Introduction to Materials Science and Engineering

Prof. Rajesh Prasad
Department of Applied Mechanics
Indian Institute of Technology, Delhi

Lecture – 143
Enhancing fracture resistance

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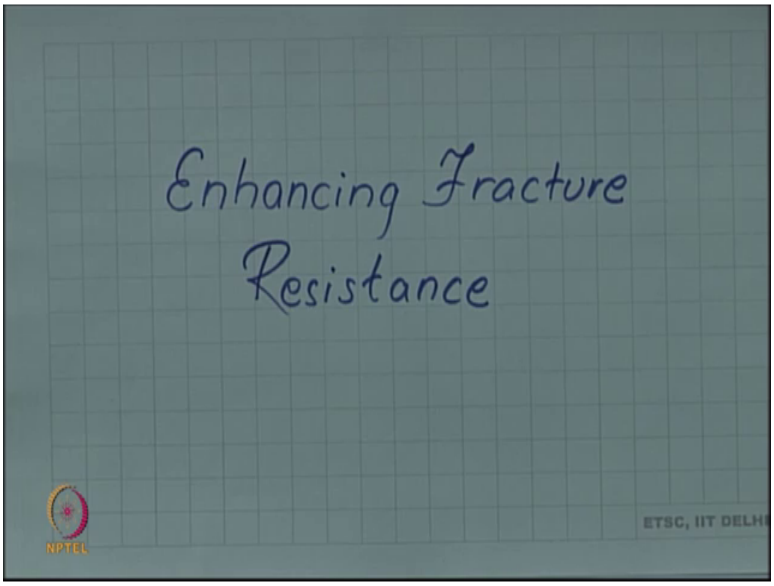

Although, we can never ensure that a component or a material will never fracture, we can do something to enhance the resistance to fracture of any given component or material. This can be done by variety of ways and we will discuss some of them now.

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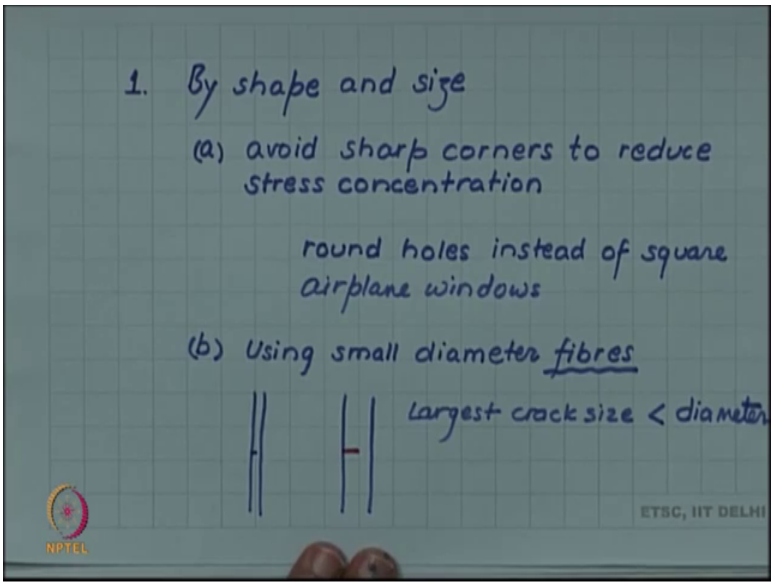

So, one possibility of enhancing the fracture stress is by controlling of shape and size, we have already seen that sharp corners lead to stress concentration. So, that is by avoiding sharp corners one can reduce stress concentrations and this will enhance the fracture stress of the material.

So, round holes instead of square is a classic example and we have discussed one particular application of this in the airplane windows. In the older airplanes, the windows were used to be square, but now in the modern airplanes, you know all windows are circular or oval to avoid the sharp corners. Now another interesting way of enhancing the fracture stress of a material is using a small diameter. This is particularly the case with fibres. We have seen fiber reinforced composite and in that those composite why do we use fibers, why do not we use for example, rods to reinforce.

So, a fiber is a much smaller diameter than a rod and if these if you think of a crack in this so, the largest possible crack in a larger diameter fiber will be much more than the largest possible crack in a smaller diameter fiber. So in fact, the largest crack size cannot be larger than the diameter the largest crack size has to be less than the diameter, this itself enhances the possibility of mean registering the fracture because thinner fiber by the virtue of their thinness by virtue of their small diameter are ensured, we have ensured that no crack larger than the diameter of this fiber is there.

So, in the statistical sense, there will always be smaller cracks in a small diameter fiber than in the large diameter fiber. So, that is why we always use thin wires for reinforcing composites.

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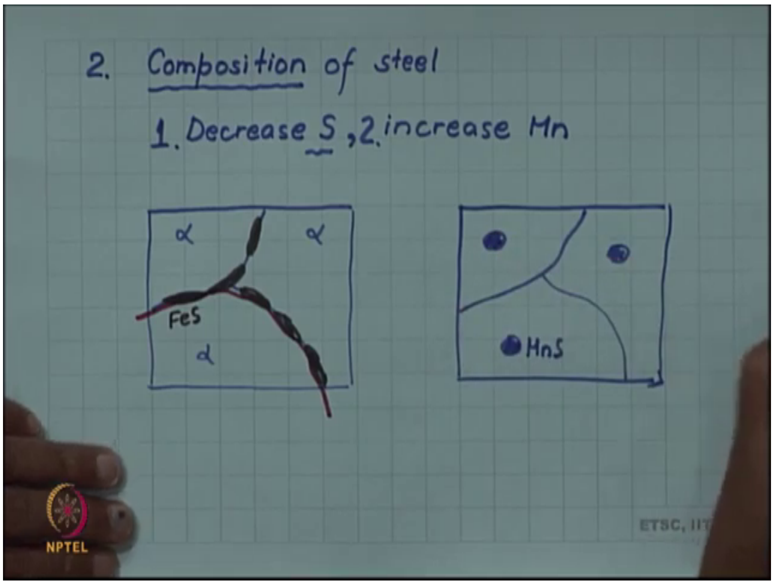

In case of steel, composition is very important in determining the brittleness and one element which causes brittleness in steel its sulfur and the way it causes brittleness is if you consider the structure of a steel. So, let us say that these are ferrite grains and these are the grain boundary, sulfur diffuses to the grain boundary and tends to segregates at the grain boundary and there, it forms by reacting with iron, if it is concentration enriched sufficiently by reacting with iron, it forms particles of iron sulfide.

These particles are hardened brittle. So, if sulfur concentration is high, the entire boundary can get coated by these brittle sulfur particles; FeS particle. So, you can see even if alpha phase is ductile through the grain boundary will act like an easy path for crack and will the fracture will propagate. So, way to avoid this in a steel is to use first use low sulfur. So, modern steel have much less sulfur than say the sulfur content of titanium; one of the reasons which people are considering a reason for the failure of titanic was very high sulfur content of the steel of which the titanic was made.

The another factor is to increase manganese into the steel. So, what this manganese does is to react with sulfur and forms globular Mn sulphide instead of sulfur going to the grain boundary it makes manganese sulphide inside the grains. So, this again avoids an easy path made by FeS in this case. So, both the decrease in low sulfur content and the presence of manganese helps to improve the fracture resistance of steel.

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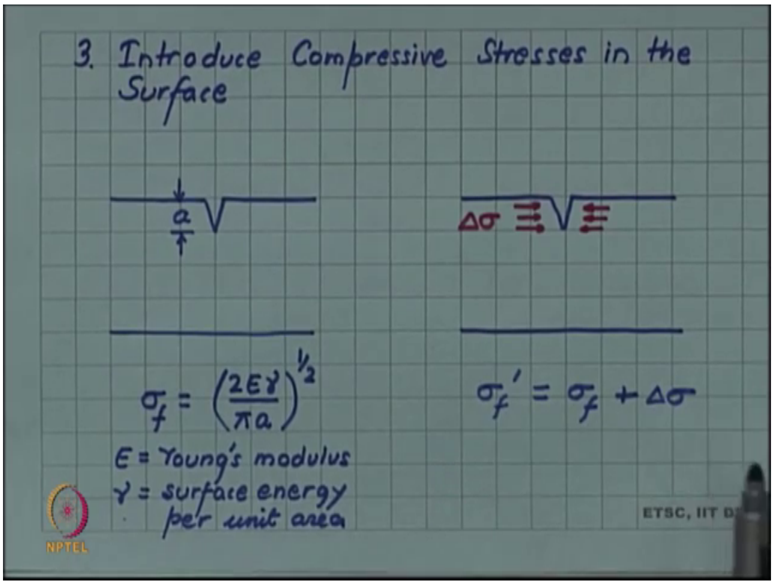

A very interesting way of enhancing fracture stress of any material is to introduce compressive stress in the surface. So, let us assume that this is a component with a surface crap of depth a. We know from Griffith's formula that the fracture stress will be 2E gamma by pi a square root of this quantity, where E is the Young's modulus and gamma is the surface energy per unit area.

Now if somehow some residual compressive stress is introduced into the surface. Suppose the crack phases now are in compression and the value of this compressive stress is let us say delta sigma, then the fracture stress in this case now will be enhanced by the same value that is sigma f, in this case, sigma f prime will be this sigma f due to the crack length a plus the compressive stress delta sigma because remember sigma f is tensile and only the tensile stress opens up the crack.

So, if we have put delta sigma compressive stress on that. So, this much of tensile stress is first required to bring the effective stress at the crack phases to 0 and then additional sigma f is required for the crack to propagate. So, the new fracture stress will be higher if compressive stress is introduced. This is the basic philosophy of enhancing the fracture strength of a material by introducing compressive surface stress.

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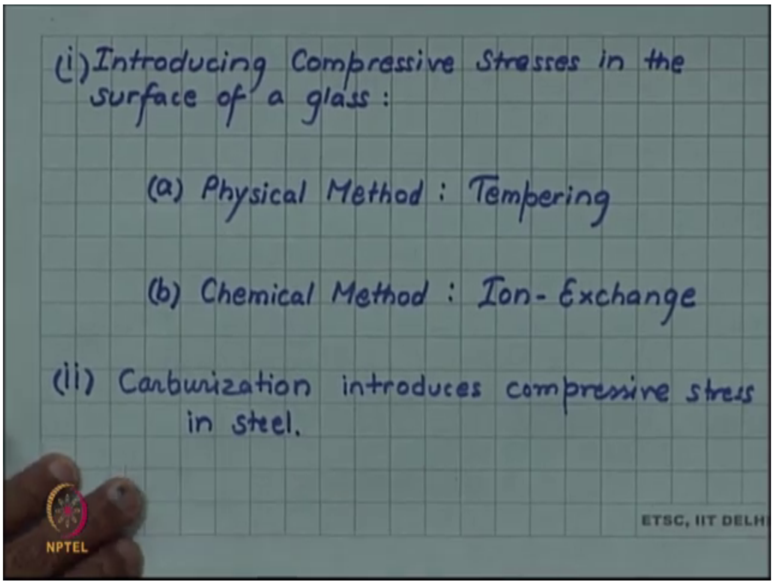

This compressive surface stress can be introduced in glass by a physical method called Tempering or a chemical method called Ion Exchange or we will discuss both of these methods in detail later and another way of doing this for steel is carburization.

We have studied carburization while discussing diffusion. So, if carbon is introduced into the surface, not only it enhances the carbon concentration and hence the hardness of the surface, it also introduces surface compressive stress and thus enhances the fracture resistance of the material.

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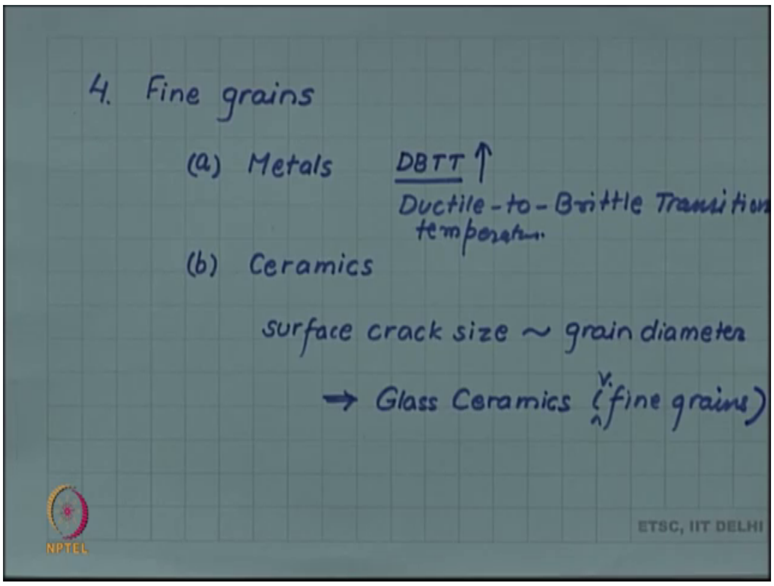

Yet another method for enhancing fracture stress is to have fine grains, we have seen that for metals fine grains leads to higher ductile brittle transition temperature; ductile to brittle transition temperature. So, higher ductile to brittle transition temperature is means that reduction or brittleness and a more toughness of the material.

Similarly, for ceramics; the grinding process of the ceramics or manufacturing process of ceramic usually introduces surface cracks of size which are close to the grain diameter. So, if grain sizes are fine, the surface cracks will reduce in size. Classic example of this process is glass ceramics which are produced with very fine grains very fine grains; we will look at glass ceramics little bit more detail later.