Nature and Properties of Materials
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Lecture 4
Mechanical Properties of Materials

Good morning students, today we are going to talk about the mechanical properties of materials. So basically the contents will be that first I will tell you a broadly about the material properties that we generally consider for example, when we will be designing a product and then we will go specifically into the domain of mechanical properties where we will talk about the concept of like stress and strain.

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And we will describe how these constitutive relationships are built, and then we will talk about mechanical properties of the material, which are very relevant towards this direction for example, the tensile strength, ductility, brittleness, resilience, toughness, impacts strength of material.

These are the things that we generally need when we have to develop a product or an engineering system which has to sustain a degree of mechanical loading. So 1^{st} of all, let us look into broadly the material properties. In the last lecture I have told you broadly about the domain of materials, now we are talking about the material properties that one has to consider.

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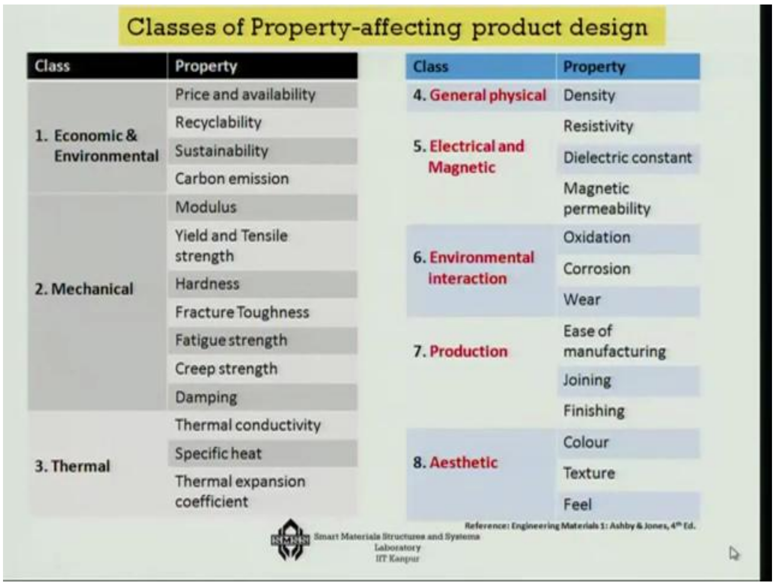

So towards that direction if you look at it that there is a 7 we call it a 7 parameter based grading of a material okay. So the 1st in this direction is of course you have to always keep in mind the economic and environmental effect okay because you know if the material is very expensive then it is of no use for a mass production system.

Just for an example that suppose you need a very high stiffness in a particular mechanical system. Now Diamond is having the highest stiffness, so something like you know that the diamond bond is something like 1200 Gigabaster, but can I make a mechanical system out of diamond? No.

So that is what we have to keep in our mind, diamond is of course an extreme example, but the price and availability is a very important aspect in terms of choosing a material. We will cover about these things in one of the talks I will tell you that what is the current prices and availability of the materials in the Indian context, okay. So that in one important point that whether the price is affordable for a particular engineering system.

Now once again so for example, you are making a screwdriver or you are making a nail cutter, so the type of material that you can afford in comparison to suppose you are making an automobile will be definitely of inferior grade that means you know the material cost is more important for products like automobile or for products like aircraft for example, so you can afford their slightly higher grade of materials.

So that is why the price plays a very important role. Another very important role in the economic factor into this context is the recyclability of a material because you know we always say that there is a life of a product and there is afterlife of a product. So when the product is of no use okay, what are we going to do with it?

The whole system you know the all the mechanical components yesterday we have seen that in the last class that 150 years even if you can retrieve a piece of steel, you can actually put it into the melting process and you can reuse the steel, steel has an excellent recyclability from that point of view. Now if you think of a plastic product, can it have that kind of recyclability?

Can you use it again and again once that product is used for one purpose? Can you melt it and reshape it and give it another life? That is the point, so recyclability refers of that. Now not all materials have a good degree of recyclability. Then the other point is sustainability, now there I can give you a very interesting example.

For example, you know couple of years or few years before there was a discussion that you should go for earthen pots for tea in terms of railway usage and things like that and the logic was given that it will be more sustainable um it will be because you are not using plastic, so it will be less you know recyclability point of view also it will be good.

And sustainability issue is that because it is clays so it will not create any harm to the environment. But a study was made at Institute of science Bangalore and people found out that actually plastic cup is more sustainable in comparison to the earthen pot because when you are making earthen pot, you are actually taking clay, you are heating up to a high temperature level.

And hence you know the energy that you are applying is actually much more and in today's context, energy is very important. So the energy that you require and the pollution that it creates while making these you know earthen pot is actually much more in comparison to the environmental pollution that will be there for making a plastic cup on a plastic mould.

So you see, sustainability is a very you know important topic which has to be thought of from all different considerations. Now the other interesting thing here is also the carbon emission because as you know that (())(6:39) the emission of you know carbon dioxide or say NOX gases and things like that because there is a foot print today.

You cannot really develop your energy or develop for that matter you know supply energy to a system by creating too much of greenhouse gases, etc. So that is what one has to keep in mind while choosing a material particularly for the transport type of applications, so these being basically the economical and environmental aspects, okay. Mechanical aspects I will come later because anyway we will be talking about the mechanical aspects.

Now there are some thermal aspects also that we generally consider. So if you look at the thermal aspects, then one very important consideration for choosing a material is the thermal conductivity. Because if you think of the railway line example that that I have given in the last class.

The railway lines you know if they have a high degree of thermal expansion, then the lines will have a high degree of thermal stress because you have to contend that expansion and that thermal stress will create failure in the lines. So hence you have to choose a material which should have a reasonably lower degree of thermal conductivity. Again for other applications, you may need actually high degree of thermal conductivity, okay.

So wherever you know you need actually the temperature for example, heat exchanger, okay so you need a high degree of thermal conductivity so that the heat that is coming from a system can be very quickly dissipated. Now the other important one is the specific heat. Now specific heat is what, that is the heat capacity per unit mass of a system.

So the specific heat plays an important role in terms of you know denoting that how much of heat can be absorbed by a system. Okay for the entire environmental issue for example, the water to land ratio is actually control by this specific heat because it is the water which has the high capacity of specific heat and hence it can absorb more heat in comparison to the land. So the water heated up much slower at a much slower rate in comparison to the land and as a result, the environmental circulation occurs.

So specific heat plays a very important role in terms of various types of systems at different steps. Then of course you have the thermal expansion coefficient here and the thermal expansion coefficient just like thermal conductivity is very-very important for this type of application where the expansion coefficient is to be either controlled in a certain degree for example I gave you the railway line example where again the thermal expansion coefficient is important.

You again have to choose a material which must have low thermal expansion coefficient so that it does not expand much about you. So and there are cases where higher degree of thermal expansion coefficient is used particularly when you make switches for make or break type of thing. So there the temperature is used in such a manner that the large expansion is possible and the switching of a system is possible through that.

So this is the thermal you know relative parameters. Then of course there are some general physical parameters, just a few of them if you look at it are like density, resistivity these are very general physical parameters but we do look it in terms of choosing a material whenever they are very important for example, a low weight that means low density is always important for aerospace type of applications.

Electrical and magnetic properties, these are becoming very important for mechanical systems today. So there are things like resistivity like dielectric constants like magnetic permeability, these are the parameters which are very important whenever you are thinking of a electro mechanical system, okay. Just for example you think of a system which contains some amount of magnetic system inside it, okay.

So if you think of any such system okay which has a magnet inside this whole thing, okay. So you know for example a motor, now the magnetic field permeability is very important because the higher the permeability, the better will be the induction by the motor, you know the more magnetic field it will be able to generate.

On the other hand, you know there are applications where you will need that there are 2 such magnets for 2 different reasons; the magnet should not interfere with each other. So that means you should need a material in between which will not allow the magnetic field to pass from one part to the other. So here we need to talk about actually EMI shielding kind of things.

So that is how the Electrical and the magnetic fields you know become important for various systems. Next is the environmental interaction, so here in the environment interactions it is specifically important for mechanical system. For example, the oxidation because you know all mechanical systems when they are subjected or exposed to environment, then there is always oxidation that happens in the system.

So you need to give a good protection from oxidation and sometimes there are other corrosive gases you need to give even protections from corrosions for them. So oxidations and corrosions you know are very important factor in terms of those mechanical systems which are generally subjected to the possibility of environmental paradigm or the possibilities of you know harmful chemicals you know conductive.

Say for example gas pipelines okay, so there the chances of corrosion is very high, so you need to choose a material which will not be getting corroded so fast or in that way ruins the life of the pipeline. So thus in oxidation corrosion are important and of course this is important because there are many mechanical systems in which the relative velocity between the 2 components always occur.

You think of a mechanism, there is always you know the relative velocity between the links of the mechanism, so in such cases you know there will be wear that will be constantly happening in the system. And this wear is to be controlled in terms of controlling the life of the system, so environmental interaction effects thus very important considerations particularly for mechanical systems.

And next is from the production perspective, we also you know look for properties which are important from the production point of view. For example, which material is good in terms of the manufacturing point of view? I can give you an example that if you consider between say iron okay and something like a titanium which is used as a space grade application because of its high temperature very good high-temperature properties.

Now in terms of ease of manufacturing however, iron you know you can shape it much better okay. You can actually work on iron in order to give various complex shapes, et cetera in a much easier manner in comparison to titanium. So from the ease of manufacturing point of view you know the material, even though they have other good mechanical properties may not be suitable from the ease of manufacturing point of view.

Similarly, you know there are certain other subclasses of productions like joints, like finishing, so all these things together have to be taken care of in the production phase and hence it affects you know when we are choosing a particular material. Now last but not the least, I told you about 7 important properties, but there is the 8th one that is of course generally beyond this scope of our dealing.

But it is actually aesthetic properties which in today’s context are to be always kept in mind because after all if you cannot give particularly for the consumer goods, if you cannot give an attractive look to a system, the product will not sell. So hence properties like colour, properties like texture, the feel of it, et cetera, this becomes important. So certain materials I told you that metals give a typical metallic lustre.

Also, metals give a typical metallic ringing sound, so from various you know aesthetic point of views metals have a different charm in comparison to the other things like ceramics or plastics okay, if you consider say for example from the thermal conductivity point of view, how that can get coupled with aesthetic? Any metallic product as you know they are highly thermally conductive.

So what happens is that if you know in an area where the climatic condition is very severe like say severe cold condition. And in such places, the metallic system, the moment you touch it, you will feel the warmth of the system. So if you develop a metallic casing let us say of a cell phone, it will not go very well.

On the other hand, if you make it out of polymers, they will be thermally insulating type, they will not lose their temperature and hence they will give a much better feel or comfort, so thus aesthetic properties often becomes important in terms of choosing a particular material. Particularly, we will talk about the consumer type of products, okay. So that is about the overall material properties.

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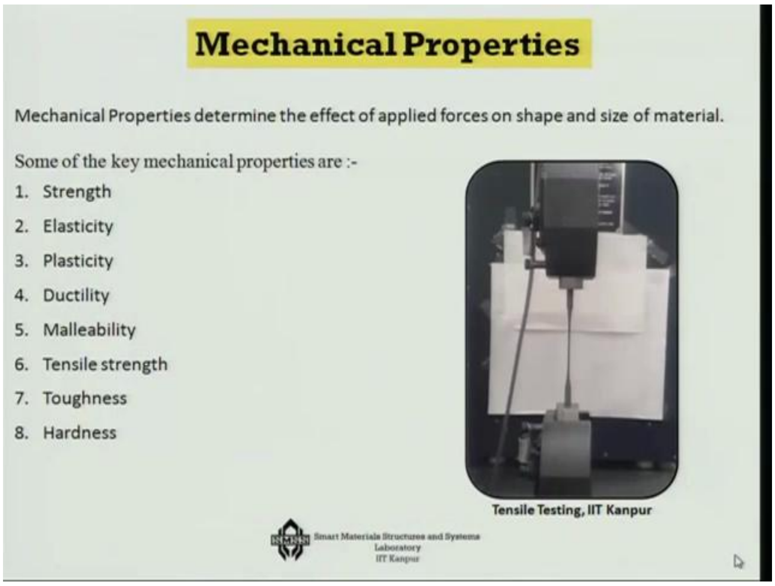

Now let us look into specifically the mechanical properties of the material. There are actually very large list of mechanical properties, but I have chosen a few of the very important ones which you will need for example for the day today mechanical design the strength of the material, the stiffness which actually you know governed by the modulus of elasticity.

Then the plasticity from the forming point of view, ductility and malleability this is one common point that you often come across that ductility and malleability are not the same okay, because both of them of course refers to that how you are deforming a material mainly the plastic deformation, but while ductility refers to the deformation on tensile condition.

The malleability generally refers to deformation on the compressive condition. So ductility for example refers to if I can actually you know reduce the thickness of a wire as I am applying a kind of a large tensile load, okay. Can I draw very thin wire from a cylinder, so if the material has a good ductility, you can draw very thin wire out of it. So that is in the context of tensile load.

On the other hand, malleability is a property which talks about that suppose if I compress something like clay, you know you can actually mould it, you can give different shapes to it, so malleability refers to the compressive loading you know susceptibility to compressive loading that is why the 2 are different. Then of course we talk about the strength specifically the tensile strength because that becomes important and the toughness and the hardness of a material. So these are some of the mechanical properties which we will be discussing in much more details okay.

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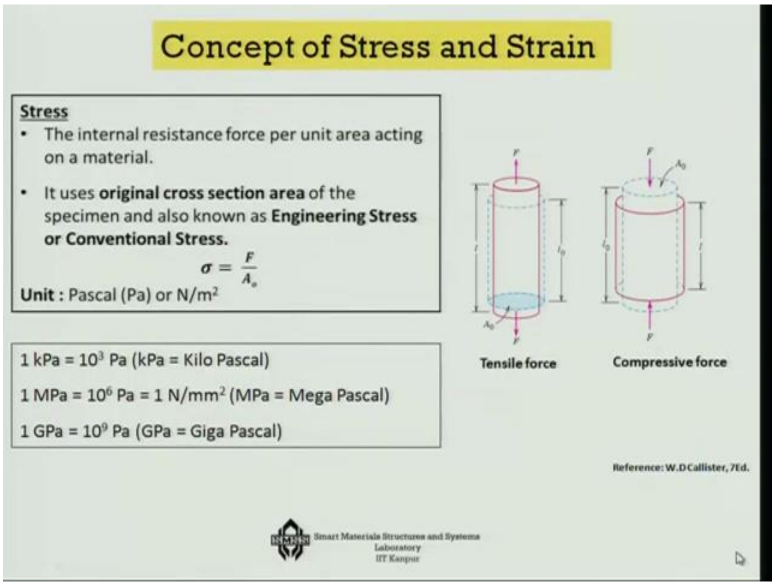

So before I talk about the strength, I should talk about the concept of stress and strain which is which is very-very basic and important for any mechanical component. Now the way we will define stress here, it is a very you know elemental definition of it is that it actually depicts the internal resistance you know per unit area in an average sense that acts on a material when you are trying to deform a material.

So for example, if you use a tensile testing machine then you will be taking a sample where you are actually going to apply the force and deform the material like you can deform it either in a tensile force system this manner then you are actually pulling it apart or you are compressing it, in both the cases you have an idea of how much of force you are applying and you know that what is the area of cross-section of the system.

Okay, the initial area of cross section of the system. So in average since, the force per unit area will give you the stress, okay. Now, this stress is generally you know actually the SI standard unit is Newton per square meter for stress, okay. And that is also called Pascal named after the famous mathematician; it was a very important contribution in terms of hydrostatic stress.

Now even though Pascal is the unit, but generally the type of systems that we come across, we will have something like kilopascal or megapascal or gigapascal kind of you know range of stress, okay. So in fact the way stress is related to strength is also called the modulus of elasticity, so you know if you look at the modulus of elasticity which has the same unit in terms of pascal.

Then just to give you a feel of it that something like a chocolate will have you know modulus of elasticity which is between 100 pascal to a kilopascal range. If you think of something like rubber, it will have modulus of elasticity between kilopascal to megapascal range. If you think of steel, you get modulus of elasticity which is between megapascal to gigapascal definitely in the gigapascal range you know 200 gigapascals and so.

That is kind of an idea which tells us that what is this you know kilopascal, megapascal or gigapascal. So next time you deform a chocolate, you may know that you are actually doing it at something like 100 pascal level. If you are doing it with rubber, it is at the megapascal level and if you are doing it with any metal it is definitely beyond you know several gigapascal, okay.

So that is where you cannot actually do it manually, you need a machine to apply the force; I will talk about that machine which is used in that context. So thus you can understand that what is stress okay, which is the internal resistive force as I told you is averaged out for an area for which the force is working on and the unit of it that is the pascal. Now what is actually the strain of the material?

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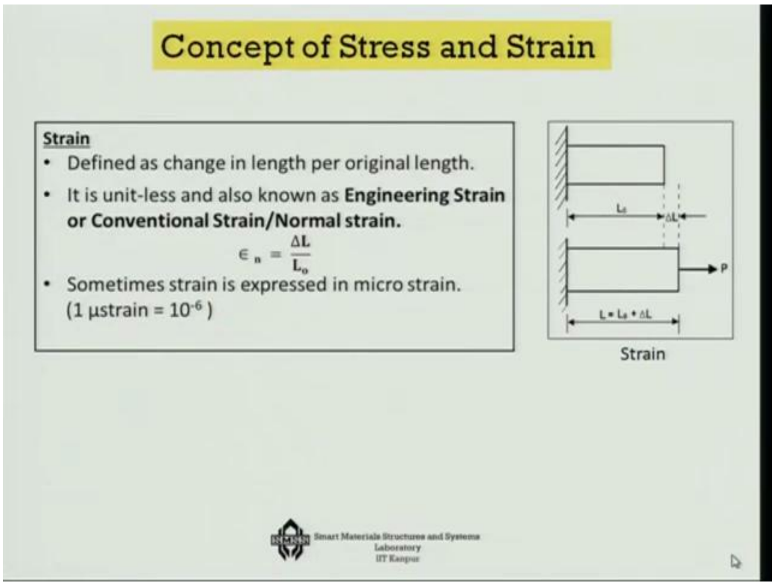

The strain is defined in terms of the change in length per original length of the material. Now here if we think that the area of cross section is not changing or the change is small enough certain range then you know the strain is actually the engineering strain or a conventional strain or a normal strain which is actually the change in length over the original length of the material.

So that is what is your strain and this strain is measured because generally this strain is very small, so the strain is measured in terms of you know 10 to the power minus 6 or micron strain using which the strain is measured in a material. So thus you know these are the 2 very basic important points about stress and strain that you need to know. Now, stress need not be always tensile in nature or need not be always compressive in nature.

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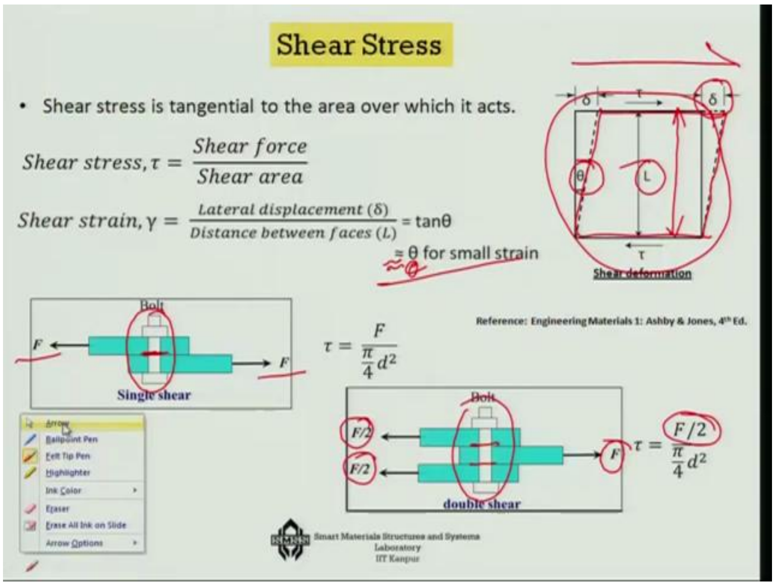

There can be stresses which can be shearing in nature, okay. And say for example in this particular case if you look at it that you know there is a block of mass here over which we are applying a shearing force, okay. So that is why the block actually deforming from its initial position to this kind of a new deformed the shape from its initial shape okay, so that is the deformed shape of the block.

So this kind of deformation where it is neither you can call it expansion or contraction, but it is moving, relative movement of one surface with respect to the other, that is what is the shear, so that type of you know resistance is measured in terms of shear stress, where it is the shearing force over the area over which the shearing is happening.

And the shear strength in this case is actually the lateral displacement that is Delta that is a displacement and over the distance between the 2 faces okay that is what is L so that is the distance between the 2 faces. So that is also you may actually express it as tan theta. Now whenever, this is very small then you know that tan theta becomes almost equal to theta.

And hence you know for small strain condition, shear is often expressed in terms of the angle theta okay. Now there are many day to day examples, see I in the last class told you about the W balanced cantilever beam that is used W balanced cantilever system that is used for the bridge the Howrah Bridge for example okay.

So there if you look at it such kind of bridge construction, you will see a beautiful manifestation of single shear and double shear, okay. So for example, if you have 2 plates which are just locked with each other and then you are using one single bolt to actually lock it and then you are applying the shearing force, okay on the plates stem, then what you have is a single shear because the bolt has to fail across this area of cross section.

So that is what is the you know shear stress that is happening okay, so that shear stress is of a much higher level, corresponding to the force you are getting only this much of area okay. But if you have a system with the same bolt and if you have a system where you have 2 such elements in one side and the other one is in the other side, so you are joining in that manner and this is how the bolt is, then there are 2 surfaces area which comes into picture.

So that actually a force becomes half in that sense, so that means the shear stress level comes down. So thus you can actually make many such you know changes intelligently in a system so that the shearing stress actually come down and thus you know gives you a stronger system with better life, so that is what is the shear stress.

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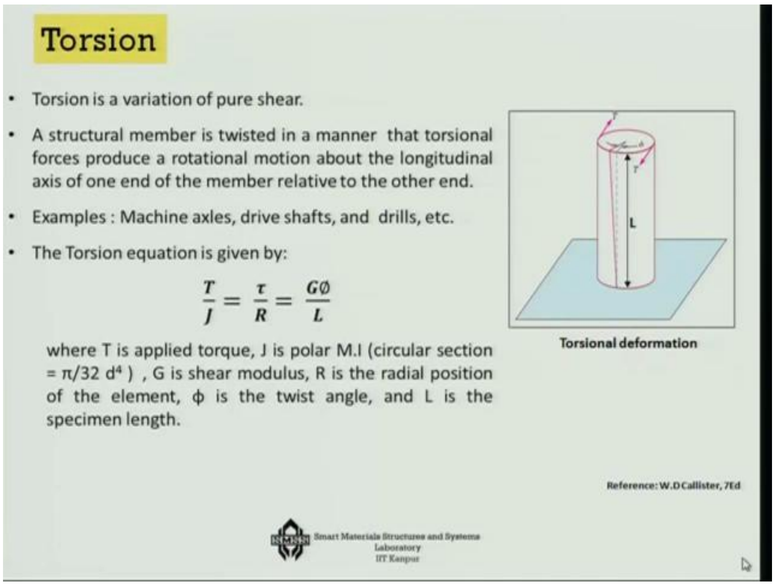

Now, there is also another manifestation of shear stress, you call it pure shear. These happen of course in terms of torsion okay, which is a variation of shear stress. Now in the torsion what happens is that a structural member is twisted in a manner that the torsional force for example, in this case you are actually twisting this member.

Okay in a manner that it produces a kind of a rotational deformation or a rotational motion of the top surface with respect to the bottom surface where it is hold. Let us say it is fixed at this point, okay so this kind of a thing where there is again a relative movement between the 2 surfaces, they are standard of any torsional situation and they are generally governed by this kind of a standard relationship for very small twisting angle okay.

So its strain is not very high and its torque over the polar movement of inertia equals to the shear stress tau over R and that is equal to the shear modulus of elasticity G over phi, phi is the angle of twist, phi is this angle over the length L of the sample, okay. So one can you know actually find out that what is the shear stress corresponding to the pure shear conditions provided you know that what is the modulus of elasticity.

You know what the twisting angle is, you know what is the radius of the shaft or the length of the specimen. So that is a special case or manifestation of shear which is called the Torsion. Where this is important there are this machine excels, drive shafts, air craft wings for example, or (())(30:02) where you know this type of a system the torsion of a system are very heavily used.

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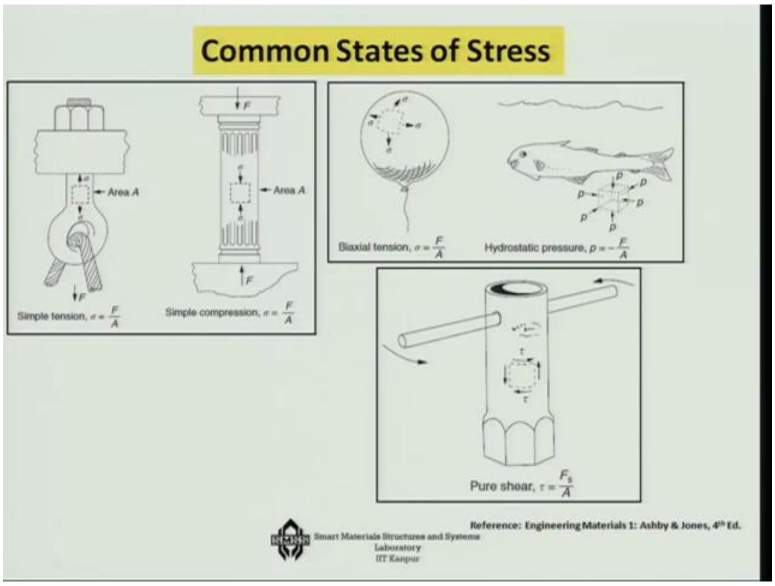

Now, what are the other common states of stress? Of course, in a day to day experience you must have seen this kind of simple tensions you know something like a copy crawl or you know something like in a pulley based system or something like you know a column, you will see a simple compression place.

But there are other cases for example, balloon okay or any such hydrostatic hoardings where you get a biaxial state of stress okay, expansion and contractions or hydrostatic pressure you can see or you know there are cases where you will be able to see the pure shear, so these are all certain cases of stress in our day to day experience. So these are certain common states of stress and this is where we will actually finish today’s lecture.

And what will be discussing next actually we will talk about this concept of stress and strain and the constitutive relationship in much more depth in the next lecture. Thank you.