Mechanical Behavior of Materials
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Lecture - 62
Fatigue - III

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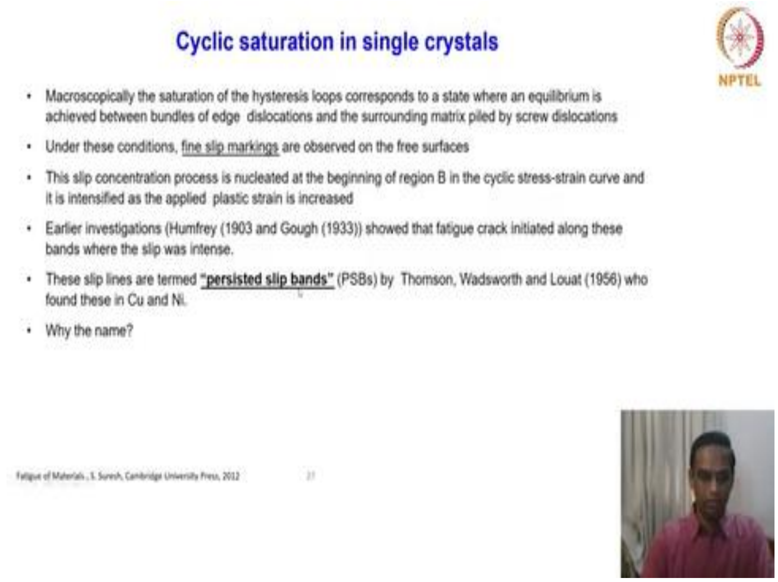

Cyclic saturation in single crystals

- Macroscopically the saturation of the hysteresis loops corresponds to a state where an equilibrium is achieved between bundles of edge dislocations and the surrounding matrix piled by screw dislocations
- Under these conditions, fine slip markings are observed on the free surfaces
- This slip concentration process is nucleated at the beginning of region B in the cyclic stress-strain curve and it is intensified as the applied plastic strain is increased
- Earlier investigations (Humfrey (1903 and Gough (1933)) showed that fatigue crack initiated along these bands where the slip was intense.
- These slip lines are termed **"persisted slip bands"** (PSBs) by Thomson, Wadsworth and Louat (1956) who found these in Cu and Ni.
- Why the name?

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Hello, I am Professor S. Sankaran in the department of metallurgical and materials engineering. Hello everyone, welcome to this lecture and we are looking at currently the deformation microstructure details of the single crystal subjected to strain-controlled fatigue or low cycle fatigue. So, in the last class we were discussing about the cyclic saturation the single crystals and I just go through review this quickly and then we will take this discussion forward.

So, in single crystal, which are subjected to cyclic deformation under strain-controlled mode results in the hysteresis loop corresponds to a state where an equilibrium is achieved between bundles of edge dislocation and surrounding matrix piled by screw dislocation. This is one hypothesis. Under these conditions fine slip markings are observed on the free surfaces. This slip concentration process is nucleated at the beginning of region B.

In the cyclic stress strain curve and it is intensified as the applied strain is increased. So, what you have to now appreciate this we are now talking about the three stages of a cyclic stress strain curve like A B C like we have divided this stress strain curve, we have discussed in the last lecture how to generate this cyclic stress strain curve. It is the peak tensile stress of all the hystersis loops are connected from the first cycle to the saturation cycle.

So, then it does and then it is analysed as a shear stress versus shear strength curve under the cyclic deformation. So, now we are looking at now the region beginning of the region of this the cyclic stress strain curve and what are the microstructural aspects which are accompanying that deformation, that is how we should look at it. So, earlier investigation showed that fatigue crack initiated along these bands where the slip was intense.

And these slip lines are termed persisted slip bands like we have seen yesterday it is popularly called as PSBs which is proposed by Thomson Wadsworth and Louat in 1956 who found these PSBs in copper and nickel. And the name is because it is the slip is through thickness slip of material. So, that is why it is called a persisted slip band.

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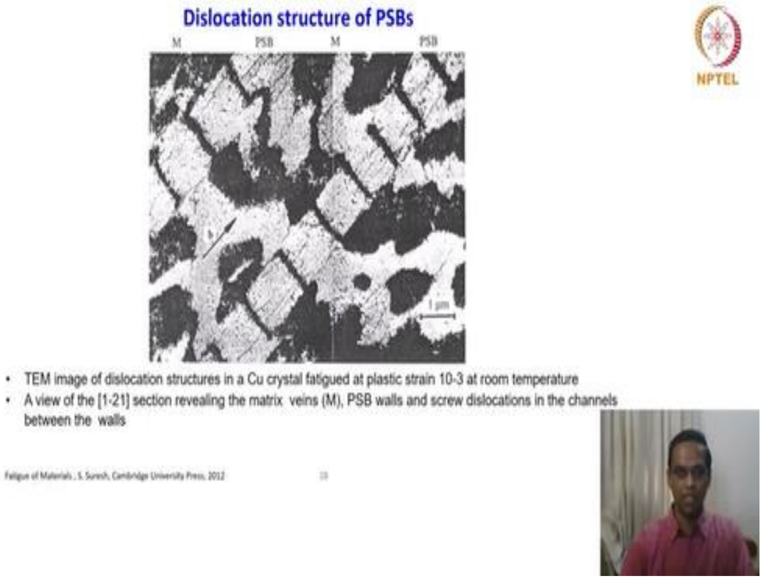

Dislocation structure of PSBs

- TEM image of dislocation structures in a Cu crystal fatigued at plastic strain 10-3 at room temperature
- A view of the [1-21] section revealing the matrix veins (M), PSB walls and screw dislocations in the channels between the walls

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So, you can see this is a typical fatigued microstructure obtained in a copper single crystal in the plastic strain of 10^{-3} at room temperature. And what you are the purpose of this slide is to give you a glimpse of you know signature microstructure or feature typical feature which you see only under 50. You do not see it under any other deformation condition. So, what you see? This is a PSBs and this is a matrix where you have bundles of dislocations are there.

And so, you can see the later structure of PSB and the PSB walls matrix veins are you know irregular and you know entangled and PSB walls and screw dislocations in the channels between the walls. So, you will have all the screw dislocations channels in the inside the I mean along the wall or inside the wall and so on. So, but you do not have to worry about these details; but what you should appreciate in this slide is. What is the primary signature of this fatigue microstructure?

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Dislocation structure of PSBs

- The dislocation found with in PSBs is considerably different from that of the matrix
- The matrix contains, about 50% by volume, vein-like structures consisting of dense arrays of edge dislocations.
- On the other hand PSB structure is generated due to the mutual blocking of glide dislocations and the formation of parallel wall (ladder) structures which occupy about 10% by volume of the PSBs (Laufer & Roberts, 1966, Woods, 1973, Mughrabi, 1980)

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That is what my intention. The dislocation found with within PSB is considerably different from that of matrix. The matrix contains, about 50% by volume vein like structures consisting of dense arrays of edge dislocations. On the other hand, PSB structure is generated due to mutual blocking of glide dislocations and the formation of parallel, that is a ladder structure which occupy 10% by volume of PSBs is reported by these authors.

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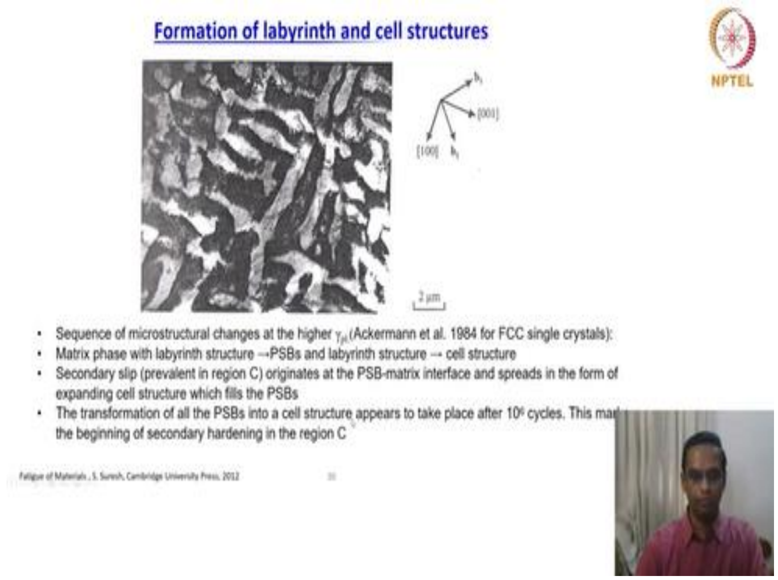

Formation of labyrinth and cell structures

- Sequence of microstructural changes at the higher γ_{pl} (Ackermann et al. 1984 for FCC single crystals):
- Matrix phase with labyrinth structure →PSBs and labyrinth structure → cell structure
- Secondary slip (prevalent in region C) originates at the PSB-matrix interface and spreads in the form of expanding cell structure which fills the PSBs
- The transformation of all the PSBs into a cell structure appears to take place after 10^6 cycles. This ma the beginning of secondary hardening in the region C

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This is where we stopped yesterday and the typical microstructure which forms after you know. The sequence of microscopy changes at higher plastic string. So, we are now looking at stage region b and then we are going to and see now this is typically for FCC semi crystals. And formation of labyrinth and cell structure so labyrinth this is nothing but because of its arrangements. You can see that it is almost appearing like a labyrinth structure.

And then you also see some cell structure so, you can see the cell structure here. So, this is a signature of the microstructural evolution at the higher plastic strain during fatigue. Matrix phase with the labyrinth structure PSBs and labyrinth structure finally cell structure. So, these are the signatures microstructural features for the higher plastic strain amplitude region. Secondary slip prevalent in the region C because it is high strain rate, I mean high strength high plastic strain.

Secondary slip originates at the PSB matrix interface and the spreads in the form of expanding cell structure which fills the PSB. So, these are all some of the key observations. The transformation of all PSBs into cell structure appears to takes place after 10^6 cycles. This marks the beginning of secondary hardening in region C. So, you can see that the stress strain curve goes up a little bit up right like the third stage.

So, that is considered as a secondary hardening so, that happens after the all the PSBs dissolves into cell structures. So, that is one way of understanding how the dislocation substructure you can witness at least.

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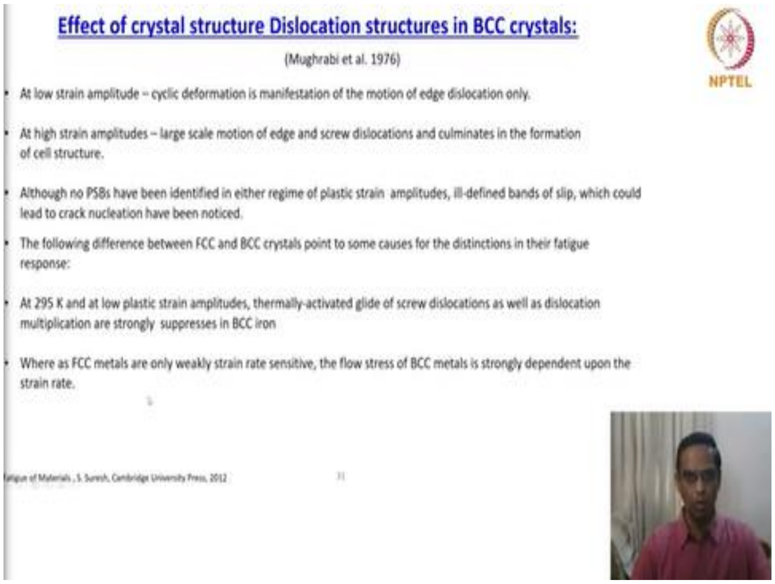

Effect of crystal structure Dislocation structures in BCC crystals:

(Mughrabi et al. 1976)

- At low strain amplitude – cyclic deformation is manifestation of the motion of edge dislocation only.
- At high strain amplitudes – large scale motion of edge and screw dislocations and culminates in the formation of cell structure.
- Although no PSBs have been identified in either regime of plastic strain amplitudes, ill-defined bands of slip, which could lead to crack nucleation have been noticed.
- The following difference between FCC and BCC crystals point to some causes for the distinctions in their fatigue response:
- At 295 K and at low plastic strain amplitudes, thermally-activated glide of screw dislocations as well as dislocation multiplication are strongly suppresses in BCC iron
- Where as FCC metals are only weakly strain rate sensitive, the flow stress of BCC metals is strongly dependent upon the strain rate.

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So, now let us discuss about the effect of crystal structure dislocation effect of crystal structure dislocation and structures in a BCC crystal. So, structure and dislocation structures in BCC. At low strain amplitude cyclic deformation is manifestation of motion of edge dislocation only. At high strain amplitudes large scale motion of edge and screw dislocation and culminates in the formation of cell structure.

So, this is in contrast to what we have seen in an FCC crystal that is what we have to see. Although, no PSBs have been identified in either region of plastic strain amplitudes in BCC crystal, ill-defined bands of slip which could lead to crack nucleation have been noticed. So, what you should appreciate here is the microstructure develops or the dislocation substructure develops in this BCC is quite different from the FCC.

That is the bottom line you have to keep in mind. Other details are I mean you can you can just learn as the as you go to the higher learn but the basic difference you have to just appreciate. The following difference between BCC FCC crystal points to some causes of distinction I mean distinctions in their fatigue response. At 295K and at low plastic strain amplitudes thermally activated glide of screw dislocation as well as dislocation multiplications are strongly suppresses in BCC iron.

Where as in FCC metals are only weakly strain rate sensitive, the flow stress of BCC metals is strongly dependent on the strain rate. So, all these aspects we know already see that is why we you know we study all the basics of you know deformations in the beginning itself. Now you can just take what is the change that happens because of the fatigue loading. That is the point we have for example PSB which we have never seen.

That is coming just only because of the pretty, but other things we have already know from the basic dislocation mechanisms during deformation the strain rate effect temperature effect all these things we know. So, we can just correlate all of them together.

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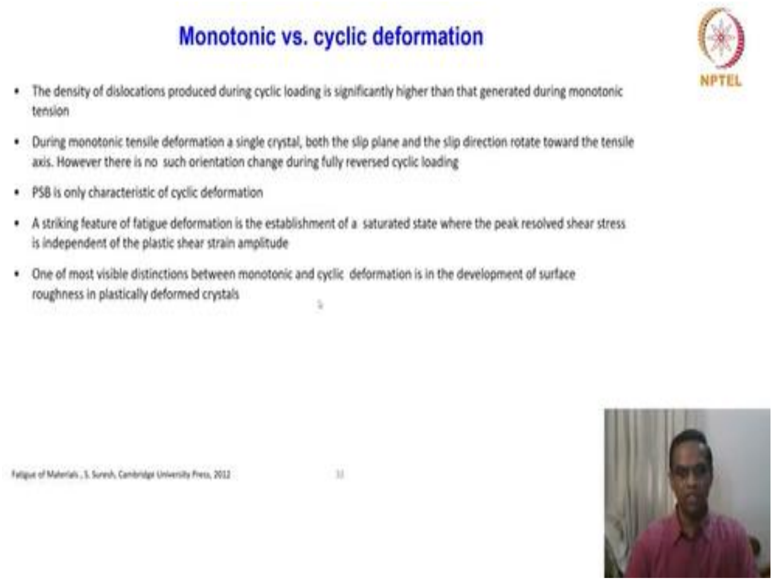

Monotonic vs. cyclic deformation

- The density of dislocations produced during cyclic loading is significantly higher than that generated during monotonic tension
- During monotonic tensile deformation a single crystal, both the slip plane and the slip direction rotate toward the tensile axis. However there is no such orientation change during fully reversed cyclic loading
- PSB is only characteristic of cyclic deformation
- A striking feature of fatigue deformation is the establishment of a saturated state where the peak resolved shear stress is independent of the plastic shear strain amplitude
- One of most visible distinctions between monotonic and cyclic deformation is in the development of surface roughness in plastically deformed crystals

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We do not have to I mean we can just move forward. Now the important point is to appreciate the one of the difference between monotonic and cyclic deformation. The primary difference in the microstructure in the density of dislocations produced during cyclic loading is significantly higher than the generated during the monotonic function. So, this is very, very important and it is clearly evident.

Yesterday we have seen that you know the stress strain curve of you know are basically a shear stress versus shear strain plots of monotonic versus cycling. We have seen that in a cyclic deformation the plot exhibits you know significant accommodation of plastic strain during cyclic load as compared to monotonic load. So, that clearly shows that these that also will clearly relate that the kind of microstructures which is going to develop during the cyclic loading.

So, that is what we are seeing now. During monotonic tensile deformation in a single crystal both the slip plane and the flip direction rotate towards the tensile axis. However, there is no such orientation change during fully reversed cyclic loading. PSB is the only characteristic of cyclic deformation. A striking feature of fatigue deformation is the establishment of saturated state. So, this is another characteristic point we have to I mean characteristic features you have to remember as far as the cyclic deformation is concerned.

So, all the hysteresis loop reaches the cyclic saturated state. That is why we even write that σstress, σ stress correspond to the saturation. That is called saturation stress but here we are talking about saturation state of the microstructure. Where the peak resolved shear stress is independent of plastic shear strain amplitude. One of the most visible distinctions between monotonic and cyclic deformation is in the development of surface roughness in plastically deformed crystals.

So, what in a monotonic deformation we develop a slip step you can see because of the slip but in cyclic deformation it is going to be very different.

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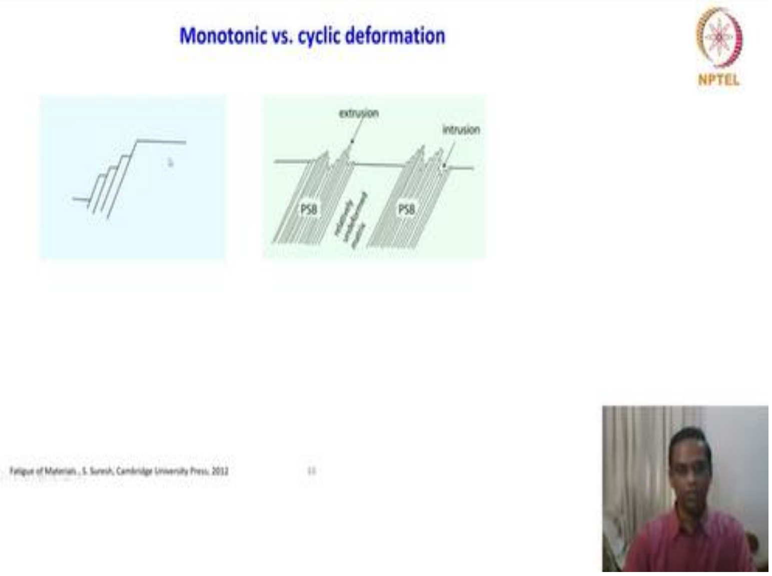

Monotonic vs. cyclic deformation

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So, this is what it is in a cyclic deformation we have a characteristic feature intrusions and extrusions. These are surface markings you can clearly identify in the fracture surface. Most of the fatigue loading I mean fatigued sample we call it you can see that you know extrusions and intrusions. And they are all happen they all happens at a bundles with some you know it is not going to happen uniformly in the matrix you have some undeformed matrix also in between.

But this you know the pile of crystals which comes out as an extruded member and then also included. On the other hand, in a slip which is like a the crystals just deforms like a steps. This is a primary difference between one of the primary differences between these two deformations.

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Cyclic hardening and softening in polycrystals

- As a general rule of-thumb, well annealed, polycrystalline metals of high purity exhibit cyclic hardening due to dislocation multiplication, as evidenced by an increase in the stress amplitude with fatigue cycles;
- Work hardened material undergo strain softening under cyclic loading
- The rearrangement of pre-strain induced dislocation networks due to fatigue is believed to cause cyclic softening

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So, now we just extend these ideas like whatever we have seen in the deformation the single crystal and then we will try to relate to the polycrystal. As a general thumb I mean general rule of thumb well annealed polycrystalline metals of high purity exhibit cyclic hardening due to dislocation multiplication as evidenced by an increase in the stress amplitude with fatigue cycles. So, in a pure poly crystalline material the especially you know a copper kind of material.

In an annealed state it exhibits completely cyclic hardening. So, that is because of the work hardened. So, work hardening in a monotonic deformation here it is cyclic loading. And work hardened material undergoes strain sharpening and cycling this is also true in even in monotonic loading. So, the work hardened material eventually softens here also the cyclically hardened material eventually softens as the number of cycles increases.

And what are the reasons? The rearrangement of pre-strained induced dislocation networks due to the fatigue is believed to cause cyclic softening. So, here we talk about recovery here also similar effects so all the dislocation rearrangement takes place which leads to cyclic softening.

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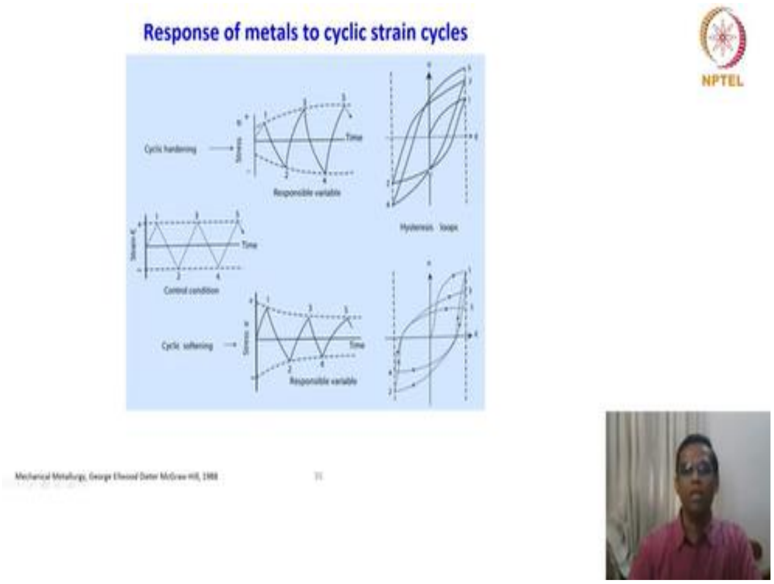

Response of metals to cyclic strain cycles

Mechanical Metallurgy, George Ellwood Dieter McGraw-Hill, 1988

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So, how do you observe whether the material is being you know subjected to cyclic hardening and softening? Just by looking at the stress strain response while the testing is going on you will get this data. So, we have this you know this is a strain-controlled test so you have a strain versus time. So, you can suppose if you are using this kind of a waveform for the test and in a cyclic hardening what you observe is see you have the controlling the strain and then observe what is the stress response.

So, that is how you should look at it. So, as the number of cycles increases then you can see that there is a stress increase the peak tensile stress increases. In terms of hysteresis loop you can see that it starts from 1 and it go through 2, 3 and 4 and 5 so it reaches, so if you can keep on the edge of this hysteresis loop is keep on increasing 1 3 5 and so on. So, this is hardening and also you see that in the strain axis the hysteresis loop becomes thinner and thinner as it goes out.

So, that is one thing and cyclic softening it is entirely opposite what you are observing there so the stress is coming down with respect to time and the strain is keep on increasing. So, that means the hysteresis loop become bulkier and bulkier as the cycle number of cycle increases the strain also increases. Please remember this is a plastic strain we are talking about because this is a strain control. All the strain-controlled fitting we are talking about plastic strain.

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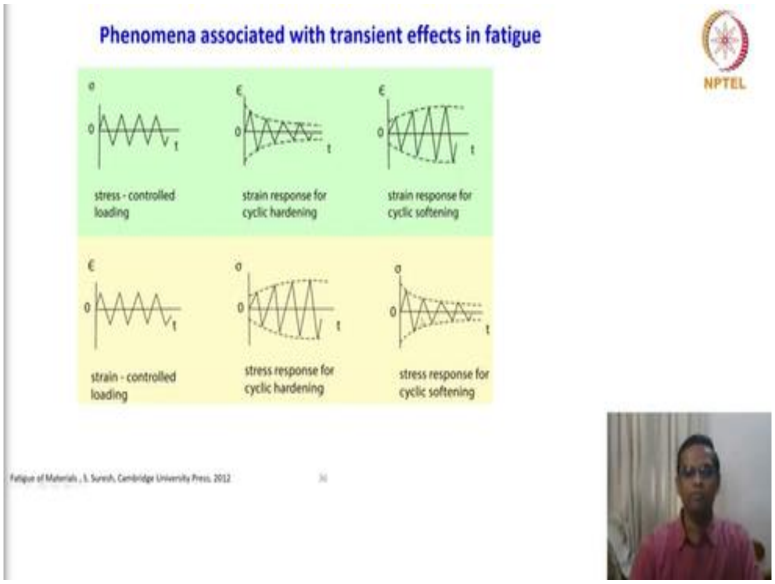

Phenomena associated with transient effects in fatigue

stress - controlled loading

strain response for cyclic hardening

strain response for cyclic softening

strain - controlled loading

stress response for cyclic hardening

stress response for cyclic softening

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So, that is similar plot and just give the comparison of these two stress control loading you observe the strain response. And if it is a cyclical harden and strain will keep on reducing with respect to time and the strain response for cyclic softening. But it will keep on increasing here like we have just seen in the previous slide. For a strain controlled loading a stress response for the cyclic hardening will be like this and stress response for the cyclic softening will be like this.

So, it is exactly this kind of behaviour you can see that but here it is strain but here is stress here is a strain and here is a stress. So, it is quite interesting to compare all of them together like this.

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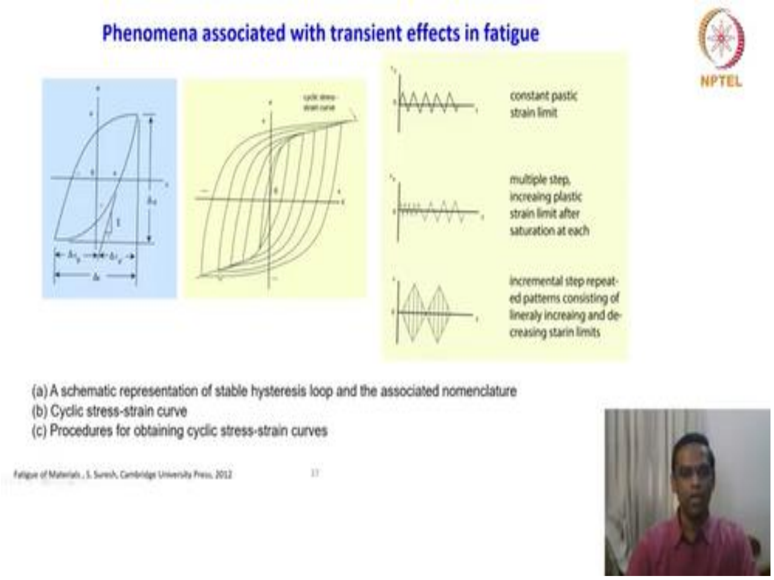

Phenomena associated with transient effects in fatigue

(a) A schematic representation of stable hysteresis loop and the associated nomenclature
(b) Cyclic stress-strain curve
(c) Procedures for obtaining cyclic stress-strain curves

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To appreciate what are the associated transient effects in fatigue? So, this plot just give you an idea about what are the parameters how they are designated. For example, since it is a range of strain, we are talking about it is always designated as Δ_ε and then this is Δ_σ. So, in cyclic loading the stress is in between the range so, it is always designated as Δ_σ.

So, hysteresis loop is shown here and this is a plastic strain and this is an elastic strain range and plastic strain range. And so, this is a typical stress strain I mean hysteresis loop and if you connect all the corners of the edges of the blue and then this this represents the cyclic stress strain curve. So, in the previous I mean previous lecture we were talking about only this portion of this so you are showing also your third stage.

So, this is the second stage, this is a stage a, b, c like that we have seen in the and then we also discussed the microstructural changes associated with this. And this particular schematic shows the procedures for obtaining the cyclic stress strength curve. So, how do we where do you stop and how do you generate cycle stress curve? Suppose if you are taking the constant strain stress then you choose particular strain amplitude.

And then waveform and then keep on cycling as a function of time till the saturation reaches. So, once the saturation is reached then you can take the data from like this. So, the final loop has to be saturated then you can take the stress strain curve data and just cyclic stress strain data. And this is for the constant strain plastic strain amplitude and if it is not constant if it is a multiple step then what you have to do is you just cycle the material at different strain amplitudes.

With the; increasing plastic strain amplitude after the saturation at each stage. So, for example this a small lower strain amplitude so, it has to reach the saturation. Then you start increasing the amplitude and then it will again start you know a new hysteresis loop and then it has to saturate. So, at every stage or every type of the strain or a waveform you choose we need to wait for the saturation to come. That is the idea.

Then it is ready to collect the stress strain data. So similarly, for an incremental step repeated patterns consisting of linearly increasing and decreasing strain limit. So, this is increasing and decreasing increasing and decreasing so you just do this till you reach the saturation. So, that is a one way of looking at how to generate the cyclic stress strain curve.

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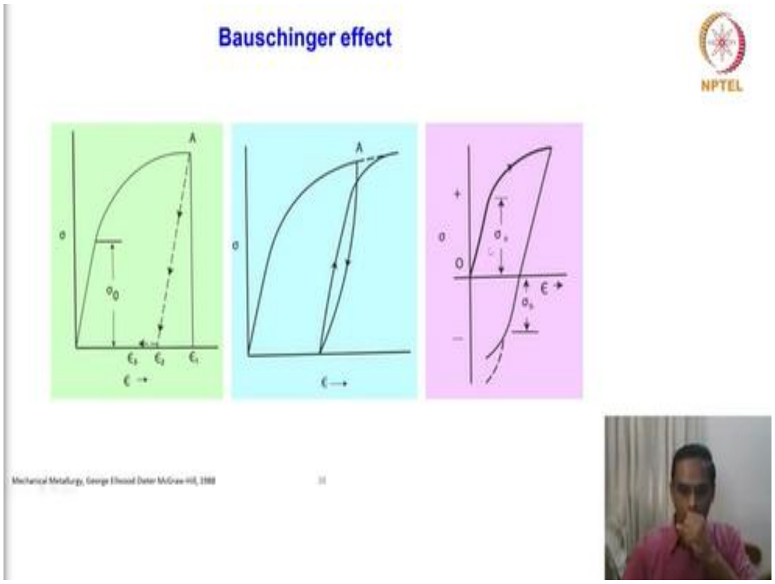

Bauschinger effect

Mechanical Metallurgy, George Ellwood Dieter McGraw-Hill, 1988

Now we will turn our attention to one important point very fundamental idea Bauschinger effect. So, we all know that a two stress two strain curve and this is a I mean the curve which is not it is a continuous yielding without any sharp yield point. So, assume this is a σ_0 a proof stress and suppose after reaching this point if you just unload then immediately you will be able to recover some elastic energy or elastic strain.

So, from ε_1 to ε_2 this is immediate but after some time also some of the materials will try to relax some more elastic strength. So, that is anelasticity that also we understand. On the other hand, if you just cross a plastic region here and then unload it is not going to come back on this because you are in the plastic range. And you are going to unload here then you reach here and then suddenly start loading then the stress strain will start from here.

So, this is we know this also we have discussed during you know tensile monotonic deformation we have discussed all this behaviour. But what we have not discussed so far is suppose if you come down in compression immediately, then what happens? We have discussed in the elastic region in the elastic properties in anelastic behaviour we have discussed. But in a plastic region we have not discussed closely.

So, what happens you are crossing this σ_0 and reaching this for a plastic region and then unload it? So, you have some elastic rectory will take this but then eventually you are changing the load direction, then what happens? So, that is the question now. So, the what you have to observe here is interestingly suppose if your σ_0 is a yield point in this direction and the material is subjected to tensile loading.

When the load is reversed in the compression direction and now the material will yield at much lower strength level as compared to in a tension. So, that is the idea. So, that is why this is considered to be or this is referred to us due to Bauschinger effect. That is why σ_b. So, now we will see in detail, why it happens?

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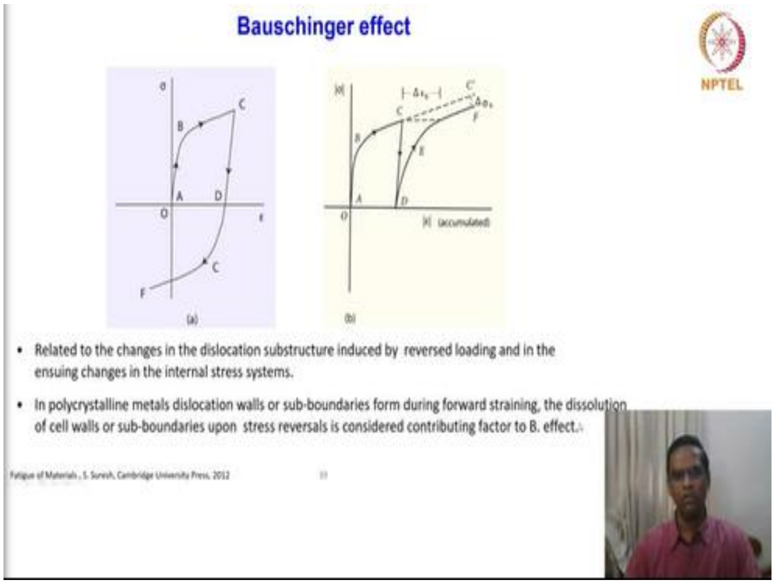

Bauschinger effect

- Related to the changes in the dislocation substructure induced by reversed loading and in the ensuing changes in the internal stress systems.
- In polycrystalline metals dislocation walls or sub-boundaries form during forward straining, the dissolution of cell walls or sub-boundaries upon stress reversals is considered contributing factor to B. effect.

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We will replot this and then it is you know. It is reconstructed in this form it is the compression only but it is just for the reference it is being reconstructed. So, do not get confused with that. So, you have this the $\Delta_{\sigma b}$ the difference in the stress in the reversal loading is given as $\Delta_{\sigma b}$. So, this is $\Delta_{\varepsilon b}$ this is a strain and this is the stress. So, this is Bauschinger effect is related to changes in the dislocation substructures induced by reverse loading.

And in ensuing changes in the internal stress systems. It is a general comment we are talking about general comment. It is related to dislocation substructure changes see you know that I know in terms of deformation particular not type of deformation substructures or dislocation substructures evolve. We in fact we have immediately we have just referred this to even work hardening behaviour and cell structure formation in cell wall formation so on.

But when it happens when it get reversed then what happens to all this dislocation substructures that is something related to this. In polycrystalline metals dislocation walls and sub boundaries form during forward straining, the dissolution of for the cell walls and some boundaries upon stress reversals is considered contributing to Bauschinger effect. So, it is basically whatever the substructures evolve it get dissolves little bit. So, that is one of the causes people have hypothesized this is one idea.

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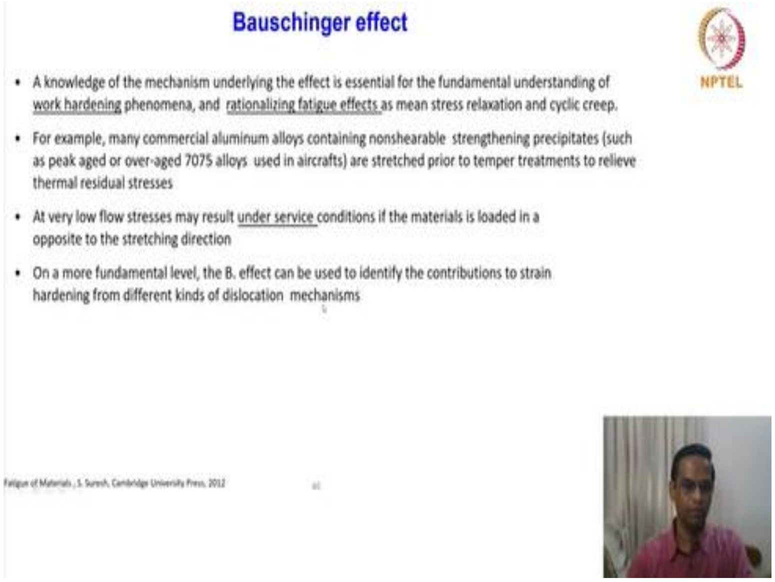

Bauschinger effect

- A knowledge of the mechanism underlying the effect is essential for the fundamental understanding of work hardening phenomena, and rationalizing fatigue effects as mean stress relaxation and cyclic creep.
- For example, many commercial aluminum alloys containing nonshearable strengthening precipitates (such as peak aged or over-aged 7075 alloys used in aircrafts) are stretched prior to temper treatments to relieve thermal residual stresses
- At very low flow stresses may result under service conditions if the materials is loaded in a opposite to the stretching direction
- On a more fundamental level, the B. effect can be used to identify the contributions to strain hardening from different kinds of dislocation mechanisms

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A knowledge of the mechanisms underlying the Bauschinger effect is essential for fundamental understanding of work hardening phenomena and rationalizing fatigue effects as mean stress relaxation and cyclic creep. So, this effect Bauschinger effect is quite important to understand because even in monotonic work hardening phenomena we have to understand because it reverses some of the dislocation substructures.

And we can rationalize the fatigue effects because fatigue is cyclic loading and also cycling creep which is important. For example, many commercial aluminium alloys containing non-shearable strengthening precipitates such peak aged over aged 7075 alloys used in aircrafts are stretched prior to temper treatments to relieve thermal residual stress. This is about you know the we have talked in fracture mechanics of proof stress.

So, this is not that proof testing in a shop floor where to generate a plastic zone at the crack tip but here we are talking about no fracture no crack. But just as a coparent which is assumed to be a defect free is subjected to a stretching in order to relieve the thermal residual stresses. That also we will take care of this kind of Bauschinger effect. At very low flow stresses may result under service conditions the material is loaded in an opposite to stretching direction.

So, this has to be monitored because this street stretching this treatment is done for the relieving the residual stresses. But then we have to take care which is not you know loaded in the opposite direction of the stretching. That is where the significance of Bauschinger effects comes. On a more fundamental level the Bauschinger effect can be used to identify the contributions to strain hardening from different kinds of dislocation mechanisms.

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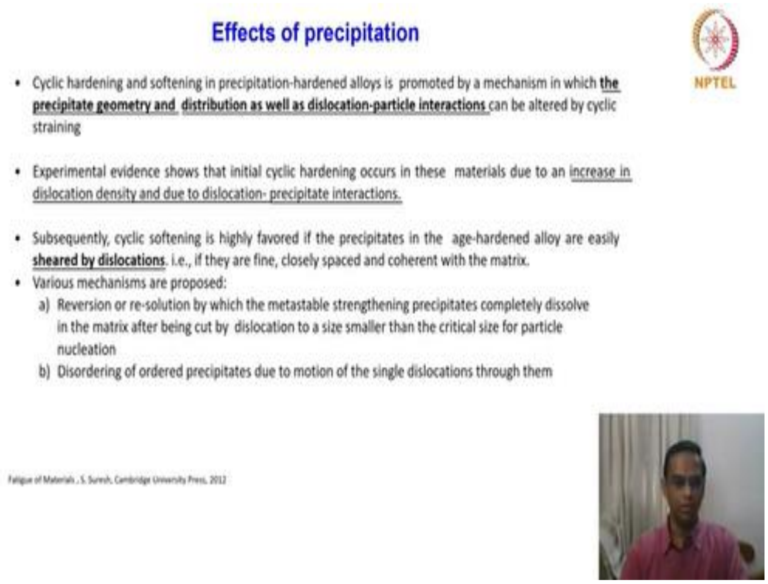

Effects of precipitation

- Cyclic hardening and softening in precipitation-hardened alloys is promoted by a mechanism in which **the precipitate geometry and distribution as well as dislocation-particle interactions** can be altered by cyclic straining
- Experimental evidence shows that initial cyclic hardening occurs in these materials due to an increase in dislocation density and due to dislocation- precipitate interactions.
- Subsequently, cyclic softening is highly favored if the precipitates in the age-hardened alloy are easily **sheared by dislocations**. i.e., if they are fine, closely spaced and coherent with the matrix.
- Various mechanisms are proposed:
  a) Reversion or re-solution by which the metastable strengthening precipitates completely dissolve in the matrix after being cut by dislocation to a size smaller than the critical size for particle nucleation
  b) Disordering of ordered precipitates due to motion of the single dislocations through them

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This is also one important aspect of Bauschinger effect. So, now we will anyway Bauschinger effect is related to fitting that is why I brought it to this section. And we will now look at what are the other aspects of you know cyclic loading. One of the important aspects is effects of precipitation. Cyclic hardening and softening in precipitation hardened alloys is promoted by the mechanisms in which the precipitate geometry and distribution as well as the dislocation particle interaction can be altered by cyclic straining.

So, we have the background of understanding the precipitate dislocation interactions. So, this how this interaction is now getting affected by the cyclic straining is, that another question. There is a new effect like the PSB formation we have discussed about a dislocated substructure even though we know some idea about dislocation substructure in monotonic loading. Similarly, we have some idea about dislocation particle interaction.

In addition to that what is the cyclic straining effect on that particular interaction is the question. Experimental evidence shows that the initial cyclic hardening occurs in these materials due to an increase in dislocation density and due to dislocation precipitate interactions. So, it contributes to cyclic hardening little bit to start with. Subsequently, cyclic softening is highly favoured if the precipitates in the age hardened alloy are easily sheared by dislocations, very important point.

That is if they are fine closely spaced and coherent with the matrix. So, this particular sentence you know we can completely understand we have a sufficient background to understand every word of it. Because we have seen how dislocation when the dislocation will shear the particle and how they are related to the size of the particle and spacing between the particle and whether it is coherent or inherent, all the aspects we know.

So, the once the cyclic strain is going to destroy all this and I mean the strain hardening mechanisms they are all going to get promote or they are going to contribute to the softening activity. Various mechanisms are proposed reversion or resolution by which the metastable strengthening precipitates completely dissolve in the matrix after being cut by the dislocation to a size smaller than the critical size of the particle nucleation.

So, once the dislocation keep on cutting the particles which is small enough to dissolve back in the matrix then also this cyclic softening will get promoted. Disordering of order precipitate due to motion of the; single dislocations through them. So, this also we know when the as long as the dislocation cuts through the order precipitate in a single entity then the order is destroyed if it comes as a pair that is a different portion.

That also gives if it comes as a pair then one will destroy the order other will restore. That also we have seen.

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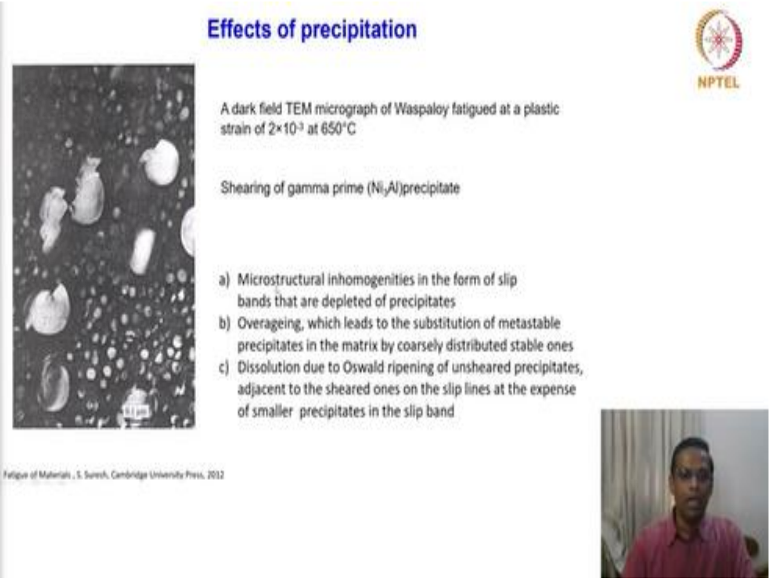

Effects of precipitation

A dark field TEM micrograph of Waspaloy fatigued at a plastic strain of 2×10^{-3} at 650°C

Shearing of gamma prime (Ni_3Al)precipitate

a) Microstructural inhomogenities in the form of slip bands that are depleted of precipitates
b) Overageing, which leads to the substitution of metastable precipitates in the matrix by coarsely distributed stable ones
c) Dissolution due to Oswald ripening of unsheared precipitates, adjacent to the sheared ones on the slip lines at the expense of smaller precipitates in the slip band

Fatigue of Materials , S. Suresh, Cambridge University Press, 2012

So, this is one typical micrograph a dark field TEM micrograph of Waspaoly fatigue that plastic strain of 2 x 10^{-3} at 650 degrees centigrade. Shearing of gamma prime Ni 3 Al presented is nicely shown here. So, hope you can see that which is reported in this reference in fact most of the texts are from this reference only. Microstructural inhomogeneities in the form of slip bands that are depleted of precipitates.

These are all the some of the features which are contributing to cyclic form. That is what I am just listed here. Overageing which leads to the substitution of metastable precipitates in the matrix by coarsely distributed stable ones. Dissolution due to Oswald ripening of unsheared precipitates adjacent to the sheared ones on the slip lines at the expense of smaller precipitates in the slip band. So, all these microstructural parameters they are going to promote cyclic softening.