Continuum Mechanics And Transport Phenomena
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Lecture - 45
Comparison of solids and fluids

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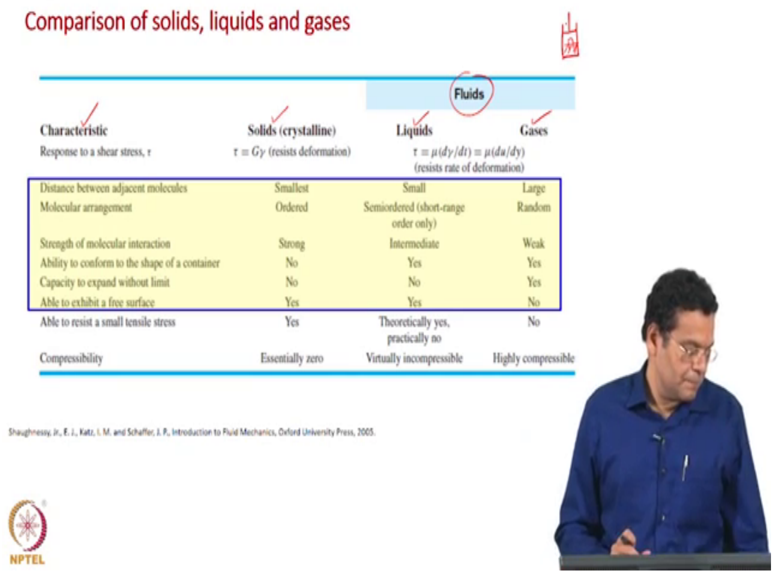

Now we are proceeding towards understanding, what is the total stress tensor, why did we call as total stress tensor, what are the components, what is the meaning for the word total there? Now to do that we will have to understand distinction between solids and fluids that is what we are going to do now. A very nice table (in the above referred slide) from this book by Shaughnessy and others Introduction to Fluid Mechanics.

This table shows the characteristics on the first column and then these characteristics are listed for solids and then within fluids we have liquids and then gases. Now there are several characteristics listed, several properties listed. We will discuss these properties in two sets; first the highlighted properties we will discuss, then the unhighlighted properties will be discussed which of course I will highlight later. What is the distinction between these two set of properties. The highlighted properties here are very well known to us. Everyone of us will easily know these differences.

The other difference are something very special to this mechanics of fluid versus solids. So, we will discuss next. What we going to discuss is just a revision of what you already know in terms of differences between solids, liquids and gases. So, let us go through that

- Distance between adjacent molecules, smallest in solids, small in liquids, large in gases known to us
- Molecular arrangement ordered in gases, it is random. So, liquids we can say semi ordered.
- Strength of molecular interaction of course strong in solids, intermediate in liquids and weak in gases
- Ability to confirm to the shape of a container if you take a container and put a solid that will have its own shape. So, it will not confirmed the shape of a container. If you take a liquid, yes it will take the shape of the container itself, gas certainly yes
- Capacity to expand without limit. Now if you once again take a cylinder that is the good example to take and then you take a solid that will occupy its own space. So, it cannot expand and if you take a liquid once again, it cannot expand to the entire region, whatever volume it occupies, it will occupy only so much volume, but suppose if you fill the gas and you keep expanding the piston larger and larger away from the bottom surface, the entire space will be occupied by gas. So, that is why it says capacity to expand without limit is yes for gases.
- Ability to exhibit of free surface if you have a solid it exhibits a free surface, if you take a liquid inside this exhibit the free surface, but gas you cannot define a free surface,.

Now these are the differences well known well known to us. We have just revised it I would say.

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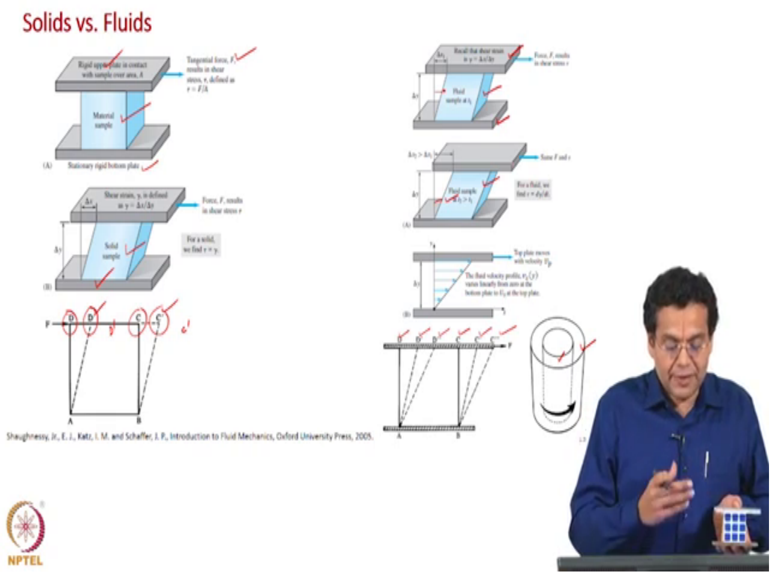

So, now we are going to discuss the difference between solids and fluids which will lead to our understanding of the total stress tensor. What I have shown on the left hand side, we have taken two plates and then let say we have a solid object.

Let us say we have solid object. Imagine it is completely solid and I have a solid object between these two plates and this object is fixed to the bottom plate and then I am applying tangential force to the top plate and that is what I have shown here stationery rigid bottom plate and the rigid upper plate in contact with the sample and then you are applying a tangential force.

Now, what happens, the solid object deforms for our case. We will see what formally deformation is later, right. Now we will say change in angle. That is what you see here. Let us say in front it was a square it becomes some like a parallelogram. That is what is shown in 3D and that is shown here in the front view. If you mark points D and C to begin with, they would have moved to D’ and C’.

So, now it starts deforming and internal shear stresses develop because of the external tangential force. Now this deforms until the internal shear stresses balance the external force and most important word is it stops deforming. That is all. It was in one state, then it deform or change in angle. So, from one equilibrium state it went to another equilibrium state. So, it means it has a resistor the shear stresses under static condition.

These are very keywords of course I will summarize in the next slide. So, there was change in angle and then you remember you continue to apply your tangential force, you are not removed it continue to apply the tangential force. There is the deformation in our case change in angle that happened until the internal shear stresses balance the external force and then it stops deforming. After that it does not move. Something like it resisting the shear stresses and it is static also.

This may happen whatever time period, but after that is independent of time. That is why we say it goes from one equilibrium state to another equilibrium state. Now if you remove the force, it will go back to the original state. Of course, all these happen at the micrometer level. We cannot so easily see even when you apply a mega Pascal. Let us say force area of that order, then these changes will be something order outer of 10 power minus 6. That is the scale.

So, in that way it is little certainly difficult to see by naked eye, but it should be able to imagine yourself. So, that is what happens for solids. One more explanation can be given by using the cylinder. I will give the same analogy in terms of this Cartesian coordinate that is in terms of cylindrical coordinates.

Now, there was some equilibrium state. Now the force required for this deformation depends on how far it is from the original equilibrium state. If you want to deform further and further let say you have D', you have C', so more force is required to deform further and further from away from the original equilibrium state. So, it depends on the angle for our purpose what happens here in a cylinder. Let say in the cylinder you put a solid and you want to let say you are interested in the force required to rotate the inside cylinder.

Now, the force required depends on how much want to deform the solid from an initial state or initial equilibrium state how far you are away from that. All these keywords we will keep and understand when it is distinguish fluids. So, how far from the original state matters in the case of solids? So, that is what happens for the case of solids.

Now let us take in the case of fluid. I think the configuration is something known to us. For the case of fluids we have come across few times. In our earlier lectures we said we consider flow between two parallel plates.

So, if you come across configuration few times and many times what we come across is where both the plates are fixed, few times come across the configuration where the bottom plate is fixed, the top plate is moving. That is a configuration we are seeing here. What is shown here, bottom plate and then a top plate which is moving.

So, now instead of this imagine this to be a fluid body instead of a solid body and then it is between two plates and then you are applying the tangential force. There also you continue to apply the tangential force, here also you continue to apply the tangential force. Now what happens in the case of fluids if you see here, this shows the configuration of the fluid, let say shape of the fluid object and then it has undergone some change. After sometime if you continue to apply the angle has further increased and that is what is shown here schematically. Let say to begin with you mark points D and C. After sometime it moves to D' C' moves to D'' C''. As long as you continue to apply the force tangential force, it continues to deform look at the distinction between solids and fluids. What did we say for the case of solids? It deforms and stops deforming no further deformation. That is why D became D' and C become C' that is all. That is why you said it went from one equilibrium state to another equilibrium state, but now there is no such static condition at all it continues to deform.

So, what does it mean? If it is stationary, it cannot resist any shear stress. Moment you apply even in the slightest shear stress, we apply slightest tangential force, you apply it will start moving. So, that is why we say that fluids cannot resist shear stress under static condition, moment you apply it, starts moving and as long as you continue to apply the fluid deforms continuously and that is why we say fluid flows. I did not use the word flow for solid for the case of fluid because it continuously deforms as long as we apply. We say the fluid flows.

Now, what happens if you remove the tangential force just retains. There is no regaining the original shape, there is no preferred shape or anything for fluids. So, if you leave at this. Leave meaning you stop applying the tangential force that is all. It will just stay there. So, just retains them final state. So, now other way of explaining is that there is no change of angle I can talk about from some initial state always that change of angle is 0 because every instant there is the shape and the deviation from that state is 0. So, I cannot talk about a change of angle, you will understand shortly.

Now, as we explained for the solids let us take in this case. I want interested in the force required to move this plate. Now this will not depend on the angle, but it will depend on the rate at which the angle changes. There is no preferred or something call initial state. So, I cannot talk about a change in angle from initial state, but if you want to move the let us say move the fluid faster, then you require larger force. So, depends on rate at which deformation takes place or rate at with the angle changes easier to understand in terms of this cylindrical geometry and between the two cylinders you now have a fluid.

Now, let say as earlier we are interested in the force required to rotate the inside cylinder. Now it depends on how fast you rotate the inside cylinder. Earlier we said the force required depends on how far we are from the initial state in the case of fluids; it depends on how fast we rotate the cylinder. It depends only on the rate of angle change or rate of defamation. These two differences deformation rate of deformation etcetera we will discuss again later in detail.

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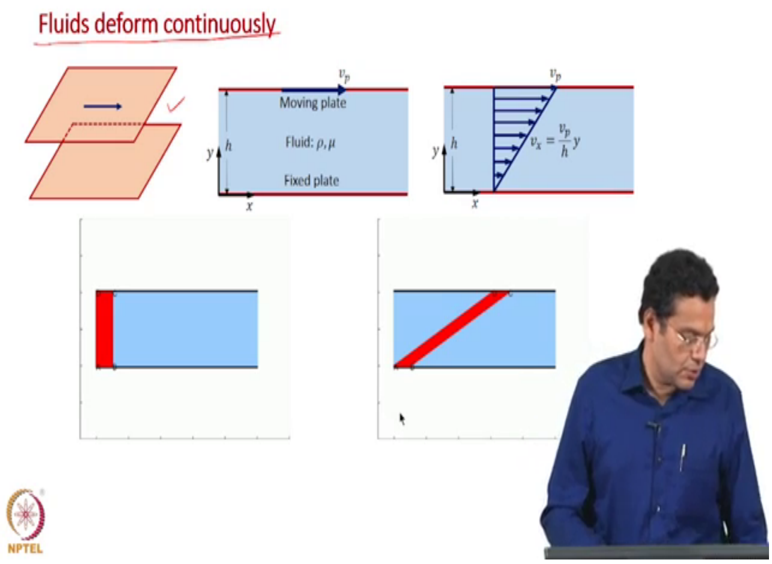

I will also demonstrate this. I think this slide we have discussed earlier when we discussed demonstration of a system. So, this slide is same as what we have discussed earlier. We have come across this slide when we wanted to demonstrate a system. In fact, the same slide is there. I will just change the title to fluids deform continuously. So, same demonstration can be shown now to show that fluids deform continuously the configuration is well known to us.

Now, earlier we said I dye a particular region of fluid and then what happens in their focus on that particular region etcetera instead of that just slightly change our imagination, change our visualization. Instead of saying you identify a part of the fluid and call it as system just like in our previous slide. So, imagine we have two plates and the red now represents the whatever region of fluid which have discussed.

Now, when you start applying the force, let us see what happens. We have seen this video earlier (Refer lecture video for better understanding), but earlier we viewed this as a system and you are following the system now you view this as a volume of fluid and then that deforms continuously as long as you apply the force. As long as I continue to move the top plate, this fluid continuously deforms. That is why we say the fluid flows. So, now we have seen in different ways the difference between solids and fluids etcetera.

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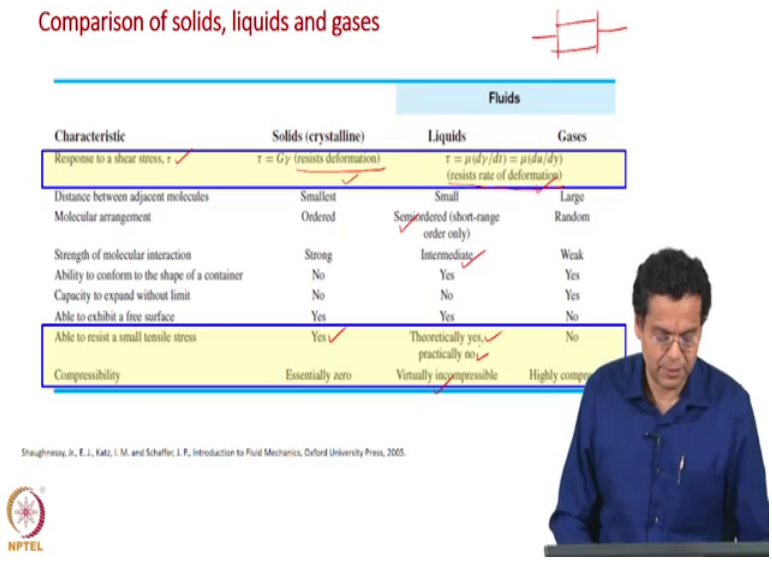

Let us summarize them before that. Let us look at the differences which I have not discussed same table. The differences now will become clear after our distinction between solids and fluids. What are the differences? Look at the first difference.

- The first difference is response to shear stress. We have discussed now how does a solid response to shear stress, how does a fluid response respond to shear stress? Now, solids resist deformation and liquid resist rate of deformation, there is no discussion of angle, but here it is rate of change of angle. That is why we said for solids how far from the initial equilibrium state, but for liquids the force depends on the rate of change of angle. Once again this particular difference we will discuss again and then discuss later as well.

- Now, what are the other differences; able to resist a small tensile stress? What does it mean? Let say you take flour and then you add water and then you apply let us say this plate. Now of course we are applying a normal stress, but if you look at the horizontal direction it is tensile. You are applying a normal stress perpendicular, but if you apply in look at the other direction it looks as if you are applying a tensile stress to the liquid. Take let us say a small full of water and applying let us say you apply this force on the plate. Now, the liquid spreads becomes thinner and thinner and thinner. It is equivalent to applying a tensile for its direction.
- Now let us discuss ability to resist a small tensile stress. What does it mean? If you have a solid object and if you are applying a tensile stress or tensile forces opposite to each other then it will resist the tensile stress. Yes in terms of liquids you can theoretically say yes, but practically as explained you as long as you apply this normal force, it keeps on thinning, thinning and thinning which means that just exchange practically there is no ability to resist a tensile stress becomes thinner and thinner and thinner which means that keeps on expanding. So, practically no but theoretically yes; always if you look at the differences, the properties or liquids are in between of course solids and gases. That is why you look at words like semi ordered, intermediate etcetera. Here also it intermediate behavior of course gases certainly cannot resist tensile force. What does it mean? Same let say you have a gas in a cylinder and let say you have some two pistons like this. We expand, as long as expand it will just keep expanding. So, there is no resistance to tensile stress.
- The last line difference is compressibility. For solids essentially 0, for liquids virtually incompressible and for gasses highly compressible.

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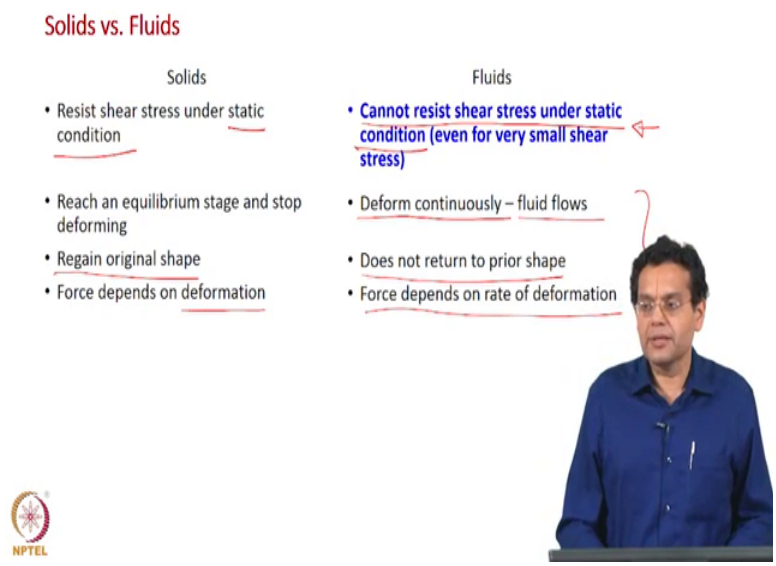

So, now let us distinguish solids and fluids. This is just summary about mentioned.

Solids	**Fluids**
Resist shear stress under static condition	Cannot resist shear stress under static condition (even for very small shear stress)
Reach an equilibrium stage and stop deforming	Deform continuously – fluid flows
Regain original shape	Does not return to prior shape
Force depends on the deformation	Force depends on rate of deformation