**Dynamic Behaviour of Materials**
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**Lecture - 41**
**Plastic Deformation Under Shock Waves 3**

Hello everyone. So we were discussing about plastic deformation under shock wave and in the last lecture, what we discussed is the different dislocation generation models and we focused on Meyer's dislocation generation model. So we are not going to discuss much on that. So we probably will not touch on other models, different models of dislocation generation. So we will talk about today point defect generation very quickly.

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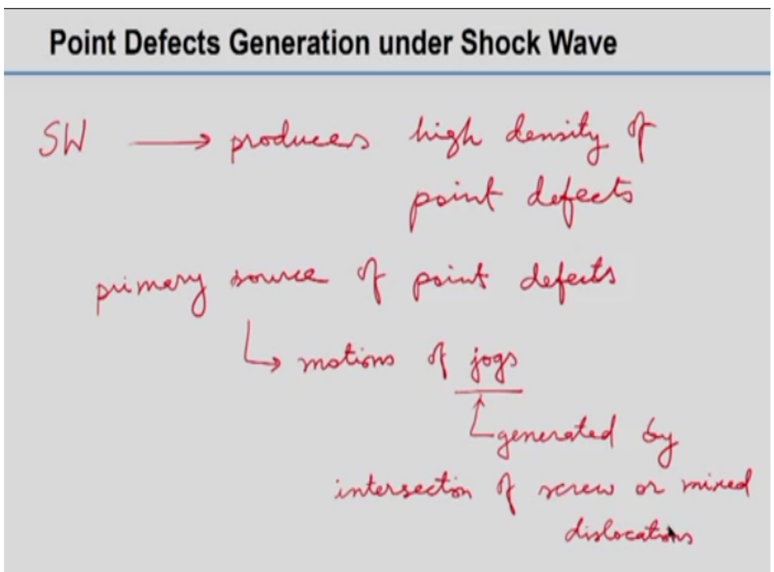


So I just want to tell you that shock wave loading produces high density of point defects. So as you know, point defects we already discussed in the material science basics class. So this point defects can be vacancy defects or interstitial. So the primary source of point defects is the motion of the jogs. So you please study about jogs if you are interested. Jogs are basically, sometimes it is called defects and defects. So jogs and kinks you can study about these defects in crystals.

So jogs are generally generated by intersection of screw or mixed dislocations. So we will talk about now the deformation twinning. We already discussed about twinning in our materials science basics class. So deformation twinning, why we call deformation twinning here because there is another one is called annealing twinning, which is formed during processing. So now this deformation is related to any kind of deformation like conventional deformation process likes quasi static deformation, but where we will talk about mostly of shock loading.

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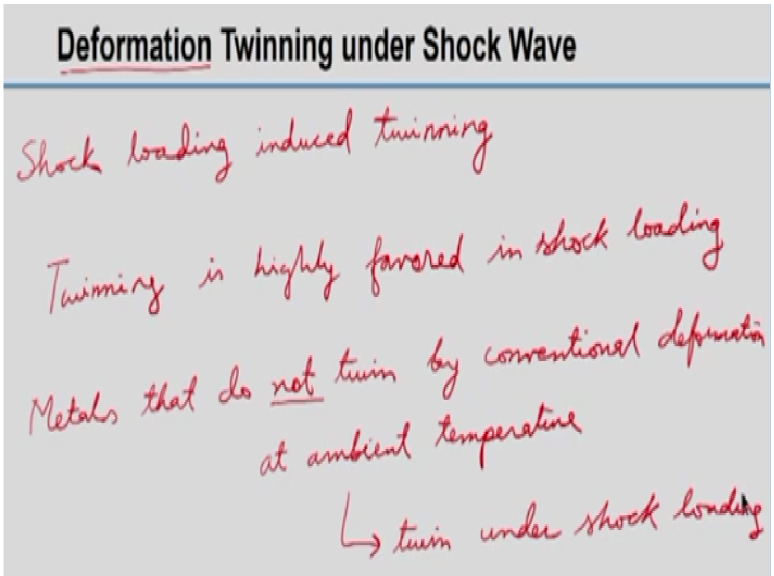


Shock loading that means deformation twinning induced, you know induced by shock loading. So I will just write shock loading induced twinning. One thing you need to understand that twinning is highly favored in shock loading. Highly favored means it is more favorable than in many cases, in many materials is more favorable than dislocation slip or slip due to dislocation motion. Suppose the metals that do not twin by conventional deformation.

Conventional deformation here we mean in the last class also we discussed is that, let us say for quasi static deformation, fatigue crepe or other kind of deformation not like very high strained loading. So high strained loading or shock loading is different. We are considering that as a different. So the metals that do not twin by conventional deformation at ambient temperature that means let us say at room temperature. It can be, you know, made to twin under shock loading.

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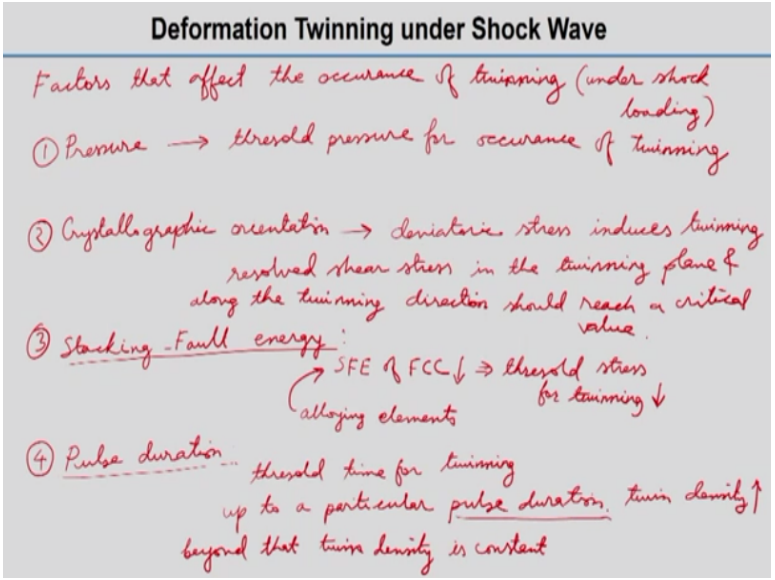


We will discuss about the different factors that affect the occurrence of twinning. So here mostly we are discussing twinning means under shock loading, but some of these are factors or effects of the factors are same in conventional deformation as well. The factors are pressure. Number two is crystallographic orientation. Number three is stacking fault energy that we have already discussed earlier also and then number four is pulse duration.

We have some more factor that we will discuss in the next slide. So or rather I would write all the factors first. So what we wrote is total five factors and then we have more factors.

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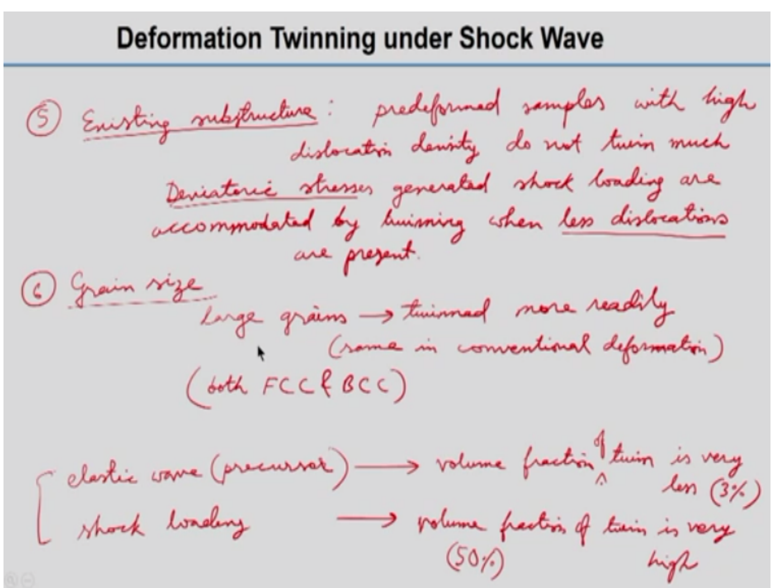

Existing substructures and then number six is grain size. So now coming back to the factors 1, 2, 3, 4, for the pressure there is one threshold pressure for occurrence of twinning and so for example for nickel some researchers found that it is 35 gigapascal. So above that the twinning occurs and then crystallographic orientation, it is important because the deviatoric stress or deviatoric component of stress is responsible for twinning or that induces twinning like what we discussed in the dislocation slip.

So the resolved shear stress in the twinning plane and in the twinning or a longer twinning direction should reach a critical value for, you know, twinning. So that is exactly same as the dislocation slip. So dislocation slip also we have the slip plane and thus some particular direction those are called slip directions and in dislocation slip also, we got that there is resolve shear stress, which should be greater than the critical resolved shear stress.

Which critical resolved shear stress is the material property, but here in this case of twinning the twinning planes are different; the twinning directions are different and the critical resolved shear stress will also be different that that is a material property. So that is why the crystallographic orientation is very important and stacking fault energy as we know stacking fault energy, especially for the obscene material.

When stacking fall energy decreases the threshold stress for twinning also decreases. So that is why if it has a lower stacking fault energy face centered cubic material, so the threshold stress will be less and that means the more tendency to form deformation twinning and sometimes alloying elements help to decrease the stacking fault energy. Alloying elements help to decrease the stacking fault energy.

And about the pulse duration some researchers found that there is a threshold time for twinning. time for twinning and some researchers they tried with you know different pulse duration and found that up to this particular time level, up to a particular actually pulse duration the twin density increases like dislocation density, twin density increases and beyond that twin density is constant. So we are talking about this, what particular pulse duration.

So before going to these factors, I just want to mention one more thing here that both the elastic precursor that means elastic wave which is called as precursor because it travels ahead of the shock wave first and so it also produces twin and then volume fraction or volume percentage of twin produced by elastic wave is very less and but about shock loading, so it should be all volume fraction of twin is very high.

For one of the material some researchers did that at 30 gigapascal with 1 microsecond pulse duration that volume fraction is 50% for shock loading at 30 gigapascal peak pressure and in this case that elastic precursor may produce only 3%. So this is just one example. So coming to the point the factor 5 the existing substructures, so it depends on the substructure present in the material sometimes if the samples are predeformed with high dislocation density.

So as you know if it is predeformed, deformed means deformation generates dislocations. So that means the dislocation density will be high. So these samples do not twin at all or sometimes they twin but less twinning, that means they do not win much. So as we know that the deviatoric component of stress, deviatoric stress generated by shock loading are accommodated by twinning when less dislocations are there, less dislocations are present.

So that I hope you understood it. So what happens if less dislocations available, then the deviatoric stress will contribute to twinning, but when there are more dislocations then the deviatoric stress will contribute to motion of the dislocation that means dislocations slip will you know dominate, if you have higher dislocation density. Coming to the grain size the factor number 6, so large grains twinned more readily than the smaller grains.

This is by the way even saying in conventional deformation not the characteristic of only shock waves. This is true for both FCC and BCC materials. So larger grain size lead to more twinning. We now understood that there are different factors that affect deformation twinning and some of these factors are same for both conventional deformation and shock loading.

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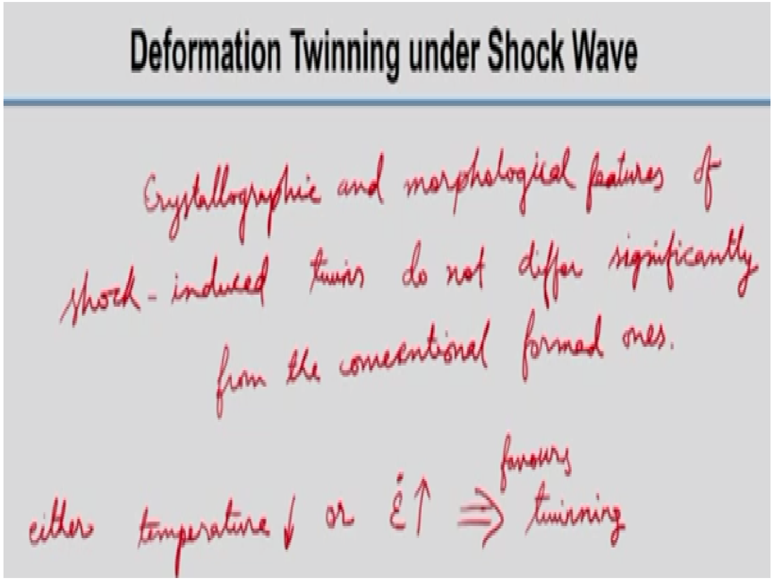


So the crystallographic and morphological features of shock-induced twins do not differ significantly conventional from the conventional formed ones, that means formed deformation twinning that formed due to conventional deformation. So it is very well established that either a decrease in temperature, either this or increase in strain rate so favours twinning. I should write favours twinning.

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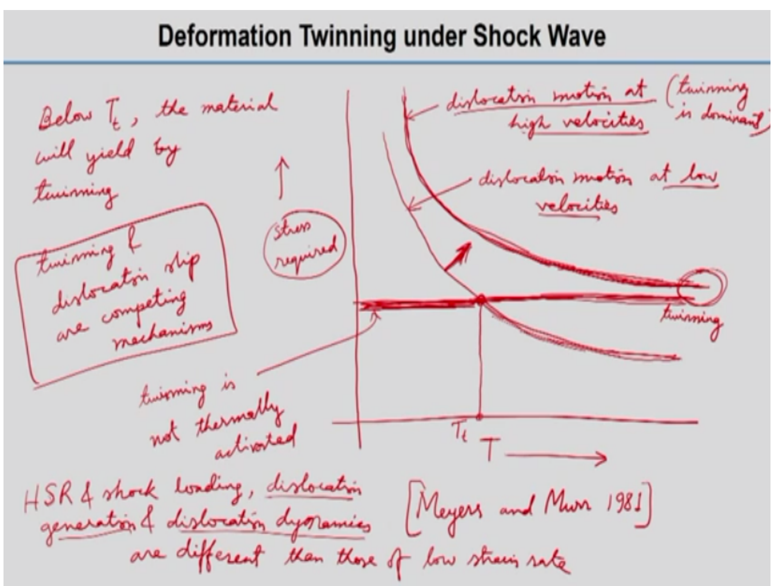


So we will just draw a plot form Meyer's and Murr in the reference, I think this is 1981. So this very interesting plot with temperature in the horizontal axis and then in the vertical axis stress required for twinning or slip. So we can see that this is a horizontal line for twinning that means stress required for twinning does not change with temperature. It almost, it is a very, by the way this is very ideal situation, probably there can be some changes.

But here it is, we can approximate as an almost constant and then there are other curves. First one is like this and another one will go something like this. So what these 2 curves, this first one is whatever we draw on first, this location, motion at low velocities and the second one is as you can guess that is this location, motion at high velocities. High velocities that means we are talking about high strain rate and shock loading.

What you can understand from this curve, the twinning curve, which does not depend on the temperature. So that means twining is not a thermally activated process. Twinning is not thermally activated. If you see, there is an intersection of the dislocation mentioned at the low velocities and the twinning curve. So this particular temperature, we can call Tt. So below Tt the material will yield by twinning and this region that means you know this region you can see that stress required.

Why we are saying that because stress required will be less. So this portion you can see that this is less, but I think above Tt that can be favorable. So as we can understand, again I am repeating this we have discussed earlier also. The twinning and dislocation slip are competitive mechanism. Twinning and dislocation slip are competing mechanisms. So that we should understand this, because whenever the stress required is probably less.

And stress required that means is all shear stress on the twinning planes on in the twinning directions or on the slip planes along the slip directions that is important and if that is higher than the critical stress value, then the slip will happen or twinning will happen and for this dislocation motion at high velocity, what you can understand from that that at high strain rate. So what we are talking is the dislocation motion at high velocities and if you see this curve.

So it is going and it is not probably intersecting, but at probably at high temperature it can intersect at twinning curve, okay but in this case we are not showing here. So high strain rate I would just write HSR for high strain rate and shock loading. So dislocation generation and dislocation dynamics, they are different than at low strain rates are different. Difference means different than low strain rate, than those of low strain rate deformation processes.

So that is why you can see that the shift from this curve to this curve. So earlier as you can understand that at low velocities the curve looked like this and that is a shift kind of it. It looks like a parallel curve and it is due to dislocation generation mechanisms and dislocation dynamics are different at high strain rate and if you can see that these curves can probably can intersect at a very high temperatures. So that means the twinning is dominant.

So that means for high strain rate, twinning is dominant. Why twinning is dominant? Because if you see, if you compare these curve at high strain rate, the dislocation motion curve and the twinning curve. So if you compare them, you can see that all the way the twinning is the lower one that means stress required for twinning is less and maybe at a very high temperatures these curves can intersect and it can happen that sometimes this dislocation motion can be more favorable.

But I think this reference Meyers reference say that this is probably can happen only, probably very high temperatures. So with that so we are closing for today. So we will discuss a little bit of more on this and we will go forward to plastic shear instabilities that is shear band and then finally to dynamic flexure. Thank you.