Dynamic Behaviour of Materials
Prof. Prasenjit Khanikar
Department of Mechanical Engineering
Indian Institute of Technology-Guwahati

Lecture-40
Plastic Deformation Under Shockwaves 2

Hello everyone, so we have been discussing on plastic deformation under shockwave propagation. So what we discussed in the last lecture is the strengthening mechanisms under shockwave propagation, I mean under this strengthening mechanisms. So we need to discuss several aspects of it like several features of it like dislocation, generation, mechanical twinning or point defect generation or let us say diffusion less transformation and maybe some other effects as well.

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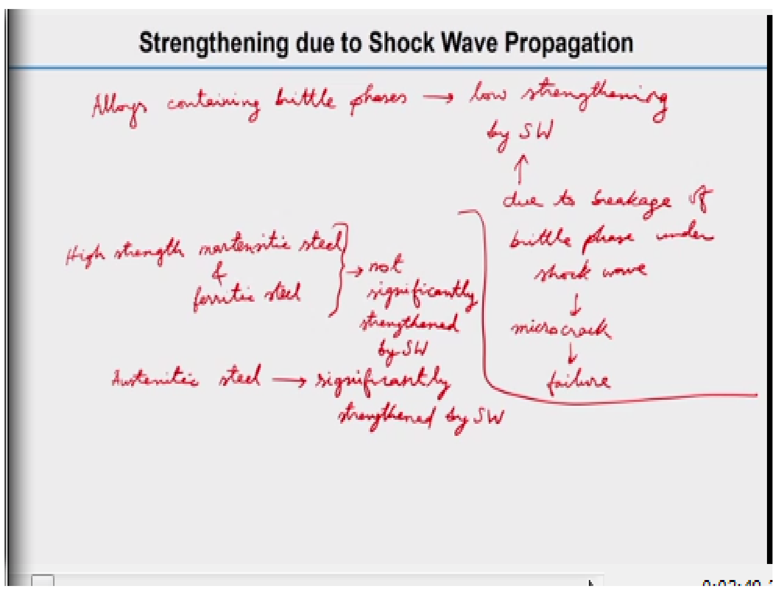

So alloys sometimes contain some brittle phases, alloys containing brittle phases let us say small phases or sometimes it may be some particles. So they can undergo like strengthening by shockwave but the strengthening is not much low strengthening by shockwave I will write SW for shockwave. And because due to breakage of the brittle phase under shockwave. So that means that can generates I would rather write micro crack instead of crack.

So micro cracks and then micro cracks can lead to failure of the material, different materials have different strengthening effect by shockwave like we can write high strength martensitic steel actually, high strength martensitic steel and ferritic steel. So both of these not significantly strengthened by shockwave, however austenitic steel is significantly strengthened by shockwave.

So there are different types of materials and they are differently influenced by shockwave that means the strengthening are different and because that is probably because of the different strengthening mechanisms.

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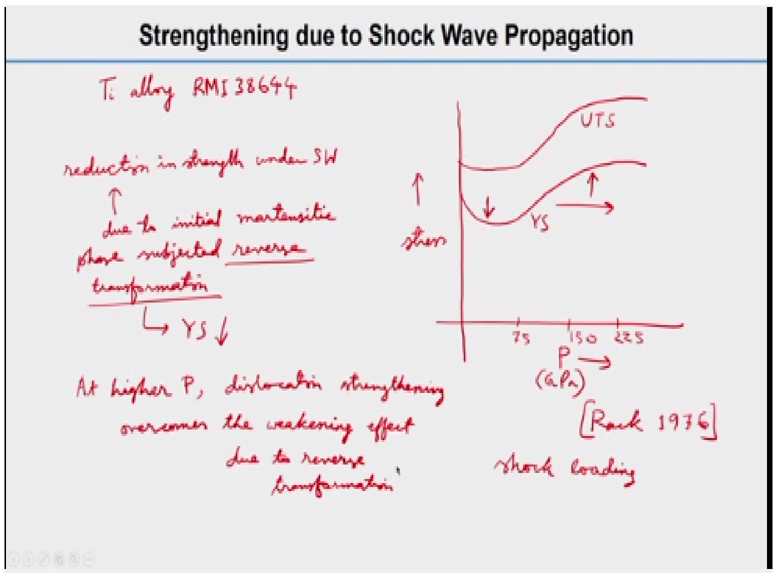

So we will talk about this alloy the aluminum alloy RMI 38644, so it shows that if we plot stress versus pressure of these alloys which is from rack 1976. The reference is, what happens if you want to draw the yield strength, so it will look like this let us say yield strength. also ultimate strength also this trend is kind of similar. So this is with increase of pressure, so what is happening here is because what lead to these decrease they will see the decrease of strengthening reduction.

So that this is actually the shock loading what we are talking about a very high pressure shock loading. So this is in let us say in Giga Pascal the unit is in Giga Pascal and we are talking about very high pressures let us say 75, 150, 225 something like that this is a very high pressure 225

Giga Pascal here. So this reduction the early reduction in strength whether it is yield strength or ultimate tensile strength.

Under shockwave is due to initial martensitic phase, so initially it is martensitic phase and that martensitic phase subjected to reverse transformation that it is not some other phase to martensitic phase but this is from martensitic phase to other phase. So that is why the yield strength or the ultimate tensile strength decreases but at higher prices that mean even higher pressure.

That means let us say in these range higher pressures, this will increase the strength will increase why it increased because the dislocation strengthening centering overcomes the weakening effect due to reverse transformation. Due to reverse transformation means just reverse transformation what we discussed above due to reverse transformation. So ultimately the strengthening will happen because this looks on strengthen will be dominant here.

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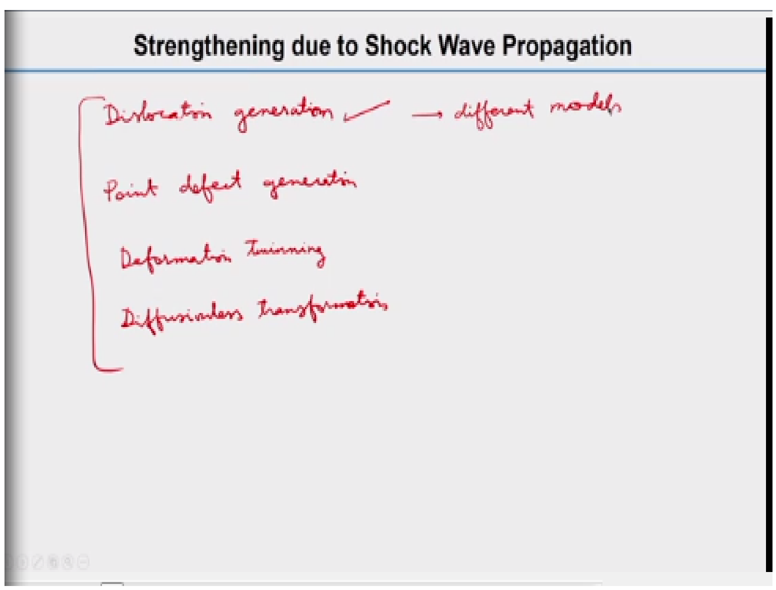

So as we have talked about strengthening due to shockwaves, so we know that this is strengthening can be happen from dislocation generation under shockwave. So that we will discuss dislocation generation and then there are other point defect generation and then deformation twinning which we also call like mechanical twinning and then diffusion less transformation and maybe some other effects.

So these we will discuss, so specifically specially we will talk about dislocation generation and we will discuss different models not different models by the way. Basically we will focus on 1 model but there are other models as well, so how this dislocation generates under shockwave, so that we will discuss now.

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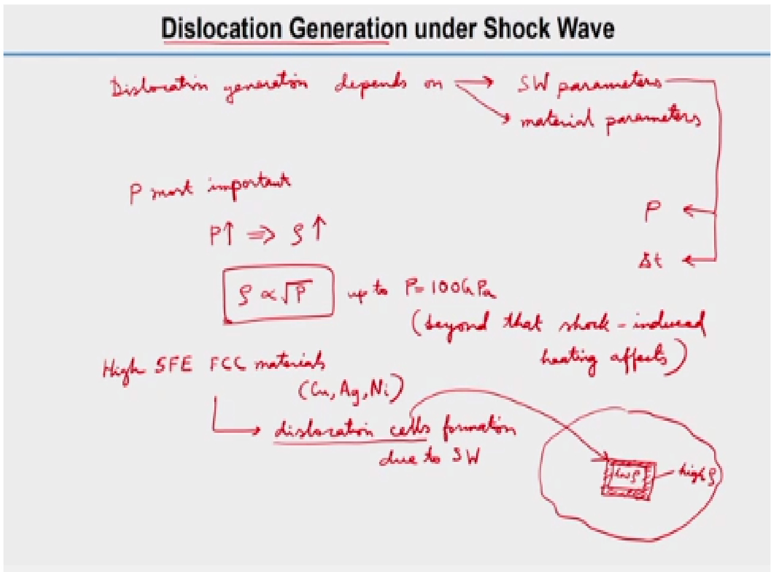

So this dislocation generation in different materials and dislocation generation also depends on number of parameters, number of shockwave parameters and some material parameters. So this dislocation generation depends on shockwave parameters and also material parameters several of the parameter. So for shockwave parameters we can say that the most important one is pressure and then we can tell that probably the delta t pulse duration we discuss in the earlier classes the pulse duration is also important.

So the pressure is the most important, pressure most important factor among the shockwave parameters most important. So what happen is the when pressure in increases that means the dislocation density rho will also increase. So generally it happens that the rho is proportional to square root of P the pressure at least up to 100 Giga Pascal pressure beyond that shock induced heating will effect heating effects.

So that means after 100 Giga Pascal this dependence will be changed. So but below hundred Giga Pascal pressure it is very likely that the dislocation density is proportional to the square root of the pressure. For a high stacking fault energy FCC material, so we will discuss about some materials and mostly it is FCC materials and specifically right now we went to tell you about the high stacking fault energy FCC metals or alloys let us say FCC materials we write.

So for example copper, silver, nickel, so these type of materials what happens that dislocation cells formation due to shockwave. We are not going to discuss what exactly dislocation cells just to give you the idea. So what happen is in a material in grain if this is a grain, so there are some cells will form where you have a walls like this. So wall means this portion have high dislocation density I would write high rho that is dislocation density and inside it has low dislocation density.

So there will be dislocation inside but that density will be low, so this is called a dislocation cell ok. So this dislocation cell forms under shockwave and this happens for these high stacking fault energy FCC materials.

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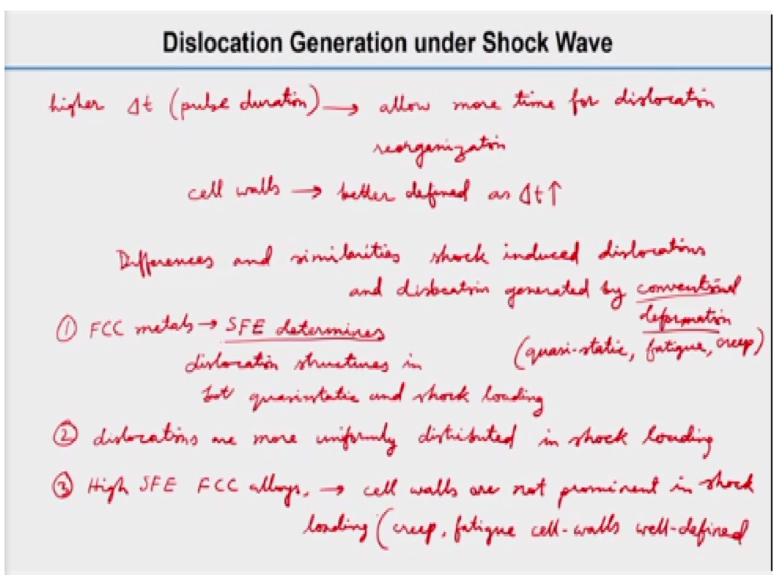

And also as we talked about the delta t shock pulse duration also effects, so what it does is it allow more time for dislocation reorganization. So rather I would write higher delta t will allow more time for dislocation reorganizations. So the dislocation cells what we have discussed in the earlier slide so the cell walls are better defined as this delta t increases.

So as delta t increases more and more dislocation will accumulated on the walls and the cell walls will be more prominent. There are differences and similarities between shock induced dislocation, dislocations and dislocations generated by other conventional means. So can use dislocations and dislocations generated by other or rather I would write by conventional deformation.

So conventional deformation means quite a static or let us say other deformations like normal fatigue or creep. So shock is the front and then we are considering others as you know conventional deformation. So we will discuss this differences all similarities, so what happens in FCC metals may it may include alloys as well. So the stacking fault energy SFE will determine you know the dislocation structure in both quasistatic and shock loading.

So this is a similarity that stacking fall another determines it and then dislocations are more uniformly distributed in shock induced case more uniformly distributed in shock loading as compared to other conventional deformation. And then in high SFE alloys that means high SFE we are talking about FCC alloys. The dislocation shield was I would rather write just cell walls are not prominent and shock loading. And as compared to others like creep or fatigue, so the cell walls are well defined that means more prominent.

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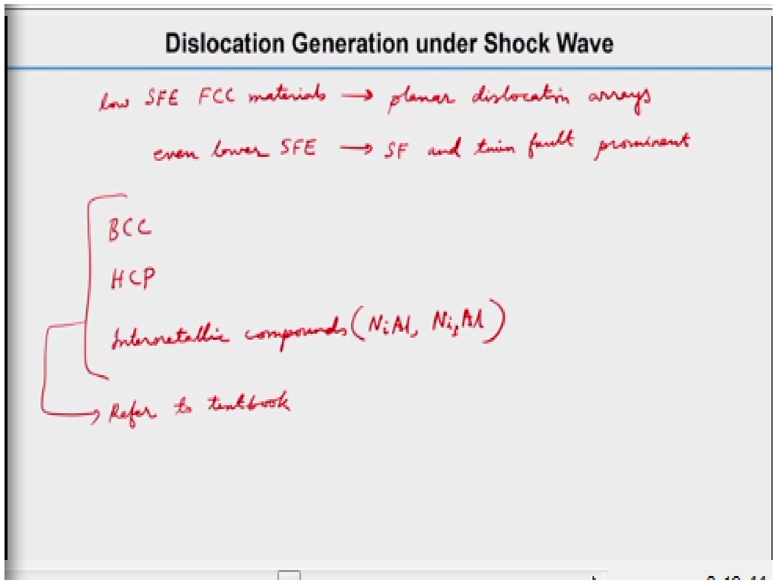

Similarly for low SFE that means low stacking fault energy FCC material, so planner dislocation arrays are generated. And even if it is lower even lower stacking fault energy, so stacking fault SF and twin fault this is another fault so twin fault are prominent ok. So then we will not talk about BCC or hexagonal close pack or let us say inter metallic compounds like in the in the Mark Meyer's book you will get Ni Al or Ni 3 Al.

So these things if you are interested probably you can refer to you know to your textbook or maybe you can search other literatures. So this is just to give you an overview of different materials have different behavior under shock loading and there are some similarities of this dislocation generation with the conventional deformation as well. So some similarities some differences but you should understand that shock loading is very different in you know for many mechanisms deformation mechanisms the generation of defects are very different sometimes.

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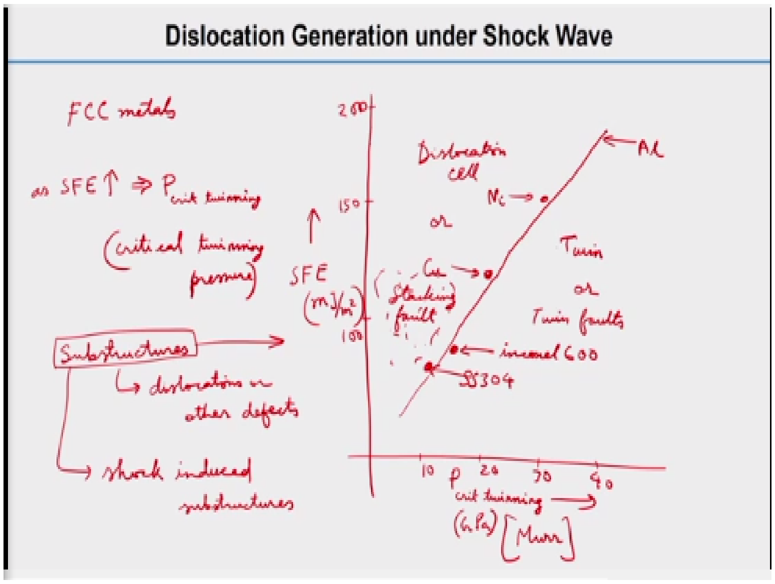

So what we will show here is we will show here in a plot, this is the reference is I think more I forgot a year though this is the reference. So that it is a very interesting plot of stacking fault energy and tracer for critical twinning so I will just like pressure critical twinning. So this is for FCC metals, so what we can see from this plot so that this plot shows that these obsessive metals will lie around this line.

So let us say we have some 304 steel here, this is 304 stainless steel or I will just write SS 304 this point here. And then let us say this one is inconel 600, then let us say here we have copper, here we have nickel and then somewhere here will be aluminum. So what happens is, so as stacking fault energy increases that you know 3 critical that is pressure for we should write just you know critical pressure sorry critical twinning pressure ok.

So from this we just want to show you the different substructures the word substructures, I think I have already told you this substructures means when we call micro structures that includes all. But when you call substructures this includes let us say dislocations or other defects. So this substructures words I should understand, so here we will show different types of soft structures these FCC materials undergo.

And these critical you know the twinning pressure **is** it high pressure this will be 10 these are in Giga Pascal it is Giga Pascal, so it let us say 10, 20, 30, 40 or something like that. So and here also this unit of this stacking fault energy will be milli Joule per meter square. So it is like 150, 100, 200 something like this, so what we need to understand here that so why we are drawing this so this area, around this area this will be you know stacking fault area, stacking fault.

And if you go higher here, so this will be dislocation cell, that means if you have a high stacking fault energy and the dislocation cell will be generated but then again if you are going on the other side right side of this probably line. So you will end up with twin at high pressure you will get twin and then for lower pressure you may get the twin false. So whether this twin or twin false will fall here or here dislocation cell or you know stacking fault.

This is just to you know show you what a different substructure at different value of you know stacking fault energy with critical twinning pressure. So these are all about we have talking here about shock induced substructures. So when you call micro structure that will give probably the mostly the grain structures and then other particles precipitates or dispersed particles or inclusions all includes I mean micro structure includes all of them.

And then the substructure means inside the grains, so what we will see like dislocations or other you know point defects or maybe some twins, so these are called substructures. So now there are different models of dislocation generation.

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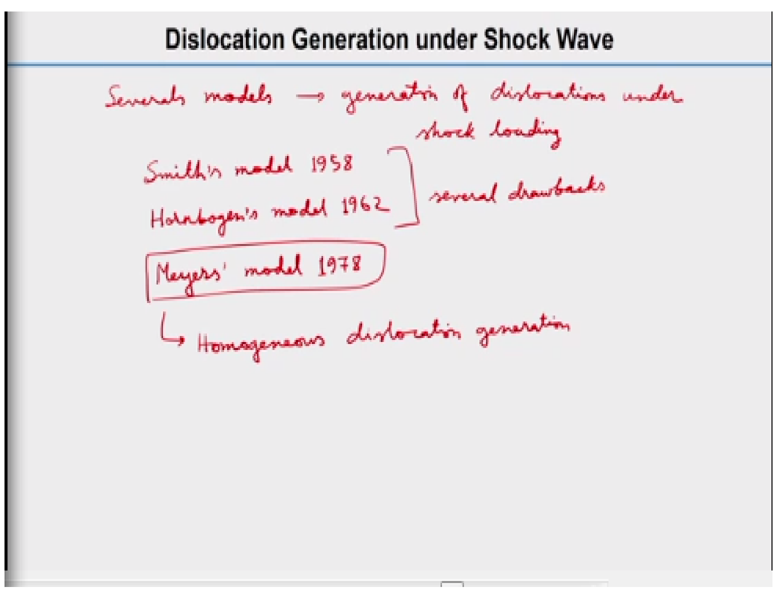

So several models were proposed for generation of dislocations under shock loading**.** So the very pioneer in this field is Smith's model Smith's model proposed in 1958 and then Hornbogen’s are proposed slightly after that 1962. And then we will discuss in this lecture about little bit about Meyer's model that is a proposed I think year 1978 and they are the models as well. So what we will discuss today is Meyer’s model, so that is called as homogeneous dislocation generation.

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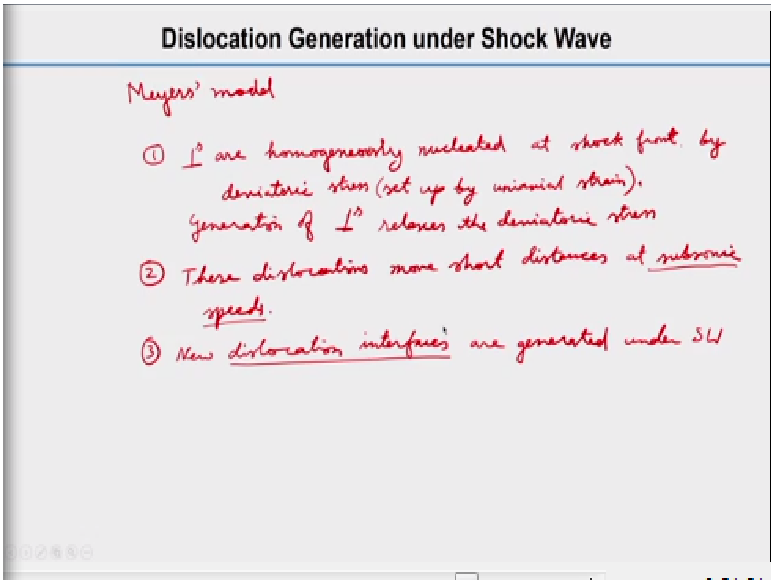

This Meyer’s model, so what it says is what are the essential features are it says that dislocations I would just write dislocations like this you know dislocations are homogeneously nucleated at shock front. When I say at shock front it can be very close to the shock front as well and by deviatoric stresses**,** this is set up by the uniaxial strain that you know that uniaxial strain is the characteristic of the shockwaves.

And what happens the generation of dislocation, so this generation of dislocations relaxes the deviatoric stress ok. And number 2, these dislocations move short distances at subsonic speeds. So why we are discussing here at the Meyer’s model and we are not discussing about this Smith’s and the other model Hornbogen models because they have several limitations, so I will just go back to that.

So these models have several drawbacks and there are more models, so we are not discussing much about what is not there in Meyer’s book. But the early models have several drawbacks and

Meyer's models try to address that and especially what we in this model it talks about the subsonic speeds but according to the Smith's model there are some supersonic dislocations but that was eliminated by Meyer's model. And number 3 is new dislocation interfaces are generated under shockwave, so what is this dislocation interfaces we will see in a diagram now.

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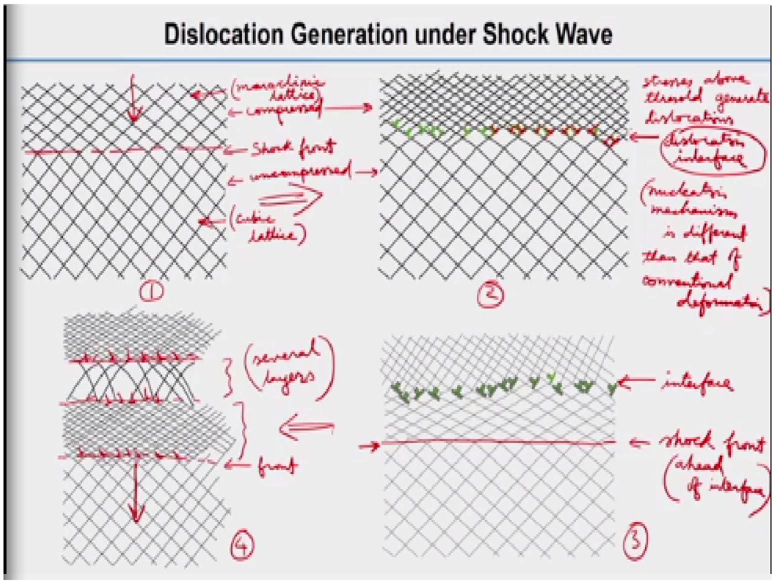

And then so we will just see with a diagram that is taken for Meyer's book, but that is not very perfect here. But just we will see here this is number 1 and then will go this way after some deformation this is number 2 and this is number 3 and this number 4, so sorry and then this is number 3 and then we will go this way this is number 4. So what happens if you can understand here there is some changes this is the shock front.

So the shock is coming from this way this is the front, so you can see that this is the compressed region and here it is uncompressed. Similarly in the second stage what we can say that this is uncompressed this is compressed region but in the stage 2 what is happening here is there are some dislocations you know generated. So what happens here and a dislocation that generated here but the first we should just I just need to tell you.

That uncompressed material this lattice was cubic, so by now you have understood these are what we are drawing these lines are these are lattice actually these are lattice the atomic planes we are drawing. And so and then here what happens is these lattices in the compressed regions are monoclinic lattice, monoclinic because of the deformation. So here it is cubic in this region and here it is monoclinic, so will the stresses will reach above a threshold level **so** so the stresses above threshold ok will generate dislocations.

So this is the generation of these dislocations you can see the extra half planes, here also these extra half planes, here extra half planes. So the planes are not continuous these are all dislocation the green ones these are all heads dislocation you are showing, so and this is called dislocation interface. So dislocation interface what is dislocation interface this is an array of dislocations that accommodates the differences of lattice parameters between the compressed and the uncompressed materials, so this is essentially you know array of dislocations.

So these nucleation mechanism dislocation nucleation mechanism is different in shock loading then that of you know conventional deformation as you know what is conventional deformation by now conventional deformation ok. And then what will happen is in the third case, so this is our dislocation interface, this is the interface we have and then the shockwave shock front will be here shock front we advance that will be ahead now ahead of interface**.**

So what happens is, this is what we got these are some dislocations we are not showing the dislocations what happens there are interface dislocation interface here, there is a dislocation interface here**.** So what will happen when the stresses at this point will be above the threshold, so then again there will be dislocation generated here, so that is what we are you know showing that dislocations will be generated this point as well ok and this is already there, so and there will be dislocations here as well.

So what happens is the front is here and this portion is a compressed zone, and then there will be a rear friction zone here. And then so that means there will be you know several layers of interfaces, so several layers of these interfaces will form, so this way it will move forward in this direction. So there are several arrays of or several interfaces of dislocations well the shockwave will propagate move.

So with that so we are closing today, so what we discussed is the dislocation generation mostly in today's lectures. So dislocation generation in shock loading is different than dislocation generation in conventional loading like quasi static loading or any creep or fatigue. So there are different models which were proposed which addresses this dislocation generation and movement during shock loading out of these we are discussing about the Meyer’s model and then we will continue this discussion in the next lecture, thank you.