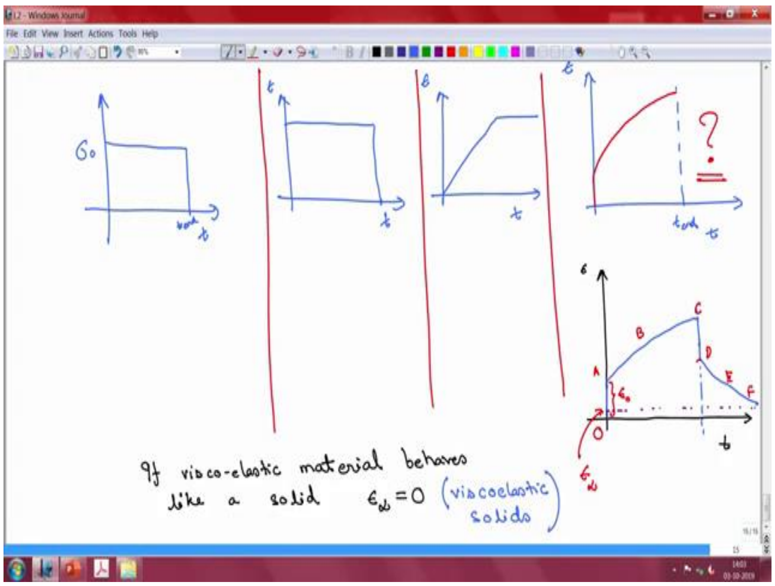
Introduction to Soft Matter
Professor Dr. Aloke Kumar
Department of Mechanical Engineering
Indian Institute of Science, Bengaluru
Lecture 05
Viscoelastic material

Okay, welcome everybody again to one more lecture on the Introduction to Soft Matter, last time we were discussing the 6 tests that are important for distinguishing the behavior of classical elastic solids and elastic viscous fluids. And then we asked ourselves a question as to when we put a viscoelastic material to the same 6 tests, what will be our result?

(Refer Slide Time: 01:02)



So, we had stopped with this diagram where we had said that the response and I am just going to draw this diagram one more time beneath it. That if you have a viscoelastic response can you do draw qualitatively a diagram which will represent that behavior? And so here we are giving a stress test and then the stress is being relaxed, so we are going to measure the strain and what we will find is that this first an increase, an immediate increase in the value of the strain which slowly increases over time.

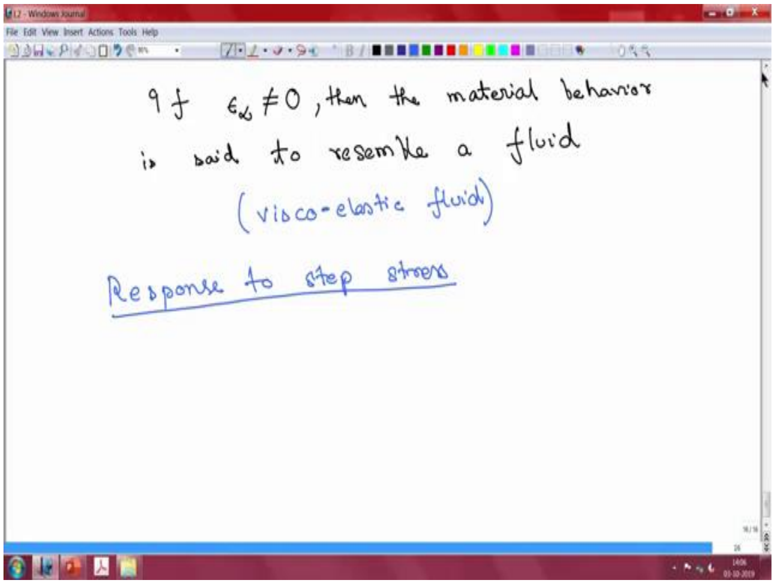
And when the experiment is completed this is going to come down and relax now when it does that this graph will register somewhat of an instantaneous recovery in a strain and then this graph will continue decreasing over time. And this is your qualitatively how the behavior of a viscoelastic material occurs.

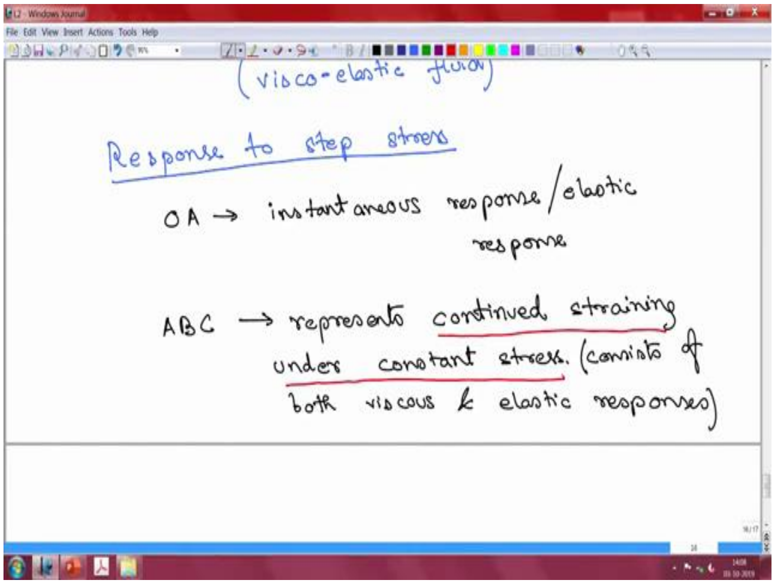
So, let us now just do, let us name some of these points on the graph, so let us say this is O, this is A, this curve let us call it A, B, C and then you have this point here we are marking it as D, this curve is D E F and this initial portion is epsilon naught or the instantaneous immediate response and this value on the other side as t tends to infinity this graph asymptotically goes towards let us say some value and let us denote this value on this curve as so we will denote this value as epsilon infinity which is basically a short form for strain at t tending to infinity.

Now, in viscoelastic materials often a categorization is done and that categorization says that if your behavior, if the viscoelastic material behaves overall like a solid body then this epsilon infinity will tend to 0. We will add a new page, so this, material this kind of materials where all of this strain is recovered overtime behaves overall as a solid body.

Because in a solid body when you release the stress all of the strain is recovered, so this kind of materials are also often called viscoelastic solids. However, we know in a fluid if you have a fluid and your subjecting into a stress that strain is never recovered, right.

(Refer Slide Time: 05:07)





So, if your epsilon infinity is not equal to 0 then the material behavior is said to resemble a fluid and this kind of materials are going to be now called and I do not think you will have to take a guess for this, you will just call the a viscoelastic fluid.

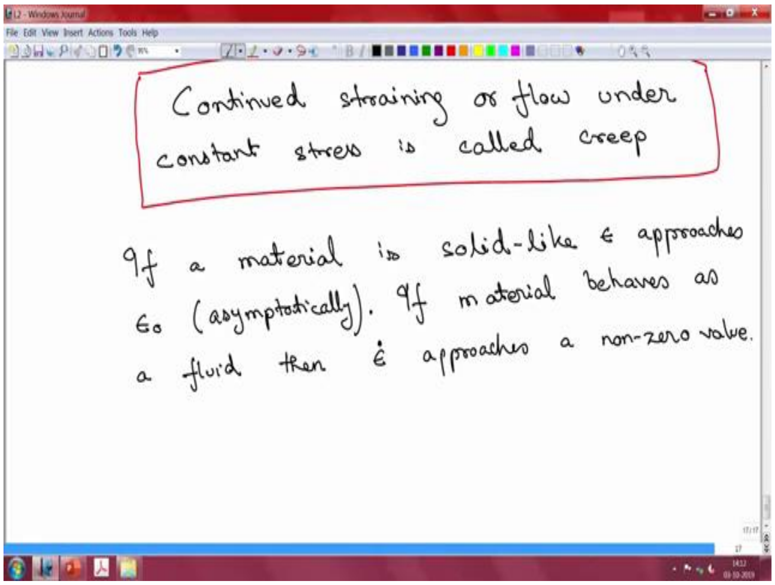
So, it is a very simple categorization okay based on a very simple straightforward idea and it is quite helpful but it obviously you can realize that this is a very qualitative discussion, right so because what exactly is 0, when will you say if you have a value which is very-very small but is still non-zero, where does it put that material? So, we can it is sort of obvious that you will not be able to characterize all viscoelastic materials into these two broad categories.

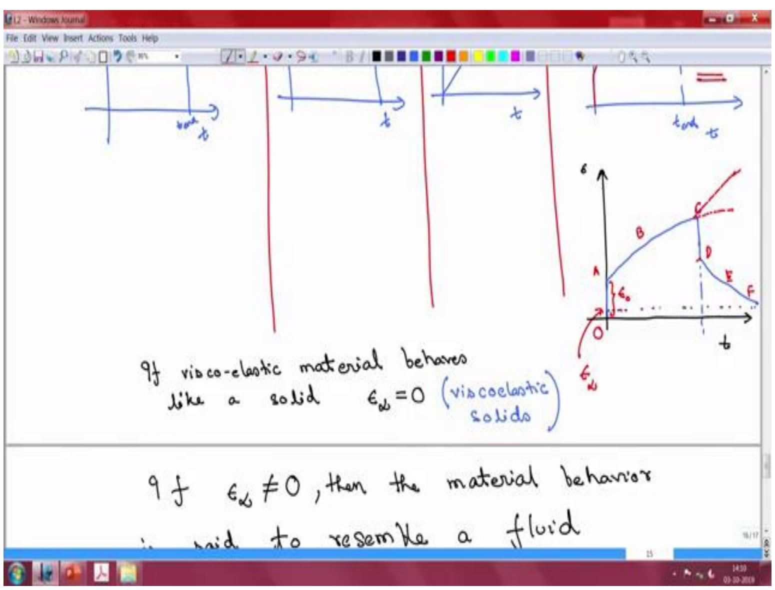
But experimentalists can broadly agree often that a certain different type of materials behave either as a fluid largely or either as a solid. So, this is a qualitative discussion. So, will not get too bothered what values, what error bounds etc. are required here. So, next what we want to see, so going back again to this graph, so what I am going to do, I am just going to insert so we were looking at the response, so we had the 6 response to step stress, right.

So, we just saw what is a typical response, let us take it to the, so the typical response consists of this initial portion O A, which is a immediate instantaneous response, so if you have to classify this sorry going to the next page so response to the step stress consists of O A part of the graph which represents an instantaneous response or an elastic response, so in a viscoelastic body you will have both this viscoelastic responses.

So, O A consists of a elastic response and this other part A, B and C this is the continued straining of the material under constant stress. So, A B C, so A, B, C portion of the graph represents continued straining under constant stress. And this is both an elastic it consists of both viscous and elastic responses will see why that is. But before I do that I will just quickly point out that this phenomenon of continued straining under constant stress, this is also called creep phenomenon. So, I will just write down this definition because will be using this word quite a bit.

(Refer Slide Time: 09:44)



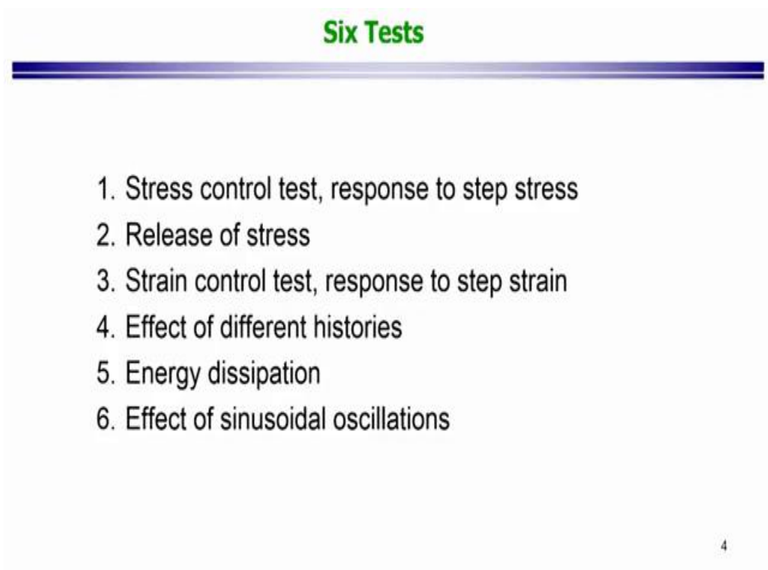


So, continued straining or flow if you want to use that word under constant stress is called creep, okay and will be using this word quite a bit here and there. So, that is why it is good to point this out in the beginning itself.

Now, going back again to this graph, we are not done with the graph A, B and C the question is does A and, A, B and C is it trying to approach, so there can be two behaviors here and I will draw it with a dashed red line may be to indicate that. Either it can asymptotically start approaching a constant value or it can asymptotically start to have a value where it will or the graph can behave such that it is going to continue straining at all times that there is a stress that is present.

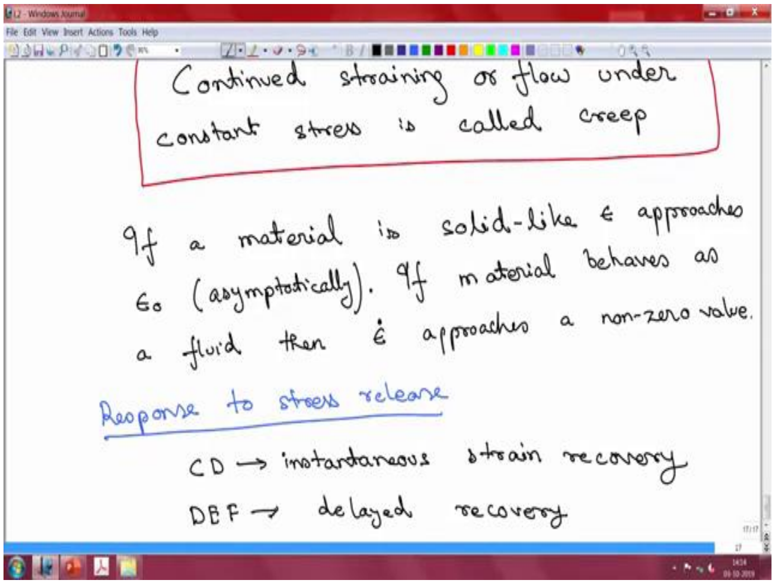
This behavior where the creep starts to attain an asymptotic value is a solid like response whereas in a condition where the strain rate restarts to reach a constant value that is a solid like behavior, so we can say that if a material is solid like then epsilon approaches epsilon naught asymptotically. If material behaves as a fluid then epsilon dot approaches a non-zero value. Once again this is qualitative in nature, we are just breaking up that response into broad features that we often find.

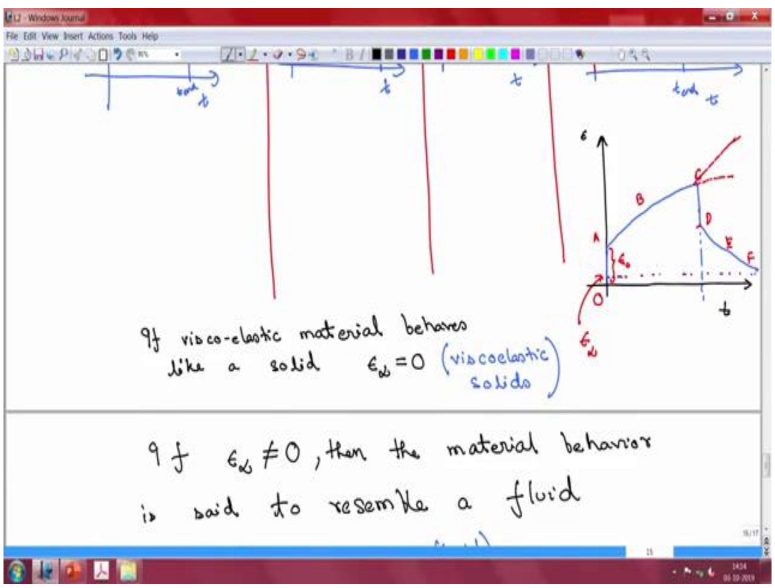
(Refer Slide Time: 13:09)

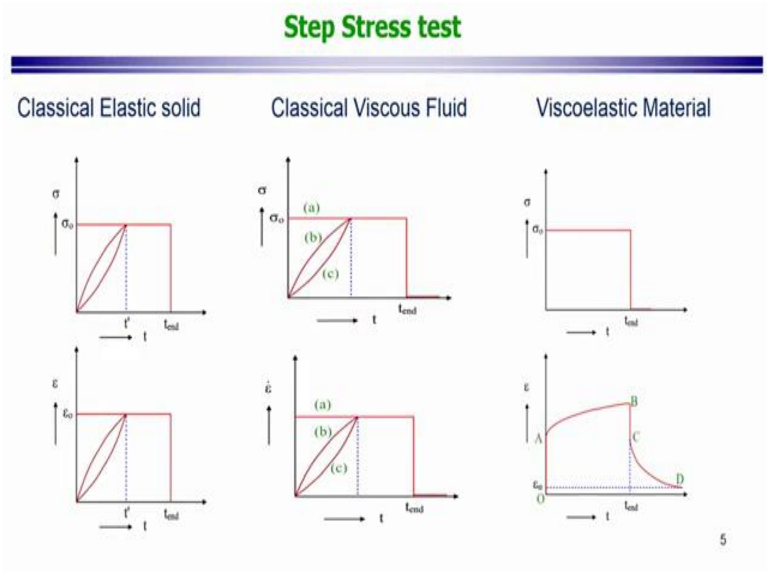


So, remember that in the 6 tests we had discussed the stress control test, the response to the step stress or the release of stress test and then the third one was the strain control test. We will see that these three are very important, fourth one will also give us very important insight into the material. The fifth and sixth we will also briefly discuss today.

(Refer Slide Time: 13:36)







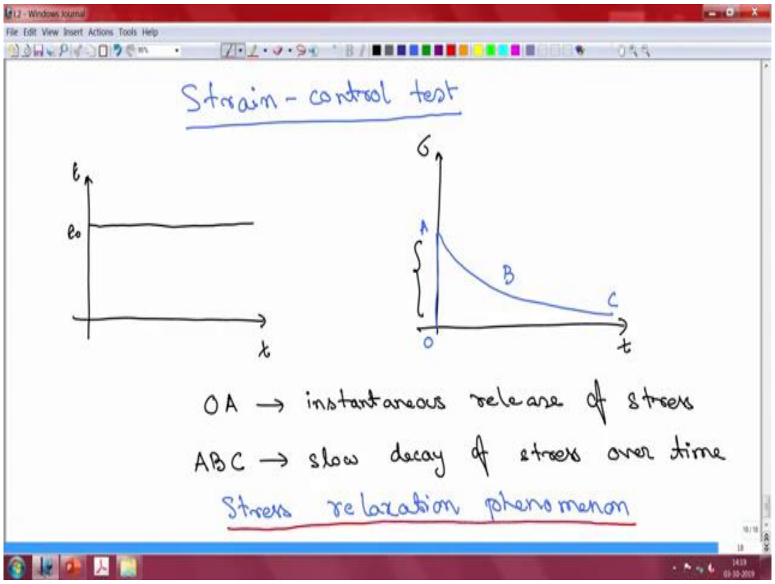
So, now we want to look at response to, so this was response to stress release, okay. So, if we go back to your graph we see that there was a C to D portion which is an instantaneous strain recovery and then there is a portion D E F, so let us just write this down, so C to D this is a instantaneous strain recovery. And then D F is a delayed recovery, right.

And we had already discussed that this D E F can approach a value of 0 at large times or it can approach a non-zero value at large times which depends again on the type of material. So, now given this we have discussed qualitatively how the materials respond, we are ready to go back and quickly give a visit to the classical elastic solid and the classical viscous fluid and compare it with the viscoelastic response.

So, we see that in a classical elastic solid we have a situation where the stress and the strain, so the strain response to the increase in stress immediately and you can hold on to this value till you release the stress. In classical viscous fluid this linear relationship between sigma and epsilon naught is present instead of as in classical viscous where you would relate sigma and epsilon.

In a viscoelastic material now what we have done is we have seen this Mu graph looks quite dissimilar to the both but actually consists of a combination of what the other graphs are, so this gives us a picture of how a viscoelastic material response and we have covered then the first two tests, which is the stress test and the release of stress which brings us back to the third test, so if we back to our list where the strain control test we still need to understand.

(Refer Slide Time: 16:57)



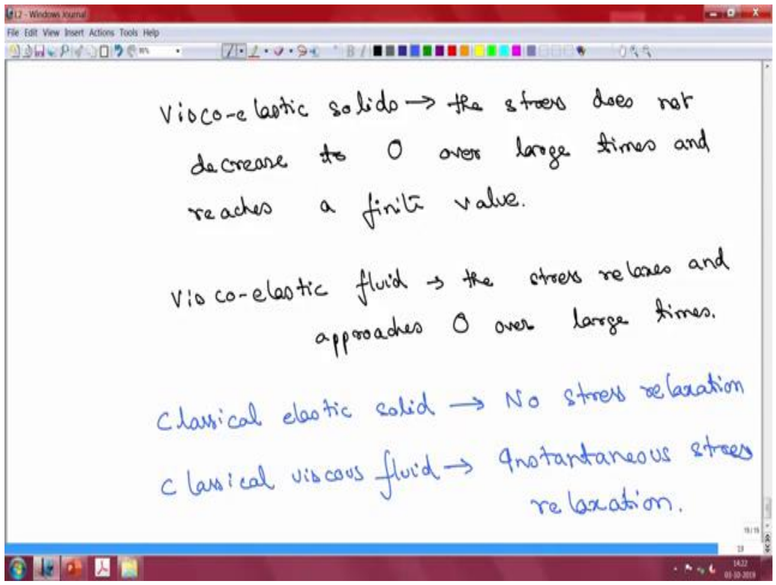
So, let us go back to our notepad and then will look at the stain control test, so in the strain control test what are we going to do? We are going to experimentally impose, so this is your epsilon t, so here you are providing a value of epsilon naught, so again here now what you will have is a situation where the responses will be the combined responses of classical elastic solid and a classical viscous fluid.

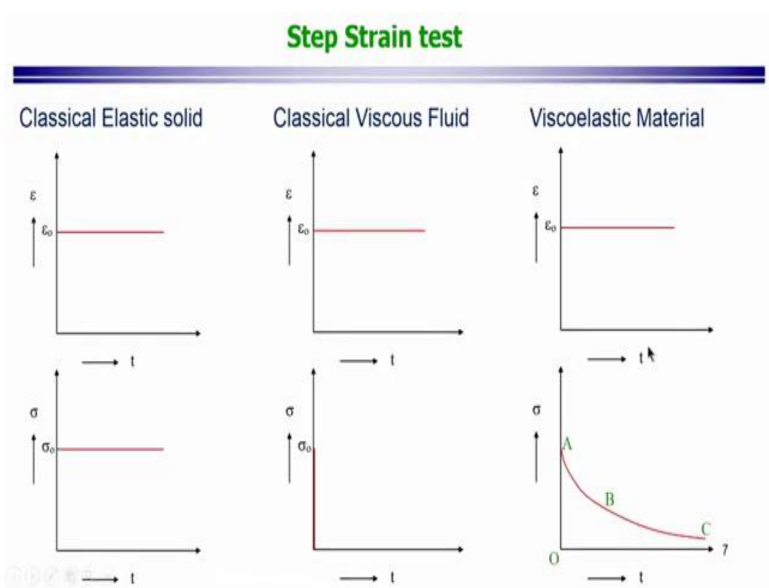
So, in a classical viscous fluid you would have an immediate stress release whereas in the case of a classical solid you would have a continuous stress that is generated. So, here again you will have an increase in stress an immediate increase and then this curve will decrease over time. So, if I again try to level this, this is A and then this is B and C, so this O A this is your immediate response to the stress sorry to the strain.

So, O A is the instantaneous release of stress and then A and A the curve A B C represents the slow decay of stress over time. And this phenomenon of A B C, so this phenomenon that in a viscoelastic material the stress slowly decreases over time is called the stress relaxation phenomenon, okay. So, we have identified two different type of phenomenon, one is the creep phenomenon and the other is the stress relaxation phenomenon.

Now, since we were discussing the qualitative behavior of viscoelastic solids and viscoelastic fluids we should just do that again for this particular case, so what do you think will happen for viscoelastic solid? For this tests you will have a residual stress in the system, so will just write that down.

(Refer Slide Time: 20:37)



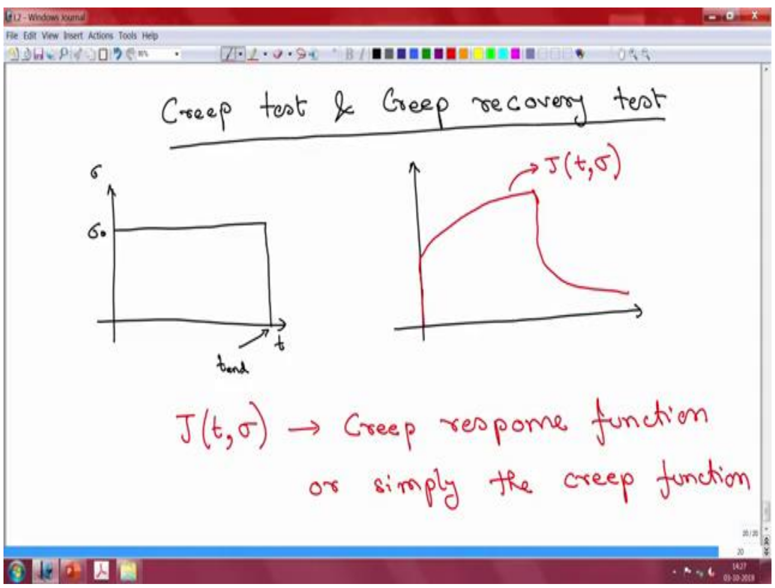


So, in viscoelastic solids the stress does not decrease to 0 over large times and reaches a finite value. This is exactly opposite to what would happen for a viscoelastic fluid, the stress relaxes and approaches 0 over large times. And just to quickly compare with the classical materials, so the classical elastic solid it shows no stress relaxation and a classical viscous fluid shows instantaneous stress relaxation. So, if you go back to our diagrams what we are saying is so this is just a comparison again of the behavior.

So, what we just wrote down in words we are just describing that is graphical format, the distinction between the behaviors to of the classical elastic solid, the classical viscous fluid and a viscoelastic material to the step strain test and we can see how the viscoelastic material once again that response is more or less a combination of the responses of the two classical systems. So, that brings us back, so we need to discuss these in a little bit more detail now.

Okay now that brings us back so we discuss that we named two phenomenon, the creep phenomenon and the stress relaxation phenomenon, so let us discuss the creep phenomenon once and let us discuss that forms the basis so the creep phenomenon becomes a basis of two important tests.

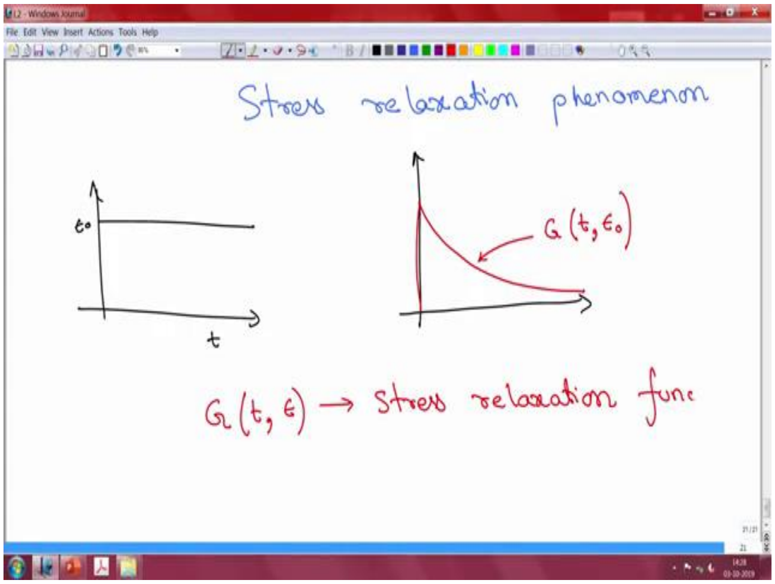
(Refer Slide Time: 24:13)



The tests are called the creep test and the creep recovery test. So, in the creep test what you are going to do, is you are going to apply a certain amount of stress and in the creep recovery you are going to see the recovery, so you will end this at a certain time, so this is the end of the experiment and then we will have graph that we just got accustomed with and then we will watch it decay. So, the first part is forms the when you apply the known amount of stress is called the creep test and the next the part where you end the experiment and you release the stress is the creep recovery test.

So, this curve is in common parlance is given, so this creep is obviously a function of time and it is also a function of the stress that you put. It is typically denoted by J in most of the literature, so this curve J t, sigma is called the creep function or creep response function sorry, just a second, it is called the creep response function or simply the creep function. And similarly, for the other test you have the stress relaxation phenomenon.

(Refer Slide Time: 27:04)



So, for the stress you what you are going to do is you need to apply this known amount of strain to the system, this curve which we have labeled separately as ABC so now you see why you had broken up the curve in different parts. This curve is again a function of time, it is again a function of the imposed strain, right. So this curve is also called the stress relaxation function.