Introduction to Soft Matter
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Lecture 04
Response of Viscous fluid

Another lecture on Introduction to Soft Matter and last time what we were discussing was the response of a classical elastic solid and today what we want to look at is the response of a classical viscous fluid. And then obviously we are going to contrast the two and you can understand that the viscoelastic response will be somewhere in between the two.

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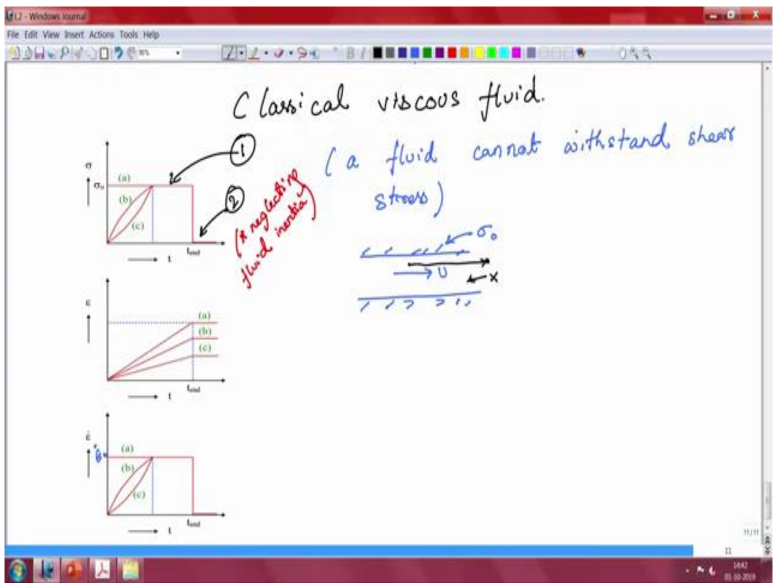

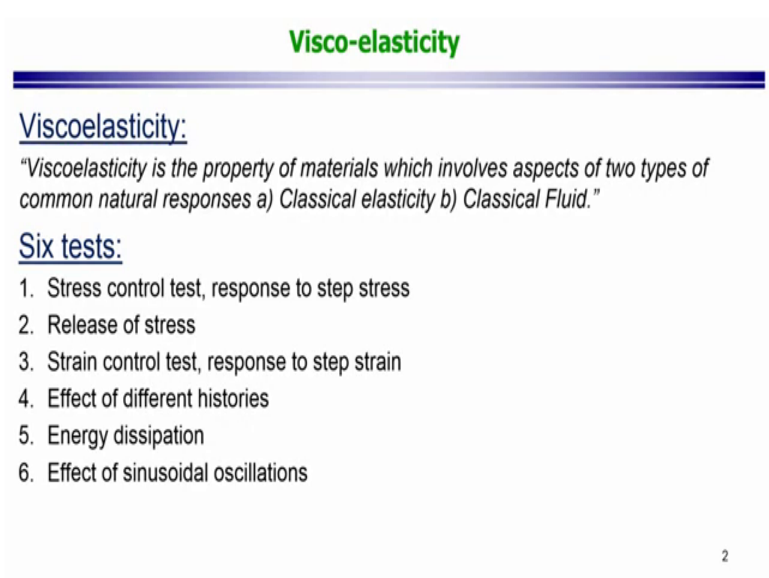

So, we are today going to look at a Classical Viscous Fluid. So, last time we had introduce these 6 different test. And we have looked at details for that. So, the first test is again the stress control test and the release of stress and then the third one is the strain control test. So, let us look at these 3 for viscous fluid.

So, once again what I have done is we have already in a sense conducted the experiment and I have already drawn for you what the response should be. So, will use that here, so the first test is the stress control test as we have already discussed that so here what you are doing is you are applying so again what we are doing is we are going to apply unknown amount of stress and then we want to see what happens to the response of the material.

Now, the linear viscous fluid what did we learn about that in our undergraduate classes is that it cannot withstand shear stress, so here when we say stress here of implying shear stress. So, it cannot withstand shear stress which means it immediately start flowing. So, in a simplistic definition we know that fluid cannot withstand shear stress. So, when we apply unknown amount of stress in this case the picture is quite different, you have a strain but this strain starts increasing immediately.

Because the material is flowing so imagine a parallel plate situation. So, if you want to imagine this you can have a parallel plate situation, where you are applying your sigma naught to this case, so the fluid initially is at rest but will immediately start to flow in response to this. So, your strain will keep on increasing till the duration of sigma naught. And if we neglect inertial effect then this increase is linear.

So, since this is diagram that has already been drawn for you please note that this neglects, neglecting fluid inertia. So, in a sense that a very-very low Reynolds number. So, now interestingly so your graph for epsilon is very different from that of a classical, classic elastic solid but if you look at epsilon naught which is the strain, the strain is going to be constant, these are straight lines.

So, the strain actually attains a constant value may be I will write epsilon naught dot here, so the strain attains a constant value and it remains at that value for as long as you provide the stress. And then the moment you release the stress which is this test, this is the release of stress, the flow stops. So, the strain which basically is a measure of flow, the strain also stops immediately.

But your strain value is going to be so the fluid element, a fluid element if it has moved from one point to another point due to your application of stress it is not going to move back. So, it is just going to stay there the moment you release the stress. Which means that the strain becomes constant in that case, so we see that there is a small amount of difference with respect to that of a classical elastic solid, in that the stress and the strain diagrams seem to be different.

But there is also a similarity in the sense that the stress and the strain rate response, the strain rate response is very similar to the strain response in the elastic solid case. This already tells you that the constitutive relationship for a classical viscous fluid will have most likely the relationship or will have the relationship between stress and strain rate in this case where they will be linearly related.

So, unlike the classical elastic solid where the strain and the stress are linearly related, here the stress and the strain rate are linearly related. Now, what happens to the application of a so that we have completed the two tests. But what happens to the third case where we apply a known amount of strain that was if you remember that was our third test, the strain control test.

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So, here earlier I had just written for you what the strain control test looks like for a elastic solid. So, I am just going to refer back to that in a for a minute, so this is your classical, this is your elastic response where you have applied a known amount of strain and you have gotten a known amount of stress, so basically even though you had flipped the experimental parameter there was no change, perceptible change. But in this case, in the case of a classical viscous fluid that is quite different. So, this is your classical viscous fluid.

So, when a known amount of strain is applied then your stress required to create that strain requires instantaneously high stress but to hold on to this epsilon, hold on to this strain you do not require further stress, so your in your diagram you now just have an instantaneously high stress response but then it just goes back to 0. So, this is a very important difference between the two. Now, we had the difference between, so what is the effect of different strain histories? So to go back to the strain histories, to go back to the previous diagram.

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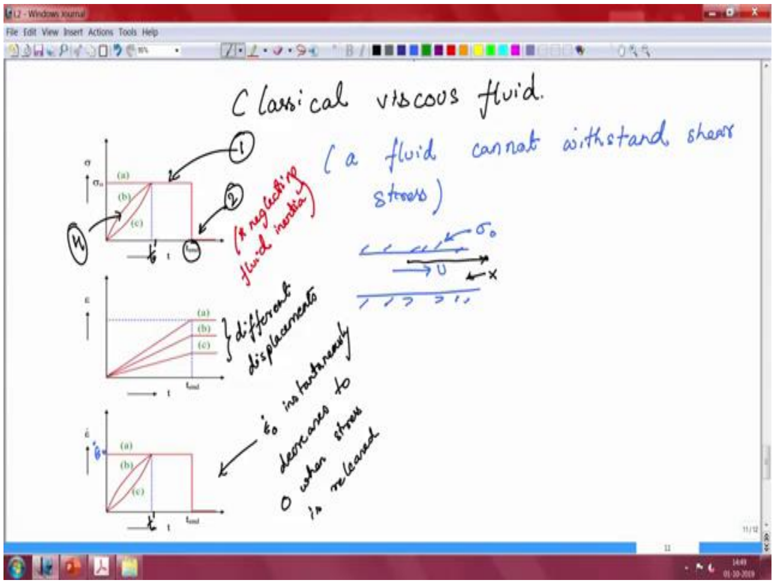

So, now we have this is your third sorry fourth test where you have applied the strain through different sorry the stress through different histories. So, when you apply when you go to when you reach sigma naught through different ones, you are going to in the strain rate diagram you are also going to reach the same strain rate at epsilon naught and let us mark this as t dash.

So what has happened is this is okay, this marking t dash, so sigma naught you are reaching through different stress histories and three possible ones has shown here A, B and C so in that case what will happen is the strain rate will also reach the previous value through different strain histories. But how it reaches the strain histories will remain will be different but it will still reach the same value at end of t dash.

So, when you look at the strain diagram that is when you start seeing that the three cases are separate in terms of the strain so they have reach very different values in this graph and in the beginning of course this is just an idealization that your the strain rate here remains constant, so at the end of the experiment when the experiment has ended at T n you end up with different displacements but here your epsilon naught has again instantaneously decreased instantaneously decreases to 0 and stress is released.

So, since they have reached different displacements the fluid is going to continue remaining in that in the state of that displacement forever till you again apply some known force. So, we have been able to discuss the 4 different problems, the 4 different cases okay, so now we have two more left which are the energy dissipated in a system and the effect of sinusoidal oscillations. So, when it comes to energy dissipated in the system.

Now, see that there is a very critical difference between the elastic solid and the viscous fluid and that is the displacement that you that have provided to the system is not recoverable, so the displacement is not recoverable then the energy that you put in, into the system is also not recoverable, so let us write that down.

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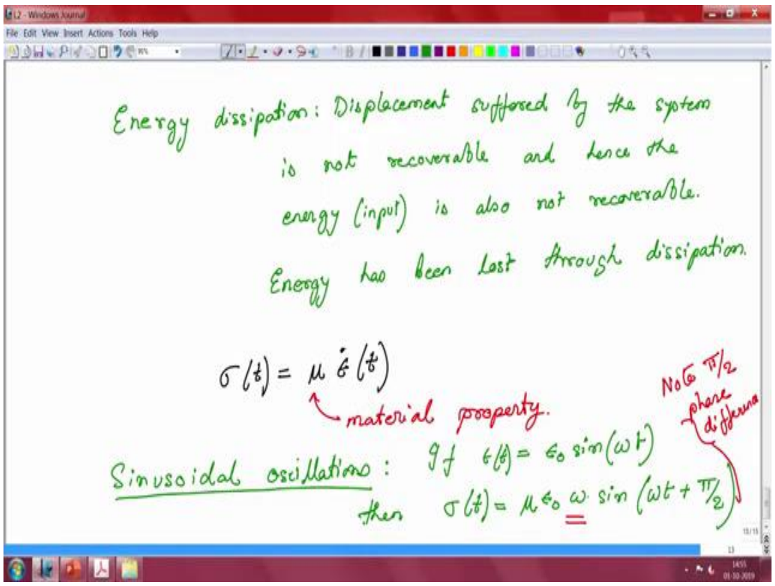

So, energy dissipation, just a second, energy dissipation, so displacement, sorry the spelling is wrong, so displacement suffered by the system is not recoverable and hence the energy input, the energy, input energy is also not recoverable. So, if the energy is not recoverable what has happened to it? It is been lost through dissipation, so energy has actually been lost through dissipation.

So, see this is a very interesting difference between a classical elastic solid and a classical viscous fluid, in the energy sense the extreme opposites while one stores the ideal classical elastic solid will store energy for infinite amount of time, the classical viscous fluid will lose all the energy that you have put in, all of it is dissipated.

So, now since you have been doing all these different experiments you are realized that the relationship between the, in the case of the classical viscous fluid the relationship, constitutive relationship will be between the stress and the strain rate.

So, your stress in this case when you do all the different experiments what you find is where Mu is a material property obviously is viscosity here, shear viscosity which now that you have determined this it brings us back to the last problem which is sinusoidal oscillations. So, in sinusoidal oscillations your input is epsilon equal to epsilon naught sin of omega t let us say

Then your sigma t is Mu naught or Mu sorry Mu epsilon naught omega sin of omega t plus Pi by 2. So, I have just used this relationship to get this, relationship between the sinusoidal oscillations.

And you see now one more interesting difference between that of a classical elastic solid and a viscous fluid rate that in that case the two were exactly in phase here they are exactly out of Pi by 2 phase, okay. So, note Pi by 2 phase difference, also note that omega now appears in the relationship. So, if you take a maybe for completeness I will just write this as epsilon t, just a second. So, if you take the ratio of epsilon t and sigma t then there is a omega term that is going to be there.

So, the, it is dependent upon the frequency of oscillations so this is another important difference between the two. So, now we have completed 6 tests, we are ready to compare our results for the classical elastic solid versus the classical viscous fluid.

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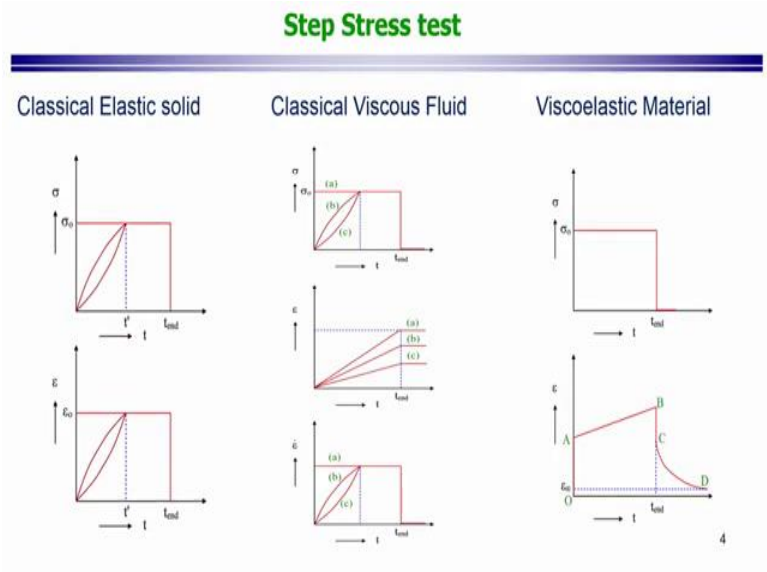

We have seen these two diagrams earlier so this is the response of stress for a classical elastic solid and you can compare that with that of a classical viscous fluid. I deliberately left one column empty which is for a viscoelastic fluid or viscoelastic material. So, you can imagine what the viscoelastic material probably would be, it would be somewhere in between the two responses.

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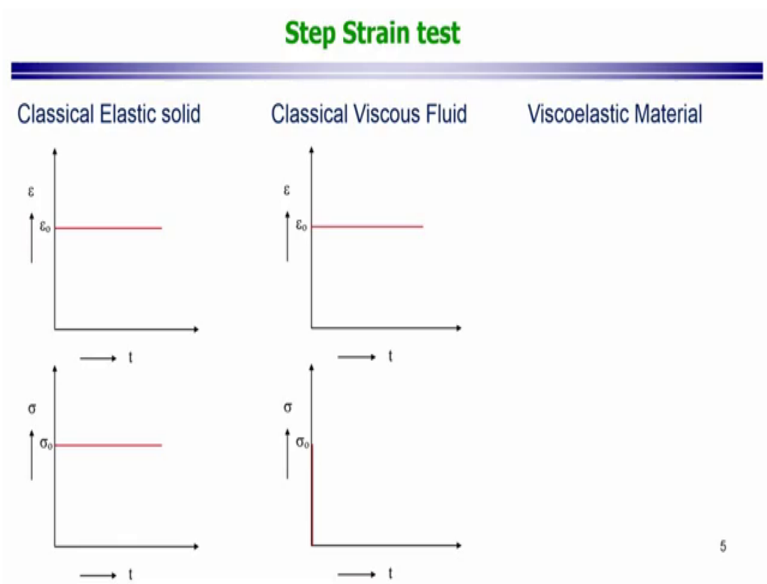

Another part was sorry I am going to come back to that, another was the step strain test where in a classical elastic solid what you had is you applied a known amount of strain and the system registered a known amount of stress, a certain amount of stress and that value of stress was being kept at that value for a long time.

In a classical viscous fluid the behavior is quite different than that, so the viscoelastic material response will probably somewhere in between these two, so now that we have done that or we have compared these two cases, we are ready to understand the response of a viscoelastic material okay.

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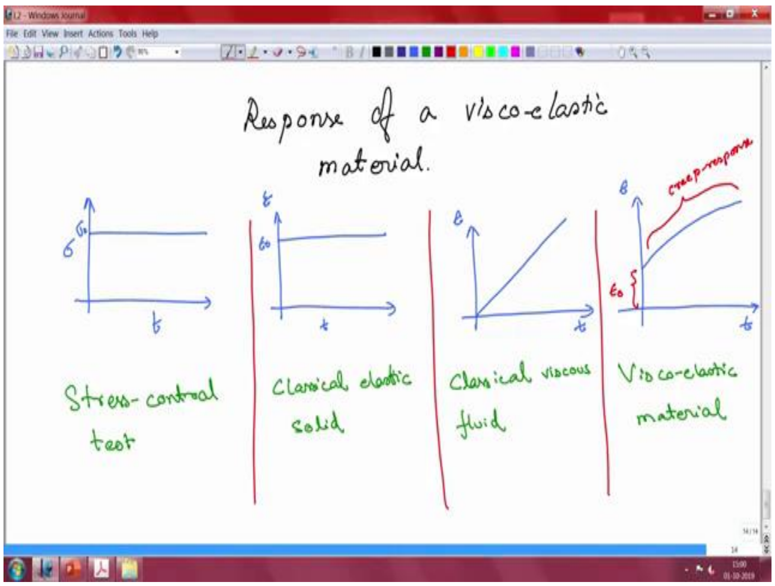

So, response of a viscoelastic material, so what we are going to do is going to do the first test where we are going to apply a known amount of, so now you are back in the laboratory, you are going to apply a known amount strain and just for quick recap you were doing I mean the reason I am going to do the recap is just because I am going to show you how, so when you are measuring the material response for your classical elastic solid what you found is you found that when you gave a sigma naught, you registered a value of strain.

In this case for that of a classical fluid this kept on increasing, so how will your viscoelastic response look like, okay. So, I am just going to write down what I have done here just a second, so this is your experimental source rather the stress control test, when you are working with a classical elastic solid you got this response, this is the response for a classical viscous fluid and here you are trying to understand the response of a generic viscoelastic material.

This is for completeness I will also say epsilon t this is also epsilon t okay. So, you will probably get a response like this where this response is composed of two parts, one is an instantaneous increase in strain, classical elastic solid and then there is a constantly increasing part which is that a (cons) there is a increase in strain with time just like your fluid. So, this is your straining with time or the flow basically which we also call creep, the creep response and what do you think will happen when you release the stress. So, I am just going to copy this previous.

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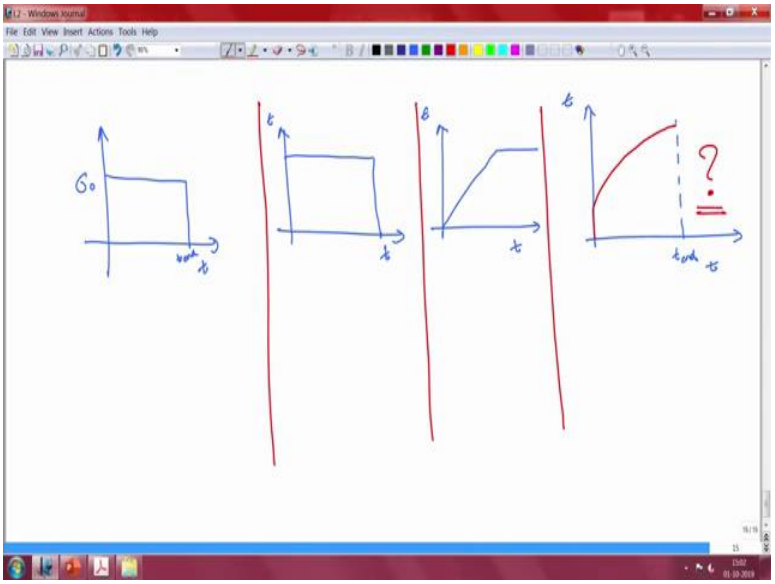

So, now I am just going to complete this diagram which was, so it will end at some point, rather this is too much space, so in this case you are going, this is your epsilon t okay the three cases, so again, so we have already drawn the first part which is, which looks like this but what happens when the stress is released? So, let us call this T end, so let us say this is the T end here and what I am going to do, is I am going to leave you with this for the next class, okay.

So, I want you to try and figure out what this response is going to be and in the next class we are going to see what it really is. So, today what we did is continuing on the six different experimental methods to evaluate a continuing material we looked at the classical viscous fluid and we just got started with the response of a classical rather sorry a (viscoelastic) generic viscoelastic material. And in the next class will continue this.