Mechanical Behaviour of Materials
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Lecture - 37
Mechanical Testing - V

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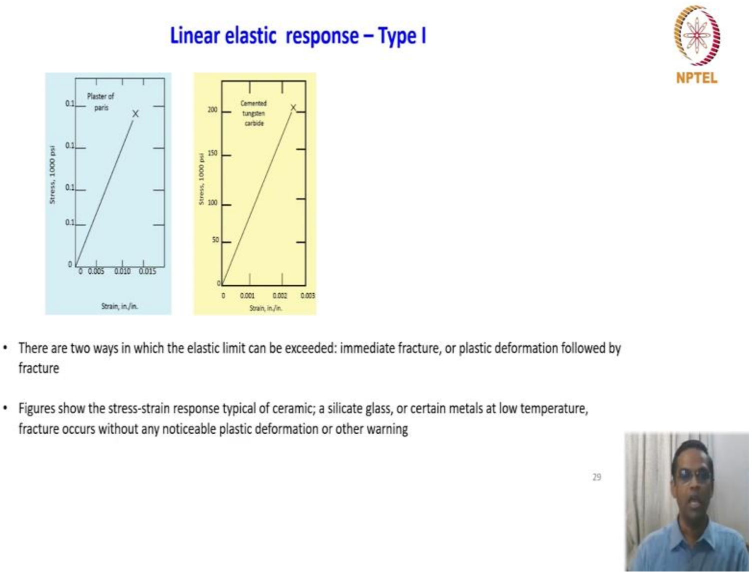

Hello I am Professor S. Sankaran in the, Department of Metallurgical and Materials Engineering. Hello let us continue our discussion on mechanical testing we are looking at the tensile test and its results and interpretation how to understand the material behaviour respect to tensile deformation. So, so far we have looked at the fundamentals of stress strain relation how it characterizes the material and what are the various simple relations how it connects to the work hardening behaviour and other tensile properties. Now, we look at the type of tensile behaviour which exhibit I mean which is exhibited by most of the class of materials. So, the first one is linear elastic response type one it is sometimes is called as type 1 which is a linear stress strain relationship for example this is plaster of Paris and this is cemented tungsten carbide and there are two ways in which the elastic limit can be exceeded immediate fracture or plastic deformation followed by fracture see if you recall the previous classes we always looked at a stress strain curve as an elastic portion yield point and then plastic portion. So, here these kinds of stress strain curves do not have the neither yield points not a plastic portion so that means how do we understand this.

This is a string behaviour it is emitted by a material almost you know insignificant plastic deformation is highly brittle in nature. So, the figure shows the strain response of typical of ceramic silicate glass or certain metals at low temperatures even you know ductile materials such as metals at very low temperature they can have the potential to exhibit similar behaviour but in general these kind of stress strain relations are exhibited by the ceramic material.

Especially whatever the examples I have shown is a plaster of Paris is a kind of ceramic and then tungsten carbide it is also a ceramic. So, what it means is these systems show very limited plastic deformation or unnoticeable plastic deformation. On the other hand you can also say that the fracture occurs without any noticeable plastic inflammation or warning see the work hardening nature of the ductile material is also a kind of a warning before fracture.

So that kind of behaviour is not seen or exhibited by these kinds of highly brittle materials. So, this is one type of stress strain behaviour we understand this why ceramics exhibits this kind of behaviour because we know that the number of slip systems available for plastic deformation is very limited at least at low temperature but at high temperatures obviously there is a possibility for these material to exhibit some plasticity. So, that we may see as we go along with high temperature deformation see as far as room temperature deformation is concerned ceramic materials are highly, I mean they will exhibit highly brittle nature.

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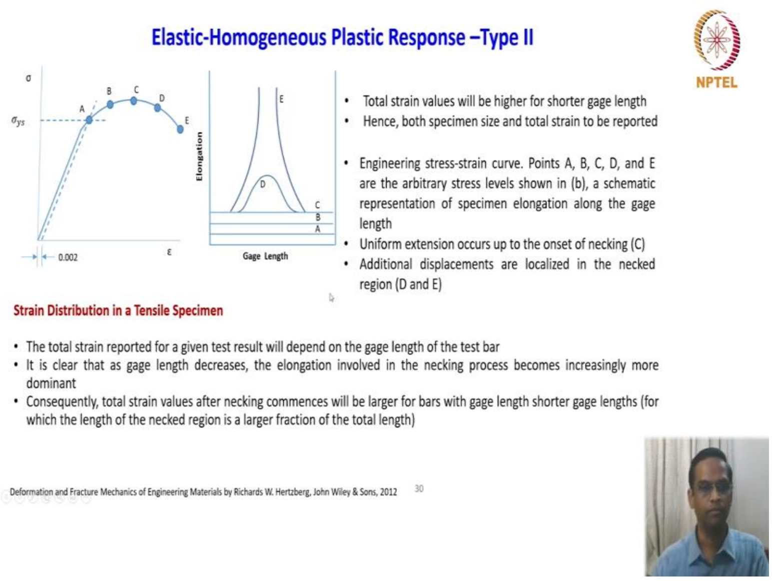

The next type of stress strain curve or the stress strain behaviour is elastic homogeneous plastic response that is type 2. So, this is a typical stress strain curve which is exhibited by most of the engineering materials especially metal, alloys and high temperature materials or any other material which exhibit similar kind of stress strain behaviour. Please note that this is elastic portion and then after that is a continuous yielding to the maximum and then it fails here.

So, it is a fracture stress and then the yield point is always determined in any material which shows a continuous yielding behaviour through this method that is called proof stress how do we do this proof stress measurement? We just mark a point at 0.002 strain and then draw a parallel line wherever it intersects in the stress-strain curve that point is considered as yield stress are normally this called point 0.2% proof stress.

So that is how it is known so what I am trying to show in this very important aspect this we have already seen in the beginning of this I mean, chapter. What is that we are trying to explain here this plot is elongation versus gage line and what you are seeing here A, B, C, D, E what here is also marked here. So, what is this? Let us look at the descriptors total strain values will be higher for shorter gage length.

Hence both specimen size and total string to be reported this aspect we have seen but what you have to see here is because of the necking how the gage length influences the percentage elongation is clearly reported here for example you look at this point D here which is just after the maximum load that is after the necking you can see the influence of the gage length from here to here the maximum gage length can be up to this point. So, which is not a true representation of uniform elongation it is influenced highly by necking and that is how it is shown. So, before fracture close to fracture it influences significantly the elongation, influences significantly. So, the engineering stress-strain curve points A, B, C, D, and E are arbitrary stress levels shown in (b), a schematic representation of specimen elongations along the gage length.

Uniform extension occurs after the onset of necking. Additional displacements are localized to the necked region D and E so these are the additional displacements because of the necking. So, let us talk about the strain distribution the total strain reported for a given test result will depend on the gage length of the test bar it is clear that as the gage length decreases, the elongation involved in the necking process becomes increasingly more dominant.

Consequently, total strain values after necking commences will be larger for bars with gage length, shorter gage length and for which the length of the neck region is larger fraction of the total length. So, this particular contribution either D or E that is larger fraction of the; total length that is what it is mentioned. So, this type of stress strain behaviour is elastic and then homogeneous plastic response by the material.

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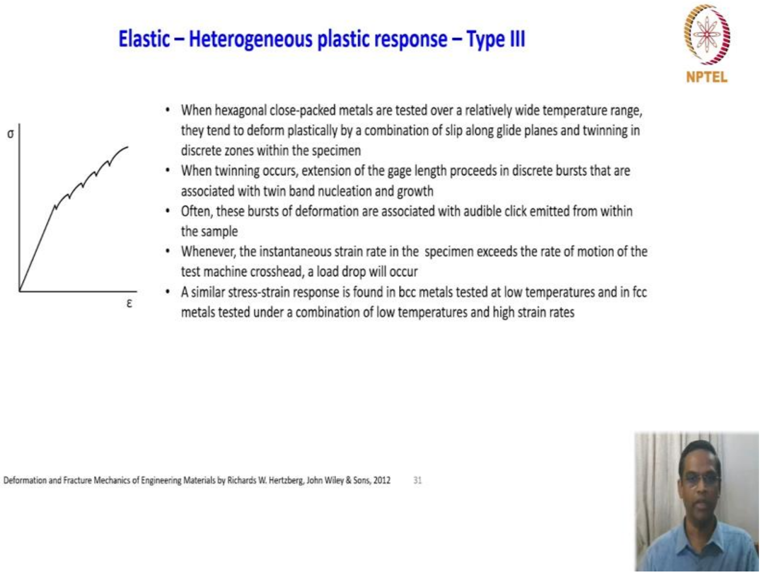

And the next one is elastic heterogeneous plastic response which is something like this. So, if you have a stress - strain behavior, by material something like this we need to know why it is so when hexagonal close packed metals are tested over a relatively wide temperature range, they tend to deform plastically by a combination of slip along glide planes and twinning in the discrete zones within the specimen.

We know that in HPC system unlike FCC they have limited slip systems. So, the deformation mode there, it is a combination of slip and twinning that is what it is when twinning occurs extension of the gage length proceeds in discrete bursts that are associated with twin band nucleation and growth very important point. You see, as the extension of the gage length proceeds that means as you pull the specimen in a tensile direction discrete bursts that are associated with the twin band nucleation and growth.

So, when the twin band nucleates, there is a burst so that is what it is shown here and that causes this kind of serration. Often these bursts of deformation are associated with audible click emitted from within the sample people have recorded this audio in most of the experiments just for observation. Whenever the instantaneous strain rate in the specimen exceeds the rate of motion of the test machine crosshead a load drop will occur. So, this is a well known fact that the instantaneous rate in the specimen wherever it exceeds rate of motion of the test machine crosshead a load drop will take place. A similar stress strain response is found in BCC metals tested at low temperatures I mean FCC metals tested under a combination of low temperature and high strain rates. So, what we have to appreciate here is whenever you have a constrained deformation. Either in the form of low temperature high strain rate or the lack of slip systems something so wherever you have a constraint plastic deformation so this kind of phenomenon can occur.

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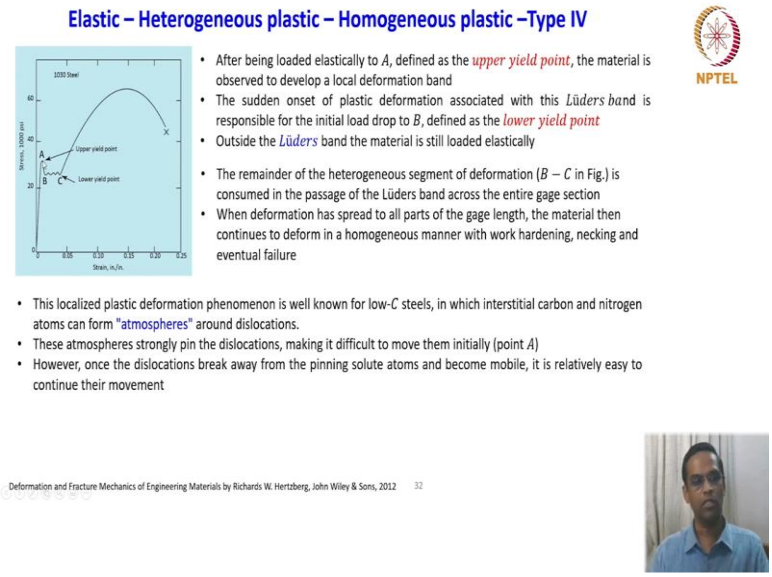

So, the next type is elastic heterogeneous plastic, homogeneous plastic so what is that? This is also well known but it has been classified like this, so you have elastic behaviour and immediately there is a heterogeneous plastic and then homogeneous plastic. So, this is a very well known and classical stress-strain behaviour which is been taught and reported in most of the elementary textbooks so let us see what it is.

So, after being loaded elastically to A, defined as an upper yield point, the material is observed to develop a local deformation band. So, this is called yield point phenomenon this kind of the material reaches a point up to A and then suddenly the load or the stress drops or load drop and it develops a local deformation band. So, it a local definition band so it is called property yield point and this is a lower yield point this level.

This sudden onset of plastic deformation associated with this Luders band is responsible for the initial load to B defined as lower yield point. So, what is the reason for this kind of you know a sudden load drop from point A to point B. People have studied that this is because of something called Luders band. So, we just mentioned in the previous sentence it is local deformation. So, it is characterized as a Luders band, we will see what it is in a minute.

Outside the Luders band the material still loaded elastically. So, outside this, this is still elastic stress is associated with the specimen the remainder of the heterogeneous segment of the deformation B to C is consumed in the passage of Luders band across the entire gage section. So, it is not just that the Luders band is responsible for this load drop or the formation of the load drop I mean the load drop we are seeing that it is associated to formation of Luders band. It is not just that it has to propagate throughout the gauge of the specimen up to C. When the deformation has spread to all the parts of the gage length the material then continues to deform in a homogeneous manner with work hardening making an eventual failure. So, after this complete spread of Luders band throughout the gage length the material try to deform homogeneously, then it exhibits strain hardening reaches a maximum and then necking and then fracture. So, rest of the other behaviour we know so we are trying to study this yield point phenomenon this localized plastic deformation phenomenon is known as or is well known for low carbon steels. In which the interstitial carbon and nitrogen atoms can form atmospheres around the dislocations. You see, now we have to go back to our dislocation lectures and then try to recall some of the mechanics of dislocation and how the interstitial atom interacts with the dislocation. So, we have seen a couple of examples especially interstitial atom like carbon how it goes and interacts with the edge dislocation we have seen that. So, recall those lectures and then so when the interstitial atom interacts with the edge dislocation information atmosphere with which also will reduce the energy of the dislocation, this also we have seen how the elemental segregation around the dislocation how we reduce the energy.

So that scenario is here described here are some atmospheres around dislocation. These atmosphere strongly pin the dislocation making it difficult to move them initially that is we are trying to explain at the point A it is the stress keep on increasing and then at the point which is locked up. So, at the point A, the dislocation and interstitial interaction is pretty strong and the dislocation motion is restricted at the point A. However once the dislocations break away from the pinning solute atoms and become mobile, it is relatively easy to continue their movement. So, there is something called unpinning force here after the point A here the dislocation has to unpin from the interstitial atoms and then try to move.

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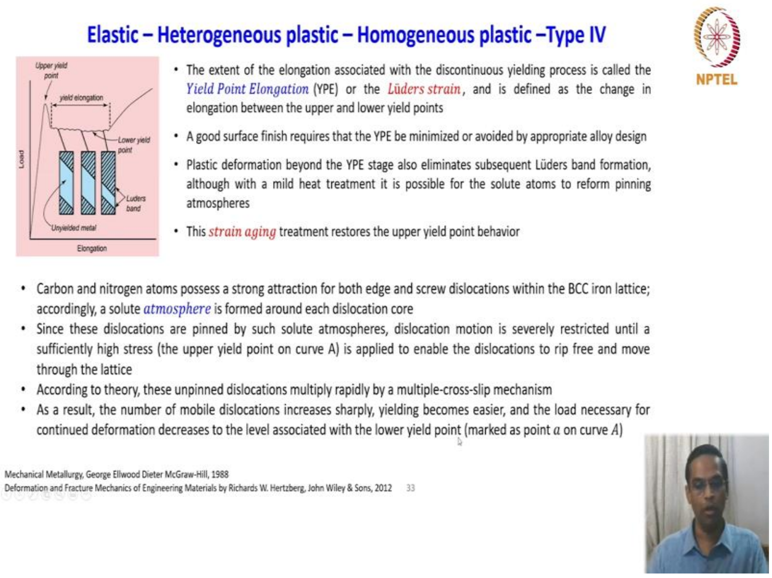

We will continue that discussion here is same stress-strain diagram in a much more elaborate manner. Here the point of interest here is I just want to show from the B to C in the previous plot, it has got some elaborate description here after the lower yield point then the complete you know the band is called yield point elongation. how this Luders band propagates from point B to point C which is nicely shown in this schematic.

So, what you are seeing here is a Luders bands nucleates from the point B of the initial I mean previous plot and then you can see that Luders band occupies and then this middle portion is unyielded metal. So, as the deformation proceeds then the region occupied by the Luders band keep on increasing and finally it is going to fill the gage length. So, this is called Luders band the extent of elongation associated with the discontinuous yielding process is called yield point elongation or the Luders strain. So, this complete strain is Luders stain and it is identified as the change in elongation between upper and lower yield points. The good surface finish requires that the yield point elongation be minimized or avoided by appropriate alloy design. You see this kind of local deformation yielding is not preferred in the application point of view. So, scientifically it is very interesting to note all this but from an application point of view these are all not preferred.

So, a good surface finish or even an alloy design alloy design is a means what there are alloy elements which can combine these interstitial elements into form a stable nitrides. So, it is a kind of fixing this interstitial atom that is called alloy design. But by a proper alloy design we can remove this elemental carbon and elemental nitrogen so on like titanium. Normally it is added to fix the oxygen to it will form, titanium dioxide and carbon, nitrogen.

All this interstitial elements can be fixed in the form of or by formation of carbonates and nitrites and oxides these things can be fixed by alloy design. As long as they are not there in the free form you do not have to worry about this yield point phenomena plastic deformation beyond the yield point elongations stage also eliminates subsequent Luders band formation although with a mild heat treatment it is possible for solute atoms to reform pinning atmospheres. So, you may do the plastic deformation to fix this but then a little bit of heat treatment again will promote the diffusion of this interstitial and again it will form the pinning atmosphere or it will interact with the dislocations. So, this strain aging treatment restores the upper yield point behaviour this is, I mean the interstitial coming out of this pinning and then it relaxing and get back to again pinning is called strain aging we will see this aspect in separately in few minutes.

Carbon and nitrogen atoms possess a strong attraction for both edge and screw dislocations within the BCC ion lattice. Accordingly, the solute across the air is formed around each dislocation core. Since these dislocations are pinned by such solute atmospheres, dislocation motion is severely restricted until sufficiently high stress that is the upper yield point on curve A is applied to enable the dislocation to rip free and move through the lattice.

According to the theory, these unpinned dislocations multiply rapidly by multiple cross slip mechanism. As a result the number of mobile dislocation increases sharply yielding becomes easier and the load necessary for continued deformation decreases to the level associated with the lower yield point marked as a point a on curve A so, here we are talking about this.

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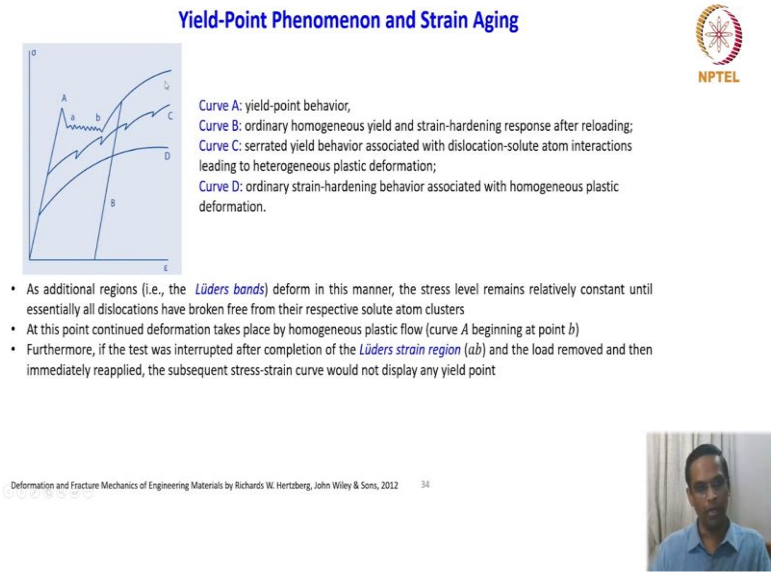

So, now having understood this yield point phenomenon we will now discuss something called strain aging aspect in the context of yield point phenomena, look at this schematic stress-stain diagram. In fact we have just combined all the type of stress strain diagrams in one block and then try to address this curve A is the yield point behaviour curve B is ordinary homogeneous this is curve B goes on this homogeneous yield and strain hardening response after reloading, curve C is a serrated yield behaviour associated with the dislocation solute atom interaction leading to heterogeneous plastic deformation, curve D ordinary strain hardening behaviour associated with homogeneous plastic deformation. As additional regions Luders bands apart from this the additional regions deforming this manner, the stress level remains relatively constant until essentially all the dislocation have broken free from their respective solute atom clusters.

At this point continued deformation takes place by homogeneous plastic flow (curve A beginning point b) so it is a similar description what I have just said in the previous slide it is a repetition here is a kind of redundant information just to give the combined description I brought them again. So, furthermore if the test was interrupted suppose after this Luders band region the material start to deform homogeneously you stop in between and then unload them or interrupt them that is what it is written here. The test was interrupted after completion of Luders strain region a, b and the load removed and then immediately reapplied, the subsequent stress strain curve would not display any yield point this we have already discussed in the previous slide but just here it is shown as a schematic. So, just after the yield point elongation, if you just unload and quickly reload them then this band will not reappear. But if you heat them it will reappear that so what you have to remember.

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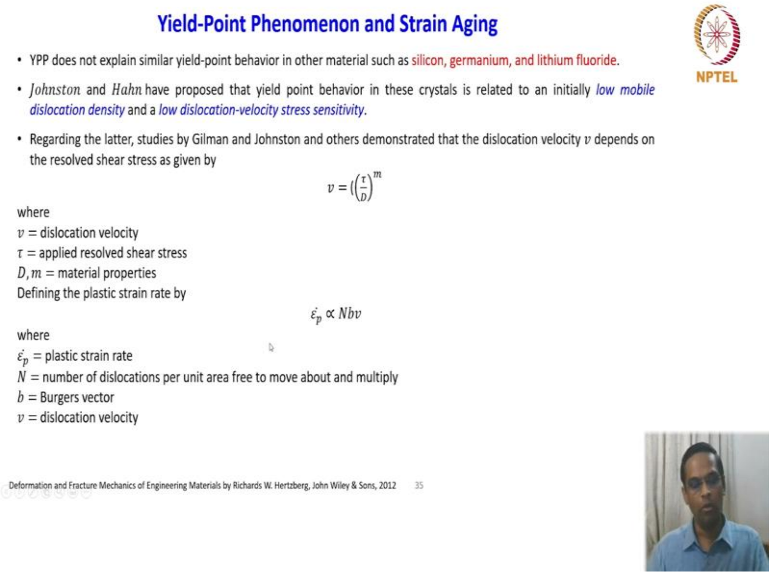

So, yield point phenomenon does not explain similar yield point behaviour in other materials such as silicon, germanium and lithium fluoride. So, the yield point phenomenon is quite popular in the context of mild steels. So, steal being a very important material this was quite a popular theory and it was giving a nice explanation the interstitial atoms interaction with the dislocation causes this yield point phenomenon. But that does not explain a similar you know yield point behaviour such as silicon, germanium, lithium fluoride. So, what is the reason? Johnston and Hahn have proposed that yield point behaviour in these crystals is related to an initially low mobile dislocation density and a low dislocation velocities stress sensitivity it is a bit complicated description but it is still interesting point to note.

We are bringing two parameters to explain the yield point phenomenon other than the low carbon steel that is low mobile dislocation density. It is not just the dislocation density is a mobile dislocation density. The low mobile dislocation density and a low dislocation velocities stress sensitivity dislocation velocity we have seen this before we related this dislocation velocity to dislocation density earlier.

So, we will look at them again regarding the latter, studies by Gilman and Johnston and others demonstrated that the dislocation velocity v depends on the resolve shear stress as given by $v = (\tau / D)^m$ where, v is the dislocation in velocity tau is applied resolve shear stress D and m are material properties. Defining the plastic strain rate $\dot{\varepsilon}_p$ is proportional to Nbv.

What is this? Where $\dot{\varepsilon}_p$ is a plastic strain rate N is the number of dislocations per unit area free to move about and multiply b is Burgers vector v dislocation velocity. So, these researchers have looked at the parameters involving these terms. So, here it is not just number of dislocations here it is number of dislocation per unit area which are free to move and above and multiply. So, this is a very specific characteristic of a dislocation so they are looking at a specific form of dislocation which can explain this yield point phenomenon in these materials like silicon, germanium.

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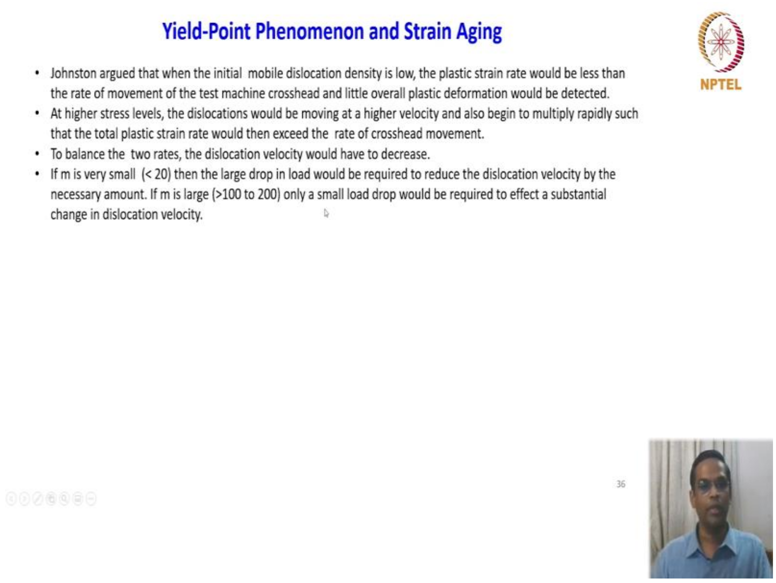

Johnson argued that when the initial mobile dislocation density is low the plastic strain rate would be less than the rate of movement of the test machine crosshead and little over plastic deformation would be detected. Now at higher stress levels the dislocations would be moving at a higher velocity and also begin to multiply rapidly such that the total plastic strain rate would then exceed the rate of crosshead moment.

So, we are now comparing two things what are two things? The plastic strain rate which is experienced by the material other one is the movement of the test machine that is a crosshead speed we are comparing these two to balance the two rates, the dislocation velocity would have to decrease to keep the deformation going in a manner something has to compensate. So, these two rates have to come into an equilibrium or balance.So, for that dislocation velocity would have to decrease. So, if m is very small that exponent what we have seen in the previous slide which is less than 20 which is typical of ionic and covalent solids. Then the large drop in the load would be required to reduce the dislocation velocity by the necessary amount if m is large which is or greater than 100 to 200 which is typical of FCC type of metals and materials only a small low drop would be required to effect they are substantial change in dislocation velocity. So, depending upon the initial mobile dislocation density and the stress state sensitivity this can be explained that is what these researchers have demonstrated that means for a small m value the large load drop will be there in the material something these studies have been reported already you can look at the references what I have given for the further details.

I just want to bring the context of yield point phenomena you should not think that this is all applied only to steel is a low carbon steel. It is there and all the other materials but then people have given a different type of interpretation and explanation which is quite interesting as well. So, for the larger m values the load drop will be much smaller. So that will compensate the dislocation velocity.