wholly within a grain.

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Effects of voids and inclusions on materials behaviour

a) initial material with inclusions
b) nucleation of new voids
c) voids growth
d) onset of necking between voids and
e) voids coalescence and sheet metal fracture

Barabie and Karam, DCR 10.1051/overcon/20181901902
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Effects of voids and inclusions on material behavior. So, look at the 5 images here a, b, c, d and e and what is happening in the (a) case, you have this inclusions or voids like this one. So, a lot of these black dots which you see here are all those inclusions or even voids we can say same thing but let us talk about the inclusions right now. Now as you keep applying this tensile stress, you can see the black arrows on each of those drawings.

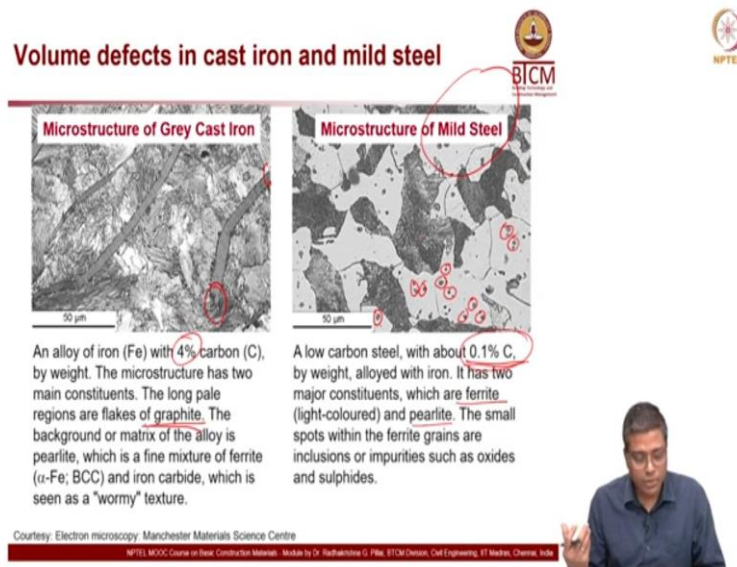
As you apply the stress what will happen is, here you can see this particular portion getting elongated, and it is getting elongated this way and then void inclusion is there. If you go back

into the previous thing, you can see this space here. So, as I pull that inclusion gets detached and then you have you know, stretching happening here.

Here you can see it is getting pulled this way. So, like that, this deformation happens. So, eventually you have this stage as in c, where this void start growing. So, here you have this, and this and you have this, it is growing here. Now eventually after some time, what will happen is they will grow in such a way and then try to you know, join kind of, so onset of necking, this is where the necking kind of happens.

So, there is a flow of material which is happening at this stage. So, you can see this region, this shaded region they get kind of connected or the voids tend to become one large void and eventually they crack. So that is your crack or coalescence and then cracking happens, cracking or even fracture happens.

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Now these are some real examples, the first picture is a microstructure of grey cast iron. You can see in the cast iron you have a lot of these flakes present. You can see this is another flake and in this picture, you have 3 big flakes of graphite present, you can see here graphite, so this is an image of an alloy of iron and 4% carbon. So, cast iron has a lot of this carbon present, 3 to 4% easily by weight.

The microstructure has 2 main constituents, the long tail regions are flakes of graphite or carbon. So, these are the reasons for the brittle nature cast iron and because when there is

some force which is applied, what will happen is these cracks will kind of follow the path of these flakes or their stress concentration will happen at one end of this, may be here.

So, along these graphite flakes, you will have some stress concentration, crack width kind of propagate through that. Now this is the reason why we do not use cast iron in many structural applications because we know that the failure is very brittle in nature and you do not really see deformed structure, we already discussed this in the previous lecture. So, we have materials like ductile iron which is having some inclusions and it has a little bit more ductility than the cast iron.

So, inclusions rather than having flakes like this, the ductile iron will have inclusions, spherical inclusions and here you have a picture of mild steel on the right side, where you can see carbon steel or you know the general name is mild steel with 0.1% carbon, much less as compared to cast iron. Cast iron is 4% and mild steel here, this particular case we are talking about 0.1% very small.

And it has 2 major constituents, ferrite which is the light colored region here and let us say I am going to call it F and then pearlite which is the this particular region, the darker shaded region. The small spots within the ferrite, within the grey space, these small spots which you see a lot of them are spread widely in this ferrite face or the light grey face are inclusions are impurities such as oxides and sulphides.

So, whatever inclusion or impurities are present there and when this will have an influence on the failure pattern etc. This can have an influence on the failure pattern because they tend to behave like a weak point when the load is applied.

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Alloys

- A process in which two or more metal elements are melted together in a precise combination to form a specific material, or alloy.
- Metal manufacturing process
– MMC:- Melted → Mixed → Cooled
- Various liquid and solid states exist and are called "phases"

Examples of Alloys

Name of Alloy	Metals present	Uses
Brass	copper and zinc	Door handles and fittings
Bronze	copper and tin	statues
Solder	tin and lead	Soldering metals together
Stainless steel	Iron, chromium and nickel	Cutlery, kitchen sinks



Now let us talk about alloys. What is alloying? It is a process in which 2 or more metal elements are melted together in a precise combination, so not just mixing but in a very precise combination to form a specific material with certain target properties. Now there could be properties like it should be malleable, like you know the ability to flat and then it could be you need to have an increased strength.

Sometimes high ductility, malleability, weldability. So, many of these properties, the corrosion resistance or sometimes we might want the material to be very shiny in nature. So, many properties are targeted, so whatever based on the target properties, we will include other elements and mix them properly in a combination and that process is what is called alloying.

Now in general we can say material manufacturing process MMC I am calling here. First materials are melted and then mixed together and then finally cooled. Now various liquid and solid phases exist and there we are going to call them different phases - solid phase or liquid phase, depending on the absolute temperature at that time in this cooling process.

So, here is just a picture to show different type of metals and each of them have different properties. It is not that all metals are of same property, like all steel need not be of same nature. Sometimes you will need steel even for construction, sometimes you will need steel which is very ductile in nature, especially when we talk about earthquake resistant structures, we want steel which is ductile in nature. We do not want it to be very brittle in nature.

So, how do we you know, make such highly ductile steel. So, it is essentially to do with the way you make steel. So, I will cover that lay in the next module on steel, but just to briefly tell you that these are all very important for civil engineering construction. You need to be aware of as a civil engineer some of these things must be known to you. More detailed stuff is for metallurgist, but we should know general stuff of this grains etc.

Now, here is an example of some major alloys which we use brass, bronze, solder material, stainless steel etc. So, copper and zinc where they are used and then copper and tin where they are used, I will leave it to you to find out the reason or what are those properties which we are targeting and then accordingly, so you can do some homework in that line, it will be good to know what are the properties for various type of uses. So, target properties for various types of uses.

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Phase diagrams

- Phase diagram exhibits the relationship between the material composition and transition temperatures
- Transition temperatures depend on material composition
- More ideally - A phase diagram is a graphical representation of the combinations of temperature, pressure, composition or other variables for which the specific phases exist at equilibrium.

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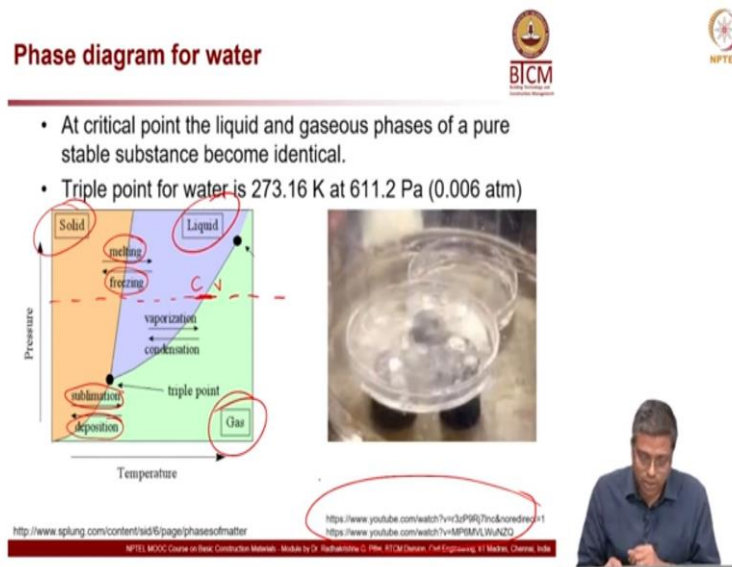
Now phase diagram, so we just discussed about different phases here. So, various liquid and solid phases might exist depending on the temperature at which the material is. So, this is generally understood by something called phase diagram. So, phase diagram exhibits the relationship between the material composition and transition temperature. So, composition versus transition or the temperature is what essentially the phase diagram is. And these transition temperatures depend on the material composition.

So, it is not that the transition temperature is same for all materials, No. It definitely depend on the combination of the materials or the mixture proportion of the material. So, more ideally, here I am going to I am showing only temperature and composition but that is not the

only thing. Ideally speaking, a phase diagram is a graphical representation of combinations of temperature, pressure and composition. It is not only temperature but plus pressure also will come.

So temperature, pressure and composition, so or even other variables, if we have something for with the specific phase exist at equilibrium. So, this is what a phase diagram is.

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We will briefly talk about this phase diagram for water. So, this is how typically it looks and you can see here there are orange region and this purple color region and then you have the green color region, so one is for solid then liquid and then gas. Now if you follow this border between each of these phases, you can say at that border, at that point, when there is a slight movement, slight change in either pressure or temperature, the phase will change from one to the other.

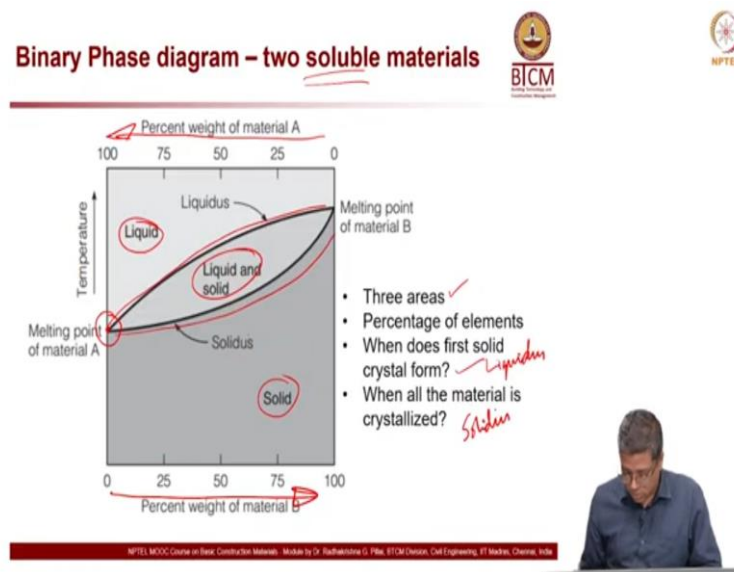
For example, if I take this curve here, a slight change in the temperature that is moving in the horizontal direction. Let me draw it more closely. Let us say here, a slight change in the temperature along this red line, if the temperature slightly increased at the same pressure then it will vaporize and if the temperature slightly decreases then it will condense, so you can have C condensation and then V vaporization.

So, like that, it also happens between solid and gas that is sublimation and deposition and between solid and liquid- melting and freezing. So, we are going to look at this solid and liquid in the next slide. But before that I request you to watch these YouTube videos, this is

actually on water you can see ice crystals formation, boiling water and also bursting of gas bubbles, all these things are visible and happen at the same time, it happens in the same petri dish which is used in this experiment.

So, all 3 kind of coexist, while in the experiment in the same dish, different locations in the dish or the H₂O in the different locations in the dish experience different combination of pressure and temperature and then slight movement in the pressure and temperature leads to this change in phase. So, please watch this video as an assignment, it is very interesting to see.

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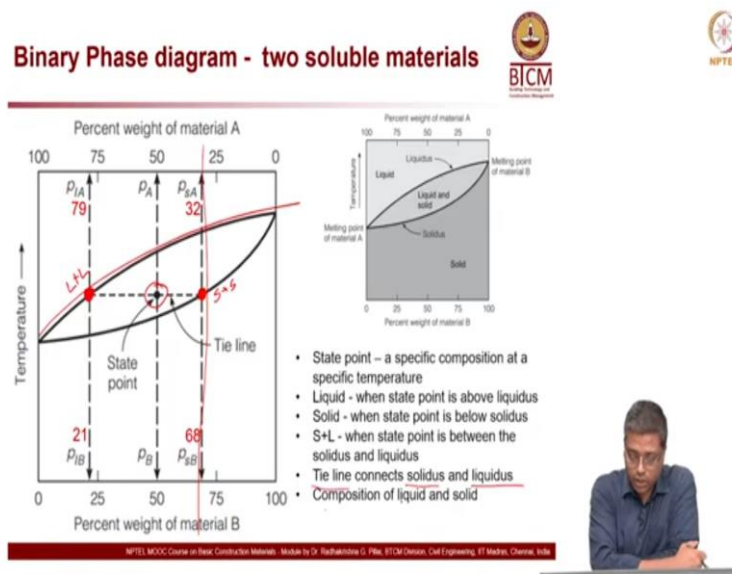
Now binary phase diagram for 2 soluble materials, this is one of the simplest phase diagram which we are going to discuss here. You can see here again this is the composition, here you can see the same thing for material A at the top axis and then material B at the bottom axis. Now that means if I draw a line along this, I have 25% material B and 75% material A is the composition.

So, now, the temperature increases on the axis you can see, so here this means, the material changes at this temperature it starts melting, that is the melting point of which material, of material A because at this line you have only material A, it is 100% A and 0% B. Now if you go to the right end of this graph, this is 100% material B and 0% material A. So, this clarity should be there because this A it is increasing towards left and B it is increasing towards right.

Now, so this is melting point of material A, similarly you have melting point of material B here. So that means here it is liquid and here it is solid. So, I think that is clear now. Now there are also phases which are having both liquid and solid. So, this curve here is called liquidus that is kind of the boundary between the liquid, 100% liquid phase and the liquid solid phase and here you have solidus at the bottom or this curve here is the solidus which is 100% solid or the boundary between 100% solid and the solid liquid phase.

So, this is about the 3 areas, you have a liquid phase, you have a solid phase and a liquid solid phase 3 phases or 3 areas and then percentage of elements. When does the first solid crystal form? When the temperature decreases from top down, if you look at the first solid crystal forms at when it goes just below or touches the liquidus line and when all the material is crystallized that is the solidus line or completely it becomes solid. So, thing is clear now, so this is liquidus and this is solidus.

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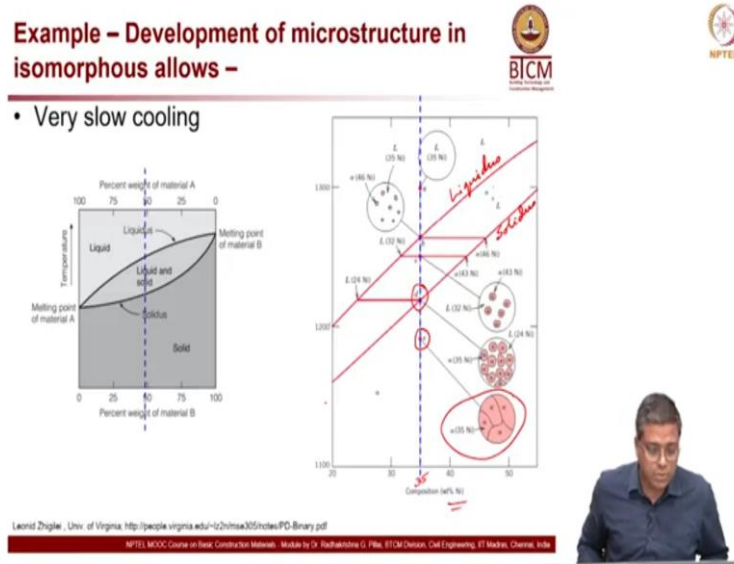


Now same diagram little bit more with an example here. Let us take a composition along this line where you have liquid phase of B, it is a percentage of B and percentage of A. A, you have 79% and B you have 21% in this line. Now on the right side here you have another composition which is 68% of B, solid and 32 percentage of solid A and this is happening at this point here.

So, the first case was here, if I take this point I can say that point has 79% of liquid phase and because this is my liquidus line and 21% of liquid B or material B in liquid phase, so both are liquid plus liquid here and here if I take this point, both are solid plus solid here. So, I think

that it is clear now. Now if I take this point here, I will have A and B present but then I have to look at whether both solid and liquid are there inside that state, that is the tie line, this horizontal dashed line is called the tie line which connects the solidus and liquidus composition of liquid and solid.

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Until now we were talking about schematics, this is a real example from a textbook. So, you can see here the blue line if you follow the one on the left side you see a blue line here and same line or similar line I have drawn on this drawing also, on this sketch and this is the liquidus line and this is the solidus line. So, you have liquidus, you have solidus and this region is 100% liquid, this region is 100% solid and this region is solid plus liquid.

Now let us start from the top of this blue line and then move downward and then let us see what happens when the temperature decreases. So, now look at the temperature this is 1300, 1200 and 1100. I am just trying to show you how the phases are different. So, here you can see alpha the point A, the point A has you know, all liquid phase 35%.

So, that this point if I take it is about 35% nickel, so entire thing is liquid. Point A is about 1300 degrees is the temperature this point here. Now if I take point B that is about let us say 1250, about 1260, 1270 something like that approximately, so that is the point B and now this point has this combination.

This is the combination and you can see that you have liquid phase and also you have alpha phase, small crystals are actually forming, the solid phases start to form because you are at

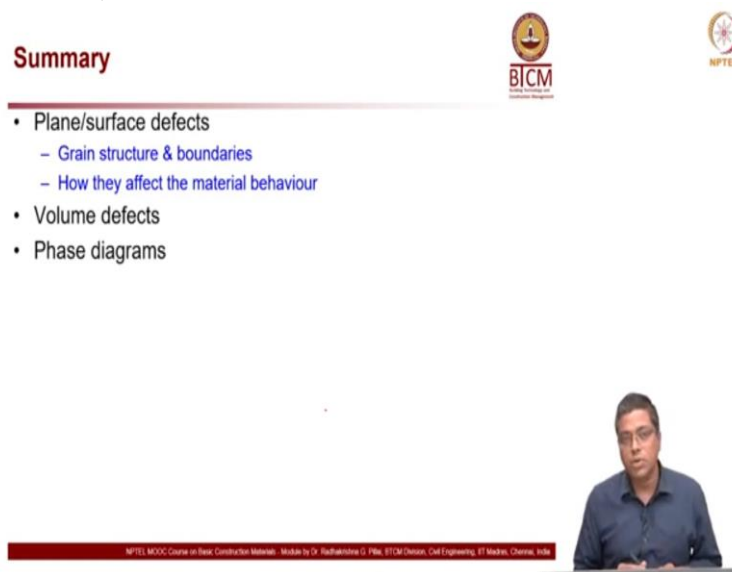
the liquidus line right now and this is the solidus. So, you are starting to form like solid faces also. Now this region in between these 2 liquidus and solidus this is the $\alpha + L$ that is solid plus liquid phase.

Let us say you move to the point C, now that is this point here. So, the corresponding micrograph or in a sketch is this. So, you have α and liquid, both are there because it is in between the solidus and liquids. So, both are present, now as you move towards point D, this is the corresponding sketch and then you can see that the size of the α is keep on increasing.

You compare with point B, here the α is very little. And here you have more and more solid phase and as you just cross the solidus, you see that it is 100% α and there is no liquid phase in that. So, you can say that this from top to down if you keep moving, temperature keeps decreasing and then you get to have more and more solid phase and gradual changes.

Now there are also systems where, this is an example of you know, 2 soluble systems or soluble materials. There are also examples where we have partially soluble materials and insoluble systems also. So, I thought, you can read that from this textbook on Memlock and Zenoisky as reading assignment, you can read about those 2 additional phase diagrams.

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Summary

- Plane/surface defects
 - Grain structure & boundaries
 - How they affect the material behaviour
- Volume defects
- Phase diagrams

NPTEL MOOC Course on Basic Construction Materials, Module by Dr. Radhakrishna G. Pillai, BICM Director, Civil Engineering, IIT Madras, Chennai, India

To summarize, we looked at plane and surface defects, we talked about grain structure and grain boundaries. And also we talked about how these grain structure and grain size, shape

etc. might affect the material behavior. We talked about how they affect the toughness in detail and also volume defects which are mainly about the air voids or inclusions inside the material and then we finally talked about the phase diagrams. We talked about the phase diagram of a soluble material systems, the partially soluble and insoluble materials I request you to go through the textbook. Thank you.