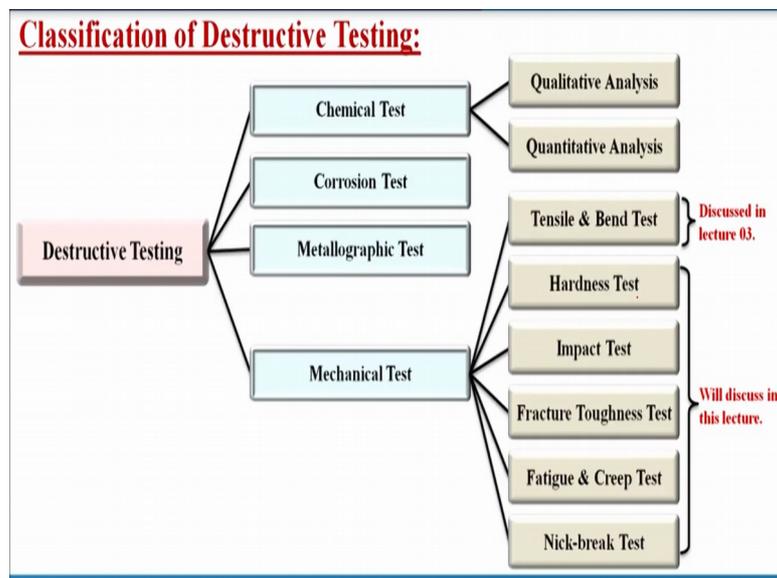


Inspection and Quality Control in Manufacturing
Prof. Kaushik Pal
Department of Mechanical and Industrial Engineering
Indian institute of Technology Roorkee

Lecture – 04
Destructive Inspection – II

Hello my friends. Today we are going to discuss about the lecture 4 on the Inspection and Quality Control in Manufacturing. So basically, these lecture deals with the destructive inspections part 2. If you remember in our last lecture, we have discussed about the qualitative analysis and quantitative analysis and also the tensile and bend test so in this particular lecture we are going to discuss about

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hardness test, impact test fracture toughness test, fatigue and creep test and the nick break test so these all are coming under mechanical test. So, what is hardness test. First hardness, what is hardness?

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3. Hardness Tests:

- Hardness is the ability of a material to resist indentation or penetration, to resist abrasive wear when a compressive force is applied.
- The ease with which the hardness test can be made has made it the most common method of inspection for metals and alloys.
- The principal purpose of the hardness test is to determine the suitability of a material for a given application, or the particular treatment to which the material has been subjected.

Classification of Hardness Tests (on the basis of amount of load applied):

- Depending upon the amount of load applied through indenter, hardness testing practices are divided into two categories: **Macrohardness** and **Microhardness**.

❖ **Macrohardness** - It refers to testing with applied loads on the indenter of more than 1 kg.

For example, the testing of tools, dies, and sheet material in the heavier gages.

❖ **Microhardness** - In microhardness testing, applied loads are 1 kg and below, and material being tested is very thin (down to 0.0125 mm, or 0.0005 in.). Applications include extremely small parts, thin superficially hardened parts, plated surfaces, and individual constituents of materials.

Hardness is nothing but the ability of a material to resist the indentation or penetration, to resist abrasive wear when a compressive force is applied to that particular material. So The ease with which the hardness test can be made has made it the most common method of inspection for generally metals and alloys. The principal purpose of the hardness test is to determine the suitability of a material for a given applications, or the particular treatment to which the material has be subjected.

There are also several classification of hardness test mainly basically on the basis of amount of load applied. So, depending upon the amount of load applied through indenter, hardness testing practices are divided into two categories. One is called the Macrohardness another one is called the microharness.

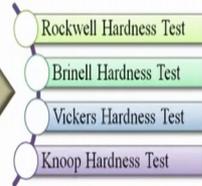
Now what is microhardness? It refers to testing with applied loads on the indenter of more than 1 kg. so, from that particular view you can understand that we are giving a maximum load over there. So of course, the consequence will be more. For example, the testing of tools, dies and sheet material in the heavier gages. Next if you talk about the microhardness, in microhardness testing, applied loads are 1 kg and below of that, and material being tested is very thin down to 0.0125 mm or may be the 0.0005 in.

Applications include extremely small parts, thin superficially hardened parts, plated surfaces and individual constituents of materials. Now classifications of the hardness test based on the type of the indenter used. So on the basis of type and size of the indenter.

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Classification of Hardness Tests (on the basis of type of indenter used):

On the basis of type and size of the indenter, four most widely used scales for hardness measurement are:



a) Rockwell Hardness Tests:

- The Rockwell tests constitute the most common method used to measure hardness because they are so simple to perform and require no special skills.
- The determination of the Rockwell hardness of a material involves the application of a minor load (F_0) followed by a major load (F_1).
- Indenters include:
 - ✓ Spherical and hardened steel balls having diameters of $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ inches.
 - ✓ Conical diamond (Brale) indenter, which is used for the hardest materials.

Four most widely used scales for hardness measurement are one is called the Rockwell Hardness Test, next one is called the Brinell Hardness Test, Vickers Hardness Test and the Knoop Hardness Test. What is Rockwell Hardness Test? The Rockwell test constitute the most common method used to measure hardness because they are so simple to perform and require no special skills.

That means a semi skill labor or may be as a undergraduate student or a PHD student or may be the PG students first time also may be we can use or we can do this kind of testing. The determination of the Rockwell harness of a material involves the application of a minor load say suppose if it is F_0 followed by a major load that is F_1 . Indenter include spherical and hardened steel balls having diameter of 1 by 16 or may be 1 by 8 or may be 1 by 4, or may be the half inches. Conical diamond indenter generally it is called the Brale which is used for the hardest material.

So, depending upon the material, depending upon the material size we are going to change the indenter materials as well as their size.

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- There are two general classifications of the Rockwell test:
 - Rockwell Hardness Test*
 - Rockwell Superficial Hardness test.*
- The significant difference between the two test classifications is in the test forces i.e. minor loads that are used.
- The initial minor load (preliminary test force) F_0 is 10 kg for the Rockwell hardness test and 3 kg for the Rockwell superficial hardness test.

From possible combinations of various indenters and different loads, several different scales are derived, which permit the testing of virtually all metal alloys (as well as some polymers).

- When specifying Rockwell and superficial hardness, both hardness number and scale symbol must be indicated.
- The scale is designated by the symbol HR followed by the appropriate scale identification.
- For example:* 80 HRB represents a Rockwell hardness of 80 on the B scale, and 60 HR30W indicates a superficial hardness of 60 on the 30W scale.

Scale Symbol	Indenter	Major Load (kg)
A	Diamond	60
B	$\frac{1}{16}$ -in. ball	100
C	Diamond	150
D	Diamond	100
E	$\frac{1}{8}$ -in. ball	100
F	$\frac{1}{16}$ -in. ball	60
G	$\frac{1}{16}$ -in. ball	150

Scale Symbol	Indenter	Major Load (kg)
15N	Diamond	15
30N	Diamond	30
45N	Diamond	45
15T	$\frac{1}{16}$ -in. ball	15
30T	$\frac{1}{16}$ -in. ball	30
45T	$\frac{1}{16}$ -in. ball	45
15W	$\frac{1}{8}$ -in. ball	15

There are two general classification of the Rockwell test. One is called the Rockwell Hardness Test another one called Rockwell Superficial Hardness test. So the significant difference between these two test classification is in the test forces that is minor loads that are used.

The initial minor load preliminary test force as I told already F_0 is 10 kilo grams for the Rockwell hardness test and for 3 kilo grams for the Rockwell superficial hardness test. So, from these table you can understand. So, from possible combinations of various indenters and different loads, several different scales are derived, which permit the testing of virtually all metal alloys as well as some polymers.

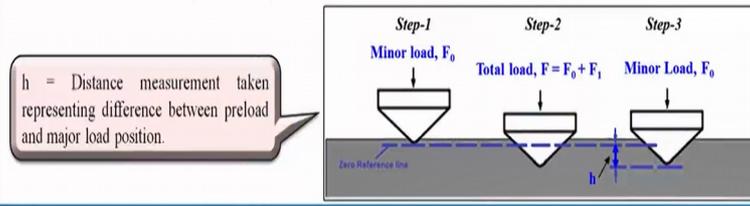
What is that if you go for this table you can see that scale symbol is capital A B C D like that and indenter size is changing or may be the indenter material is changing. And major load say for diamond it is 60 kilo for 1 by sixteen in ball shapes it is 100 kilo. So that varies. When specifying Rockwell and superficial hardness, both hardness number and scale symbol must be indicated.

The scale is designated by the symbol HR followed by the appropriate scale identification. Say suppose for example 80 HRB this is the numeric number numerical and with the symbol represents a Rockwell hardness of 80 on the B scale, and 60 HR30W indicates a superficial hardness of 60 on the 30W scale. So, from these particular we are getting the symbols and as well as the number. Now, how to conduct this particular test?

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Test Procedure:

- The determination of the Rockwell hardness of a material involves the following procedure:
 - ❖ *Step 1:* The indenter is brought into contact with the test specimen, and the preliminary test force F_0 is applied. After holding the preliminary test force for a specified dwell time, the baseline depth of indentation is measured.
 - ❖ *Step 2:* The force on the indenter is increased at a controlled rate by the additional test force F_1 to achieve the total test force F . The total test force is held for a specified dwell time.
 - ❖ *Step 3:* The additional test force is removed, returning to the preliminary test force. After holding the preliminary test force for a specified dwell time, the final depth of indentation is measured.
- The Rockwell hardness value is derived from the difference h in the final and baseline indentation depths while under the preliminary test force.



So, the determination of the Rockwell hardness of a material involve the following procedure. Step 1 the indenter is brought into contact with the test specimen and the preliminary test force F_0 is applied. You can see from this particular image. So, this is the step 1. After holding the preliminary test force for a specified dwell time, the baseline depth of indentation is measured.

Now come to the step 2 the force on the indenter is increased at a controlled rate by the additional test force F_1 to achieve the total test force F so F is nothing but the $F_0 + F_1$. The total test force is held for a specified dwell time. Now come to step 3 the additional test force is removed, returning to the preliminary test force that means again we are coming back to F_0 . After holding the preliminary test force for a specified dwell time, the final depth of indentation is measured.

So that is nothing but the step 3. So here you can see that h that is the height, and the distance that the indenter has gone that h inside the material itself. The Rockwell hardness value is derived from the difference h in the final and baseline indentation depths while under the preliminary test force. So, h is the distance measurement taken representing difference between preload and major load position. Now, how to calculate?

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Calculation of Rockwell Hardness:

- The unit measurement for h is mm. From the value of h, the Rockwell hardness number is calculated as:

✓ For scales using a diamond spheroconical indenter:

$$\text{Rockwell Hardness} = 100 - \frac{h}{0.002}$$

$$\text{Rockwell Superficial Hardness} = 100 - \frac{h}{0.001}$$

✓ For scales using a ball indenter:

$$\text{Rockwell Hardness} = 130 - \frac{h}{0.002}$$

$$\text{Rockwell Superficial Hardness} = 100 - \frac{h}{0.001}$$



The unit measurement of small h is in millimeter from the value of h the Rockwell hardness number is calculated as for scales using a diamond spheroconical indenter. Rockwell hardness is equal to 100 minus h by 0.002. Rockwell superficial hardness is generally 100 minus h by 0.001. For scales using a ball diameter may be the ball indenter, Rockwell hardness is equal to 130 minus h by 0.002 and for superficial hardness it is 100 minus h by 0.001. Next come to the Brinell hardness test.

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b) Brinell Hardness Tests:

- This test consist of impressing a special hardened steel or tungsten carbide ball into the specimen under test, using a definite load for a definite time and accuracy.
- The load for steel is generally 3000 kg and for softer metals, 500 kg.
- The diameter of the impression is measured by the eye, using a special high power Brinell microscope (graduated in tenth of millimetres).

Test Precautions:

- ✓ The surface to be tested should be flat and scratch free.
- ✓ Impressions should be taken at the representative locations.
- ✓ The load applied must be normal to the surface of the specimen.
- ✓ The test should not be used on the specimen of thickness less than about ½ inch (13 mm).
- ✓ Impressions should not be taken closer than about two diameters from each other, else the cold work caused by the previous impression will produce wrong data.



This test consists of impressing a special hardened steel or tungsten carbide ball into the specimen under test, using a definite load for a definite time and accuracy. The load for steel is generally 3000 kg and for softer metals, it is generally 500 kg. The diameter of the impression is measured by the eye, using a special high power Brinell microscope graduated in tenth of millimeters.

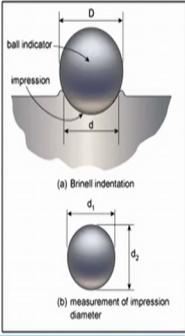
Test precautions. The surface to be tested should be flat and scratch free. Impression should be taken at the representative locations. The load applied must be normal to the surface of the specimen. The test should not be used on the specimen of thickness less than about half inch that means 13 millimeter. Next impression should not be taken closer than about two diameters from each other, else the cold work caused by the previous impression will produce the wrong data. Next is the test procedure.

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Test Procedure:

- ❖ **Step 1:** The indenter is brought into contact with the test specimen in a direction perpendicular to the surface, and the test force F is applied. The test force is held for a specified dwell time and then removed.
- ❖ **Step 2:** The diameter of the indentation is measured in at least two directions perpendicular to each other. The Brinell hardness value is derived from the mean of the diameter measurements.

$$\text{Brinell Hardness (HBW)} = \frac{2F_{kgf}}{\pi D(D - \sqrt{D^2 - d^2})}$$



Symbols and Designations:

D = Diameter of the ball, mm
d = Average diameter value of the indentation, mm
F = Test force, N
 F_{kgf} = Test force, kgf
 $F_{kgf} = F/g$, where g is the acceleration due to gravity.

So, step 1 the indenter is brought into contact with the test specimen in a direction perpendicular to the surface, and the test force F is applied. The test force is held for a specified dwell time and then removed. So, in this particular case. Now come to the step 2 the diameter of the indentation is measured in at least two directions perpendicular to each other. The Brinell hardness value is derived from the mean of the diameter measurements.

Generally, Brinell Hardness we are giving it like a HBW is equal to $2 F_{kgf}$ by πD into D minus root over D square minus small d square. So now capital D is the diameter of the ball in millimeter, small d is the average diameter value of the indentation that is also in millimeter, F is the test force that is N so here you can see this is the capital D this is the small d then F_{kgf} is the test force kgf and F_{kgf} is equal to F by g where g is the acceleration due to gravity. Indenters of the Brinell hardness test

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❖ Indenters for the Brinell hardness test shall be tungsten carbide balls of four allowed diameters (1, 2.5, 5 and 10 mm).

❖ **Brinell Hardness Scales** - The combinations of indenters and test forces define the Brinell hardness scales.

❖ Some of the standard Brinell hardness scales are given in the table. ➡

Designation of Brinell Hardness Values:

- Brinell hardness numbers shall be followed by the symbol HBW, and be supplemented by an index indicating the test conditions in the following order:
 - ✓ Diameter of the ball, mm.
 - ✓ A value representing the test force, kgf.
 - ✓ Applied force dwell time, s, if other than 10 s to 15 s.
- For HBW 10/3000 scale with 10 s to 15 s dwell time, Brinell hardness scale designation can be reported simply as HBW.

<i>Brinell Hardness Scales</i>			
Brinell Hardness Scale	Ball Diameter D (mm)	Nominal Value of Test Force F (N)	Nominal Value of Test Force $F_{10} = \frac{F}{9.8}$ (kgf)
HBW 10/3000	10	29420	3000
HBW 10/1500	10	14710	1500
HBW 10/500	10	4903	500
HBW 5/750	5	7355	750
HBW 5/250	5	2452	250
HBW 2.5/187.5	2.5	1839	187.5
HBW 1/10	1	98.07	10

Examples:

220 HBW = Brinell hardness of 220 determined with a ball of 10 mm diameter and with a test force of 29.42 kN (3000 kgf) applied for 10 s to 15 s.

600 HBW 1/30/20 = Brinell hardness of 600 determined with a ball of 1 mm diameter and with a test force of 294.2 N (30 kgf) applied for 20 s.

shall be tungsten carbide balls of four allowed diameters like 1, 2.5, 5 and 10 millimeters. Brinell hardness scales. The combinations of indenters and test forces define the Brinell hardness scales. Some of the standard Brinell hardness scales are given in this particular table. So, when we are talking about the HBW 10 oblique 3000 that means ball diameter is 10, nominal value of test force is 29420 and nominal value of test force which is F kgf is equal to 3000.

In this case suppose if we talk about the HBW 5 oblique 250 so in this case the ball diameter is 5 millimeter, nominal value of test force is 2452 neutral and in this particular case nominal value of test force is 250 kgf. Now Designation of Brinell hardness values. Brinell hardness numbers shall be followed by the symbol HBW which I have already told, and be supplemented by an index indicating the test conditions in the following order.

Diameter of the ball, a value representing the test force kgf, applied force dwell time s if other than 10 seconds to 15 seconds. For HBW 10 oblique 3000 scale with 10 seconds to 15 seconds dwell time. Brinell hardness scale designation can be reported simply by HB and W. So now I have given the examples for this one. So, suppose if give another example say suppose if you take 600 HBW then 1 oblique 30 oblique 20 that means Brinell hardness of 600 determined with a ball of 1 mm diameter and with a test force of 294.2 Neutron that means 30 kgf applied for 20 seconds.

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c & d) Knoop and Vickers Microindentation Hardness Tests:

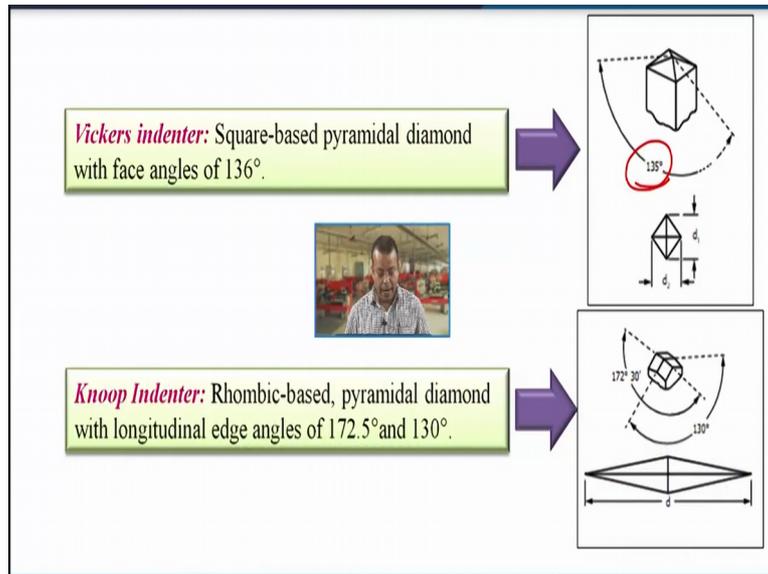
- Two other hardness-testing techniques are Knoop and Vickers (*sometimes also called diamond pyramid*).
- For each test a very small diamond indenter having pyramidal geometry is forced into the surface of the specimen.
- Applied loads are much smaller than for Rockwell and Brinell, ranging between 1 and 1000 g.
- The resulting impression is observed under a microscope and measured; this measurement is then converted into a hardness number.
- Careful specimen surface preparation (grinding and polishing) may be necessary to ensure a well-defined indentation that may be accurately measured.
- The Knoop and Vickers hardness numbers are designated by HK and HV, respectively, and hardness scales for both techniques are approximately equivalent.
- Knoop and Vickers are referred to as microindentation-testing methods on the basis of indenter size.
- Both are well suited for measuring the hardness of small, selected specimen regions; furthermore, Knoop is used for testing brittle materials such as ceramics.

Next is called the Knoop and Vickers Microindentation Hardness test. So, in this particular case two other hardness testing techniques are Knoop and the Vickers sometimes also called diamond pyramid. For each test is very small diamond indenter having pyramidal geometry is forced into the surface of the specimen. Applied loads are much smaller than for Rockwell and Brinell, ranging between 1 to 1000 gram. The resulting impression is observed under a microscope and measured; this measurement is then converted into a hardness number.

Careful specimen surface preparation like grinding and polishing may be necessary to ensure a well defined indentation that may be accurately measured. The Knoop and Vickers hardness numbers are designated by HK capital H capital K and capital H capital V HV, respectively, and hardness scales for both techniques are approximately equivalent or may be the same. Knoop and Vickers are referred to as microindentation testing methods on the basis of indenter size.

Both are well suited for measuring the hardness of small, selected specimen regions, furthermore, Knoop is used for testing brittle materials like ceramics. So Vicker indenter generally square based pyramid diamond with face angle of 136 degree or may be 135 degree so generally we are using these degrees over there and

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When we are talking about the Knoop indenter about the Rhombic based pyramidal diamond with longitudinal edge angles of 172.5 degree and 130 degree.

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Test Procedure:

- ❖ **Step 1:** The applicable specified indenter is brought into contact with the test specimen in a direction normal to the surface, and the test force F is applied. The test force is held for a specified dwell time and then removed.
- ❖ **Step 2:**
 - For the Vickers hardness test, the lengths of the two diagonals are measured and the mean diagonal length is calculated, which is used to derive the Vickers hardness value.
 - For the Knoop hardness test, the length of the long diagonal is measured, which is used to derive the Knoop hardness value.

Calculation of Vickers hardness value:

$$HV = 1.8544 \times \frac{F_{(kgf)}}{d_v^2}$$

$F_{(kgf)}$ = Test force (kgf).
 d_v = mean Vickers indentation diagonal length (mm).

Vickers Test

Test procedure. So, step 1 the applicable specified indenter is brought into contact with the test specimen in a direction a direction normal to the surface, and the test force capital F is applied. The test force is held for a specified dwell time and then removed. And step 2 for the Vickers hardness test, the lengths of the two diagonals are measured and the mean diagonal is calculated, which is used to derive the Vickers hardness value.

And for the Knoop hardness test, the length of the long diagonal is measured, which is used to derive the Knoop hardness value. Now calculation of Vickers hardness value. That is capital H capital V is equal to 1.8544 into F kgf by d v square. So, F kgf is test force, d v is

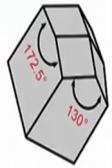
mean Vickers indentation diagonal length that is in millimeter. Calculation of for Knoop hardness value.

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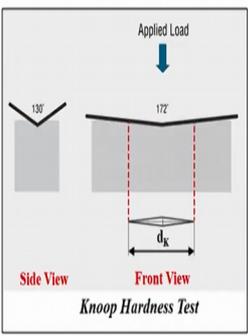
Calculation of Knoop hardness value:

$$HK = 14.229 \times \frac{F_{(kgf)}}{d_K^2}$$

$F_{(kgf)}$ = Test force (kgf).
 d_K = Knoop indentation long diagonal length (mm).



Indenter



Applied Load

130°

172°

d_K

Side View

Front View

Knoop Hardness Test



HK is equal to 14.229 into F kgf by d k square. So, d k is Knoop indentation long diagonal length in millimeter. So, this one. We can get it from the front view of that particular indenter. Next come to the impact test.

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4. Impact Tests:

- Prior to the advent of fracture mechanics as a scientific discipline, impact testing techniques were established so as to ascertain the fracture characteristics of materials.
- Impact testing determines the relative toughness of a material, where toughness is defined as the resistance of a metal to fracture after plastic deformation has begun.
- In an impact test, this plastic deformation is begun and finished by swing of a weighted pendulum which strikes the test piece as it swings through its path along an arc.
- The energy that is required to fracture the test piece is recorded in Joules on the scale.
- Two major tests for determining impact toughness are:



Izod Test



Charpy Test



Prior to the advent of fracture mechanics as a scientific discipline, impact testing techniques were established so as to ascertain the fracture characteristics of materials. Impact testing determines the relative toughness of a material, where toughness is defined as the resistance of a metal to fracture after plastic deformation has begun. In an impact test, this plastic deformation is begun and finished by swing of a weighed pendulum which strikes the test piece as it swings through its path along an arc.

So simple you are having one sample and then you are having one pendulum you are putting the weight in this particular case and it is going like this and then it is going and it is hitting the sample and breaking the samples. The energy that is required to fracture the test piece is recorded in Joules on the scale. Two major tests for determining impact toughness are one is called the Izod test and another one is called the Charpy test. Generally, it is called the Charpy and Izod test

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Charpy and Izod Test:

- The Charpy and Izod, are used to measure the impact energy, sometimes also termed notch toughness.
- For both Charpy and Izod, the specimen is in the shape of a bar of square cross section, into which a V-notch is machined.
- In Izod impact test, the specimen is supported as a cantilever beam.
- In Charpy impact test, the specimen is supported as a simple beam with load applied at the center.
- The notch in Izod test specimen is off the centre to facilitate holding in vice whereas the notch is in the centre of the specimen for Charpy test.
- V-notch in Izod specimen faces the load whereas it is opposite to loading in Charpy test.

Specimen Used for Charpy and Izod Impact Tests

Specimen Placements for Charpy and Izod Tests

Schematic of an Impact Testing Apparatus

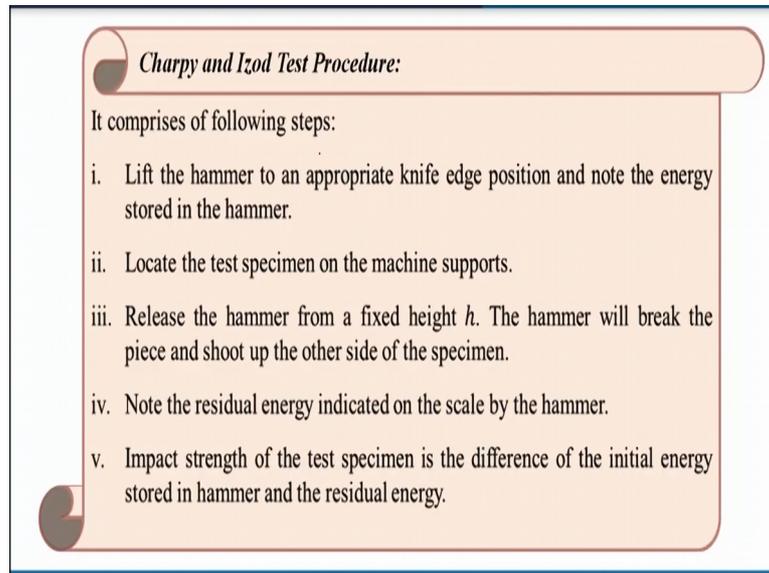
The Charpy and Izod are used to measure the impact energy, sometimes also termed notch toughness. For both Charpy and Izod, the specimen is in the shape of a bar of square cross section, into which a V-notch is machined. In this particular case you can see that we are given a v notch over there. In Izod impact test, the specimen is supported as a cantilever beam.

So, in this particular case so it is like a cantilever beam the pendulum will come and it will hit from this angle and it will break the sample. In Charpy impact test, the specimen is supported as a simple beam with load applied at the centre. So, in this particular case the load is coming it will hit it and the sample will break. Only the thing is that how we are keeping the samples. The notch in Izod test specimen is off the centre to facilitate holding in vice whereas the notch is in the centre of the specimen for Charpy test.

V-notch in Izod specimen faces the load whereas it is opposite to loading in Charpy test. So, in this case the V-notch for either test is in this side and also, we are hitting from this side only. But in the Charpy test it is opposite of the V-notch. And it is the whole thing so we are

keeping the sample or may be the specimen over here and then we are having one pointer or scales we are having one hammer with a fixed load it is coming over in a particular height or distance and then here it is hitting directly hitting the materials.

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Charpy and Izod Test Procedure:

It comprises of following steps:

- i. Lift the hammer to an appropriate knife edge position and note the energy stored in the hammer.
- ii. Locate the test specimen on the machine supports.
- iii. Release the hammer from a fixed height h . The hammer will break the piece and shoot up the other side of the specimen.
- iv. Note the residual energy indicated on the scale by the hammer.
- v. Impact strength of the test specimen is the difference of the initial energy stored in hammer and the residual energy.

Charpy and Izod test procedure. It comprises of following steps. Lift the hammer to an appropriate knife edge position and note the energy stored in the hammer itself you can get it from the scale. Locate the test specimen on the machine supports. Release the hammer from a fixed height small h . The hammer will break the piece and shoot up the other side of the specimen. Number 4 note the residual energy indicated on the scale by the hammer.

Then number 5 impact strength of the test specimen is the difference of the initial energy stored in hammer and the residual energy. That means easily you can get how much energy is required to break that particular sample. Next, Fracture toughness tests

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5. Fracture Toughness Tests:

- Fracture toughness is defined as fracture resistance of a material in the presence of cracks.
- It is used to refer the fractures as either ductile or brittle.
- Fracture toughness study of brittle materials is now fairly well established by Linear Elastic Fracture Mechanics (LEFM) and critical crack lengths for given stress condition.
- In LEFM the critical value of stress intensity factor (K) is referred to as the fracture toughness.
- The corresponding fracture toughness value for the materials of elastic-plastic region is referred to as J_c , which is a measurement of the energy required to grow a thin crack.

K_{Ic} - Test Technique:

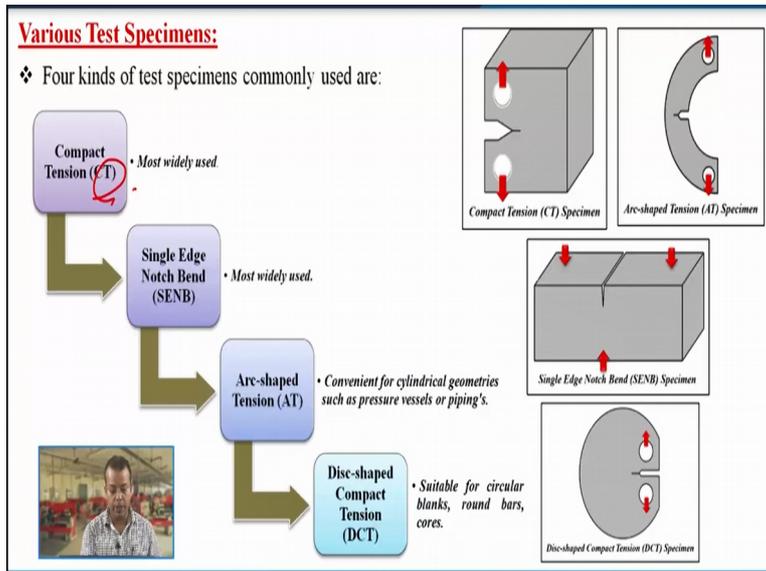
- Experimental determination of the critical stress intensity factor (K_{Ic}) is most widely studied and developed.
- The critical stress intensity factor of a material depends on the thickness of the plate. However for a thick plate it is independent of the thickness because the material in front of crack tip deforms in plane strain.
- The experiment should be controlled so as to have its loading in plain strain only.

Fracture toughness is defined as fracture resistance of a material in the presence of cracks. It is used to refer the fractures as either ductile or may be the brittle. Fracture toughness study of brittle materials is now fairly well established by Linear Elastic Fracture Mechanics in short it is called the LEFM and critical crack lengths for given stress condition. In LEFM the critical value of stress intensity factor K is referred to as the fracture toughness.

The corresponding fracture toughness value for the materials of elastic plate region is referred to as J_c , which is measurement of the energy required to grow a thin crack. Then K_{Ic} test technique. Experimental determination of the critical stress intensity factor K_{Ic} is most widely studied and developed. The critical stress intensity factor of the material depends on the thickness of the plate.

However, for a thick plate it is independent of the thickness because the material in front of crack tip deforms in plane strain. The experiment should be controlled so as to have its loading in plain strain only. Various test specimens. 4 kinds of test specimens commonly used are, compact tensions in short it is known as the CT it is mostly used.

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Next single edge notch bend SENB it is also mostly used. And then arc shaped tension that is called the AT, convenient for cylindrical geometries such as pressure vessels or may be the piping's. And the last one is called the disc shaped compact tension DCT suitable for circular blanks, round bars, cores etc. So, these are all the image that how to prepare the samples.

Next K_{1c} test procedure.

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K_{1c} Test Procedure:

- To begin with, K_{1c} of the specimen is guessed.
- Then, the specimen is prepared following several dimensional constraints which are based on the guessed value of K_{1c} .
- The crack tip is made very sharp with a fatigue growth.
- The specimen is pulled in a tensile machine to obtain a relation between the load and the crack mouth opening displacement. This relation provides the critical load P_Q .
- Accounting for the crack length and geometry of specimen, the stress intensity factor K_Q corresponding to P_Q is determined using LEFM.
- If K_Q satisfies all constraints on the geometry of the specimen and of fatigue growth, it becomes K_{1c} .

➤ Other more popularly employed test methods for to determine the fracture toughness values for the elastic-plastic region are:

- Charpy V-notch (Cv) Test,
- Drop Weight Nil-ductility Temperature (NDT) Test,
- The Dynamite Tear (DT) Test,
- Crack Tip Opening Displacement (CTOD) Test.

➤ Cv and NDT test are ASTM standard methods, while DT test is a military standard and CTOD is a British standard test.

To begin with K_{1c} of the specimen is guessed. Then the specimen is prepared following several dimensional constraints which are based on the guessed value of K_{1c} . The crack tip is made very sharp with a fatigue growth. The specimen is pulled in a tensile machine to obtain a relation between the load and the crack mouth opening displacement. This relation provides the critical load P_Q .

So simple we are pulling the samples. Accounting for the crack length and geometry of specimen, the stress intensity factor K_I corresponding to P/Q is determined using LEFM. If K_I satisfies all constraints on the geometry of the specimen and of fatigue growth, it becomes K_{Ic} .

Other more popularly employed test methods for to determine the fracture toughness values for the elastic plastic region are Charpy V-notch test, drop weight Nil-ductility Temperature test, the Dynamic Tear test and Crack Tip Opening Displacement test. CV this one and NDT are ASTM standard methods, while DT test is a military standard and CTOD the last one is a British standard test. Next one is called the fatigue test.

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6. Fatigue Tests:

- Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses (e.g., bridges, aircraft, and machine components).
- Components subjected to repeated cyclic stress have a tendency to break at a stress considerably below their ultimate tensile strength.
- *The term "fatigue" is used because this type of failure normally occurs after a lengthy period of repeated stress or strain cycling.*
- Fatigue is important inasmuch as it is the single largest cause of failure in metals, estimated to comprise approximately 90% of all metallic failures; polymers and ceramics (except for glasses) are also susceptible to this type of failure.
- The stress under which such a failure take place is called fatigue strength and the number of cycles after which failure occurs with the given conditions is called as fatigue life.
- Fatigue tests are designed to measure the effect of cyclic stress loading on the welded joint.
- Furthermore, fatigue is catastrophic and insidious, occurring very suddenly and without warning.

Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses example bridges, aircraft and machine components. Components subjected to repeated cyclic stress have a tendency to break at a stress considerably below their ultimate tensile strength. So, suppose you are having any materials and continuously you are giving the load and removing the load so after that may be the material can fell.

So for testing that particular properties of that materials, generally we are doing the fatigue test. The term fatigue is used because this type of failure normally occurs after a lengthy period of repeated stress or strain cycling. Fatigue is important inasmuch as it is the single largest cause of failure in metals, estimated to comprise approximately 90% of all metallic failures; polymers and ceramic except for glasses are also susceptible to this type of failure.

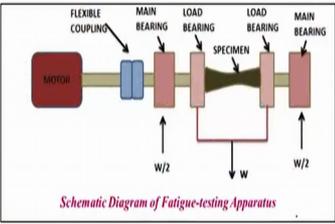
The stress under which such a failure take place is called the fatigue strength and the number of cycles after which failure occurs with the given conditions is called as fatigue life. Fatigue tests are designed to measure the effect of cyclic stress loading on the welded joint. Furthermore, fatigue is catastrophic and insidious, occurring very suddenly and without warning.

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- The process of fatigue consists of three stages:
 1. **Crack Initiation** - Initial fatigue damage leading to crack nucleation and crack initiation.
 2. **Crack Propagation** - Progressive cyclic growth of a crack (crack propagation) until the remaining uncracked cross section of a part becomes too weak to sustain the loads imposed.
 3. **Fracture** - Final, sudden fracture of the remaining cross section.

Fatigue Test Procedure:

- i. To perform a fatigue test a sample is loaded into a fatigue tester or fatigue test machine.
- ii. The specimen is first subjected to the pre-determined test stress, then unloaded to either zero load or an opposite load. The applied stress may be axial, flexural, or torsional in nature.
- iii. This cycle of loading and unloading is then repeated until the end of the test is reached. The test may be run to a pre-determined number of cycles or until the sample has failed depending on the parameters of the test.



The diagram shows a horizontal shaft assembly. From left to right: a red motor, a blue flexible coupling, a blue main bearing, a red load bearing, a central specimen, another red load bearing, another blue main bearing, and a final red motor. Vertical arrows labeled 'W/2' point upwards at the main bearings, and a vertical arrow labeled 'W' points downwards at the specimen. The caption below reads 'Schematic Diagram of Fatigue-testing Apparatus'.

The process of fatigue consists of three stages first one is called the crack initiation next one is called the crack propagation and last one is called the fracture. Suppose this is the materials we are giving repeated load after sometimes you can see crack has been generated on the surface that is called the crack initial. After that slowly, slowly the crack will enlarge or it will go inside the material that is called the crack propagation. And then after certain time the material will break that is called the fracture.

Fatigue test procedure. To perform a fatigue, test a sample is loaded into a fatigue tester or fatigue test machine. The specimen is first subjected to the pre-determined test stress, then unloaded to either zero load or an opposite load. The applied stress may be axial flexural or torsional in nature. This cycle of loading and unloading is then repeated until the end of the test is reached.

The test may be run to a pre-determined number of cycles or until the sample has failed depending on the parameters of the test itself. So, you can see the specimen it looks like this so we are having the motor flexible coupling, main bearing, load bearing. So simple we are holding the materials and constantly we are giving the load and allow to that particular materials and then we are trying to determine the fatigue life of that particular material.

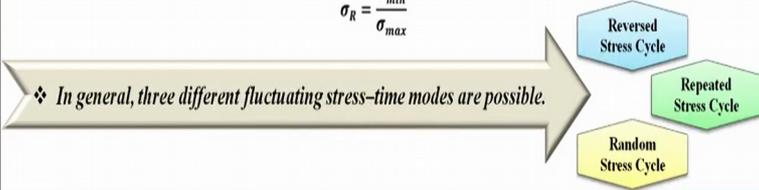
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Modes of Fluctuating Stress Cycles:

❖ Several parameters used to characterize the fluctuating stress cycle.

- **Mean Stress:** It is the average of the maximum and minimum stresses in the cycle.
$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$
- **Range of Stress:** It is the difference between σ_{max} and σ_{min} .
$$\sigma_r = \sigma_{max} - \sigma_{min}$$
- **Stress Amplitude:** It is the half of the range of stress.
$$\sigma_a = \frac{\sigma_r}{2} = \frac{\sigma_{max} - \sigma_{min}}{2}$$
- **Stress Ratio:** The stress ratio R is just the ratio of minimum and maximum stress amplitudes.
$$\sigma_R = \frac{\sigma_{min}}{\sigma_{max}}$$

❖ In general, three different fluctuating stress-time modes are possible.



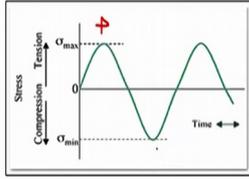
Modes of fluctuating stress cycles. Several parameters used to characterize the fluctuating stress cycle. First one is called the Mean stress. It is the average of the maximum and minimum stresses in the cycle. So, σ_m is equal to σ_{max} plus σ_{min} by 2. Range of stress. It is the difference between σ_{max} and σ_{min} . So that is known as σ_r is equal to σ_{max} minus σ_{min} . Stress amplitude. It is the half of the range of stress. That is called the σ_a is equal to nothing but σ_r by 2.

And last one is called the stress ratio. The stress ratio R capital R is just the ratio of minimum and maximum stress amplitudes. σ_R is equal to σ_{min} by σ_{max} . In general, three different fluctuating stress time modes are possible. One is called the Reversed stress cycle, repeated stress cycle and the random stress cycle. Repeated stress cycles. In this fatigue loading the stress alternates from a maximum tensile stress to a maximum compressive stress of equal magnitude. So plus, and the minus.

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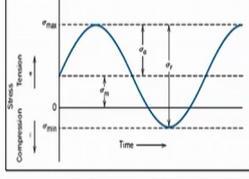
Reversed Stress Cycle:

- In this fatigue loading, the stress alternates from a maximum tensile stress (+) to a maximum compressive stress of equal magnitude.



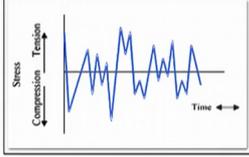
Repeated Stress Cycle:

- In this stress cycle, maximum and minimum stresses are asymmetrical relative to the zero-stress level.




Random Stress Cycle:

- In this stress cycle, no regular loading pattern is observed.



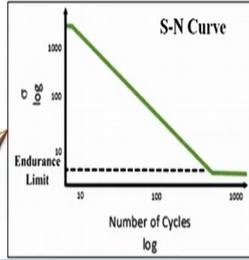
And the magnitude is equal. Next repeated stress cycle. In this stress cycle, maximum and minimum stresses are asymmetrical relative to the zero-stress level. So this is the main line and then we are giving the load like this. So, it is not equal the positive and negative sides are not equal. Then random stress cycle. In this stress cycle, no regular loading pattern is observed. So, you can see a zig zag pattern over there on the min line. Next come to the S-N Curve.

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S-N Curve:

- A series of tests are commenced by subjecting a specimen to the stress cycling at a relatively large maximum stress amplitude and the number of cycles to failure is counted.
- This procedure is repeated on other specimens at progressively decreasing maximum stress amplitudes.
- Data are plotted as stress S versus the logarithm of the number N of cycles to failure for each of the specimens.
- The values of S are normally taken as stress amplitudes (σ_a); on occasion, σ_{max} or σ_{min} values may be used.

- The typical curve or S-N line shows that the fatigue strength, i.e. the stress at which the metal fail, drops as the number of stress cycles increases. The greater the number of cycles, lower the fatigue strength.
- It also shows that, below a certain level of stress material does not fail by cracking, no matter how many stress cycles is loaded. This is called as endurance limit of the material.

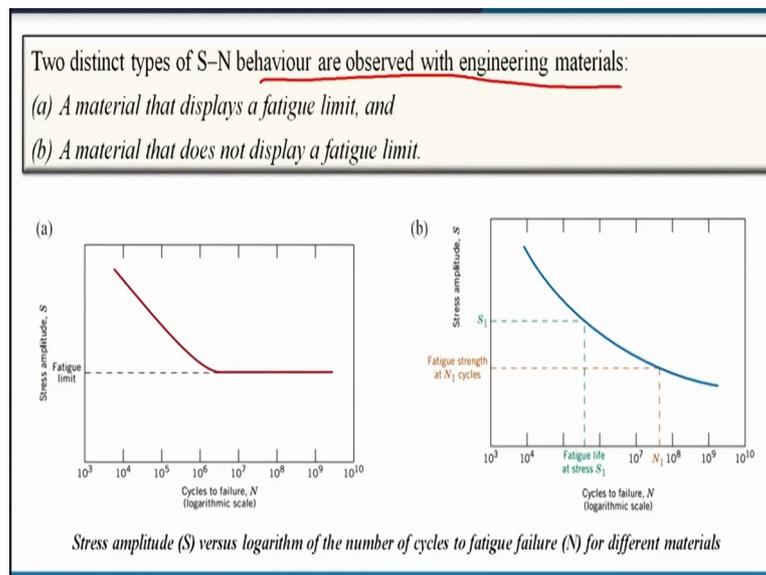


A series of test are commenced by subjecting a specimen to the stress cycling at a relatively large maximum stress amplitude and the number of cycles to failure is counted. This procedure is repeated on other specimens at progressively decreasing maximum stress amplitudes. Data are plotted as stress capital S versus the logarithm of the number N of cycles to failure for each of the specimens.

The value of S are normally taken as stress amplitudes σ_a ; on occasion, σ_{max} or σ_{min} values may be used. The typical curve or S-N curve lines shows that the fatigue strength, that is the stress at which the metal fail, drops as the number of stress cycles increases. The greater the number of cycles, lower the fatigue strength.

It is also shown that, below a certain level of stress material does not fail by cracking, no matter how many stress cycles is loaded. This is called as endurance limit of that particular material. So, from this graph we can get that this is the endurance limit of that particular material. Otherwise it is rapidly decreasing and after that it became constant.

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Two distinct types of S-N behavior are observed with engineering materials. One is call the material that displays a fatigue limit and a material that does not display a fatigue limit. So, these are the two graphs. In this particular case stress amplitude S versus logarithm of the number of cycle of fatigue failure for different materials has been shown. So, in this particular case you can see there is a clear distinct visibility of the fatigue limit. But in this case, there is not.

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7. Creep Rupture Tests:

- The gradual elongation or plastic deformation at higher temperature is called Creep while the eventual fracture is called Rupture.
- Materials are often placed in service at elevated temperatures and exposed to static mechanical stresses (e.g., turbine rotors in jet engines and steam generators that experience centrifugal stresses, and high-pressure steam lines).



Creep Test Procedure:

- ❖ A typical creep test consists of following two steps:
 - i. Subject a specimen to a constant load or stress while maintaining the temperature constant.
 - ii. Measure the deformation or strain and plot it as a function of elapsed time.
- ❖ Most tests are the constant load type, as constant stress provide a better understanding of the mechanisms of creep.

Then next one is called the creep rupture test. The gradual elongation or plastic deformation at higher temperature is called creep, while the eventual fracture is called rupture. Materials are often placed in service at elevated temperatures and exposed to static mechanical stresses that called may be the example is turbine rotors in jet engines and steam generator that experience centrifugal stresses, and high-pressure steam lines.

How to do this test? A typical creep test consists of following two steps. One subject a specimen to a constant load or stress while maintaining the temperature constant. Two, measure the deformation or strain and plot it as a function of elapsed time. Most tests are the constant load type, as constant stress provide a better understanding of the mechanism of creep. Additional information of creep rupture test.

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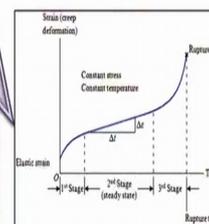
Additional Information of Creep Rupture Tests:

- The test specimen used to determine creep rupture strength is similar to that used for the already described tension tests
- The test is conducted in an appropriate furnace and load is generally applied in the form of constant dead weights.
- Elongation can be monitored by the help of some attachments like extensometers or LVDT.
- The creep test is monitored up to a predetermined time and elongation is measured in this time period.
- In rupture test, the test is carried up to the failure of the specimen.
- Creep and rupture data are most often reported as log-log plots of stress versus time to attain a specific percentage creep elongation or time to rupture at a constant temperature.

Creep Rupture Elongation Curve:

A typical creep curve shows three distinct stages with different creep rates.

- ❖ **Stage 1:** On initial application of load, the creep rate is high and decreasing with time. This is first stage creep or primary creep.
- ❖ **Stage 2:** The second stage of have minimum creep rate and the period is maximum in creep.
- ❖ **Stage 3:** In the third stage, the creep rate is again increased and results as necking.



The test specimen used to determine creep rupture strength is similar to that used for the already described tension tests. The tests is conducted in an appropriate furnace and load is generally applied in the form of constant dead weights. Elongation can be monitored by the help of some attachments like extensometers or may be the LVDT. The creep test is monitored up to a predetermined time and elongation is measured in this time period.

In rupture test, the test is carried out up to the failure of the specimen. Creep and rupture data are most often reported as log-log plots of stress versus time to attain a specific percentage creep elongation or time to rupture at a constant temperature. Creep rupture elongation curve. So generally, this is the curve in this particular curve you can see that stage 1, stage 2 and the stage 3.

So, in stage 1 on initial application of load, the creep rate is very high you can see it is rapidly increasing and decreasing with time. This is first stage creep or primary creep. Then come to second stage. the second stage of have minimum creep rate and the period is maximum in creep. So, you see here Δt is more but $\Delta \epsilon$ is very, very less. In stage 3, the creep rate is again increased and results are necking. The material is failing at that particular point. The nick break test.

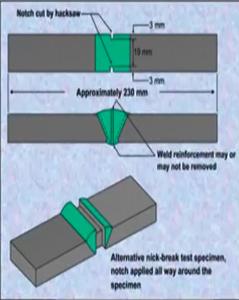
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8. Nick-Break Tests:

- A nick break test is a type of destructive testing that is used to evaluate the quality of a weld.
- This test shows up any centerline defects, such as lack of fusion, gas pockets, slag inclusion, incomplete penetration and the degree of porosity in the weld bead.
- Fillet welds may be similarly tested by notching and bending. One requirement of the fillet nick-break test is that there should be no tack welds on the other side of fillet weld.

Nick-Break Test Procedure:

- To perform a nick break test, a specimen is prepared out of the weld metal.
- An artificial notch or a groove (act as stress concentrator) is intentionally introduced by a hacksaw or a cutting disc on the weld face, along the primary axis of the weld.
- The specimen is then broken and the fracture surface is observed at the conclusion of the nick break test.

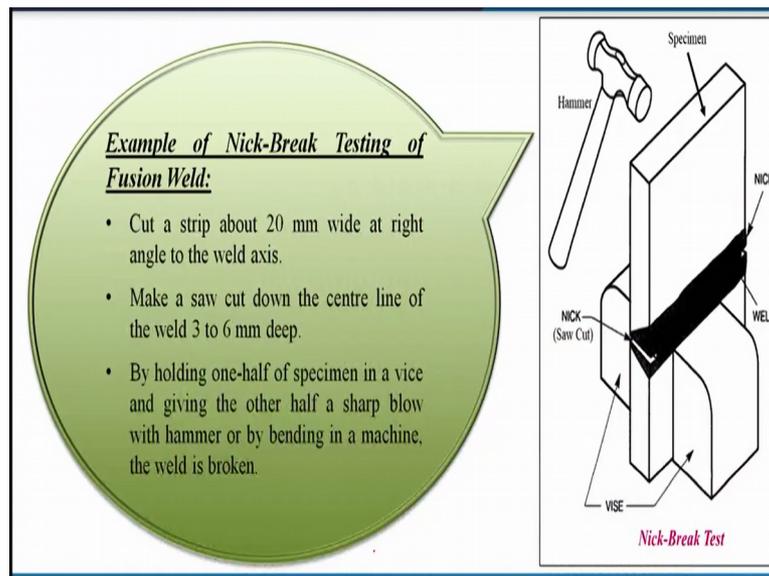


Nick Break Test Specimen

A nick break test is a type of destructive testing that is used to evaluate the quality of a weld. This test shows up any centerline defects, such as lack of fusion, gas pockets, slag inclusion, incomplete penetration and the degree of porosity in the weld bead. Fillet welds may be similarly tested by notching and bending. One requirement of the fillet nick break test is that there should be no tack welds on the other side of fillet weld.

How to conduct this one. So first we are doing the welding then we are preparing the notch over there at that welding zone. To perform a nick break test, a specimen is prepared out of the weld metal. An artificial notch or a groove act as stress concentrator is intentionally introduced by a hacksaw or a cutting disc on the weld face, along the primary axis of the weld. So you can see we are making this one. The specimen is then broken and the fracture surface is observed at the conclusion of the nick break test. Example of the nick break testing of fusion weld.

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So how we are preparing the sample and how we are doing it. So first by the saw or may be by any sharp disc, cutting disc so first we are making the mark over there generally it is calling as a nick and then by hammer we are breaking that particular samples and then we are observing that one. Cut a strip about 20-millimeter-wide at right angle to the weld axis. Make a saw cut down the center line of the weld 3 to 6 millimeter deep. By holding one half of specimen in a vice and giving the other half a sharp blow with hammer or by bending in a machine the weld is broken.

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Summary:

- ❖ Mechanical testing techniques e.g. hardness tests, impact tests, fracture toughness tests, fatigue tests, creep tests, and nick-break test have been discussed.
- ❖ The ease with which the hardness test can be made has made it the most common method of inspection for metals and alloys.
- ❖ Materials are often placed in service at elevated temperatures and exposed to static mechanical stresses, which requires to understand their creep behaviour.
- ❖ Nick-break test of weldment is performed to detect centreline defects, such as lack of fusion, gas pockets, slag inclusion, incomplete penetration and the degree of porosity in the weld bead.

Now we have come to the last slide of this particular lecture. So, in summary we can see that generally the mechanical testing techniques say for example hardness test, impact test, fracture toughness tests, fatigue tests, creep, and nick break test have been discussed in this particular lecture. The ease with which the hardness test can be made has made it the common method of inspection for metals and alloys too.

Materials are often placed in service at elevated temperature and exposed to static mechanical stresses, which requires to understand their creep behavior. Nick break test of weldment is performed to detect centerline defects, such as lack of fusion, gas pockets may be the porosity may be some kind of inside cracks, slag inclusion, incomplete penetration and the degree of porosity in the weld bead. Thank you very much for your kind patience.