Creep Deformation of Materials
Metallurgy and Materials Science
Creep Testing Methods Part 1

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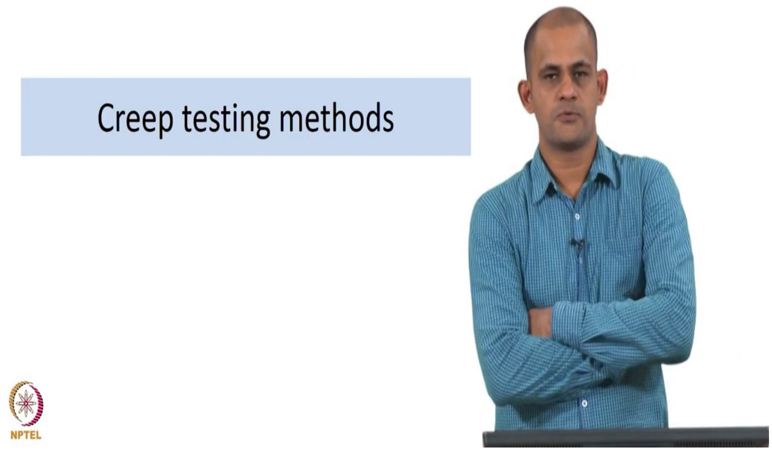

Okay so up to the last class we were talking about different mechanisms of creep and how you can identify the stress and temperature window where one particular mechanism of creep would be dominant over others and things like that, so now we are going to talk about creep testing methods, so all the analysis required for the analysis of data you need live data and how do you generate the creep data, so what we will be talking in this lecture as I will introduce you to certain creep testing methods.

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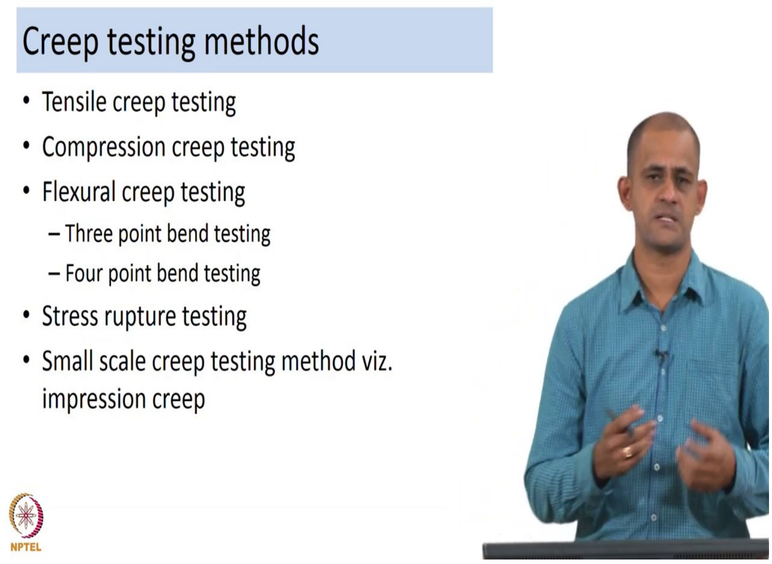

So the well-known creep testing methods are listed here so the creep testing can be carried out under tensile or it can be carried out under compression. You could also carry out creep testing in the flexural mode and there are also certain creep testing methods which involves stress rupture under internal pressurisation, if you want to study the creep behaviour you can internally pressurised that tube with some inert gas and study the change in dimensional as a function of time

There are other small scale creep testing methods such as impression creep which people regularly use these as alternates to the conventional creep testing methods. So in this particular lecture we will be talking about tensile and compression creep testing methods and briefly about flexural and then I would introduce you to one of these small scale creep testing method which is the impression creep method.

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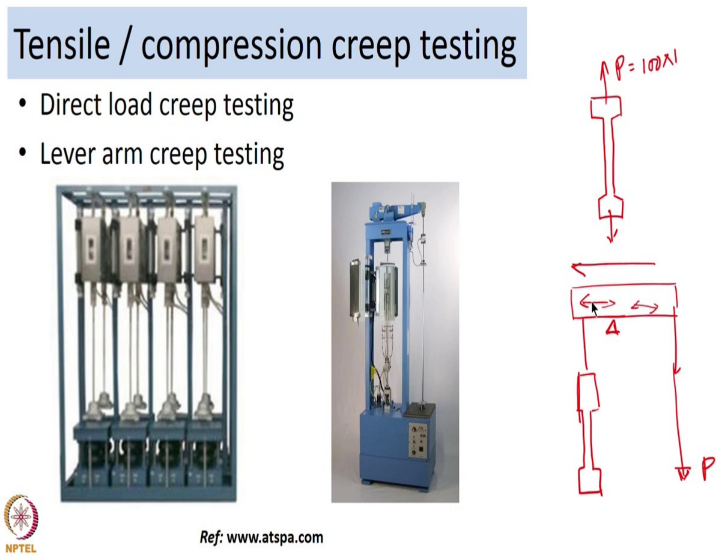

Now coming to tensile or compression creep testing methods, so these are the type of load frames that you can use for carrying out tensile or compression creep testing, so you could use the direct load testing method so for example in the direct load creep testing method what you can do is you can take your sample and apply the load that you are interested in directly onto the sample.

So the load of say if you want to do your test as 100 newtons then you directly apply 100 newtons to your sample, whereas in the lever arm creep testing method the load is not directly applied it is transmitted through a lever arm, so what the lever arm does is there is… So say this is your arrangement there is a point fulcrum point and then you apply the load here and the load gets transmitted through the moments onto the sample and usually the load that eventually gets applied on the sample is an amplification of the applied load that is because of the balance of moment.

So you have a moment acting on, the right arm of the liver then you also have a moment acting on the left side of the fulcrum and that based on your balancing of moments the load that is applied is eventually amplified and transmitted to the sample, so these are 2 approaches that have been developed you can have a direct load creep testing method or you have lever arm creep testing method.

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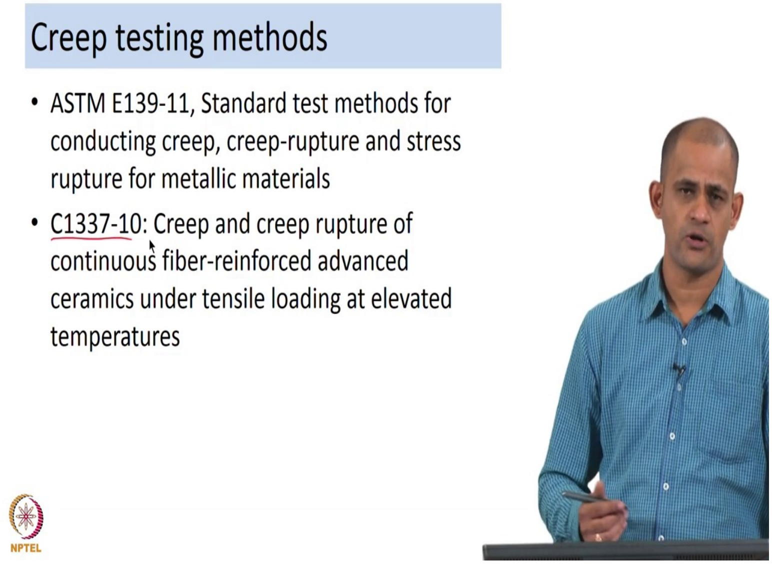

The creep testing methods, so there are many standard creep testing methods so I have listed down here 2 of them over here one is the ASTM E139 which is a standard test method for conducting creep, creep rupture and stress rupture for metallic materials and for ceramics you could have creep and creep rupture of continuous fibre reinforced advanced ceramic under tensile loading at elevated temperatures, so for that the standard is C1337 -10, so there are a few others as well but here I am listing only these 2 for you to know the type of standards that are available and in the next set of slides I will be talking briefly about the ASTM E139.

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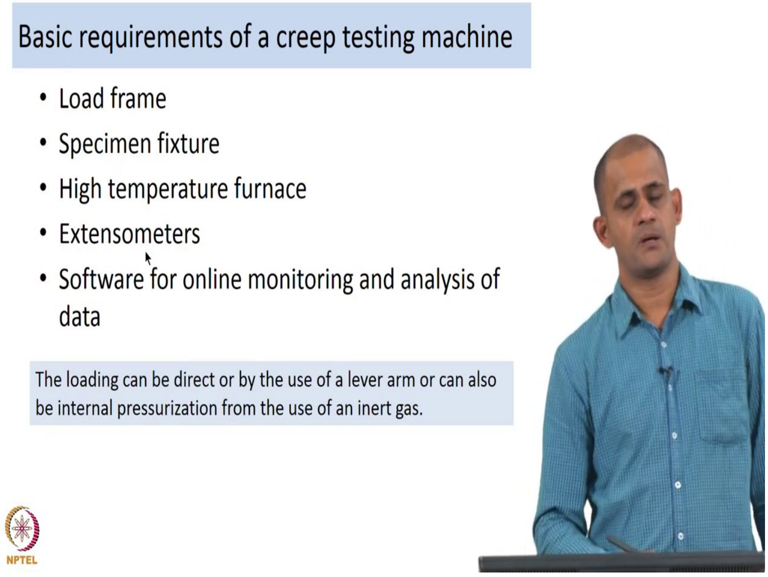

So when you want to carry out a creep test, the basic requirements that the creep testing machine should have is one you should have a frame or a load frame on which you can load your sample and then you need a specimen fixture to hold the sample or to hold the specimen and then since creep is a high-temperature test, so typically you need a high-temperature furnace, the furnace which can provide you the temperature of interest, the test temperature that you are interested in.

Then you also need some extensometers in order to measure the strain that the sample is experiencing, the sample is exhibiting, the plastic strain that should be measured by the extensometers and the latest creep machines also have software which allow you to monitor the defamation continuously and some of them are also capable of analysing the data generated.

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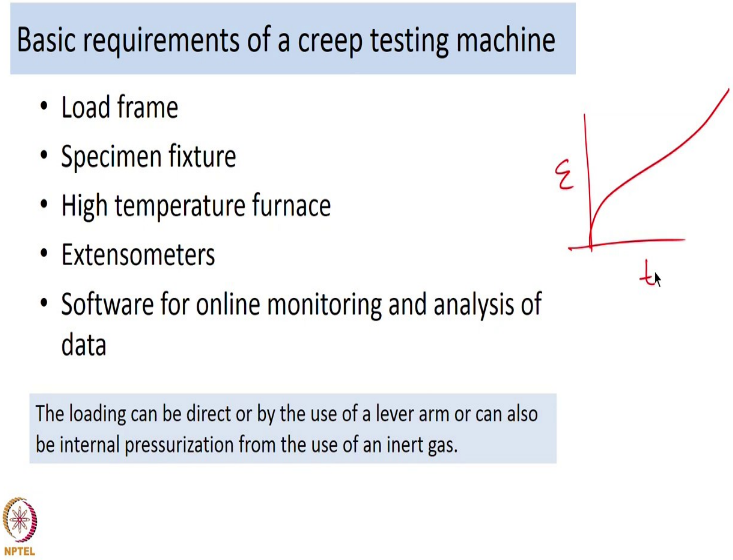

So say if you are generating strain versus time curve and then the software are also capable of analysing the data and giving you the strain rate of deformation things like that and like I mentioned earlier the loading can be direct or can be transmitted to the sample by using a liver arm.

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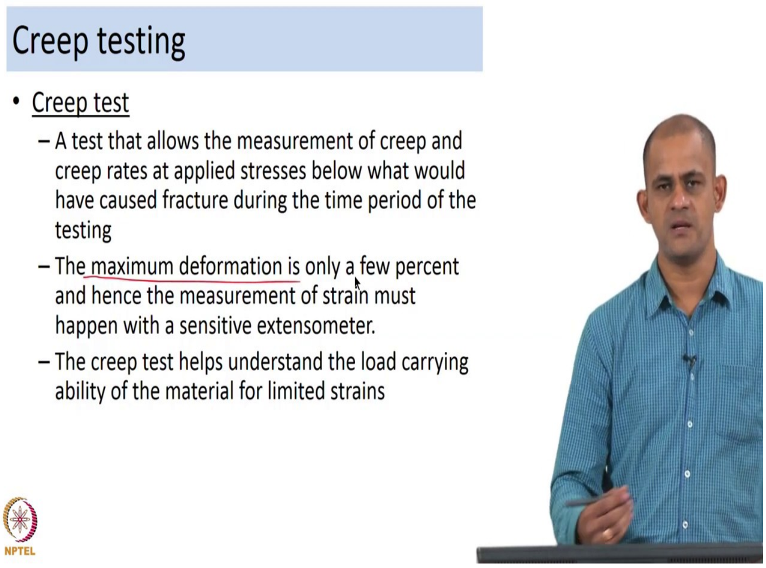

So coming to creep testing creep test is basically a test that allows the measurement of creep and creep rates at applied stresses below what would have caused fracture during the time period of the testing, so what this definition this is the ASTM E139 definition what it tells is that the creep test is a test where you are not taking your sample to fracture, so here in this particular type of test your focus is only on measuring the amount of deformation that the material undergoes in a certain time period of testing and typically the test is carried out only to a few percent of plastic deformation.

So the maximum deformation that is allowed in this kind of test is only a few percent and hence the measurement of the strain, the management of the plastic strain requires the use of a sensitive extensometer. Now the creep test, the advantage of the creep test is that it helps understand the load carrying ability of the material for limited strains. So I will explain what I mean by the load carrying ability.

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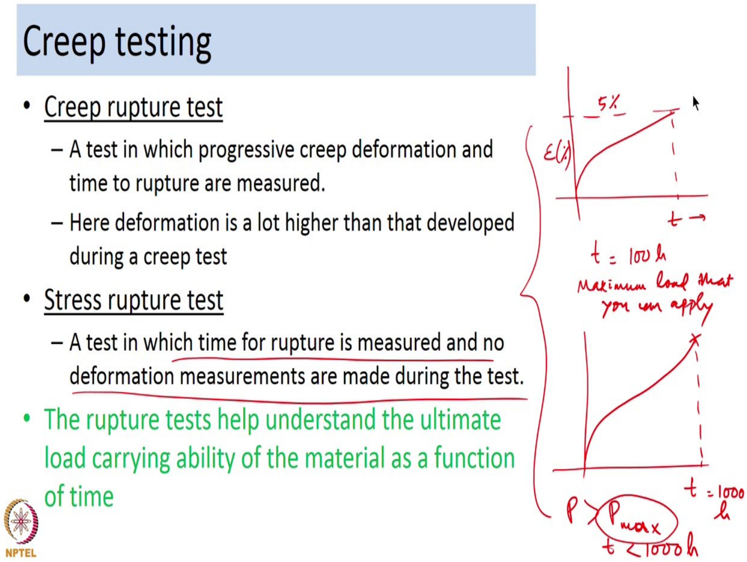

Now in contrast to the creep test a creep rupture test is one where the defamation is carried out until rupture, so a creep rupture test is a test in which progressive creep deformation and time to rupture both are measured, so you are measuring both the defamation as well as the time to rupture and here the plastic deformation that the sample experiences is a lot higher than that developed during a regular creep test because load applied is higher, in the creep rupture test you take your sample till rupture so the amount of deformation that the material experiences is significantly higher and a variant of the creep rupture test is a stress rupture test and in this type of test… here the only measurement is the time to rupture.

So a stress rupture test is a test in which time for rupture is measured and no deformation measurements are made during the test, so if you see there are 3 things that are coming out you have a creep test then you have creep rupture test and then finally you have a stress rupture test. In the creep test you are only measuring deformation up to a few percent, so a few percent plastic strain is what you are measuring and you are measuring the time taken to reach that few percent of plastic strain.

In the creep rupture test you are allowing the test to run until rupture and during the test you are measuring both the plastic deformation and then you are also measuring the time taken to rupture but in the stress rupture test what you are basically doing is you are only measuring the time for rupture and you are not providing any information or gathering and information on the plastic deformation experienced by the material during test.

Now the rupture test that is both the creep and the stress rupture test, they allow you to understand the ultimate load carrying ability of the material as a function of time, so what I am trying to say here is unlike the creep test, the creep test basically is carried out up to a few percent, so say this is Epsilon and Epsilon versus time, so if you define your creep test as time taken to a certain strain let us say 5 percent and you have already define the time say you are saying the time is 100 hours and the maximum allowable strain is 5 percent then basically based on that you can know what is the maximum load that you can apply.

So if you define that time for which you are going to allow the material to strain and the maximum strain that you are allowing is only 5 percent as an example then you know what kind of loads you can apply that means you know what is the load carrying ability of the material and in the 2nd case if have defined the sample up to rupture and if you are saying that the time to rupture let us say it is 1000 hours and you are saying you want a time to rupture of 1000 hours then again you know how much is the maximum stress that the material can take so that it provides you at least at time of 1000 hours, so here if your load exceeds P max then your time to rapture will become less than 1000 hours.

So P max is the maximum load that the material can take so that it provides you a time to rupture of 1000 hours, so if you look at both these plots these together can tell you the entire behaviour or the entire load carrying ability of the material. If you are defining the strain that you are allowing and the time to reach that strain then you know what kind of loads you want the material to experience but if you are defining the time to rupture and then accordingly you know what is the maximum load that material can experience.

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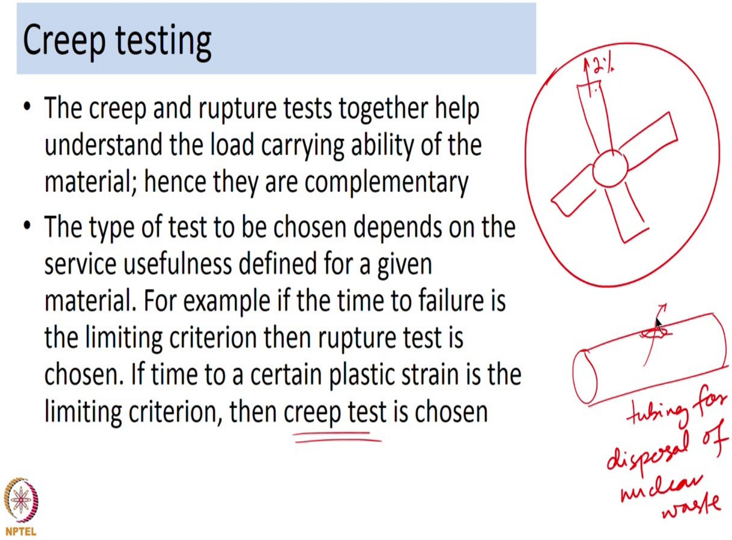

So basically the creep and the rupture test together help understand the load carrying ability of the material and hence they are complementary to each other and the type of test that you going to choose depends on the service usefulness defined for a given material. For example if the time to failure is the limiting criterion then rupture test is chosen however if time to a certain plastic strain is the limiting criteria, then creep test is chosen, so for example if you are looking at the gas turbine blades, say you have a gas turbine blades and it is enclosed in a casing and here you know even a strain of few percent like let us say 2 or 3 percent is going to cause the gas turbine blade to hit the casing which means that the engine is going to get damage.

In that case you are going to choose a creep test because all that you are interested in is knowing what is the time taken to reach 2 percent of plastic strain, so in such a case you may want to go for a creep test, however in other cases if you are talking about a tubing, tubing for disposal of nuclear waste, so if you are looking at using for disposal of nuclear waste here your main concern is when is the tube going to rupture and if it ruptures it is going to allow the nuclear waste to come in contact with soil and other environment which means there are environmental hazards possible if the tube ruptures, so in this condition probably your interest is to know what is the time to rupture for a certain applied load, so based on your end application you can decide which particular type of test you want to adopt.

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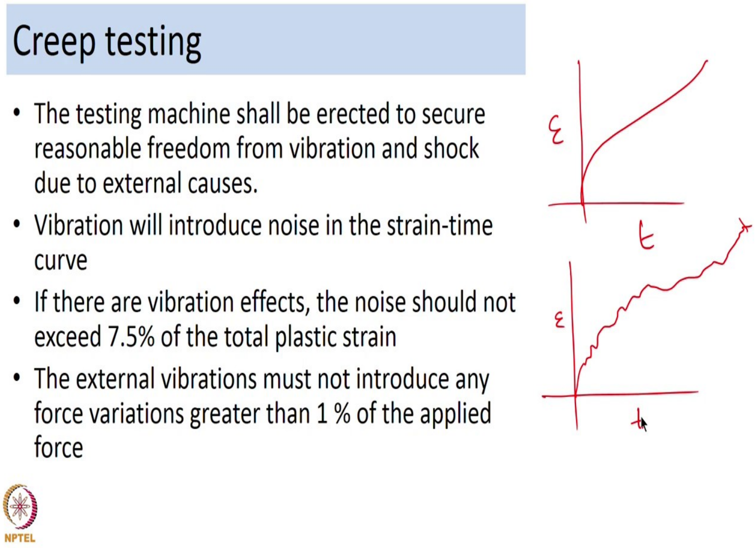

Now when you are doing your creep test, so now once you know the type of test you are planning on doing then what becomes important is the actual creep test, so here when you are doing your creep test and you have a creep testing machine you have to ensure that your creep testing machine will be erected in a place which is free from vibration and shock due to external causes, so if your creep testing machine is located in a place where vibrations and shocks from external factors are regular then your data is going to get influenced by those factors.

So essentially your testing machine should be isolated from external vibration and shocks because vibration and shocks will introduce noise in the strain time curve, so if we have strain versus time you want as smooth curve as possible so that you can analyse your data better but if there is a lot of noise then probably you will see a lot of variation or fluctuation in your measurement and this will prevent analysis of your data. This will interfere with good analysis of your data so that is why you want to reduce the amount of noise that is generated to your strain time curve.

However if there are vibrations affects which cannot avoid then one of the specification provided by the ASTM is that the noise should not exceed 7.5 percent of the total plastic strain, so if vibration is unavoidable then probably and if you have to live with it then the maximum vibration maximum effect brought about by the vibration should not exceed 7.5% of the total plastic strain and the external vibrations should also not introduce any force variation greater than 1 percent of the applied force, so if I am applying a certain force and you do not want the external vibration to make their own contributions to the applied force and in case these contribution are unavoidable then the maximum that you are going to allow is only 1 percent of the applied force.

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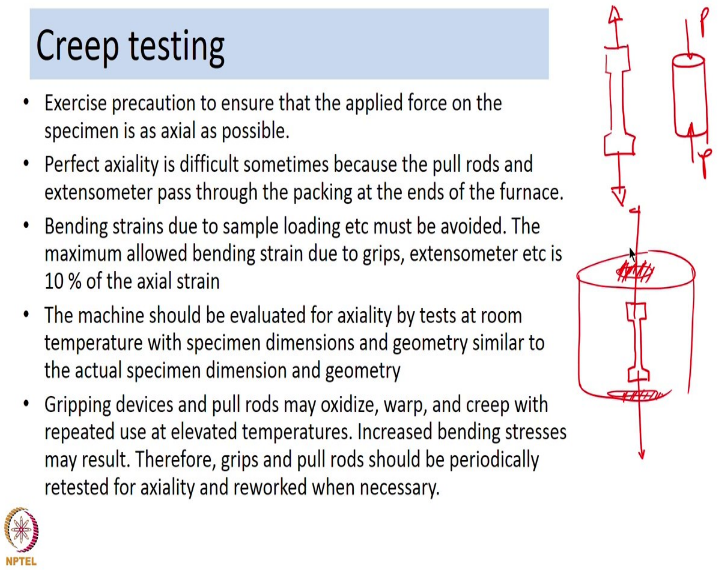

The other precautions that you should exercise are as follows you should exercise caution to ensure that the applied force on the specimen is as axial as possible, so if you are doing your tensile or compression test the load that is getting applied should be as axial as possible, so the load should be as axial as possible. Sometimes perfect axiality is difficult because the pull rods and extensometer pass through the packing at the ends of the furnace, so say this is your sample and then you have the furnace around your sample, so your sample is inside the furnace and then this is connected to a pull rod, so this is connected to a full rod.

So for the sake of insulation you going to pack some materials around the pull rod so that the heat losses that the sample and the pull rod experience is minimised, so when you are applying when you are including some packing material around the furnace or at the entrance or the exit of the full rod these packing material could also lead to some kind of disturbance or misalignment and so this can create issues with axiality.

So if such a case is there then the bending strains due to the sample loading et cetera which have to be avoided and even if it is unavoidable then the maximum bending strain due to grips extensometer et cetera should be maximum allowed bending strain is 10 percent of the axial strain, so if a loss of axiality is unavoidable and if the loss of axiality leads to some amount of bending strains the maximum bending strain that the creep test or the ASTM standard allow is only 10 percent of the axial strain and the machine should be evaluated for axiality by test at room temperature with specific dimensions and geometry similar to the actual specimen dimensions in geometry.

So before you carry out your test you should also evaluate your machine for axiality and what you can do is you can create some dummy samples but these samples should have dimensions and geometry similar to the actual sample and using this dummy samples and by testing at room temperature you can find out the amount of non-axiality that your sample is experiencing. Also important thing to notice that the gripping devices and the pull rods generally tend to oxidise, warp and creep with repeated use at elevated temperatures and when they start reforming or start losing the geometry or warping et cetera this can also lead to bending stresses and so the grips and pull rods should be periodically evaluated and retested for axiality and rework if necessary.

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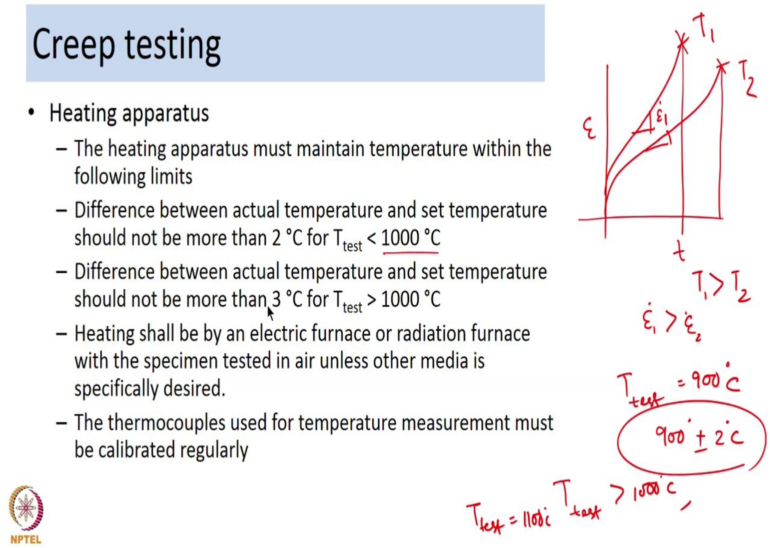

Now one of the important components of your creep test is the heating apparatus or the furnace, now because creep is a high temperature test and the data generated is dependent on the temperature at which you are testing, so it is quite clear that if your temperature is higher, the strain rate of defamation will be higher and your time to failure will also change, so T1, T2. If T1 is greater than T2 your strain rate Epsilon dot 1 is going to be greater than Epsilon dot 2, so the temperature has important role to play, so the heating apparatus must maintain temperature within certain limits, say if your test temperature is T-test and you are carrying out your test at temperatures lower than 1000 degrees centigrade then the maximum variation of the sample temperature is 2 degrees.

So if you are T-test as an example is 900 degrees centigrade then your sample temperature should not be, maximum allowed is 900 degrees centigrade plus minus 2 degrees centigrade, so your sample temperature should be in that range. Similarly, if your T test is greater than 1000 degrees centigrade let us say T-test is 1100 degrees centigrade then here your maximum availability or allowed availability is only 3 degree centigrade. Also the heating should be carried out by an electric furnace or radiation furnace and with the sample tested in air unless other media is specifically designed.

So typically these tests are carried out in normal environment, in air environment unless other media such as argon or oxygen et cetera has been specifically mentioned for the test and the thermocouples use for temperature measurement must be calibrated regularly because the thermocouples will tell you what is the sample temperature, so if there is an error in the measurement by the thermocouples then that could also lead to a faulty test, so the thermocouples should be regularly calibrated.

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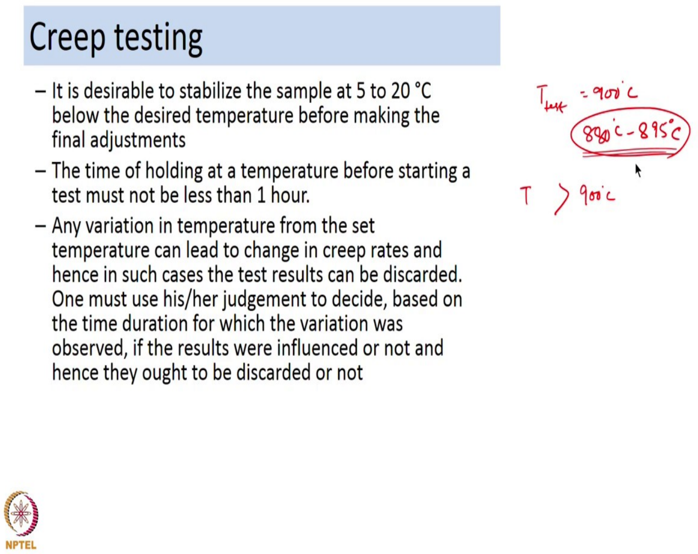

Also when you are going to do your creep test it is desirable to stabilise the sample at 5 to 20 degrees centigrade below the desired temperature before making the final adjustment, so what here I am trying to say is if your test temperature is 900 degrees centigrade then first you should stabilise your sample at maybe 880 to 895 degree centigrade, so you can stabilise your sample in this temperature range and then make your final adjustments so that the sample temperature reaches 900 degrees centigrade.

The advantage of this approach is in case you are trying to stabilise your sample directly at 900 then there is always a possibility of overshooting so the furnace may end up overshooting and providing temperature greater than 900 degrees centigrade and since some phase transformations can happen at high-temperatures, so that is why it is always better to stabilise your furnace at lower temperatures, slightly lower temperatures and then make the final adjustment so that the sample temperature does not overshoot your test temperature.

Also the time of holding at a temperature before starting a test must not be less than 1 hour, so basically if you are doing a test at 900 degrees centigrade after you reach 900 degrees centigrade hold the sample at that temperature for at least one hour and then only you start your test and any variation in temperature from the set temperature can lead to change in creep rates and hence in such cases the test results can be discarded and here the operator or the person carrying out the test or the person interested in the data should use his or her judgement to decide based on the time duration for which the variation was observed. So if there is a variation in your test temperature then you will have to use your judgement on deciding whether the data should be used or the data should be discarded and of course your point of judgement is based on the time duration for which the variation was observed.