Heat Treatment and Surface Hardening (Part–1)

Professor Kallol Mondal
Professor Sandeep Sangal
Department of Materials Science and Engineering
Indian Institute of Technology, Kanpur

Lecture Number 17

Solid-Solid Transformation and Nucleation rate

Let us start our lecture which is lecture number 17.

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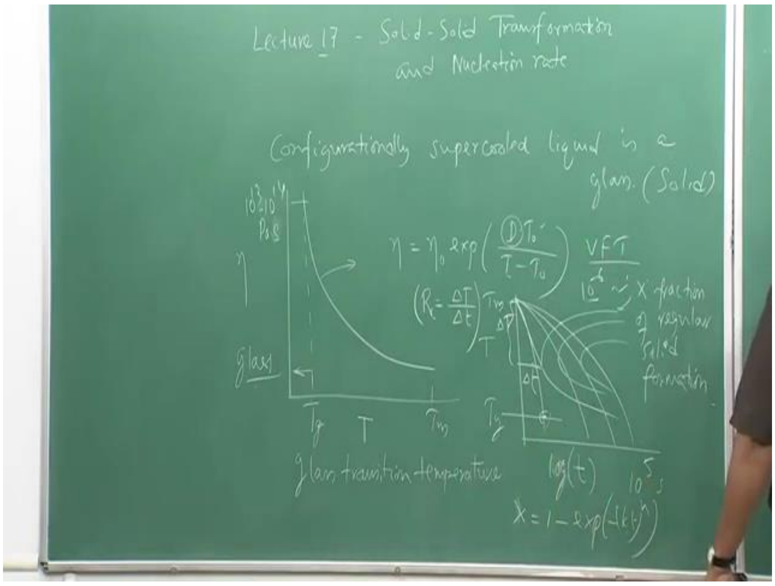

So today will start our discussion on solid transformation and nucleation rate. See whenever we talk about solid solid transformation and nucleation rate because this is extremely important. We started with liquid solid transformation but most of our heat treatment will be associated with solid solid transformation, of course solid liquid transformation also warrant lot of heat treatment procedures.

For example during casting we have to look at different temperature and time consideration in order to get desired structure and finally desired properties. But in case of steel, we always come across heat treatment like annealing, heat treatment like normalizing, Martensite formation which is called hardening. So those will be in solid solid transformation situation.

so we need to look at solid solid transformation and before we go to solid solid transformation. So whatever we have treated that is liquid solid transformation which is extremely critical from the point of glass formation . For example this is one particular section of materials which is called glass glasses or liquid glasses like structure but it is in a solid condition.

That means the atomic arrangements will be random like liquid but it will be in solid condition. this glass formation in polymer is very common, but in case of solid solid also, in case of (me) metallic system we do experience glass formation which is famously called as metallic glass and which are also called amorphous alloys. So there we do experience transformation of liquid into solid without going for (liq) atomic rearrangements.

The classical definition of glass if I consider the definition is configurationally configurationally super cooled liquid configurationally super cooled liquid is basically a glass. from this definition it is very (clrd) very cleared is a it is a liquid which is super cooled and it is configurationally super cooled means the liquid configuration is super cooled.

And it forms a solid which is a glass. This is a solid and a short discussion if we start cooling particular material let us say temperature and this is melting point and this is if we consider the viscosity. Generally the viscosity variation of liquid firm has a nature like this which is actually related to Arrhenius increase and more refined situation for viscosity change with under cooling.

We relate to n0 exponential DT0 T-T0, so this is called VFT equation which is Vogel Fulcher Tammann equation and there this is called fragility of glass. Now this is a temperature which is kind of it it it has a relation to glass transition temperature and this is the temperature below Tm. Now if we see this viscosity whenever viscosity reaches to temperature (vesco) 10 to the power 13 to 10 to the power 14 pascal second, pascal second.

So that time that temperature we call it Tg which is the glass transition temperature, glass transition temperature. So that time whenever this viscosity reaches there as we keep undercooling the liquid it immediately stops the shear movement of atoms. And whenever the shear movement of atoms (stors) stops that time we can call it as a solid. So the liquid is actually without transforming to solid of regular atomic structure, it goes into the solid where the liquid configuration is maintained.

So that is what it is called glass, so below this temperature we form glasses and Tg is the glass transition temperature, where liquid converts to solid. So this is a kind of situation where we do experience glassy alloys and that time the solid liquid transformation is a critical issue and that time we can also construct TTT diagram for if we consider TTT diagram for solid liquid transformation, if this is Tm and generally we consider this axis in the form of log.

So because this time is, time can become a large value, so it can reach to 10 to the power 5 second. So in order to put it on the same access, we take the temper time as log so then the graph becomes like this. There is also c curve and this particular lines, this particular lines are indicating the fraction of prosommation so which is regular solid formation, ok. And regular solid means it is a basically crystal in case of metallic system, we do experience crystal.

And liquid to glass transition and at the same time liquid to solid transformation at a different heating rate. For example if I see the heating rate, if I heating rate then this is my Tg. So below this particular X value, if this X value close to 10 to the power -6, so then we say that below that point we cannot measure the amount of crystal. So that time we can consider it to be a liquid.

And that if, if by cooling rate is pretty fast so then I can cross this particular c point. The the maximum the nose point and then we can go we can take this liquid to this temperature and glass formation is possible, ok. But if we see other heating rates we see at different fractions of and whenever this line this cooling curve crosses any of those fraction lines, we say that that much fraction of solid has formed in the liquid and the rest would be liquid and the amount of solid would be that much.

So that this particular situation would come across and that time the solid liquid (int) transformation process the I whatever we have calculated the I value would be needed to plot this particular diagram. Of course there will be one more parameter which will be needed that is the growth rate. So we will come across that growth rate once we consider the nucleation rate.

So this as we have seen if we go if we, if you go back to earlier lectures you might have experience you might have seen this particular expression X equal to 1 minus exponential (-KT) to the power n. Where k involves I as well as U, U is the growth rate. And that is what we need to measure I as well as U, in order to get this TTT diagram. And this TTT diagram will be valid while finding the kinetics of phase transformation from liquid to solid.

So this is a kind of use of that I measurement, of course the growth rate will start looking at soon. So finally we can see whether the liquid can form glass or not or it can forms some crystal, when it should form the crystal, what would be the critical cooling rate that means what would be the critical cooling rate is this one where this is my del T and this is my del t. So the critical Rc which is critical cooling rate is measured in the form of this.

So this is the critical cooling rate means the cooling rate greater than this that means cooling rate if we go towards left liquid would remain as liquid, ok. So that time I can take the liquid to glass forming temperature, ok then it will form glass. So this thing this information will be thought in later lectures, but let us go to solid solid transformation where we would be also looking at nucleation rate expression and before that we also see how the nucleation treatment is taken in case of solid solid transformation.

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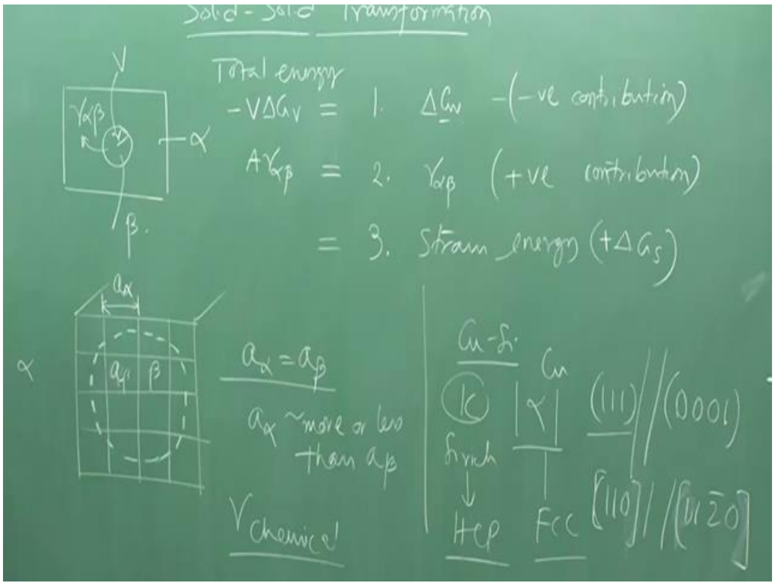

Now in case of solid solid transformation the treatment would be almost similar like solid liquid transformation. But there will be little difference and that difference comes in the form of strain energy, ok. In case of solid liquid case we have not seen this particular term called strain energy and here we do experience strain energy. Now that makes a lot of differences and at the same time the interfacial energy in the previous case we looked at then we saw that half of those bonds are broken.

And it is at much simpler rather much simpler but in case of solid solid case it will be little complicated. So we will just philosophically say why this interface energy becomes complicated. Now if I try to see in case of solid solid transformation, of course initially we can see homogeneous nucleation. So there also a sphere forms of radius are and that time that solid is basically let me term it as beta.

And it is forming in alpha at a temperature less than equilibrium temperature. So I am here putting not Tm, it is rather equilibrium temperature. The Tm is also equilibrium temperature but since it (())(12:53) towards melting that is what we say Tm. But here the transformation equilibrium temperature is Te that is, that is what we have said the T equilibrium. Now this temperature which is less than T and that time transformation is taking place and alpha is forming in a solid of alpha and where the beta is forming.

And the interface which is forming is gamma, alpha, beta. Now what are the energy terms and here also in the beginning we are not considering volume change, ok. Now this volume is same as before and there is no need volume change. So now if I try to see the energy contribution one is of course delta GV which is negative contribution. As we have seen in case of solid liquid transformation.

Now second part which is free energy joule per unit volume. Second part ofcourse gamma, alpha, beta which is positive contribution, positive contribution. Now if I try to see the energy, total energy so that means if this volume is V, so it would be V delta GV with a negative sign. And here if the area is A, so A gamma alpha beta, this is the total energy. Now similarly there will be third one which is basically this contribution third is strain energy.

Now where from this strain energy appears, we call it delta GS. And interestingly this becomes positive, now we need to see why these positive terms come. Now if I try to see a solid, now if I see this solid and we can extend it when 3D mention, but let me do only the 2 Dimension part. We see that the if the solid is a regular crystal so atoms are arranged in a periodic manner. Now if this the alpha there could be a second phase which can appear, the second phase can appear like this in this volume, in this volume.

And this is if this is the alpha lattice parameter which is a alpha and if this is my second phase, if this is my second phase which is beta. Now in case of beta the lattice parameter is a beta. And from this it is very clear that there is no volume dilation because the lattice parameter if before it form beta everything was alpha. Now after formation of beta also this lattice parameter does not change.

So this lattice parameter it is a alpha equal to a beta. So that means the lattice parameter of parent phase as well as product phase both are same. And that time there is a perfect alignment of those planes, ok. But whenever we have a perfect alignment of those phases, it is not necessary that there would be a perfect alignment of this particular lattices throughout this body.

It may happen that this a alpha is slightly more or less than a beta, ok. So that time situation would be little different, now whenever we talk about this situation either it can happen in case of pure metal or it can happen in case of alloy system. For example if we try to see the complete match, one particular example let us say in case of copper solid cons alloy, we form silicon rich phase which is (())(17:44) phase and then this copper phase is alpha this is copper and this is silicon rich. This is copper, this is alpha which is the base, which is the parent phase and this is the product phase if it forms.

So we have we if we see 111 plane, as well as 10001 plane for this two panes of this particular crystal because this phase is HCP and this one is FCC. So this is hexagonal close packed and this is phase centered cubic, so this particular plane and the plane of this HCP which is the basal plane are parallel, ok. And that time this two atomic arrangements are absolute similarity.

So that case they will have a perfect match, ok. And at the same time 110 plane would be parallel to 112 bar 0 plane, ok. So this is the direction rotation, so this would be the situation, ok. Now how come this comes, ok.

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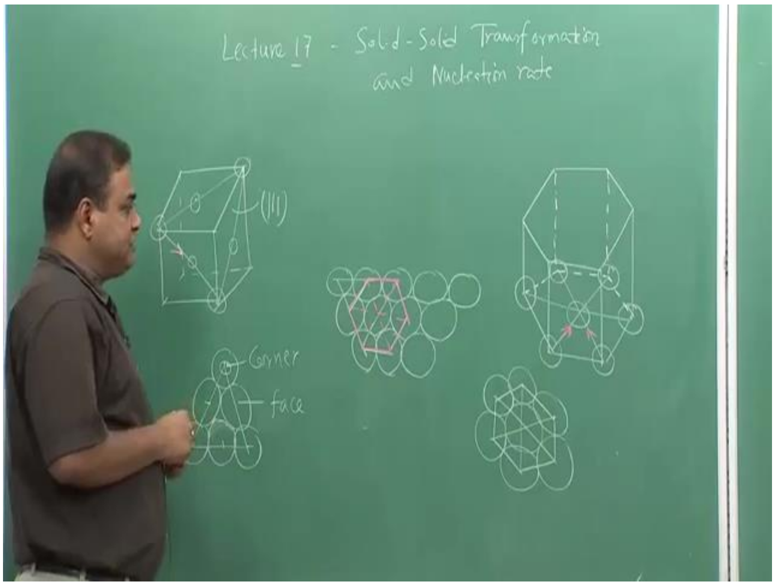

Let us look at that part, now if we see a phase centered lattice. So if we see this, this is let us say 11 plane. The atomic arrangement would look like for example if I start doing, if I see I think this will be enough, now if I see the plane where this atoms are lying this is the phase centered plane, this is the phase centered plane, this is the phase centered plane, and these are the corner planes. The atomic arrangement is like this. So this is like this, so would we see some atomic management there, yes we do see atomic arrangement like this, this is that, ok so this is that plane.

So this is the corner atom, this is phase atom and this is corner, this is corner, this three are phase. Similarly I am seeing that particular arrangement. Now if I try to draw a phase (cen) hexagonal close packed, now this is let me draw this particular plane as a dotted so then things will be clear. So this is the back of the plane, back of the phase, so this is the situation. So now that case the atoms are arranged like this.

Now though I have given a lot of space but atomic arrangement will be like this, this is the atomic arrangement if I see this, so this is the arrangement. So now if I see this, ok. Now do you see anything like this, yes we do see that kind of thing. If I do it with a different color then it will be clear. So I see that if this phase is parallel to this phase then there would be exact matching of the planes, ok.

Planner atoms at the same time if I see the direction, this direction and in this case the direction like this then in case of 112 bar 0, so that means 112 bar 0. So 11, so it would be one of those kind of directions. So now we have seen that the direction wise also these directions and these directions are parallel. So this is 110, so this (dire) this direction is one of those 110 group of directions.

And here these are the 112 bar 0 group of directions, so they are also parallel each other. So that is why they have a very good match. But ofcourse there would be see this if this kind of phase formation alpha in beta (where) beta in alpha. So we have an interface between alpha and beta, that interface energy is constituted by the chemical affect. So we have gamma chemical.

But the situation would be different if we do not find such kind of match. That case we do experience another kind of energy which is called structural interfacial energy.

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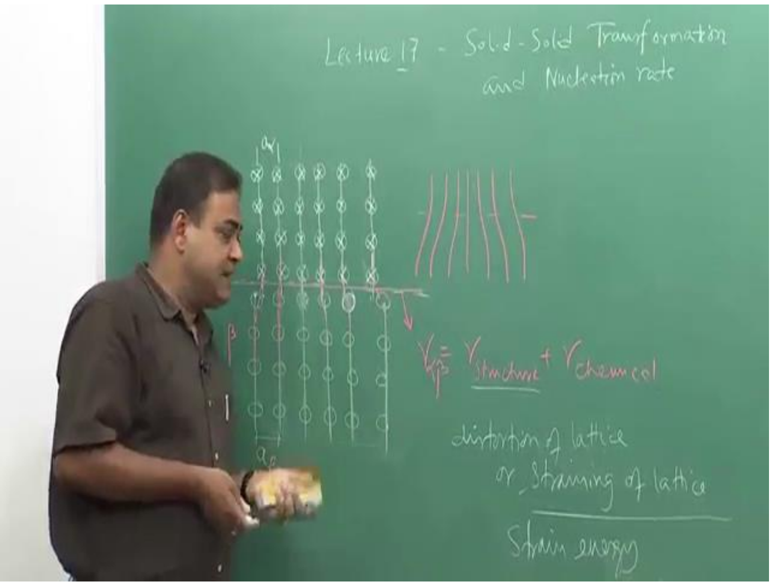

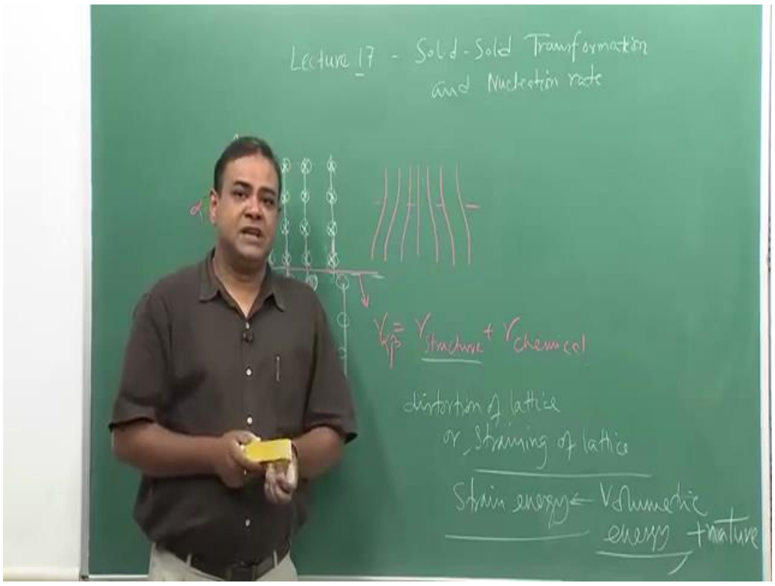

Let us look at that part, now if we let, let us draw it first. If we see this particular arrangement, now these are let us say alpha atom, these are alpha atom and this open sphere square (cir cir), open circles are beta atom. There is an interesting thing, so if we see this, this is let us say a beta which is the lattice parameter and this is the a alpha lattice parameter. I see there is an interface along this line but at the same time I do see that this (latti) since there is a one lattice plane which is perfectly matching, it is perfectly going through.

Now there are other lattice planes which are not exactly matching. For example if you see this, so there is a little deviation. So from here to there, there is a little deviation, so but the system would always like to have a match, ok. So that time in order to match this, this lattice will be distorted like this. See if I try to draw in red color, you will see that these lattice will be little distorted.

So this distortion would be there. So now you can see that distortion is like this, so like this so this is the interface. So same as like this so that time this interface, this interface is having two contribution one is gamma, this is alpha beta let us say, this is beta, this is alpha, gamma structure plus gamma chemical. And out of this, this structure part is related to the lattice distortion.

You can see this in order to have a match, this lattice are not flat not straight rather they are distorted. And this distortion is going inside the lattice, ok. So distortion has started from here it has gone inside. So this distortion is actually trying to distort the lattice and this lattice distortion is related to this structure affect. That means the because of the structure matching they are having distortion. And this is called distortion or (strain) straining of lattice.

And whenever there is a straining of lattice, it would also associate with some energy which is called strain energy, ok. And this strain energy is not situated at the surface rather it is going inside the volume that is what this is a volumetric energy and another thing this volumetric energy is to be create, is to be created in order to have this match, in order to have this beta.

And that is why this is a, this is having positive nature. So that means this volumetric strain which is strain energy has a positive sense and this is coming from distortion of lattice of straining of lattice, ok. So let us stop here will continue this discussion in our next lecture, thank you very much.