Materials Science
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Lecture No 28
Plastic Deformation

Now having at a look at the elastic deformation we shall now move on to the plastic deformation which is permanent deformation though it is not a function of time it's a instantaneous deformation.

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Plastic Deformation

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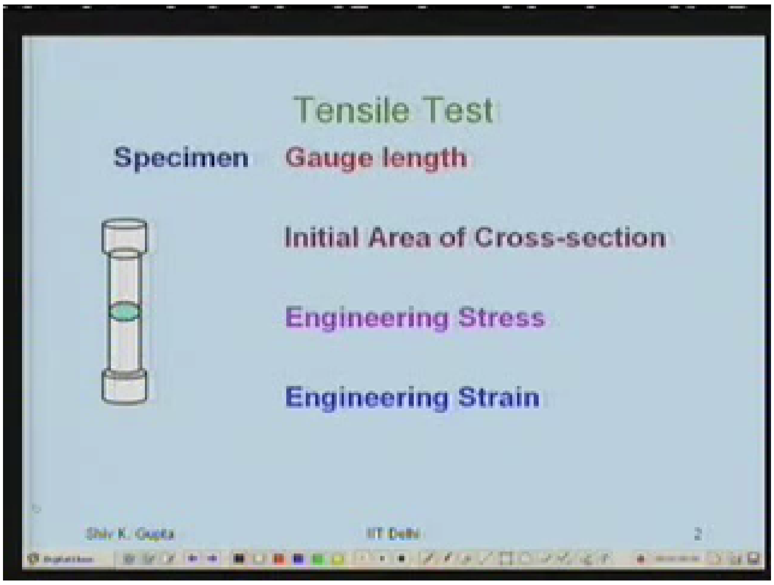
Tensile Test

Specimen

Gauge length

Initial Area of Cross-section

Engineering Stress

Engineering Strain

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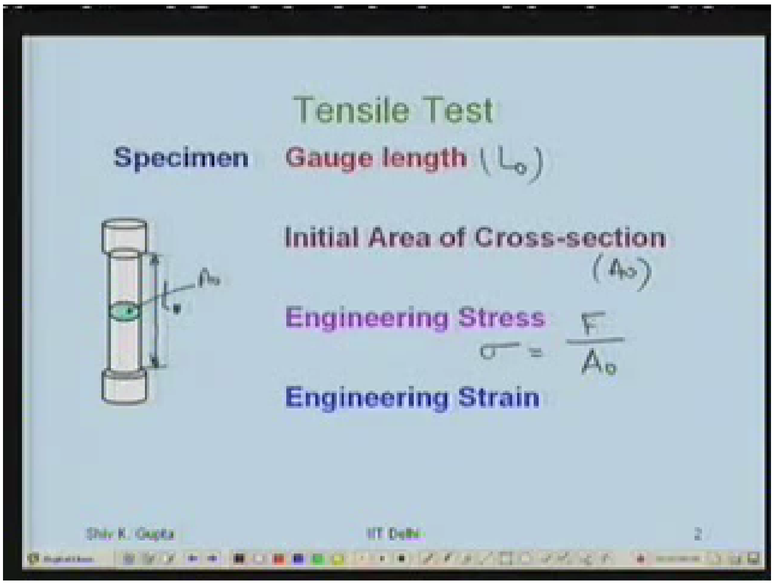

Tensile Test

Specimen Gauge length (L_0)

Initial Area of Cross-section (A_0)

Engineering Stress $\sigma = \frac{F}{A_0}$

Engineering Strain

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Now you have done a tensile test in the class for aluminium and steel, I should just repeat a few slides on that now you know about it. This is cylindrical specimen with a collar on both ends for holding in the grips and the way its constant diameter of this specimen in the cylindrical region and that length way its a constant diameter its called gauge length. And it might be presented by L0.

Then the cylindrical specimen has a constant diameter that diameter provides this area of cross section here as its shown me in this or refer to this initial area of cross-section. Because during deformation this area cross section also changes and we define the engineering stress on to the cylindrical specimen as the force divided by the area of cross- section which is initial area of cross section at any time the engineering stress is define like this the area of cross section may not be A0 at that moment.

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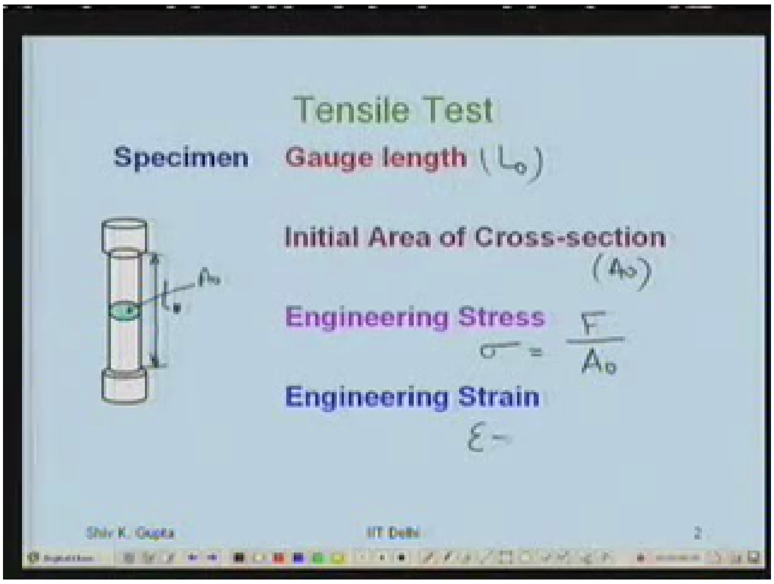

Tensile Test

Specimen

Gauge length (L_0)

Initial Area of Cross-section (A_0)

Engineering Stress

$\sigma = \frac{F}{A_0}$

Engineering Strain

$\varepsilon =$

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Similar in engineering strain is define as the elongation of the specimen divide by the initial length of the specimen. A new experiment what your nation on the Y axis was the force and X axis your measure the elongation if we divide the X axis by constant L0 it becomes strain engineering strain and if we divide the Y axis by the constant A0 it becomes stress. So stress versus strain curve is identical to what you have got all the thing is scale changes.

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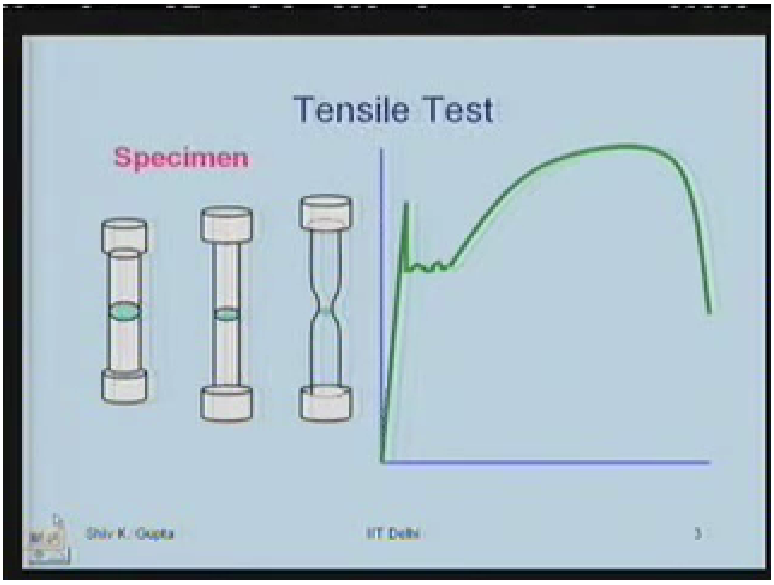

Tensile Test

Specimen

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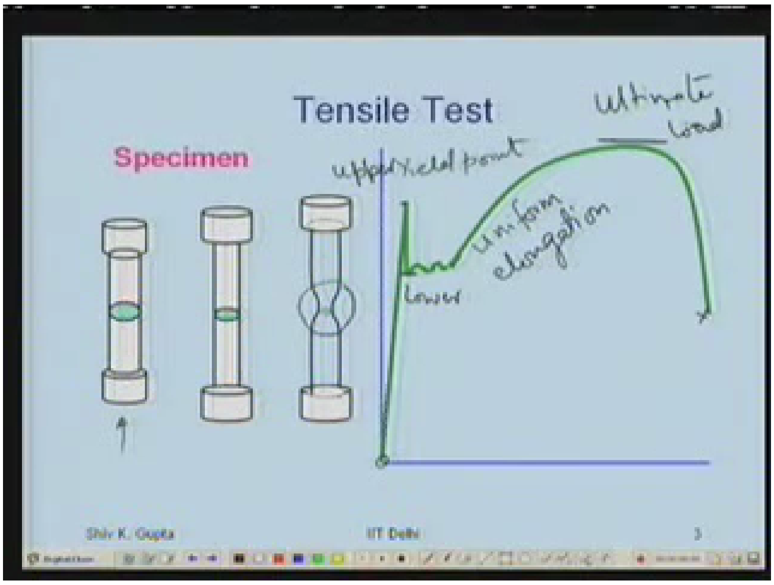

Tensile Test

Specimen

Now this specimen for steel which we tested is started like this initially in this manner at this point it goes to show you the elastic deformation and there is not much change in its area of cross section also but then it suddenly a we reach a point what you call the yield point of the specimen suddenly there is a drop therefore we still call it a yield point but this one is lower yield point and this is the upper yield point.

Of course it shows some increase in stress decrease in stress for a while and then monotonously it increases till it reaches at maximum in this region where it is deforming up to the maximum its like this area of cross section remains uniform its an illusion of uniform elongation. But by the time it reaches at maximum they starts a formation of a neck somewhere in the middle of the specimen like this.

Its way the area of cross section reduces as compare to the rest of the region in the specimen so at this in the region now the actually stress in this region is much more than the stress anyway (())(5:07) in the specimen and the further deformation gets localised in this region only and you feel that the stress is falling really speaking if I work on the stress in this region stress is all the time increasing (())(5:21) falling till it becomes a very small cross sectional area and material is unable to with stand the load applied it breaks, okay.

This is the ultimate load which is applied so this is the kind of test you have done and the (()) (5:50) tensile test and further you have also noticed. Alright this is I defined already for you the.

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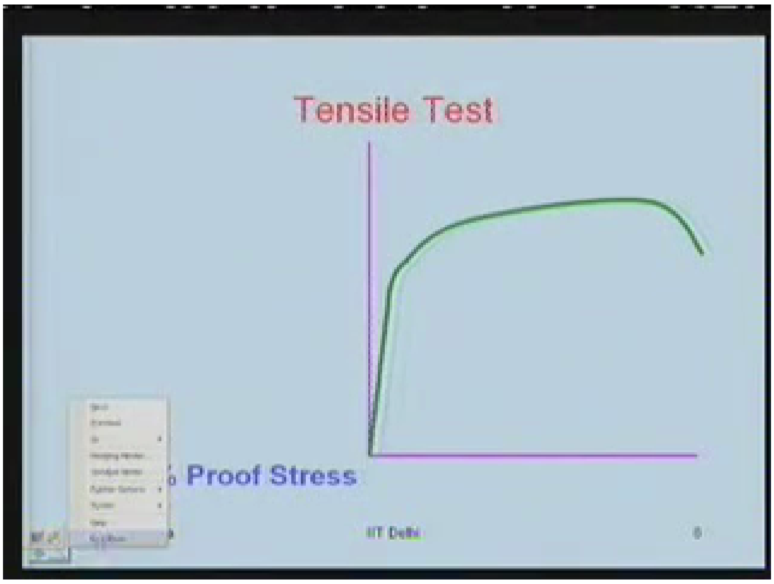

Tensile Test

Proof Stress

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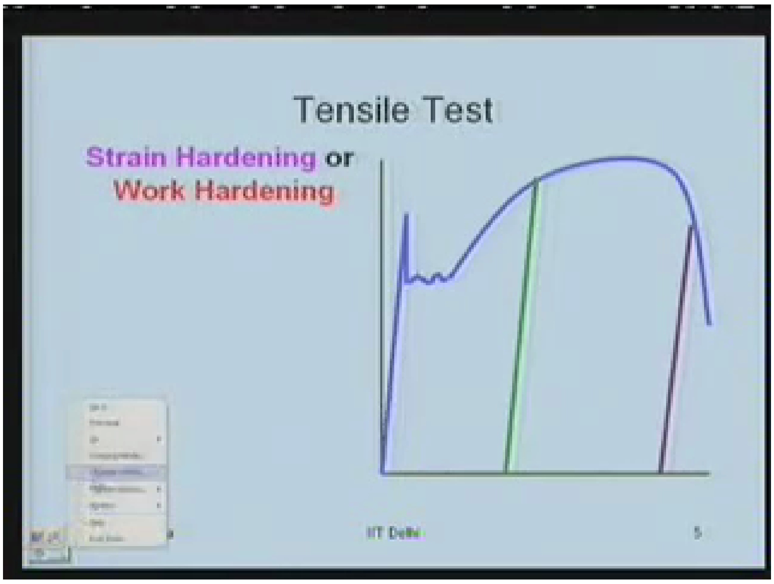

Tensile Test

Strain Hardening or
Work Hardening

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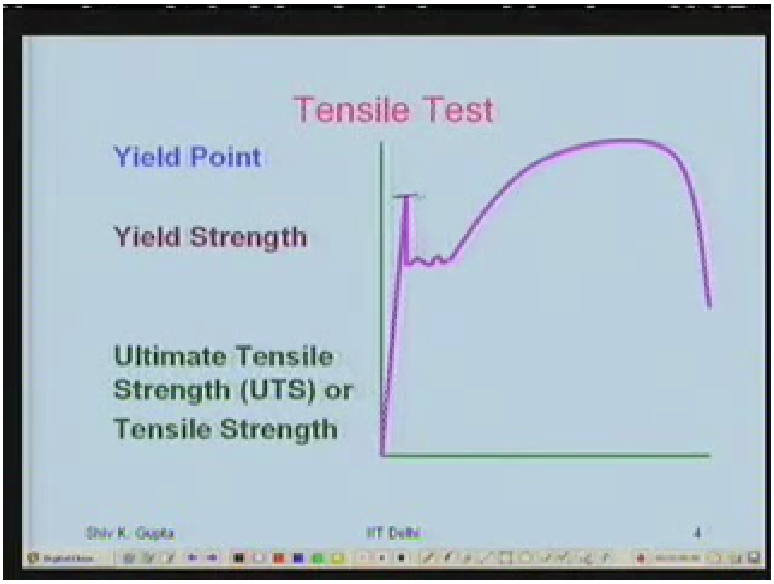

Tensile Test

Yield Point

Yield Strength

Ultimate Tensile
Strength (UTS) or
Tensile Strength

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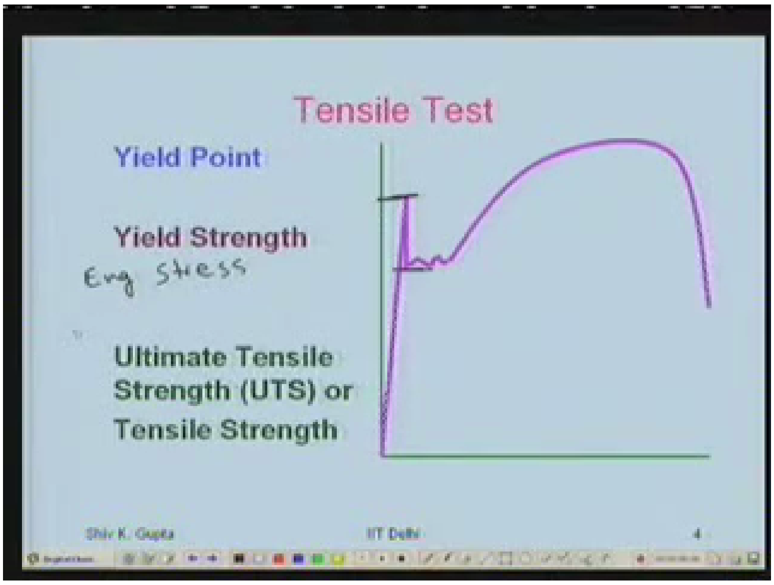

Tensile Test

Yield Point

Yield Strength

Eng stress

Ultimate Tensile Strength (UTS) or Tensile Strength

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Yield point, upper yield point and lower yield point corresponding to this point we have to workout the engineering stress.

Student: Sir

Prof: Yes please

Student: (())(6:35) stress to get localised (())(6:37)

Prof: Why its get localised I never said that, okay that there is some instability of course in the specimen for this you have to understand little bit of mechanics of deformation and I will not able to explain that in on hour today.

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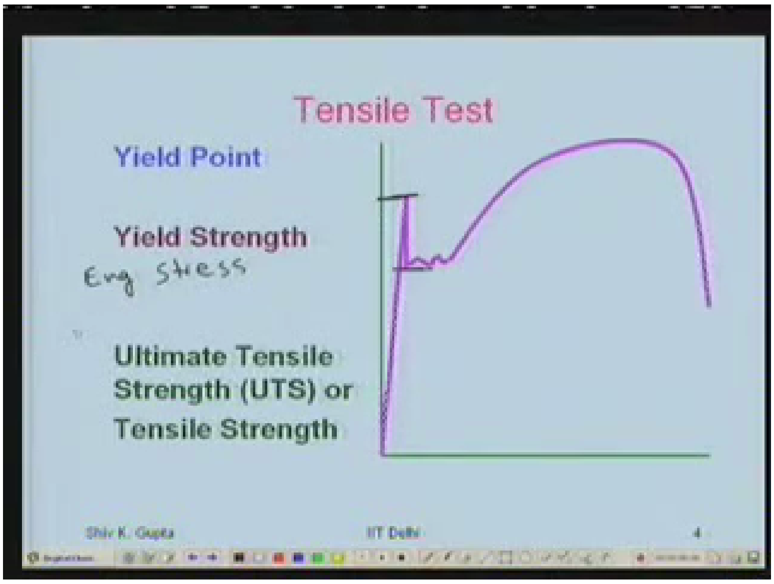

Tensile Test

Yield Point

Yield Strength

Eng stress

Ultimate Tensile Strength (UTS) or Tensile Strength

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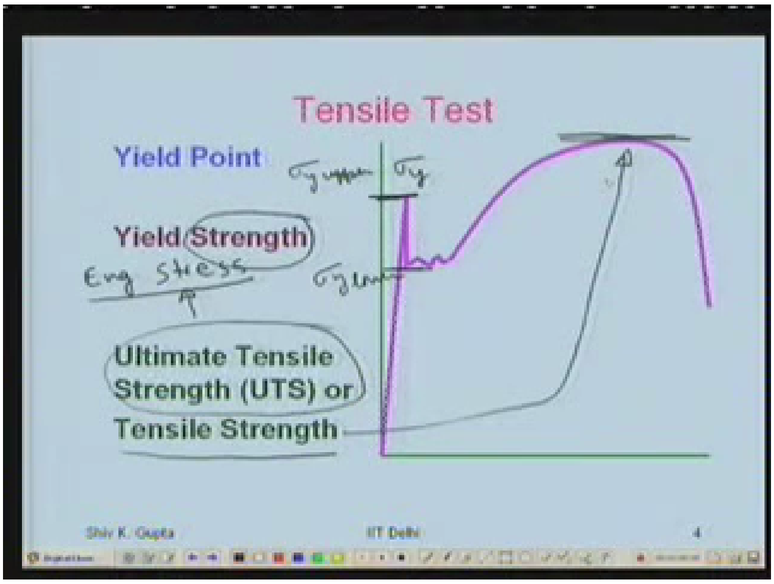

Tensile Test

Yield Point

Yield Strength

Eng stress

Ultimate Tensile Strength (UTS) or Tensile Strength

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So engineering stress corresponding to the upper yield point becomes the upper yield strength and corresponding to lower yield point becomes the lower yield strength. That is the definition okay, so yield strength values whatever I called about strength it is nothing but the value of the engineering stress corresponding to that point so there I get the yield strength which can write like this right.

And upper and lower you want to specify you can say that and this one lower then at the ultimate load corresponding to that again you can work out the engineering stress divided by force divide by the area of cross section that is initial area of cross section that engineering stress is called the ultimate tensile strength and most of the time I'll simply be calling the tensile strength of the material.

This is some definition the terms for the yield strength, the tensile strength. There is a difference in the yield strength and the tensile strength at the yield strength deformation begins plastic deformation the permanent deformation begins right. At the ultimate tensile strength I have reached the maximum finished of the uniform deformation uniform plastic deformation finishes there.

And there is instability starts in a material the neck formation and because of the neck formation load seems to be falling actually stress in the neck region is increasing all the time. Then another term which I have been define.

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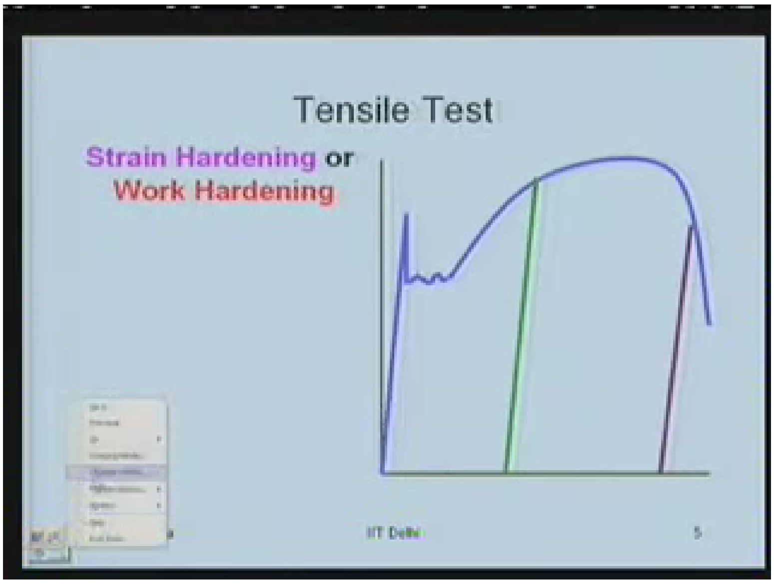

Tensile Test

Strain Hardening or Work Hardening

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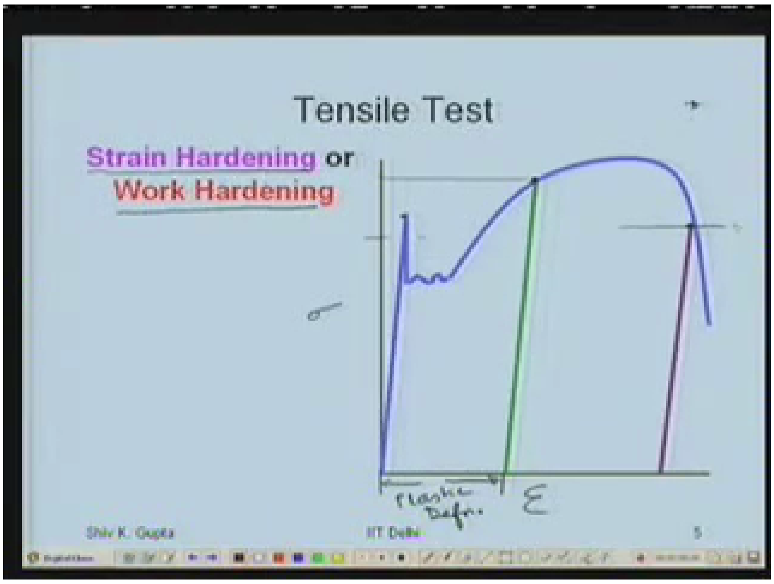

Tensile Test

Strain Hardening or Work Hardening

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Strain hardening or work hardening which are synonyms both terms are synonyms a material is strain hardened or material is work hardened what is the meaning of that here I have the stress and the strain I deform it into the uniform region uniform plastic region and from the unload it. I shall get this permanent deformation in the material is it plastic deformation of the material.

Now again want to deform this material it begins to deform like this and start to yield at this point rather than at that point strength is gone up thats what I mean by material has become harder. Because of the formed it I deform it so much I strained it so much it became harder means it has become stronger the yield strength is gone up.

So I don’t see this point I don’t see this region this starts here this remain still in the uniform region while when I cross this that gone the necked region it starts here. It will deform then only does it mean it has softened? No, if I work out this stress and the local region at this point is going to be higher what I refer to as a true stress in a material.

Thats going to be higher okay and that shows that the material is strain hardening all the time when I am deforming it. That means if I deform it to let us say 5 percent permanent deformation I want to deform it more out of time more stress if I deform another 5 percent I want to deform it further I have to apply still more stress so my stress which I have to apply the deformed material more.

And more becomes more and more that the strain hardening thats a work hardening I worked the material it becomes harder it becomes stronger right. You have done the test of aluminium also.

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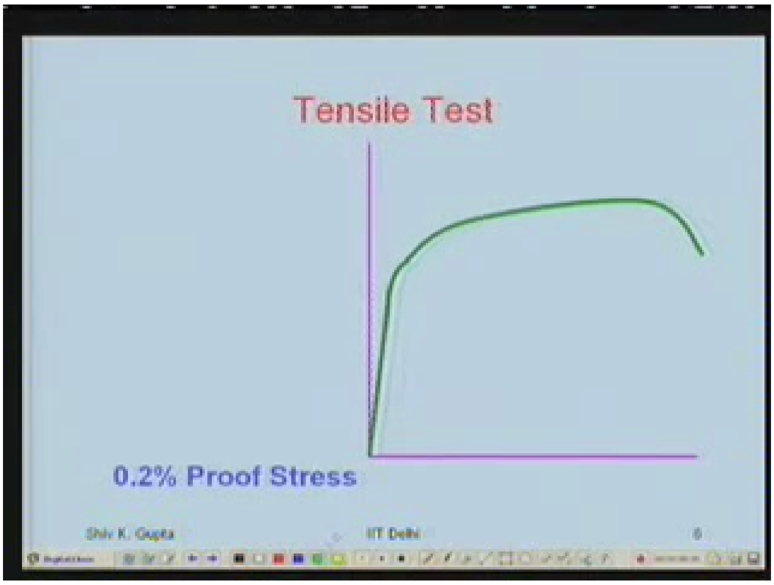

Tensile Test

0.2% Proof Stress

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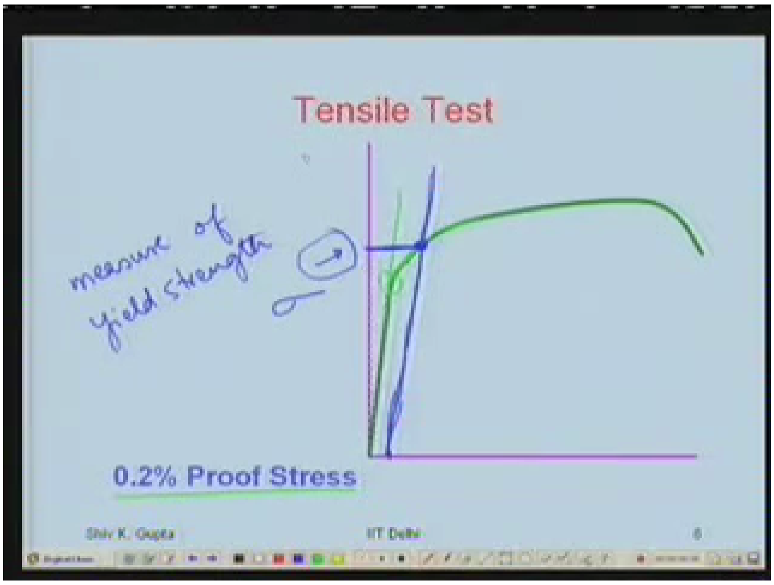

Tensile Test

0.2% Proof Stress

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In the aluminium test which you performed it went smooth like this didn't show any specific yield point you cant see the yielding now how to find what is the yield point for such a material most materials other than steels show the deformation characteristics like this be it copper, be it brass, be it aluminium okay this show like this.

Now the problem is we want to find way the elastic deformation as finished and plastic is began one way of doing this is initially you draw a tangent or a straight line we stalks about the elastic deformation extend this and find out the point where it begins to deviate. I am sure in such a situation its not possible for us to tell exactly where it begin to deviate here or begin to deviate there or begin to deviate here.

There will be a difference of opinion when different people are looking at it. Because its a tingent to get the pin point back its where the plastic deformation is began is not easy and you will be incorporating some error in your observation to avoid that observation what we do is we define the yield point or yield strength to the material in rather than the yield strength a proof stress which is called the zero point two percent proof stress.

Meaning there by at that point of stress level because I said the strength values are always stress values, at that point of stress there is a point two percent permanent deformation in the material. So what I do is I take a point two percent permanent deformation the material and draw a line parallel to the elastic region like this and say this is the point of intersection I gone little far it will not be that far from this line point two percent is a small deformation.

So this is a intersection of two curves it can be pin point it and sharp you can work out and you can say that this level of stress is the proof stress of the material and can be taken as a measure of yield strength of the material its not the yield strength but it is a measure of the yield strength of the material.

The plastic deformation is began there just around there right. As I already said that I have exaggerated so this I have gone little far off and you will be doing this for much more than point two percent you have done that probably for 1 millimetre elongation I said you work it out because that you can see of the graph 1 millimetre which is actually 1 by 16 millimetre of elongation and the specimen and you will be able to work or the intersection point very clearly.

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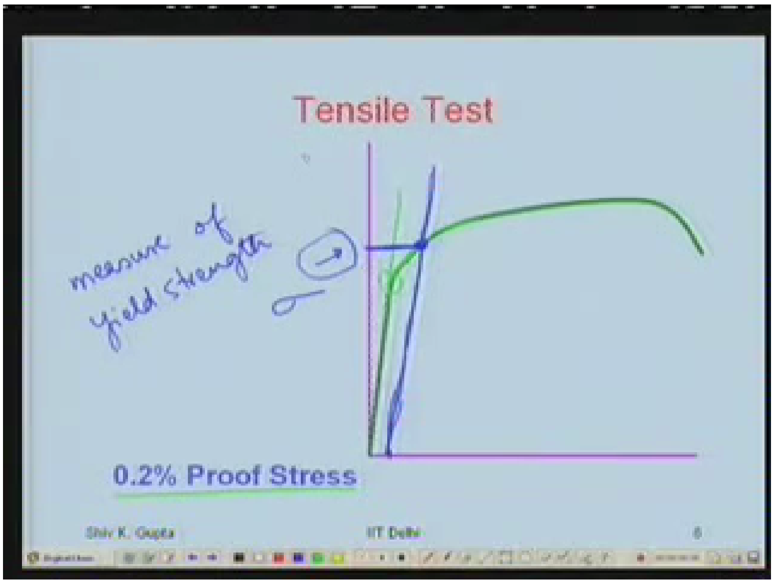

Tensile Test

0.2% Proof Stress

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This is the problem with materials other than steel so where yield point is not very well defined.

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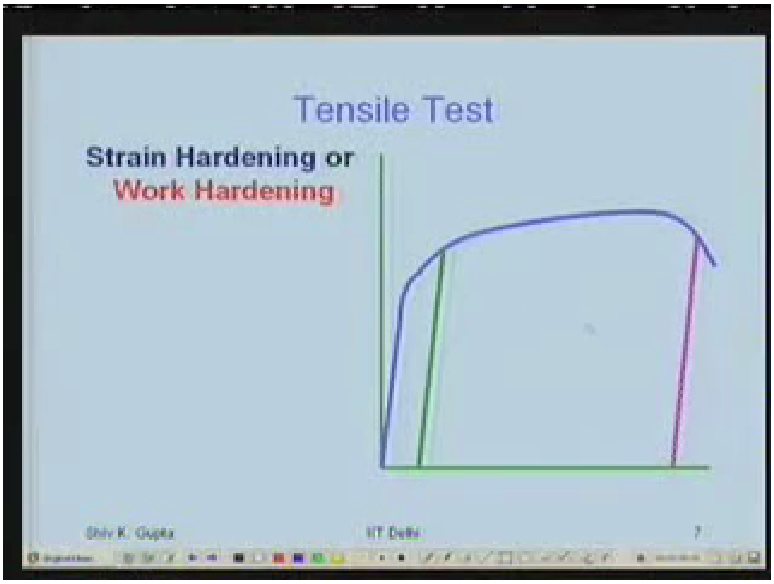

Tensile Test

Strain Hardening or Work Hardening

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While we also see the steel hardening or work hardening in this materials. Beyond the neck though there is a seems to be load seems to be falling but it is actually the two stress is increasing in the material.

Student: Sir what is the neck region in this? Ultimate strength.

Professor: That neck region is always the maximum once you reach the maximum the neck begins to form.

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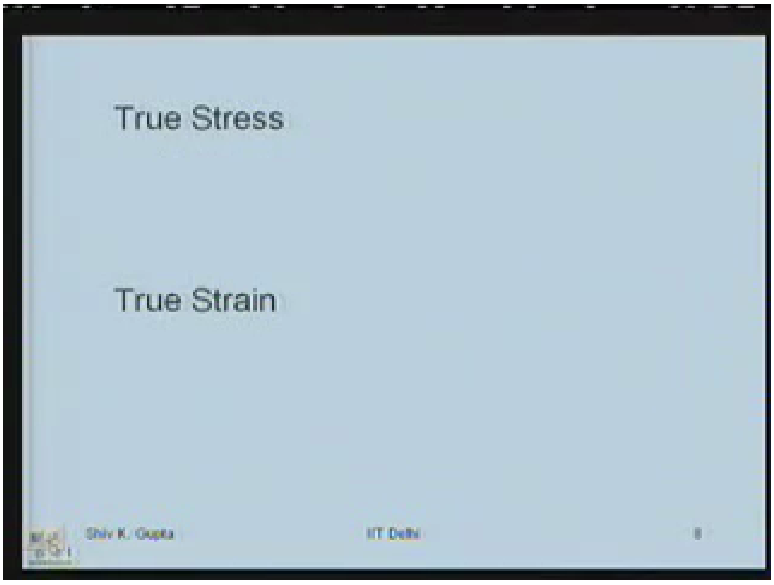

True Stress

True Strain

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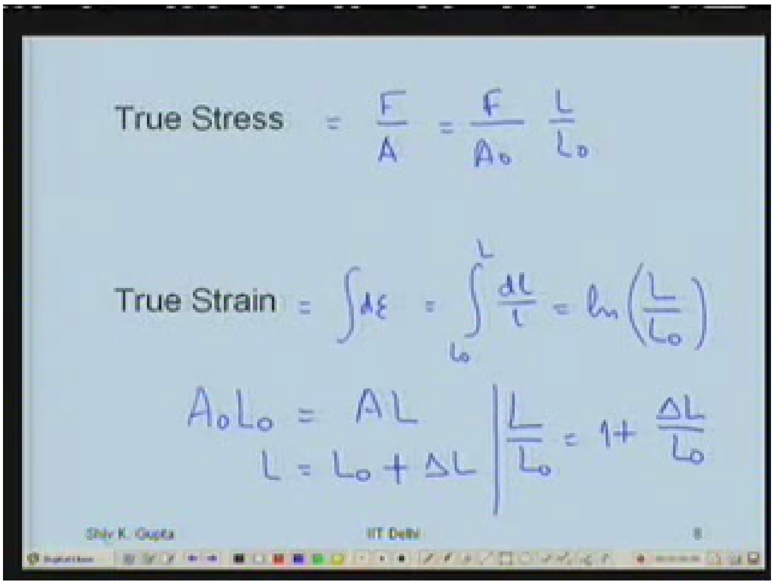

True Stress $= \frac{F}{A} = \frac{F}{A_0} \frac{L}{L_0}$

True Strain $= \int d\varepsilon = \int_{L_0}^{L} \frac{dL}{L} = \ln\left(\frac{L}{L_0}\right)$

$A_0 L_0 = AL$

$L = L_0 + \Delta L$

$\frac{L}{L_0} = 1 + \frac{\Delta L}{L_0}$

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Now since I have been talking about the true stress and true strain I need to define that in a slightly different from the engineering stress and engineering strain this F divided by the initial area of cross section. And we can relate it to the engineering stress I'll show that and similarly true strain is define as integral of the strain which is can be define at any point as and you can integrate it from the initial length to the final length.

At that any point you can define the true strain in the material like this and this A is different from A0 its instantaneous area of cross section this in instantaneous length and this is the incremental length which you have. At possible with this definition you can relate knowing the fact that during plastic deformation there is no change in volume. Therefore there is no change in volume means A0, L0 is equal to A into L it is a instantaneous area (())(17:36) instantaneous length.

Talking the uniform elongation region volume remains constant and therefore if you want to write A here you can write this A as F divided by A0 into L by L0. Right and L by L0 can also be written from here this will be a logarithm of L y L0. Okay so thats how its possible for us to relate and L at any time is nothing but L0 plus the increment in length and if I define this L by L0 would become 1 plus delta L by L0. What is delta L by L0?

Student: eng

Professor: Engineering strain, so L by L0 becomes 1 plus engineering strain so true strain is logarithm of 1 plus engineering strain okay. So thats you can relate this term its not difficult but you will always find that true strain is less than the engineering strain and a true stress is more than the engineering stress all the time.

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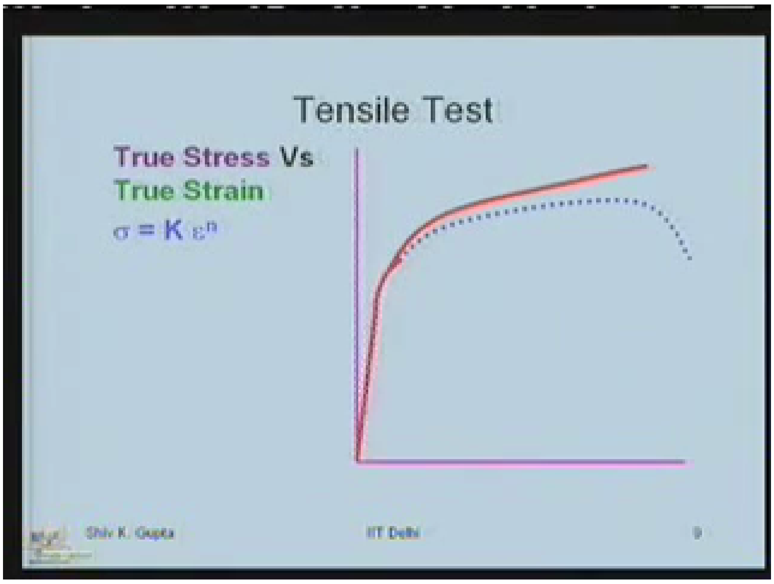

Tensile Test

True Stress Vs
True Strain
$\sigma = K \varepsilon^n$

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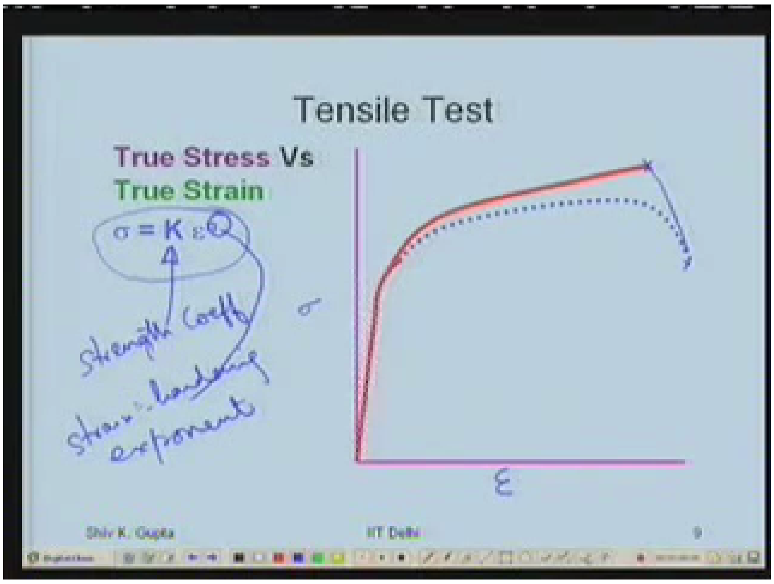

Tensile Test

True Stress Vs
True Strain
$\sigma = K \varepsilon^n$

strength coeff
strain hardening exponent

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And thats what I shown here. In this graph I plotted the stress this is a strain this is our engineering stress, engineering strain curve this is the true stress, true strain curve this point as reached there see to the left. Actual strain is less and the stress is more that is true strain is less and true stress is more every point, you know. And it is this curve with the true stress true strain which can be model and one can write expressions like this.

A variety of expressions available depending upon the material but most commonly used one is this. Where K is called the strength coefficient of the material, lets say constant of the material and N is called the strain hardening exponent. It is possible to relate the strain hardening exponent to the strain at the ultimate tensile strength if I can deform the material more uniformly its more ductile material may be then the strain hardening exponent would be more if you cannot deform it more strain hardening exponent will be less.

So as the material which can be strain hardened more strain hardening exponent is more usually the maximum value have you have is about point 5 and for hardened steel like material which has been quaint and tempered I may have a very small value of N like point 1 or point 12. Brass is typical brass is and material like copper would have got point 5 right.

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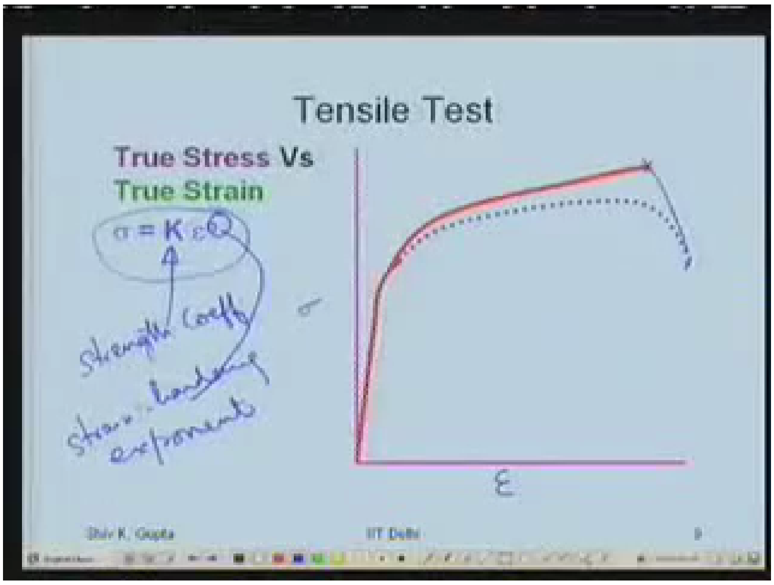

Tensile Test

True Stress Vs True Strain

$\sigma = K \varepsilon^n$

So the material which can be more work hardened means the strain reason in this after the yielding through this point of the maximum I have more region where I can deform uniformly and would be more okay. Now we shall try to look at the structural aspect during the plastic deformation and then see how can we make materials stronger.

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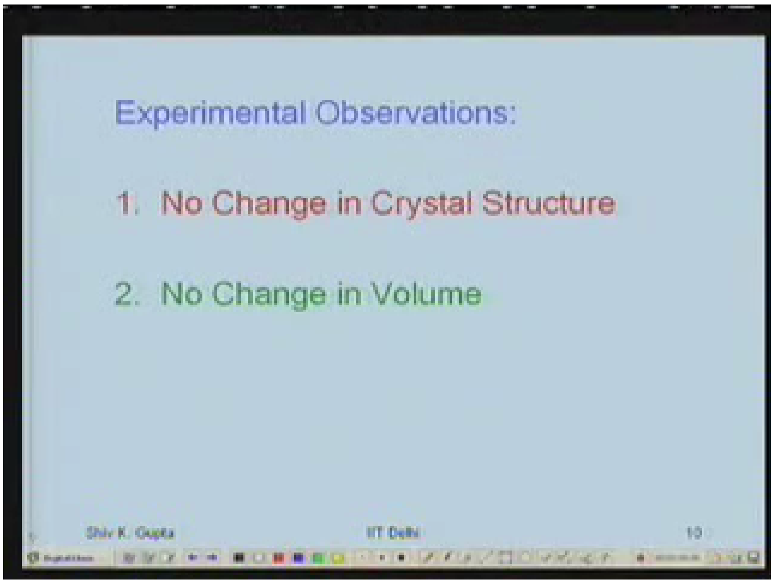

Experimental Observations:

1. No Change in Crystal Structure
2. No Change in Volume

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During the experimental observation when the (())(22:08) plastic deformation is occurred lets say you done a tensile test deform it about 5 percent take the deform specimen take it to the (())(22:19) machine. Work out its crystal structure you will find there is no change in the crystal structure of the material. As CC remains FCC let its parameter doesn’t change and if you measure the volume of the material which can also do in a laboratory there is no change in the volume.

It goes to show that unit cell of the crystal structure has not changed. So lattice parameter is a same and this structure of FCC is remains FCC, BCC remains BCC in a same lattice parameter there is no change in that. So we have to now look at the and what way the material will be deforming where by there is no change in volume of the material and there is no change in crystal structure of the material. Right lets look at those things.

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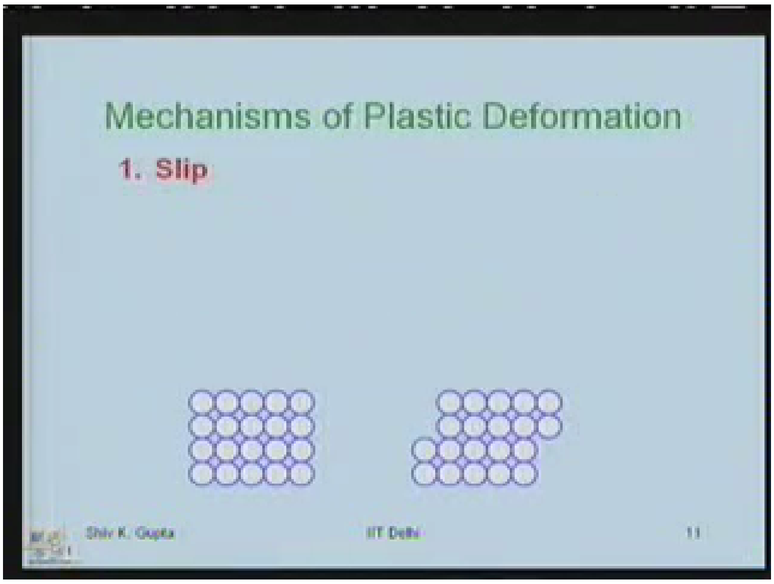

Mechanisms of Plastic Deformation

1. Slip

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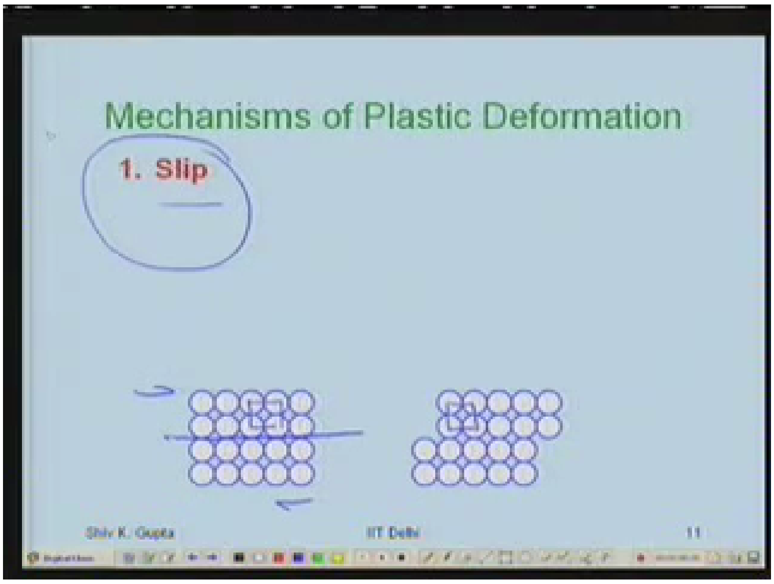

Mechanisms of Plastic Deformation

1. Slip

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One possibility is the material deforms by a mechanism what I called slip. In this there is a plane like this on which one part of the crystal slips in the reference to the lower part of the crystal may be like the shear stress like this. When you apply the shear stress like this you make in the lower part go to the left and top part of the right probably moves like this in here you would notice that is I taken a simple cubic structure unit cell dimension after deformation are the same they are not changed.

Volume of the material is not changed is remain the same. By enlarge at most temperatures in most materials this is a mechanism of deformation right. However there is another possibility by which this deformation maintaining the same crystal structure maintaining the same volume can also take place and that is twinning.

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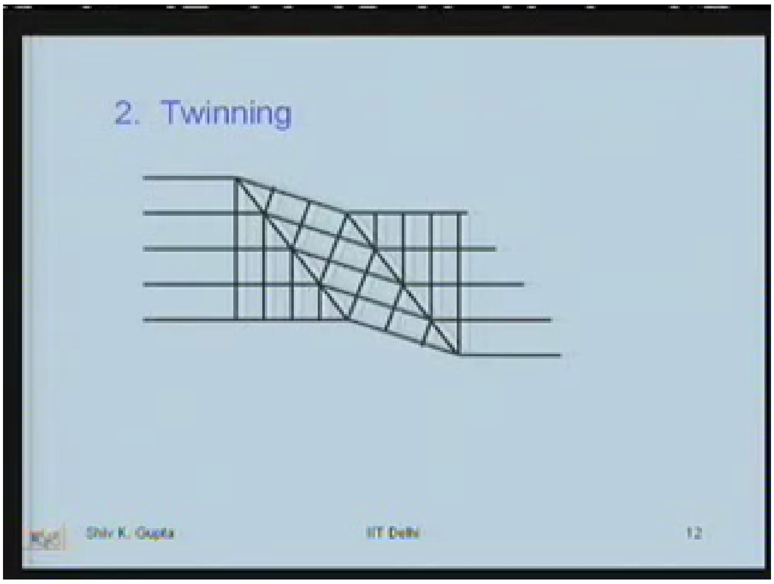
2. Twinning

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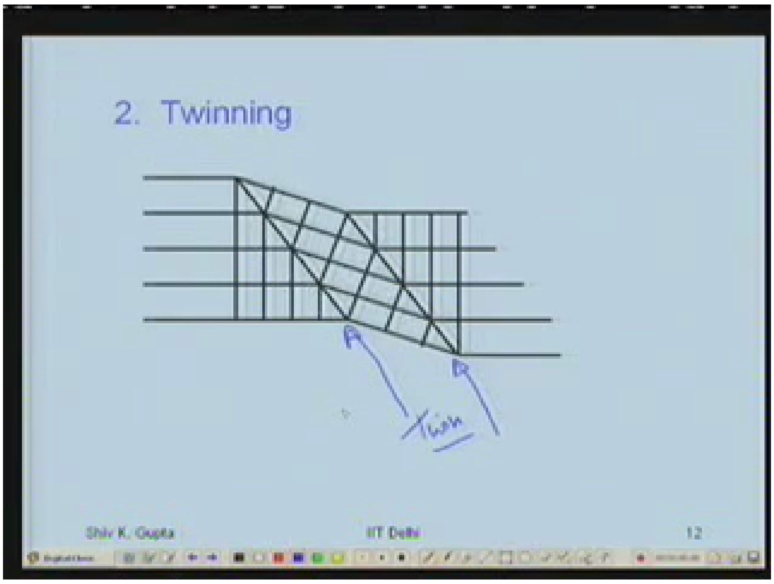
2. Twinning

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This is the unit cell dimensions this a twin plane or twin boundary from which it twins and the unit cell remains the same there is a small displacements taking place but the shape of the crystals are changed. Permanent deformation has taken place in the material and there is no change in volume of the material there is no change because unit cell remains the same every way is the same.

And there is a mirror reflection of these unit cells in this region and is again a mirror reflection and these are the two twin boundaries. They come in parallel okay. We have seen the twins in micro structure of copper its how these twins are and this how they are related to the two sides this structure is mirror reflected across this boundary here and this structure is further mirror reflected so this become is the same as that in here also there is no change in volume there is no change in crystal structure.

You can see that only thing is formation of twin boundary is taking place this kind of deformation takes place in some materials at low temperatures where slip is not possible or slip becomes difficult so we shall not be talking about this mechanism of deformation in this course we shall be only talking about the slip mechanism because that is the one by in large working at most mater most materials at most temperatures al right. That to understand that there is an another mechanism available for deformation.

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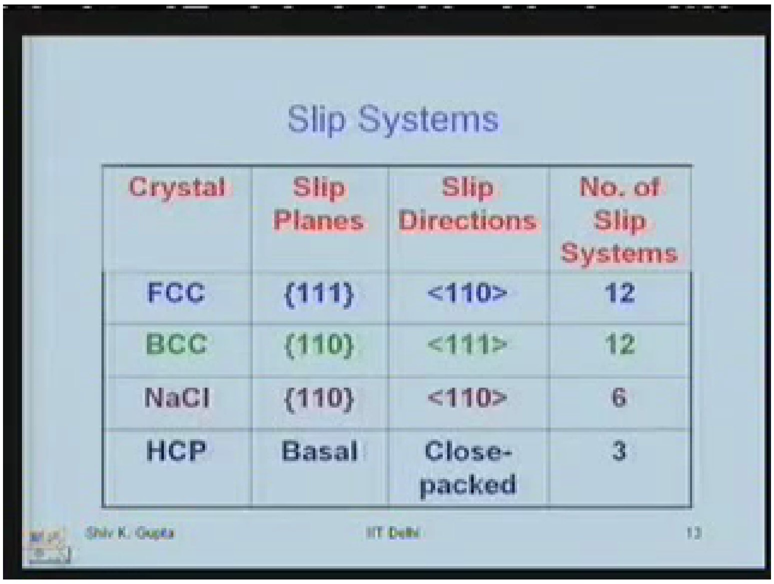

Slip Systems

Crystal	Slip Planes	Slip Directions	No. of Slip Systems
FCC	{111}	<110>	12
BCC	{110}	<111>	12
NaCl	{110}	<110>	6
HCP	Basal	Close-packed	3

Just to (())(26:35) the picture. Now slip as I showed you apply a shear stress and the material is slipping over a plane and in a particular direction so this deformation which is taking place over a particular plane in a particular direction we define this in the form of the slip system slip system is a combination of a slip direction and a slip plane.

If on a plane I can deform not only in this direction I can also deform in this direction then these are the two different slip system because a combination of a slip direction and a slip plane what we called a slip system and generally in a system on a crys crystal close packed plane will tends to become the slip planes but why just look at this.

This is lets say a slip plane one part of the crystal second part of the crystal and this is they are bound together whatever the strength of the binding is lets say not so strongly bound and I want to slip it I don’t have to put much efforts but if they are strongly bounded together rather difficult for me to slip this. Now when I say closed packed planes usually tends to be the slip plane that means the binding between the closed packed plane is not so strong and binding is not so strong if the distance between the plane is larger.

You see the distance between them is smaller binding is stronger. And closed packed plane is tend to have the largest distance between them why? Why the closed packed plane tends to have the larger distance between them? interprena space I am referring to consider only the cubic systems. Yes

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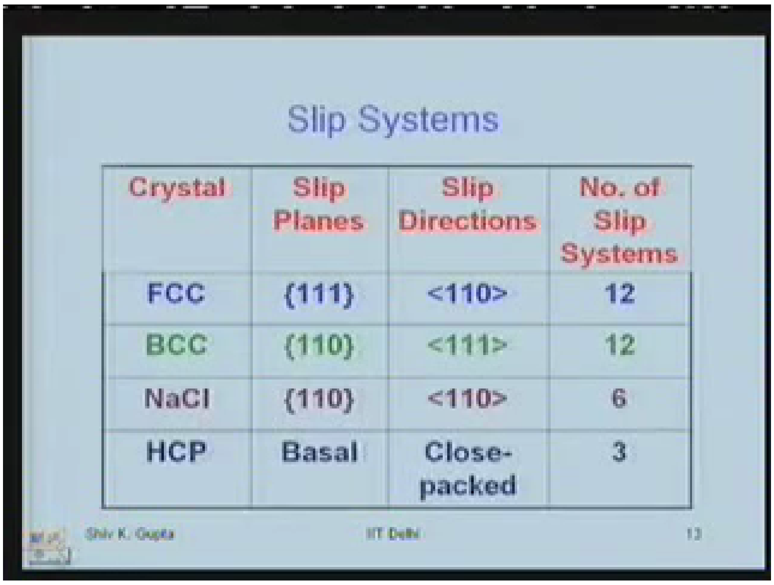

Slip Systems

Crystal	Slip Planes	Slip Directions	No. of Slip Systems
FCC	{111}	<110>	12
BCC	{110}	<111>	12
NaCl	{110}	<110>	6
HCP	Basal	Close-packed	3

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In the cubic systems what is the spacing? A divided by under root X square plus K square plus L square, and a closed packed plane tend to have the smallest X square plus K square plus L square. In FCC it is 111 if you look at 100 thats actually 200 plane there. Spacing is half and if you look at 110 the actual plane is 220 spacing is further half then in that case also so it is only 111 which is a closed packed plane spacing is A by under root 3.

A by under root 3 is larger than A by 2 right A by under root 3 is larger than A by 2 and A by case of 220 will be 2 under root 2 larger than both of them. so therefore 111 the closed packed plane tends to be the slip plane in FCC. Another way you can look at it you see in any given crystal number of atoms per unit volume is going to be constant whatever plane you consider whatever plane you consider it shall have a certain height.

Certain work thickness of some volume of the material it will take and closed packed plane has maximum number of atoms per unit area so to get the same constant number of atoms per unit volume this height corresponding to that plane will be the maximum thats why the closed packed plane tend to become the slip plane in the system.

Okay so FCC has 111 family in the 111 family if you expand you will have 8 members out of this 8 members there only 4 which are non parallel other 4 will be parallel to 1 of these each. Okay like bar1, bar1, bar1 is parallel to 111 bar 11 is parallel to 1 bar 1 bar 1 there only 4 known parallel members in the family similarly it is easy for a crystal to slip a least effort is required to slip it.

If it is done in the direction where it reaches the next equilibrium position by moving the least space or least distance and thats the closed packed direction to go from one equilibrium position to next equilibrium position the least distance you have to travel in the closed packed direction so closed packed direction tends to become the slip directions family is 110 which also has non parallel members 6 of them 4 of this 6 of these should make it 24 but I have only 12 slip systems.

Can you tell me why? Can you tell me why? Any slip plane does not have all these 6 closed packed direction on it. It has only 3 are to go take you back to the. I never thought that it will be so difficult for you.

Student: ())(33:23)

Professor: its not coming. It will come. Not looking yet. It came camera is not working. Alright not working go back to area. Alright I can make it on this only.

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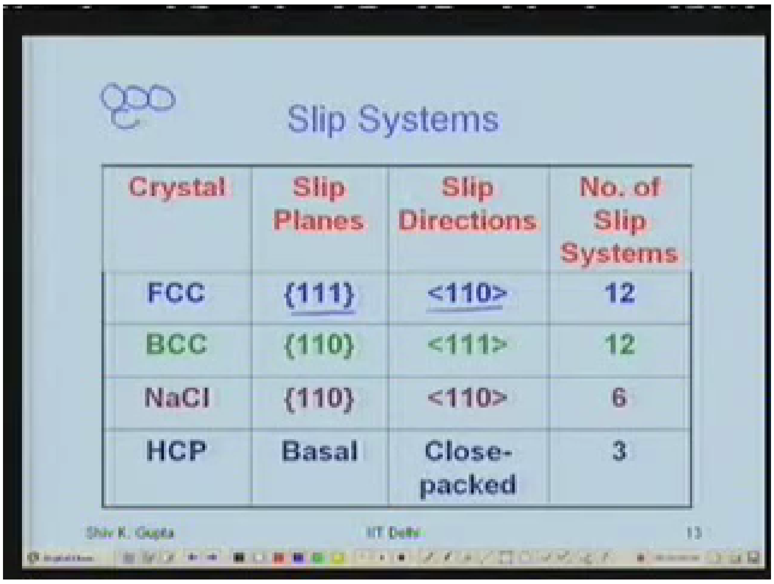

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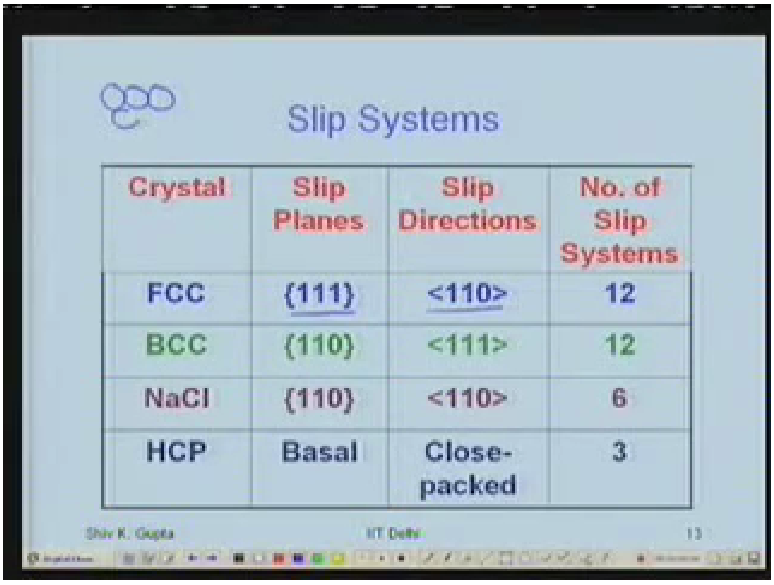

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Thats the closed packed plane length lets make. In this this is one closed packed direction, this is the second closed packed direction, and this is third closed packed direction. Out of the six when the family 110 the other 3 are across the plane they are not on the plane. So an any of these closed slip planes which are talking of the closed packed planes they are only 3 directions which are the closed packed direction and there will be 3 slip directions on it.

So it will be actually 3 into 4 12 slip systems. I define this slip system as combination of the slip direction and the slip plane in this slip plane I have3 directions it may give me 3 slip systems. And I have 4 such planes non parallel planes in the crystal so I have 4 into 3 12 such slip systems. In the crystal same way it is possible to work on the BCC where a closed packed planes there is none but the closest possible plane is 110.

And there is far just a part and the closed packed directions are there which are 111 they lie on the 110 and when everyone 110 there are only 2 body diagonals lying on there. And there are 6 such planes and 2 such directions 6 into 2 makes it 12. In sodium chloride which is belongs to the FCC space lattice closed packed planes are we where slip planes are not 111 because that shall have all ions of the same kind.

And the next plane, next to it will be 222 will be ions of the different kinds thats spacing is less. But look at this 110 plane has both the plane as kinds of atoms ions rather. At ions as well as anions and in the direction of the 110 which is the face diagonal it can slip without problem. 2 ions of the same sign will never come together when it does that there are only 6 slip systems.

You see that 12 slip systems and these material are mostly ductile the deform plastically. The 6 slip systems is limited ductility in the sodium chloride kind of crystals and I go to XCP crystal like zinc there is only 1 closed packed plane AB AB stacking has only 1 closed packed plane they are not like in FCC they are 4 there is only 1 and in 1 they are only 3 closed packed directions so I got only 3 slip systems so that is what I said some of the materials where slip is difficult to take place.

And temperatures are low that we get twinning taking place like at the HCP materials slip is going to be difficult and they tend to become brittle materials just about the slip systems.

Student: sir, the slipping (())(37:40) the slipping (())(37:43) by CN force but how is twinning is (())(37:46) twinning can be done by

Professor: done by shear, its only by shear force?

Student: (())(37:52)

Professor: shear force.

Student: If the material is like HCP

Professor: No, you have to go back to see that actually.

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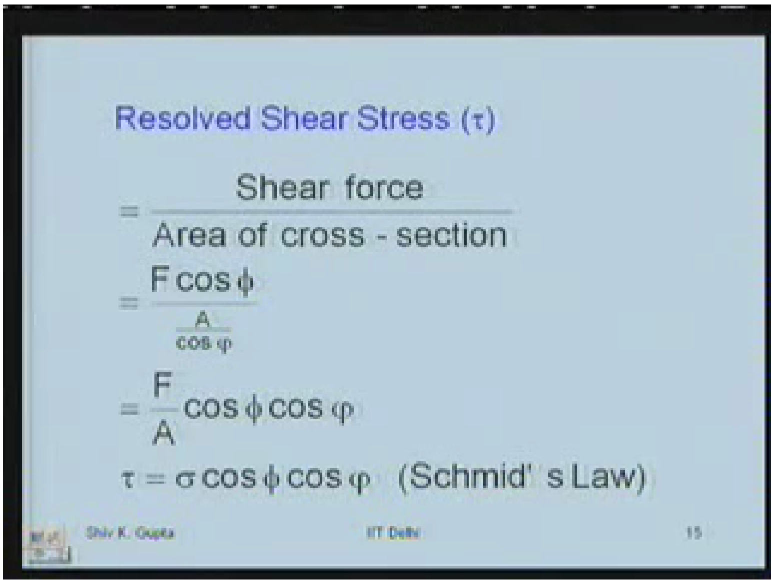

Resolved Shear Stress (τ)

$$= \frac{\text{Shear force}}{\text{Area of cross - section}}$$

$$= \frac{F\cos\phi}{\frac{A}{\cos\varphi}}$$

$$= \frac{F}{A}\cos\phi\cos\varphi$$

$$\tau = \sigma\cos\phi\cos\varphi \quad \text{(Schmid' s Law)}$$

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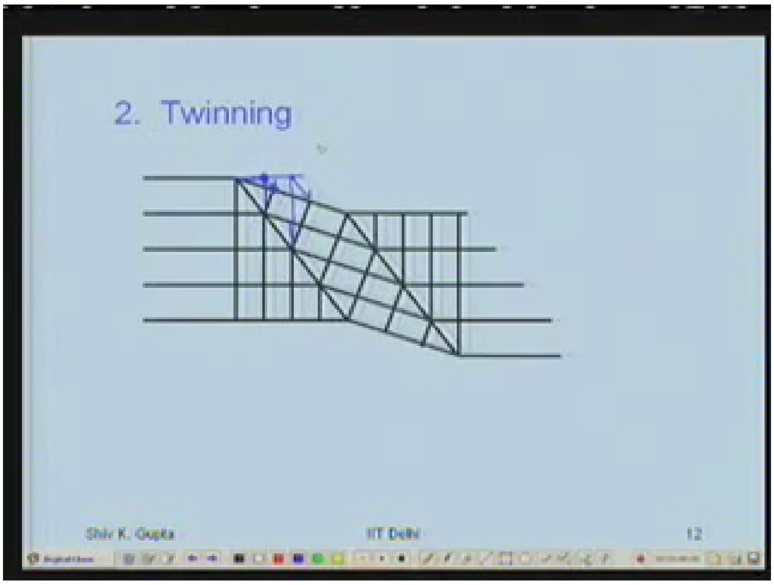

2. Twinning

Yeah, if you carefully look at this atom is a one which has been brought there this is the shear taking place. Its been sheared in that direction okay. If you go further this is the one which is gone in the air. Right?

Student: The material which is more deformed will tend to have more slip planes or into it.

Professor: (())(38:54) if you have said that more deformed means more slip planes its slip planes in a given volume given units cell will be the same. Right thats not going to be different so there is a shear taking place in twinning also. And whatever stress we apply okay I thought thats what you would ask. When this deformation of slip has to take place under the shear stress holds it that when I am done the tensile test I apply the force along the axis of the cylinder tension its slips or deforms okay. Thats what I want to show you here. I take this cylindrical specimen.

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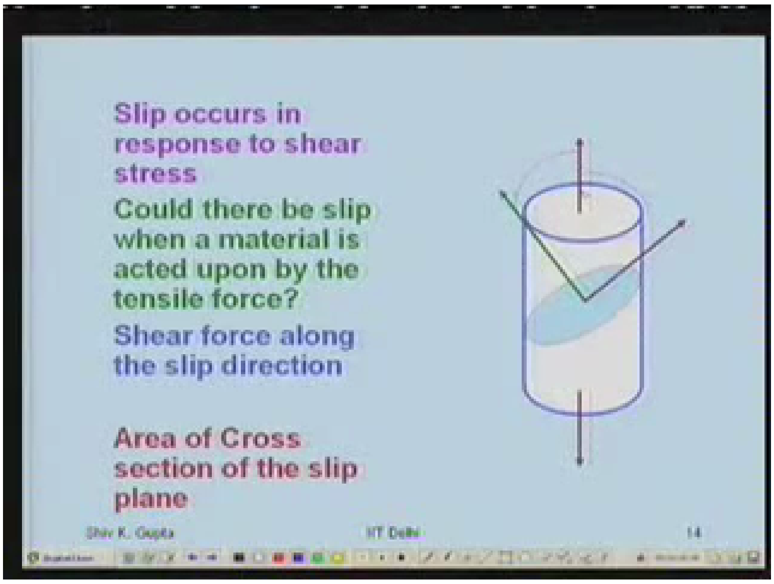

Slip occurs in response to shear stress

Could there be slip when a material is acted upon by the tensile force?

Shear force along the slip direction

Area of Cross section of the slip plane

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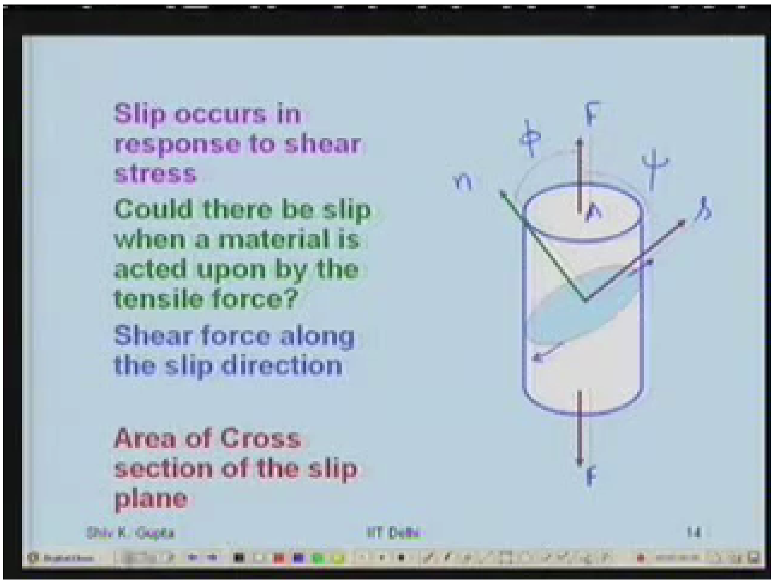

Slip occurs in response to shear stress

Could there be slip when a material is acted upon by the tensile force?

Shear force along the slip direction

Area of Cross section of the slip plane

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This is my tensile axis on which I apply the force F. And I define the area of cross section for this specimen let us say as A and lets say this is my slip plane in this crystal this a crystal this is a slip plane. And this a normal to the slip plane lets call it N. And lets say this is a slip direction lets call it S.

While if I want to find a where is a shear stress acting on this plane a must part of this component of the force in this direction of S once I know this component of this force then the direction of S and I know this area of cross section or area of the slip plane I can find out the shear stress acting on to the plane like this is acting in this direct component of this force component of this force will act in this direction opposite direction.

This will act in that and this will act in this direction okay so it will become shear I define the angle between the tensile axis and the plane normal let us say as 5. And the angle between the play the tensile axis at the sleep direction lets define as sai.

Alright so I can find out the component of the force in the direction of S and I can find out this area of cross section this is a ellipse as compare to the circular section and if I now this angle phi I can work that out it has been done in the next slide.

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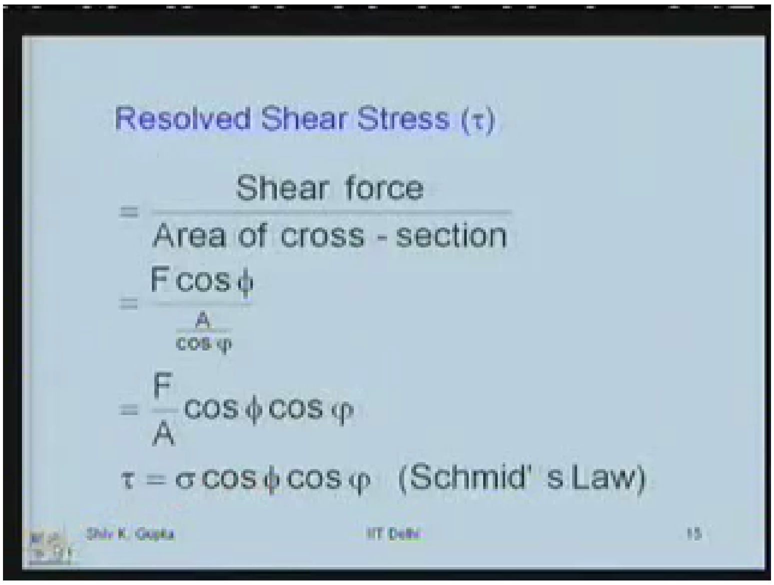

Resolved Shear Stress (τ)

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$$= \frac{F\cos\phi}{\frac{A}{\cos\varphi}}$$

$$= \frac{F}{A}\cos\phi\cos\varphi$$

$$\tau = \sigma\cos\phi\cos\varphi \quad \text{(Schmid' s Law)}$$

I define other way around its C here. I think this angle is define as phi sorry.

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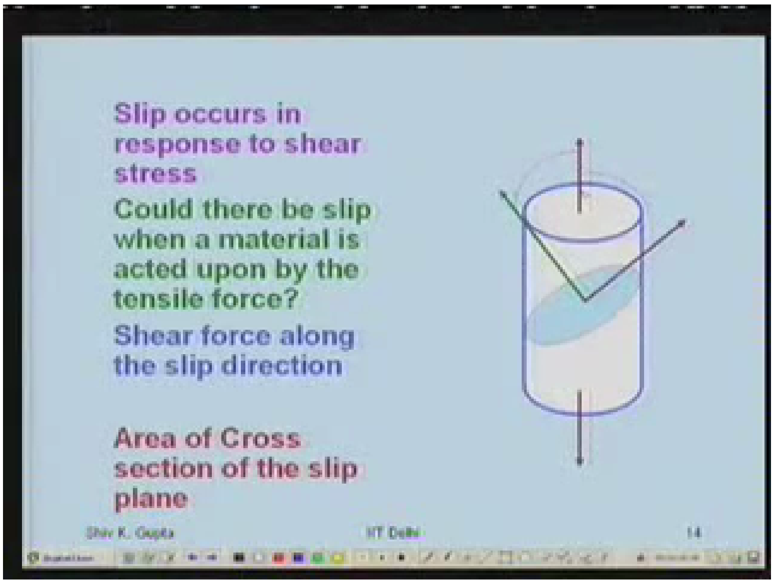
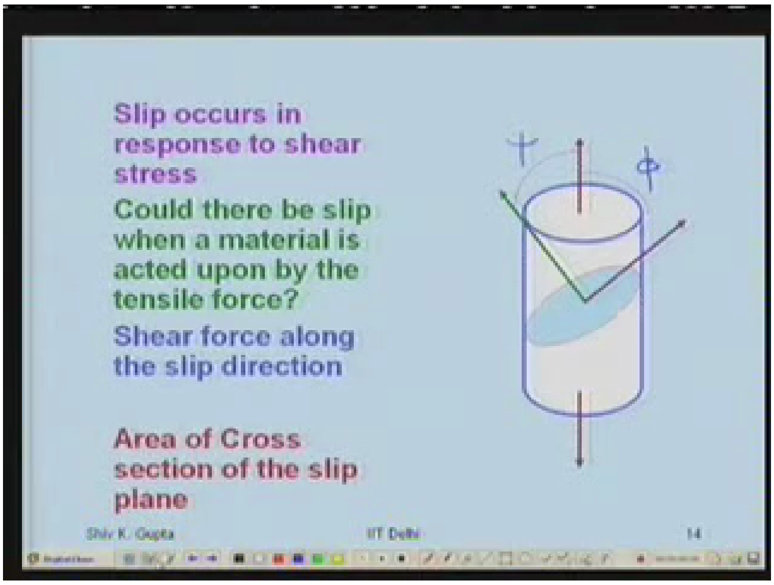


Slip occurs in response to shear stress

Could there be slip when a material is acted upon by the tensile force?

Shear force along the slip direction

Area of Cross section of the slip plane



Slip occurs in response to shear stress

Could there be slip when a material is acted upon by the tensile force?

Shear force along the slip direction

Area of Cross section of the slip plane

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This angle is define as phi and this angle is define as sai.

Student: (())(42:43)

Professor: Is it necessary that N should be perpendicular to S? Tell me? It is, it is.

Student: Sir, phi plus sai (())(42:58)

Professor: Phi plus sai should be 90 degrees yes it would be provided the tensile axis lies in the same plane in which plane normal and slip direction lie. Plane normal will always be at perpendicular to any direction in which lies in the plane but tensile axis unless it is in the same plane in which these two vector lies the sum of phi plus sai will not be 90 degrees.

In other words phi plus sai is 90 degrees at minimum value of two angles phi plus sai the minimum value is 90 degrees. And any of the location it will be more than that. Right alright so the shear force becomes.

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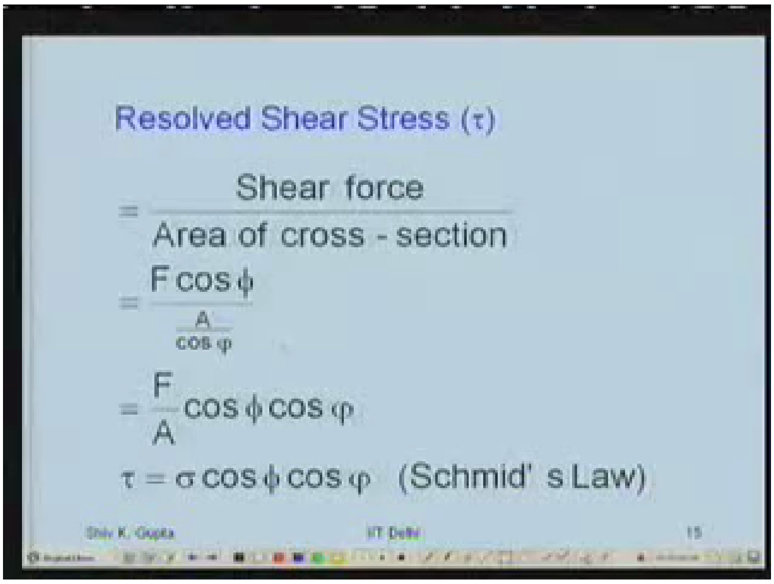

Resolved Shear Stress (τ)

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$$= \frac{F\cos\phi}{\frac{A}{\cos\varphi}}$$

$$= \frac{F}{A}\cos\phi\cos\varphi$$

$$\tau = \sigma\cos\phi\cos\varphi \quad \text{(Schmid' s Law)}$$

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As cross phi component of force in the direction of shear direction and area of cos section is A divided by cos Sai. Sai is the angle between the tensile axis and the plane normal so this can be written as F divided by A Cos Phi Cos Sai is the shear stress and F by A is nothing but the engineering stress you know that tensile stress so it is tensile stress time cos phi time cos Sai this is what is called shmid’s law.

That means when I did a tensile test on a cylindrical specimen I was able to create the shear stress on to the slip system. Slip system consisting of slip direction lying on a slip plane and therefore crystal can slip plastic deformation can take place on that but if so what is the value of that stress which is required to cause a plastic deformation.

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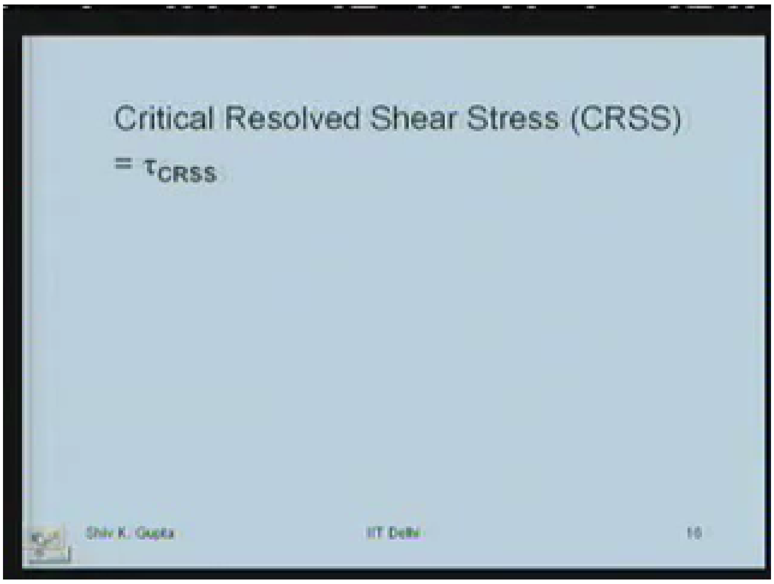
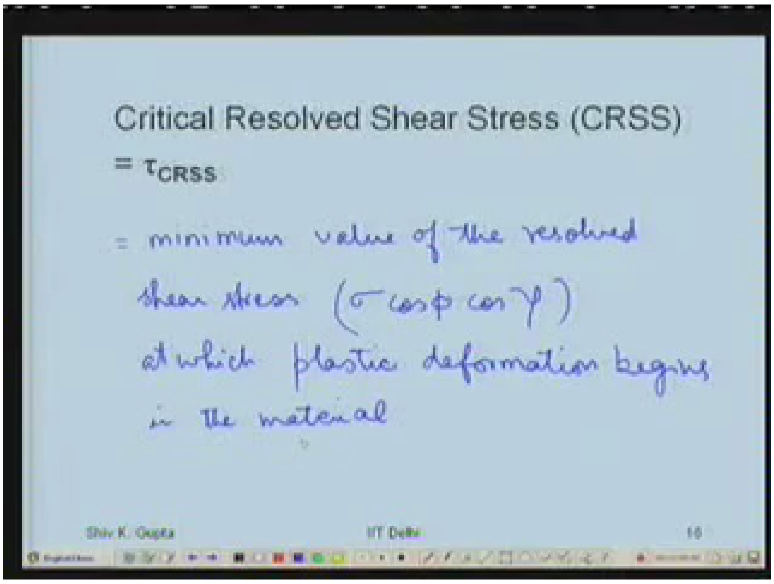


Critical Resolved Shear Stress (CRSS)

= τ_{CRSS}



Critical Resolved Shear Stress (CRSS)

= τ_{CRSS}

= minimum value of the resolved shear stress ($\sigma \cos\phi \cos\psi$) at which plastic deformation begins in the material

I call it the critical resolved shear stress that is minimum value of the resolved shear stress if I have applied the tensile stress on a cylindrical specimen it will be sigma cos phi cos sai, okay at which plastic deformation begins in the material at a stress less than that plastic deformation will not begin that means its all going to be elastic deformation.

This is the minimum value critical is all shear stress at which slip mechanism begins to function plastic deformation begins in a material right.

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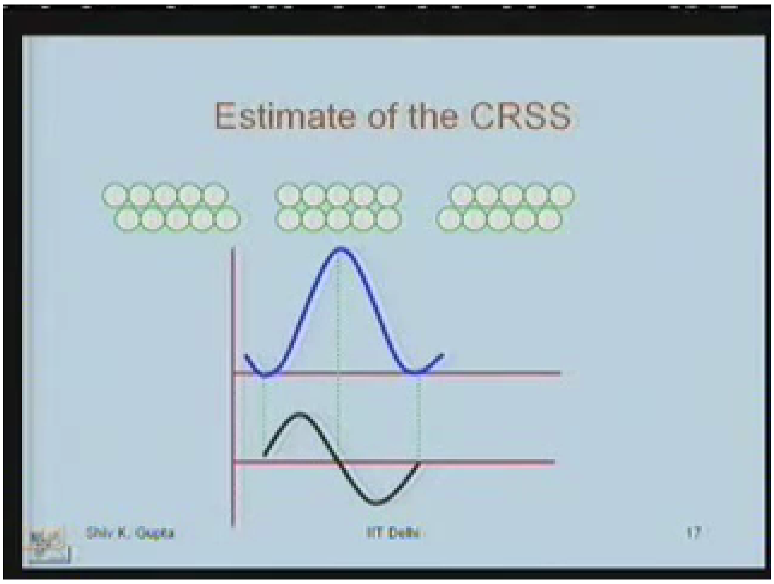

Estimate of the CRSS

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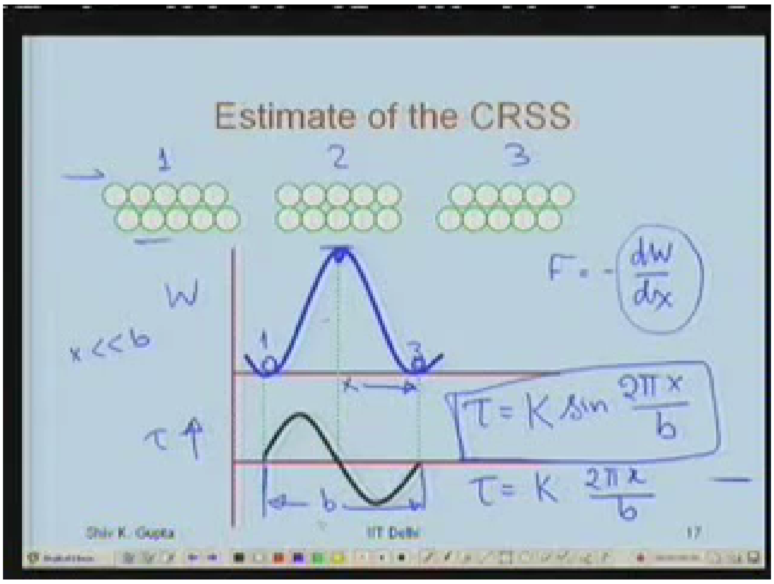

Estimate of the CRSS

$F = -\left(\frac{dW}{dx}\right)$

$\boxed{\tau = K \sin \frac{2\pi x}{b}}$

$\tau = K \frac{2\pi x}{b}$

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I want to now make an small estimate a simple estimate of this I consider a situation like this in a equilibrium position of atoms in a crystal then I push it by applying it goes to the another equilibrium position like this. This atom has moved there this has moved there, this has moved there like that this has moved there. But before reaching there in between it will pass through this situation this is the one a situation corresponding to this where the potential energy is a maximum potential energy is minimum in this position number one.

And in this position number 3 thats a minimum but when its here in position number 2 this is a maximum potential energy you see you have see the condon morse curve between two atom its to the minimum potential energy when the bond is formed. But when I add up all the condon morse curves in a row what it do actually in three dimensional volume it will become some kind of a periodic function.

Okay and the (())(48:05) would be from one minimum position to next minimum position from this position to the next the minimum positions. Okay all the equilibrium positions you can say that as a lowest energy this is equilibrium position right. I conveyed this into the force you know that can differentiate this we define at F equal to minus DW by DX while last class we talk about the elastic deformation define the force right and the applied first will have a opposite of that.

So the shear stress which you are applying will be some derivative of DW by DX of the curve of this. It is zero at the equilibrium position it is zero at this position it is zero at the position 2 but in between it passes through the maximum this is positive its positive increasing here inflection point then its slope begins to decrease goes to a (())(49:13) zero here again it goes to the negative direction goes to a maximum and such thing.

And its going to be again a periodic function, and the period is lets called this is a period our repetition call it to a distance B the equilibrium spacing between 2 locations if I assume this to be a semis idol function I can write tou is equal to some constant K time sign of 2 pie X by B where X is this this placement along this axis B is a period so it becomes a periodic function.

Right alright now lets make it for a very small stress or so that I am getting a very small displacement X when X is less than less than B what will happen here? Sin 2 pie X by B will be equal to 2 pie X by B then sin theta, theta tends to zero sin theta becomes theta so I can write this as sorry. In such way small deformation when I am resting towards less than less than B deformation would be elastic and hooks law must be obeyed so that is the case. Do we have another sheet? Yeah, alright yeah, so I have already got.

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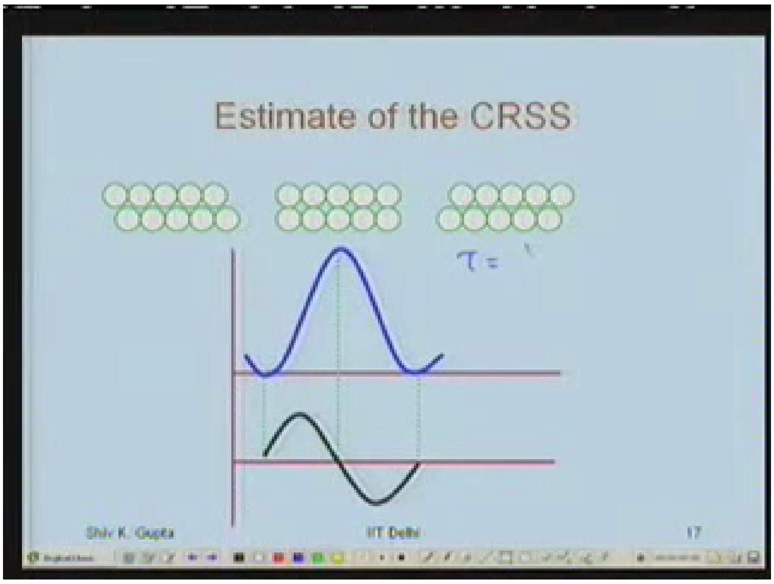

Estimate of the CRSS

$\tau =$

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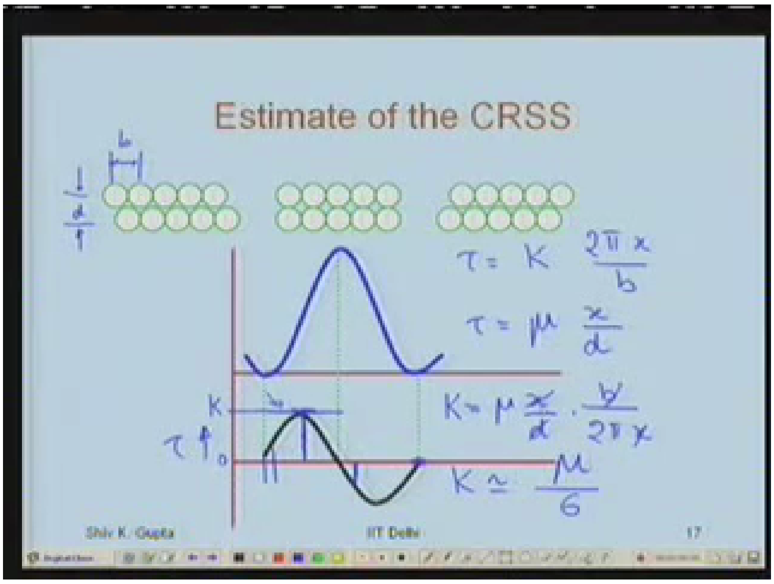

Estimate of the CRSS

$\tau = K \frac{2\pi x}{b}$

$\tau = \mu \frac{x}{d}$

$K = \mu \frac{x}{d} \cdot \frac{b}{2\pi x}$

$K \simeq \frac{\mu}{6}$

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Tou is equal to K times 2 pie X by B and for small displacements like which we are talking about hooks law should be obeyed stress must be proportional to strain and strain is going to be given by the displacement divided by the distance between the planes lets call it D so it will be shear modulus times X by D and in such small values of X these two must be equal and that is the case in K is equal to Mu times X by D into B divided by 2 pie X.

And what is K in this graph. K is this value of the tou when sin is 1 and when sin is 1 theta is 90 degrees where here you can see that if you apply that much force stress taking it further you need not apply that much stress. As a matter of phi it becomes difficult for you about you want to hold it back at this position you have to apply the force in the opposite direction because negative now this is zero here you have to apply the negative force.

But to apply the opposite otherwise you automatically go to that position so once you cross this level of force it will reach here automatically and that will keep moving so this is that level of stress required actually thats why I am trying to work out K. Okay this is that critical resolved shear stress which I require so that there will be automatically there will be moment from one location to the next to the next to the next right.

So if I simply this X cancels with X if you look at this distance between B and D they are the same order of magnitude if 1 is 1 (())(54:01) other might be point 8 yield strong, point 8 yield strong point 85 yield strong right. So there out of many (())(54:08) is the same so I kept also approximately cancel them and then it get K equal to approximately Mu by 2 pie which I can say 6 so K is approximately Mu by 6 where Mu is a shear modulus of the material. Okay so this is what I called what I call it I tell you later.

Student: Sir, (())(54:46) why there critical space is required? For and (())(54:52) so what is the reason. (())(54:57) critical space.

Professor: You have to look at the force versus distance curve that is the stress which I have shown here just look at this carefully.

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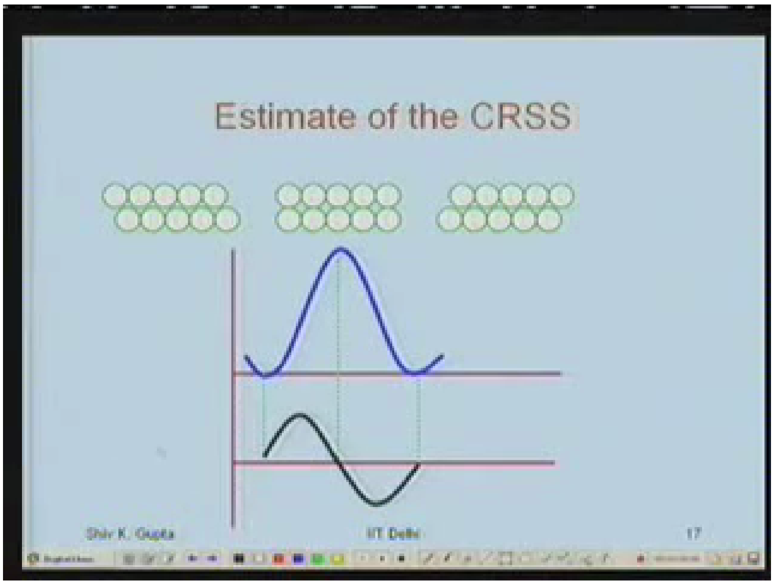
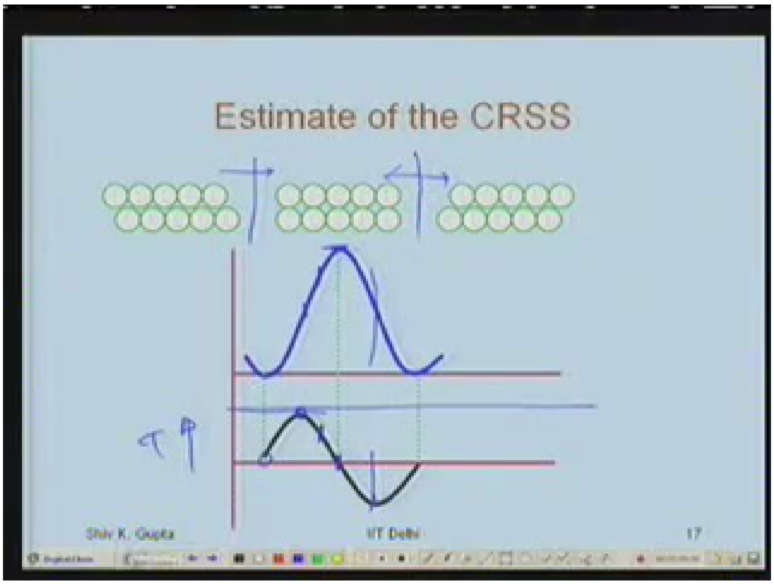


Estimate of the CRSS



Estimate of the CRSS

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To take the material from this position to that position that is somewhere here in between these two I have to apply this stress, but to take it to this position I have to apply stress less than that I already applied stress more than that.

What it go there automatically and to take it here I have to apply zero stress to keep it here it is reached that position and then to hold it to the at this position that is between this and this somewhere I want to hold it I have to apply stress in the opposite direction.

Then it will go it will be jumping running to that side okay so I want to stop it to apply that I would apply the force in a negative direction. Thats why you also reach this for (())(56:12) will be automatically it will be going okay I'll stop it here now.