Introduction to Materials Science and Engineering
Prof. Rajesh Prasad
Department of Applied Mechanics
Indian Institute of Technology, Delhi

Lecture – 118
Strain Hardening

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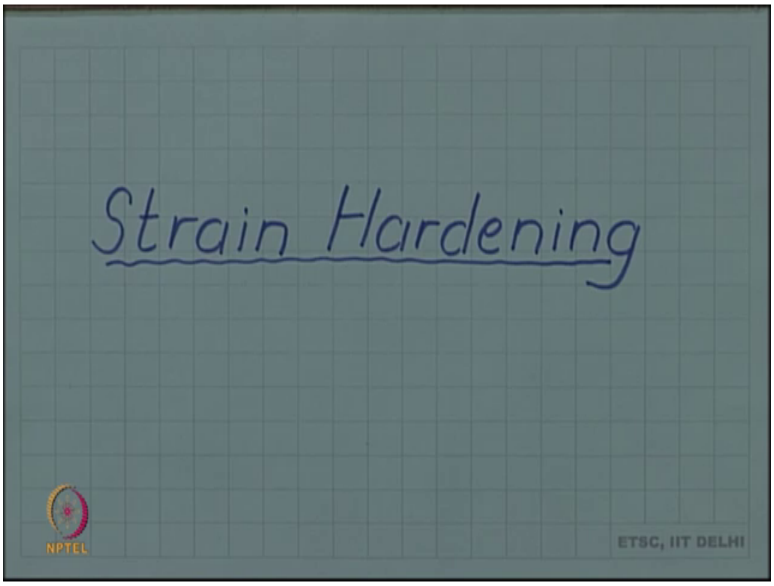

At one point; we listed various strengthening mechanism, in particular force strengthening mechanisms, which can be used to strengthen a crystalline solid, which is deforming plastically with aid of dislocations. Strain hardening is one such phenomenon. So, let us look at what happens in strain hardening.

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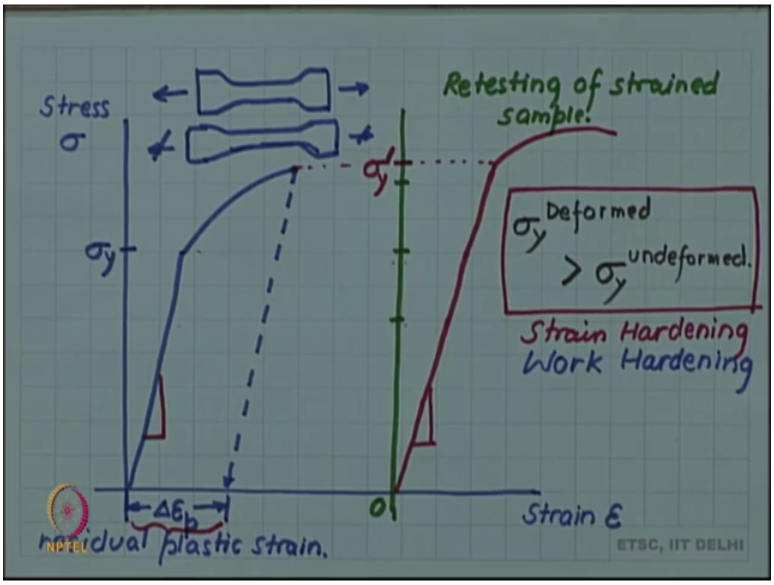

So, let us have a stress strain diagram we have seen this; and we see that if you apply stress and trace the stress strain of some object, initially it deforms elastically, but then and it remains a straight line in the elastic part, but then the curve becomes non-linear and the plastic deformation begins and we continue the plastic deformation in a normal test; we will continue the plastic deformation right up to the fracture point.

But, let us do a different kind of test where, let me note this point this is the yield stress. So, we deform the material beyond the yield stress. So, there is plastic deformation in it, but we stop the test much before fracture and then we unload the specimen, unloading curve is found to be parallel. So, we load it and then we unload it and this much as we have seen before also this much of plastic strain remains in the material; residual plastic strain remains in the material.

Now, so what we have done? We started with remember our dog bone kind of specimen for tensile test. So, we were pulling this under tension and we were generating this curve. Now, although the sample has plastically deformed, so it is elongated. So let me try to draw the deformed sample, it is slightly longer now and maybe diameter is also little bit reduced, but otherwise the sample is still intact. So, this is the unloaded specimen. So, let me switch off the stress now. So, after plastic deformation, I have an unloaded specimen, which is little longer and maybe a little smaller in diameter than the original specimen.

Now, suppose since this specimen is still existing; we have not lost it has not broken, suppose we repeat the tensile test on this what will happen? So, let me create a new axis for our repeated tensile test. So, we are shifting the origin. So, now, I am taking the 0 of the strain here, the new 0 of the strain here and we are loading; we are retesting the loaded sample or we are retesting the strained sample strained or deformed sample.

So, what we will see? What we will find? That is the question. In particular in terms of the yield stress will it show the same yield stress sigma y or will the yield stress be higher or will it be lower.

So, that is the question in a retest, is the dull; is the deformed is the deformed specimen weaker than the original specimen. So, it will show a lower yield stress or it is a say yield stress is some sort of property, which does not affect by deformation and remains the same. So, yield stress remains the same, in the deformed and undeformed specimen or the final answer that; the yield stress is actually larger. You have deformed the material and due to deformation the material has become stronger, which of these three options will you choose. Again we have seen again and again in this plastic de particularly in this plastic deformation chapter that, such questions cannot be answered philosophically you have to actually do the experiment and find the answer.

So, we propose the question to the nature. So, we actually do the test again. So, in our retest, what we find? First thing we find to the slope of the stress strain curve does not change. So, the modulus is exactly the same. So, there is no effect of straining or no effect of deformation on the modulus; however, the curve does not show a deviation from linearity or it does not undergo plastic deformation at a stress lower than the original yield stress. So, it continues up to the original yield stress; by does not stop there it continues further beyond up to the point, where you have started unloading; which sort of remembers it point from which you had unloaded it. So, that becomes that point becomes your new yield stress and then it continues it is plastic deformation.

So, which means that after deformation, when the test is done on a plastically deformed specimen; the deformed specimen has a higher yield stress than the undeformed specimen. Let us write this important conclusion; that sigma y deformed is greater than sigma y undeformed. And this effect; this is the phenomenon which has been termed a strain hardening. The question is why it is happening? We will look at that; but at the moment at the level of definition or at the level of observation, what we see is that; if a material is plastically deformed and then tested in a uniaxial tensile test, it will show a higher yield stress than an undeformed specimen.

So, in a way this plastic strain; what was the difference between the red the red curve and the blue curve. The blue curve was originally tested and had no plastic strain whereas, the red curve has an inbuilt; this much amount of plastic strain is already there in this and it is that is why this is called strain hardening. In engineering it is also called sometimes work hardening, because process of plastic deformation engineers called cold-working or working, so it is also called work hardening. Strain hardening and work hardening are synonymous.

Now, let us think of it; since plastic deformation is involved dislocations are involved. So, let us look think of it in terms of dislocations.

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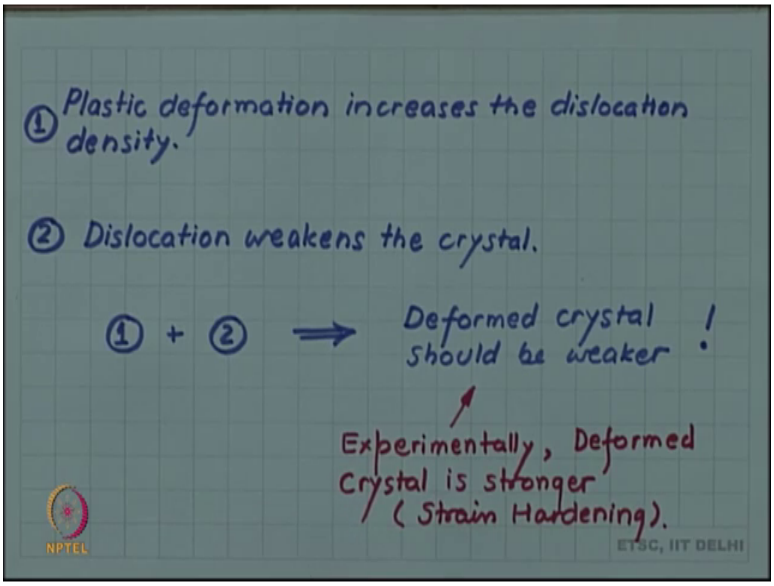

So, we have already seen that plastic deformation; increases the amount of dislocation in the material, increases the dislocation density dislocation density. But we have all also seen and that is how the dislocation was proposed in the literature of science, as a mechanism or as a device, by which you can deform the material at much lower stress than the real than the ideal or perfect crystal. So, we have also seen that dislocation weakens the crystal. So, if you put 1 and 2 together the normal conclusion will be dislocation weakens the crystal; plastic deformation is generating more dislocation density.

So, deformed crystal should be weaker, but we have seen that this is not true experimentally not truth. This conclusion is incorrect; experimentally deformed crystal is a stronger; that is what we call strain hardening. So, there how do we resolve this conundrum this problem that; dislocation is weakening the crystal we are generating more dislocation during plastic deformation; still crystal instead of weakening is a strengthening. This conundrum is explained by what we call Dislocation - Dislocation interaction.

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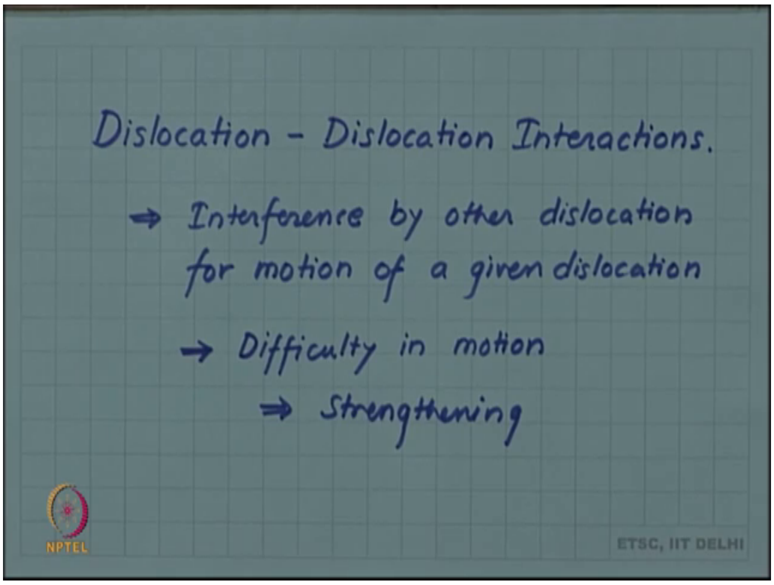

So what really happens that when plastic deformation starts generating more and more dislocations one dislocation comes in the way of other. So, and they start interfering with each other's motion; making each other's motion more difficult. So, there is an interference; interference by other dislocations for motion of a given dislocation and this will of course, if the dislocation motion is becoming difficult, so the yield stress or the stress required to move them will go up and the strengthening will happen; so difficulty in motion which will lead to strengthening.

We are talking in a very general term. In the next video, we will actually we will try to see in a little bit more detailed fashion, what do we mean by such interfering Dislocation - Dislocation interaction.