Materials Science and Engineering
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Lecture -37
Non destructive testing: Hardness measurement

Hello friends, today's lecture will be on a very important topic that is a Non-destructive testing. For any industry, these are the techniques sometime used for quality control also. So, before any component goes out of the company, you have a quality control division and in quality control divisions, lot of these techniques are used to find out if there is any flaw in the component ok.

So, that it should not go to the customer, if any defects are present beyond a certain limit. Then, it should not be sold ok. So, it will be rejected and again it can be processed. So, a Non-destructive testing is one of the very important idea to understand here.

And I have clubbed this lecture with another measurement called Hardness measurement. It can be used as a some kind of quality control or some kind of NDT kind of thing. But this is a very important measurement as such to find out or to have some idea about the mechanical properties of the material ok.

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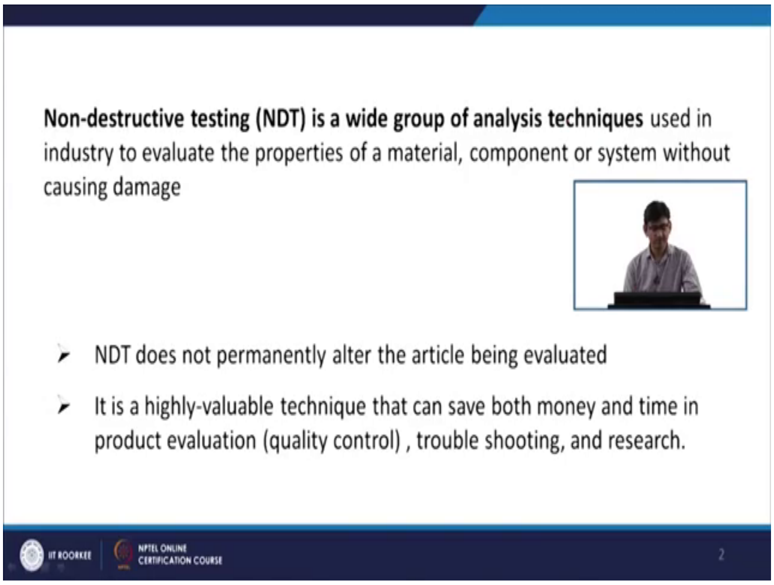

So, Non-destructive testing is a wide group of analysis technique used in industry to evaluate the properties of a material, component or system without causing damage. So, this is one of the most important aspect of the NDT techniques or NDT testing. Because if you do any tensile test; for example, you have to take out a sample and you have to destroy the sample during the test, it will fracture. Similarly, impact testing if you do it is going to fracture the sample. So, you will know about the defects or about the properties of the material by doing some destructive testing.

So, when you have a component which you cannot destroy, you want just want to know that if there are defects present and what is the size of these defects; whether these defects are critical or not. A very small defects with which is in micron size for example, or even in some micron size, maybe is not maybe not a critical defect ok. So, under your stress condition, under your service conditions maybe this defect is of not of any criticality ok.

You have to understand that in any material at any point of time or after any processing, there is always going to be some defects in the material ok. So, that you cannot avoid; defects are always going to be there in the material. As a as an engineer our purpose is to find out whether these defects are critical or not?

Maybe I can live with this defect or it is like all you have some disease some disease are like you just take medicine and you can live throughout your life without with the disease, but just by taking medicine or if that disease is not able to you cannot a cure that by medicine it is it cannot be managed by the medicine; then, maybe some operation you have to do ok.

So, this is the same kind of idea that some defects will always going to be there. Whether I will be able to live with that defect in the given service condition and that is what we have to find out ok. So, my I can I cannot keep testing each component there and keep it destroying every for every test ok. So, my point is to find out whether any defect is present there; what is the number of these defects in a given volume and what is the size of the defect and whether it is critical or not ok.

So, basically NDT does not permanently alter the article being evaluated. So, you do not change anything, the dimension or any property or nothing ok. We just check whether the defects are there or not. It is a highly valuable technique that can save both money and time in product evaluation. So, basically you can do a quality control using this NDT technique, you can do troubleshooting and of course, in research also it is a very important technique to use.

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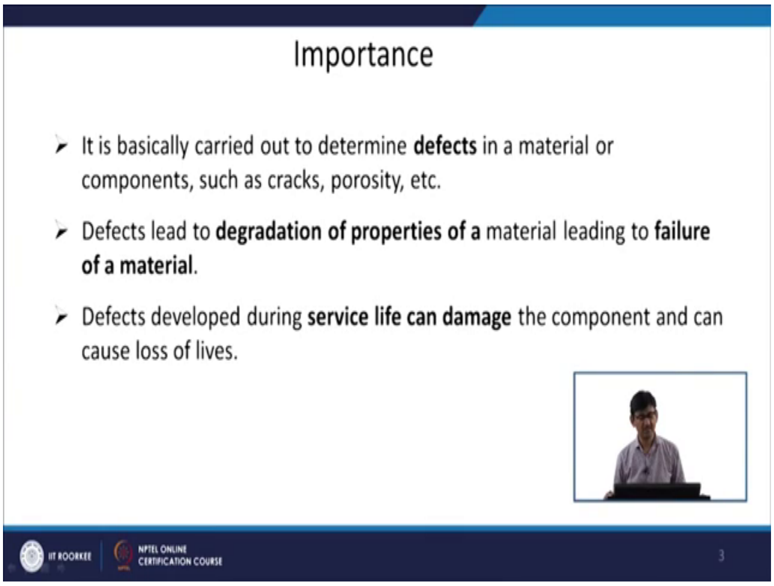

Importance: It is basically carried out to determine defects in a material or components, such as cracks, porosity etcetera. Why we want to know these defects because they will degrade your properties of a material and it may lead to failure of a material. So, if the defect or is of a critical size and the given stress condition in which your this component is going to be used, this crack can be can start propagating.

So, I want to see whether this crack is of critical dimension or much lower than that. Defects developed during service life can damage, the component can cause loss of lives ok. So, NDT is not only for components which are going out of a industry ok. As a quality control tool, it is a very important technique to find out whether if any component is used under service whether still it has some life remaining ok. For example, some bridges, railway bridges for example, are made 50 years back ok. Now, I am not sure whether during this many years of service life ok, whether some defects are introduced in the material due to so much loading continuously.

There is a fatigue loading continuous movement of trains for example. So, I want to know whether I have to demolish this bridge and make a new bridge or I can use this bridge for another let us say 10 years ok. Now, how to find out that; So, the way to find out that is you do some NDT measurements and Non-destructive testing. Find out if there are any flaws present and whether these flaws are of critical dimension or not ok.

Similarly, you will see a lot of this NDT kind of techniques are used in finding out, if any railway track is damaged or not ok. You must have seen some time some people are pushing a cart over the or the railway track and they have some kind of instrument mounted on that. So, they are doing and Non-destructive testing of the of the railway track and trying to see that because of the usage, if any flaws are have been introduced during the service.

And whether these are of critical nature or not; So, if they found out that this track is not can be not be used anymore; they will remove that much part and put a new railway track there and do the welding and so on ok. So, it is one of the important technique for any component which is going out of the industry and it is a very important technique to find out if any component which is in the service ok, whether during the service it is in we have introduced any defects in the component and whether they are of critical nature or not. So, origin of these defects can be during the processing of material ok.

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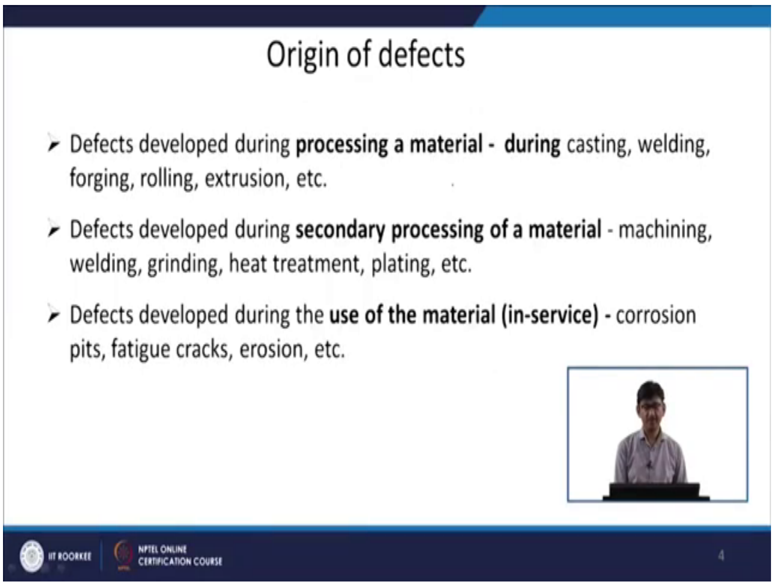

In terms of metallurgical engineering if you see. So, either it can be during casting welding forging extrusion and so on or it can develop during the secondary processing of materials. So, for example, machining ok, grinding, heat treatment etcetera or it can developed during the use of material. So, in service you can have. So, may be due to corrosion the material is exposed to a corroded environment and corrosion is introducing some defects in the material caught due to fatigue loading, as we told you that during fatigue loading you can initiate some cracks or erosion process.

So, there are lot of ways in which you can introduce defects during service ok. So, in these 3 cases, we want to know whether the any defects are there and what is the dimension of those defects. So, if you look at the NDT techniques, one is the of course, Visual inspection ok. Lot of time, you must have seen when the train is coming to the station; people keep changing checking the on big station.

They check the temperature of the wheel and they kind of do some hammering kind of thing just to kind of see the check the sound ok, whether if any defect is there or not or and everything is all right or not ok. So, these are visual is inspection you just go visually check whether you are seeing a extensive deformation for example, in certain structural component, you just by visual inspection you can see there is a sagging in some part.

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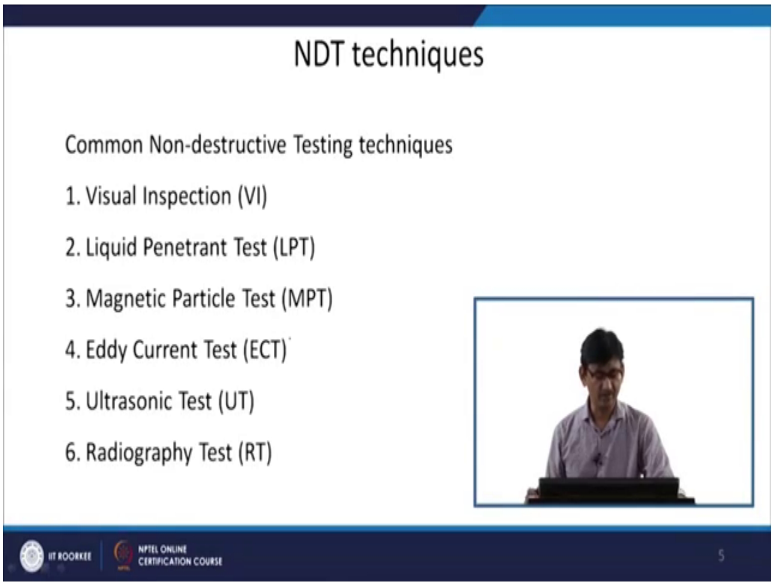

So, there is one, Visual Inspection ok; that is that depends on the experience of the engineer and his analytical or practical skills which he can use there itself. Then another is called Liquid Penetrant Test. So, we will see each one of them now, the Magnetic Particle Test, Eddy Current Test, Ultrasonic Test and Radiography Tests.

So, Liquid Penetrant Test, if you see for example, these are for surface cracks ok. So, you can see and we already know that surface cracks are the critical defects because it you will have maximum stresses on the surface and it can easily propagate, these surface divots can easily propagate under the service condition. So, if you have surface cracks like this an open crack.

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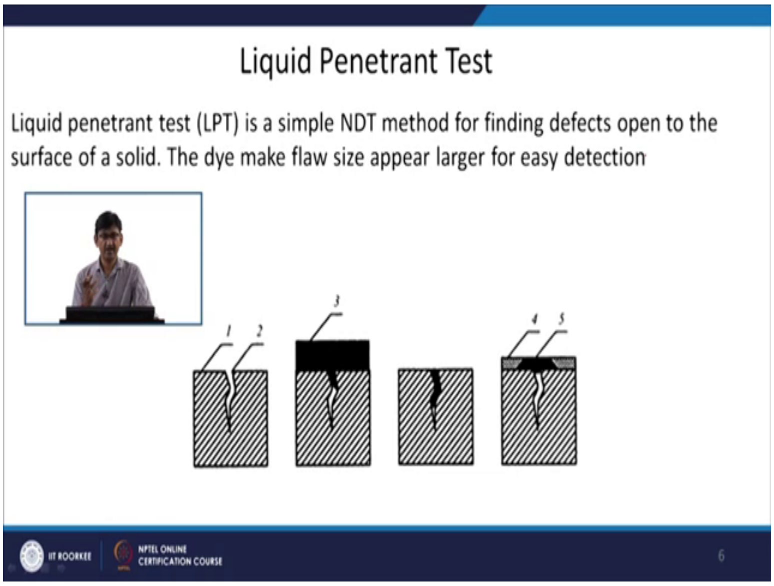

What we will do? I will show you the steps in the next slide ok. So, if this is the Liquid Penetrant Test is a simple NDT method for finding the defects open to the surface of a solid. The dye make flaw size appear larger for easy detection. So, basically liquid means we will be use dye, some colour and that we try to we try to enhance the size of the defect by this dyes, the liquid which we are going to use ok.

So, that it can be easily seen by naked eye or maybe by some magnifying apparatus. So, basically first is the surface preparation you will do for whichever component you want to do this kind of testing ok.

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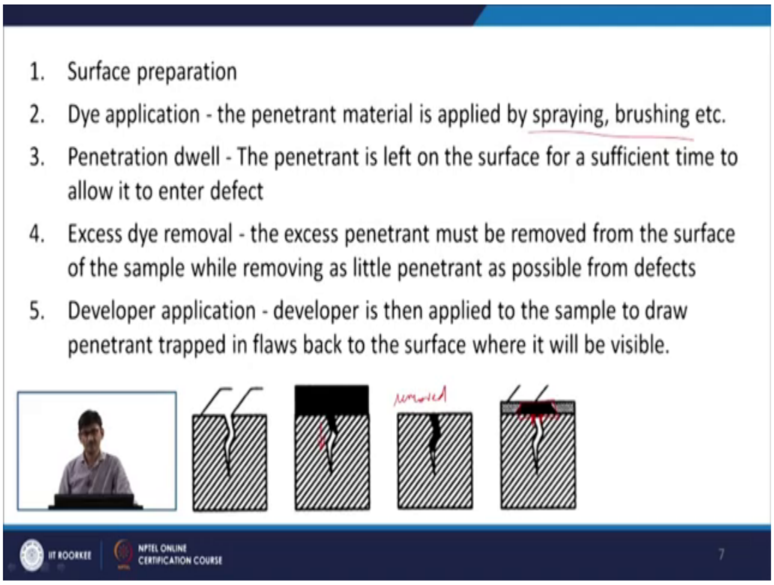

Then, we will apply the liquid or the dye on this surface, it can be applied by spraying or brushing whatever. Then this dye will penetrate ok. So, you have to give some time for it to penetrate these are liquid, it will penetrate through the crack.

So, you have to leave it for a sufficient time to allow it to enter the defect. Then you remove the excess dye from the surface ok. So, after the after this penetration in the within the defect, the rest of the dye is removed here ok. So, it is now removed. So, that now you can apply the developer ok. So, now, the developer is applied on the surface ok. So, what it does is, it draw the penetrant out on the surface. So, now, this was the size of the defect ok; when that dye from within the defect is taken out by the developer ok. So, now, this is the size of the dye ok.

So, that small crack is kind of expanded by using this dye, not expanded the only the visually it is now seen as a bigger thing which can be easily seen by a naked eye ok. So, the developers work is to draw the dye out from the from the defect or the crack and to spread it on the surface of the sample. So, that now you will have a bigger area ok, where this dye will be there and that will give you an indication that below this there is go there is some defect.

So this is a Liquid Penetrant Test, very quick way to find out if there is any crack or any defect on the surface of the material or component; Another for materials, which show magnetic properties ok. It is called Magnetic Particle Test ok.

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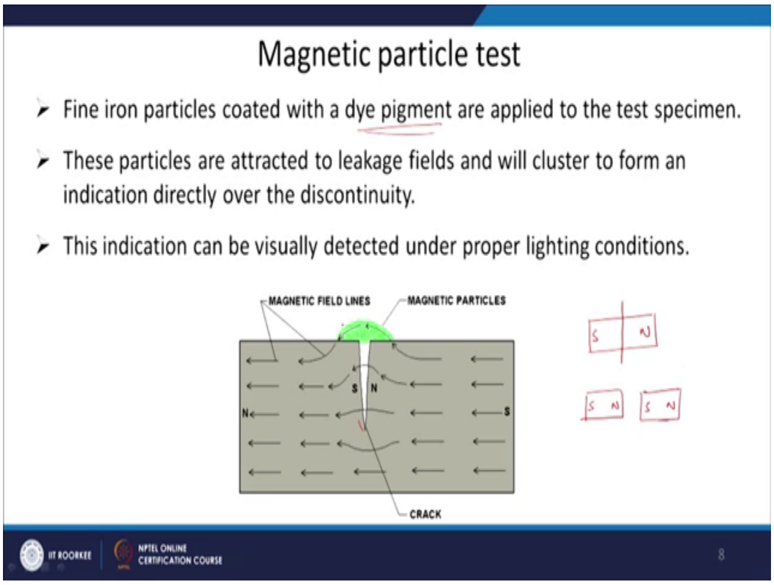

So, basically fine iron particles coated with a dye pigment are applied to the test specimen. Now we have we will magnetize the component first ok. So, what will happen? We know that if there is any defect present ok. So, this is a open surface or it is open to the air. So, now, this magnet the whole magnet is divided into 2 magnets now. So, you will have additional 2 poles coming here; one is South Pole, another is North Pole; because your magnetic lines are disrupted here. So, wherever you have this kind of defect, there is a leakage field due to that. So, your particle will cluster around these discontinuities.

Because you will have a additional magnetic poles here wherever the defects are there and this indication can be visually detected under proper lighting conditions ok. So, this magnetic particles will accumulate wherever the, there is a disruption in the magnetic field and that will be because of if any cracks are there you will have additional poles coming because of the crack.

For example, if I take a magnet like this ok; it will have South Pole and North Pole and suppose, I break it into two parts. So, now, I have 2 magnets ok, one is again this is South; this will become North and this will be South and this will be North ok. So, whenever you if you keep on dividing that you will get additional magnets with 2 poles. So, the same thing is happening here, when the crack is there.

So, locally you will have now to poles additional poles and there will be a disruption in the magnetic field. So, there is a leakage field here and the and the my magnetic particle will accumulate here and that can be easily seen by a naked eye that those magnetic particles are kind of arranged in particular fashion. So, you will be able to know that what is the shape of the defect and so on.

The another type of test is called Eddy Current Test ok. So, basically whenever you have alternating current flowing through a coil ok. So, there will be a magnetic field around that coil because of the alternating magnetic field and this magnetic field when you bring this coil close to another conductor, you will generate the eddy currents in the in the another component because of the alternating current in the coil.

You have magnetic field around that and made that magnetic field which will induce a electric current in the conductor and these will be in form of eddies ok. So, eddies means you must have seen in a flowing river, you sometimes is that the water is rotating in a rapidly in one direction and these are called eddies ok. So, similar electric current eddies will be induced in the component and then, these eddy currents are moving, they also affect they affect the impedance of the coil.

So, if any defect is there and because of that there is any change in the path of the eddy currents that will be seen as a impedance in the coil and that can be characterized and used to find out if there is any defect or any local deformities there in the material ok. It has to be calibrated. It cannot be done just like that, you have to calibrate it for a given material. And then, you will be able to see whether there are any defects in the material at a particular location ok.

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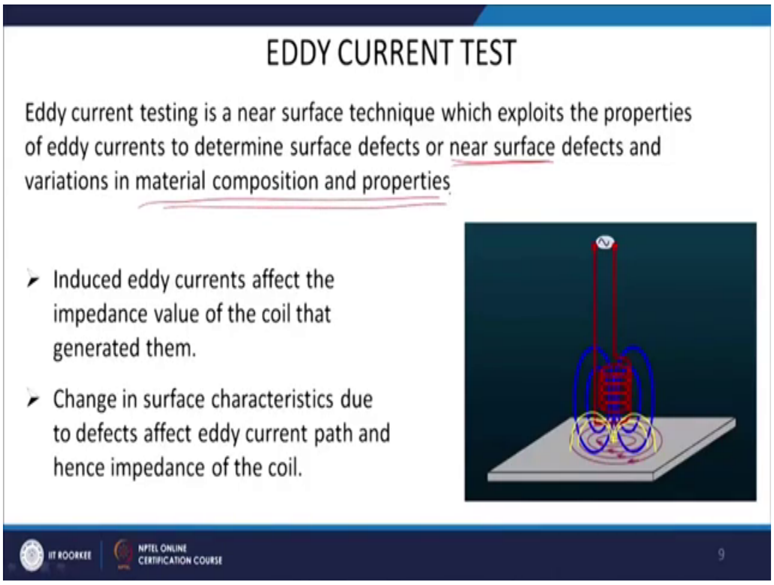

So, this is how the Eddy Current Test can be used to find out the sub defects near the surface ok. You do not have to be very open to the surface, it can be a subsurface defect also which can be easily find out with the Eddy current. And in fact, you can also find out if there is any material composition variation in the material ok. The other one is Ultrasonic Test ok. So, basically ultrasonic probe is there, which sends the ultrasonic wave in the material.

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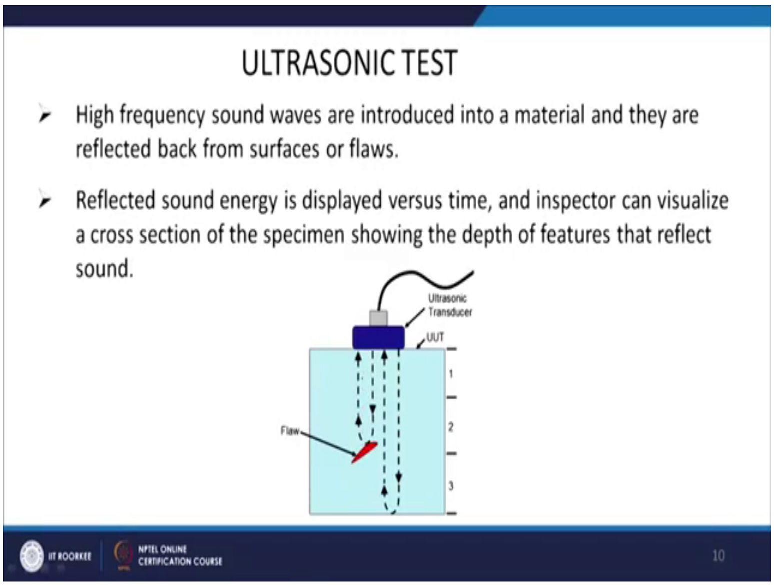

So, it will go and wherever any open surface is there it will so, the ultrasonic wave will easily travel in the material, but it will be find difficult to travel in the open atmosphere or any gap if it is there is no material is there. So, it gets reflected from that and again, it will be detected by the by the probe. So, it is it is a it is a receiver as well as transmitter. So, the ultrasonic wave goes if material is ending here, it will get reflected and it will be seen by the probe. So, the time it takes to travel that can be easily you can do a calibration that it this much time should be taken by wave to strike the other surface and come back.

Now, any flaw defect is there then it will come in a shorter time ok. Then, whatever time it takes to go to the end of the surface and come back ok. So, now, we will know that what is the depth at which the flow is there and what is the size of the flow. So, this is a very good technique to find any flaws which are well within the material not on the surface ok. So, the ultrasonic wave will go and when it hits back and come back that can be used to find out that what is the depth of this flaw and when you move the probe you will also know that what is the size of this flaw.

So, a very good technique to find out the flaws which are well within the material and not on the surface. The Radiography is another test and maybe not you, but you must have seen around you if any small accident is there, if any fracture is there in the in our bone any hairline fracture or that what we do is we go to the the doctor and he suggests that you do some X-ray. You have to go to us on X-ray machine and for to take a and take a photograph of that bone and from that he will be able to find out if there is any hairline crack or micro crack is there in the bone and of course, after that it plaster has to be applied ok.

So, that technique is already been used and we have seen very you must have seen frequently around you that this is the technique to find out flaws in the bone may be due to some accident or so. The same thing can be used in materials also that I can use Radiography or use X-rays to find out if there are any flaws present in the material.

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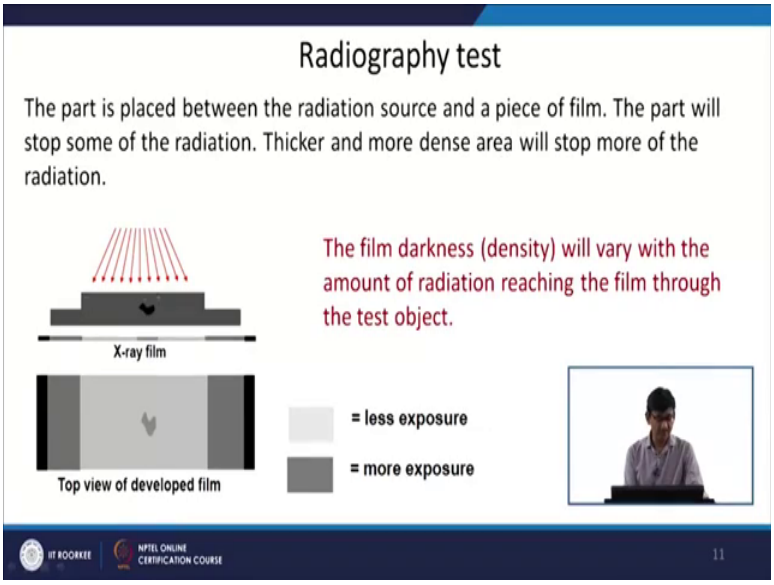

So, basically if this is the component and there is a flaw, you are exposing this material to X-rays and there is a X-ray film behind it. So, wherever the flaw is there my absorption of X-ray will be less in that region ok. So, that will affect the film more. So, it will appear dark here and the rest of the part way which is affected more by the X-rays that appears light; sorry in this part the X-rays are absorbed more. So, it will be affected by X-ray less ok. So, that appears light and so on. So, this is the less exposure and this dark region is more exposure because there was a flaw there. So, there was no material to absorb the X-rays and that is how you can detect it.

In humans also the bones are dense ok, if any flaw is there then; that means, there is hardly any calcium or any bone is there ok. So, when you expose this to X-rays and the absorption of X-rays will be lower wherever the flaw is there ok. So, that can be noticed on the X-ray film because the exposure of X-ray film will be more wherever the flaw is there and exposure on the film will be less wherever there is no flaw because X-ray absorption will be more by the material. So, this can be used to find out any flaws in the material.

Now, these are these were the NDT techniques and now, we will come to the another part ok; one of the measurement which we could not cover earlier in mechanical properties that is the Hardness ok. This can also be kind of you can consider a Non-destructive way of finding out the mechanical property because you just put a indent indentation on the surface rather than doing a tensile test to find out what is the mechanical properties of the material ok.

Of course, it is not a very good quantifiable way, but if you want to compare the suppose material with different heat treatment ok. So, rather than doing tensile test for each heat treatment, what you can do is you can find out quickly that how the hardness of the material is changing. And that will give you some indication about the strength of the material or flow properties of the material. So, the Hardness, if you see can be defined as resistance to deformation.

So, it is part of the mechanical properties only and through how it is measured through Indentation. So, you have to have an indenter to measure the properties.

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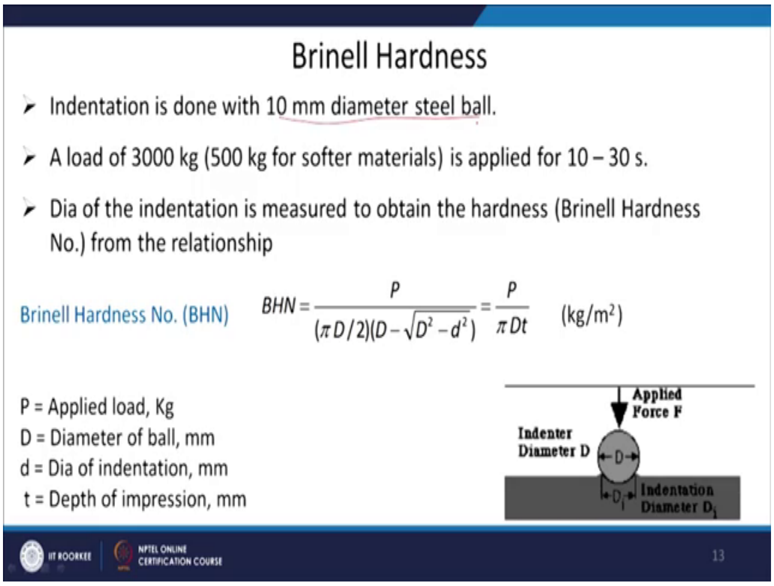

So, the first idea which was proposed to find out the hardness was at 10 millimetre diameter steel ball ok, kind you press in the material ok. So, the impression which it creates on the material, it will give you the indication of the hardness. So, if it is hard material and when I press this steel ball it will give you a smaller impression; if it is a soft material and I press the steel ball with the same load ok.

It will give you bigger impression. So, you can at least find out which is the soft material, which is hard material. So, indentation is. So, first one to propose is what we call as Brinell Hardness. So, indentation in this is done with 10 millimetre diameter steel ball with a load of 3000 kg ok. For a softer material you can reduce it to 500 kg and that is applied for 10 to 30 seconds.

So, you take a steel ball, press it using this much load for 10 to 30 seconds. Diameter of the indentation is measured to obtain the hardness. So, whatever is the diameter? So, if steel ball has gone too much inside the circle inside the material. Then, you will have a larger impression or larger the diameter of the impression; if it is gone for a smaller depth, you will have a smaller impression and low a smaller size of indentation.

So, this can be used to find out a number which is called Brinell Hardness Number, BHN which is given by a relationship like this; where, P is your applied load ok; D is your diameter of the ball; the capital D. The small d is your diameter of the indentation. So, whatever impression is created and t is the depth of the impression ok. So, either you find out from this or you can find out from a relationship like this ok. In both ways you can be find out and this will be the units of the Brinell Hardness Number. Another measurement for finding out the hardness is called Rockwell hardness ok.

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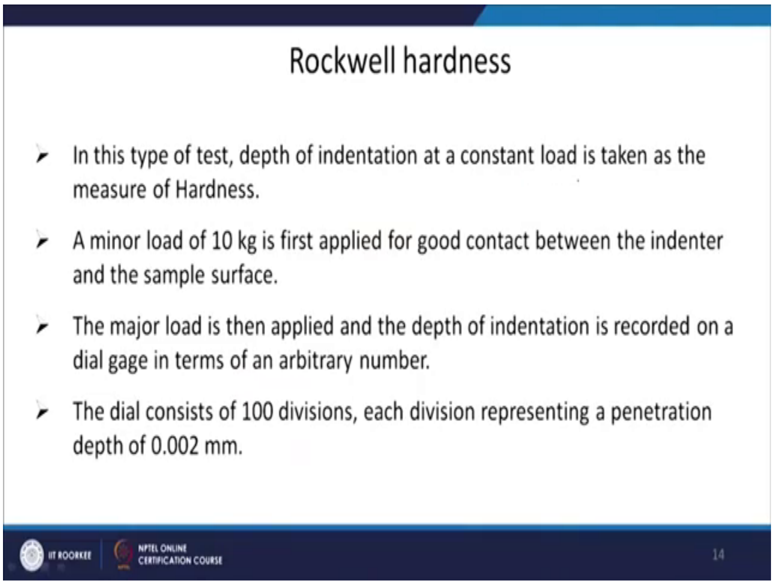

So, in this type of test depth of indentation at a constant load is taken as the measure of Hardness. In this case you are now applying a much smaller load than what we did in the Brinell hardness. So, 10 kg is applied for good contact between the indenter and the in the sample surface and then, you apply a major load.

So first we apply a smaller load to prepare a good contact between the sample and the and the indenter and then, we apply the major load to give an indentation and then, it is recorded directly on a dial gauge in terms of an arbitrary number. So, this is not a you will not have a unit here, this is an arbitrary number to give you the hardness of the material. So, the dial gauge consists of 100 divisions each division representing a penetration depth of 0.002 mm ok.

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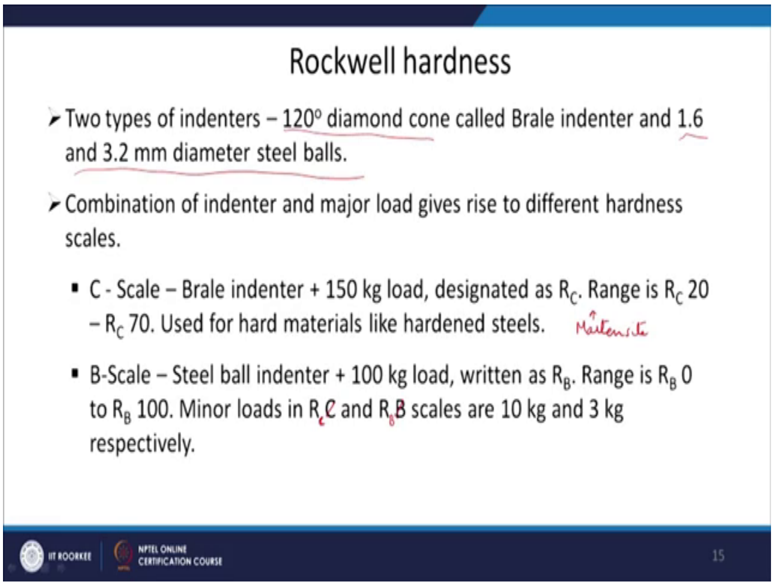

So, indenter is basically a diamond cone of 120 degree cone angle which is called a Brale indenter and 1.6 and 3.2 mm diameter steel balls are also used in case of Rockwell ha for finding out Rockwell hardness. So, either you will use this diamond cone or you can use these steel balls. Combination of indenter and measure ball the load give rise to different hardness scale ok.

So, there are different scales, this is arbitrary number. So, different scales are there to give you the hardness value. So, C-scale takes the Brale indenter with 150 kilogram load and it is designated as Rc. Range of Rc is from till 20 Rc values to 70 Rc values used for harm hard material like hardened steel.

So, for example, in plain carbon steel marten site hardness will be expressed in terms of Rc values because the hardness of the marten site is very high ok. So, the hardness of marten site will be expressed in terms of Rockwell hardness and the scale will be taken as Rc, around 65 to 70 Rc values you get in case of marten site. The B-scale takes you use steel ball indenter instead of the Brale indenter and load is around 100 kg and it is written as Rb. Range of Rb is from 1 to 100 Rb values.

So, minor loads in Rc and Rb scales are 10 kg and 3 kg respectively ok. So, the minor loads are a 10 kg or 3 kg, I think this should be Rc and this should be Rb. This case are 10 kg and 3 kg respectively. Another hardness measurement is called Cickers hardness ok.

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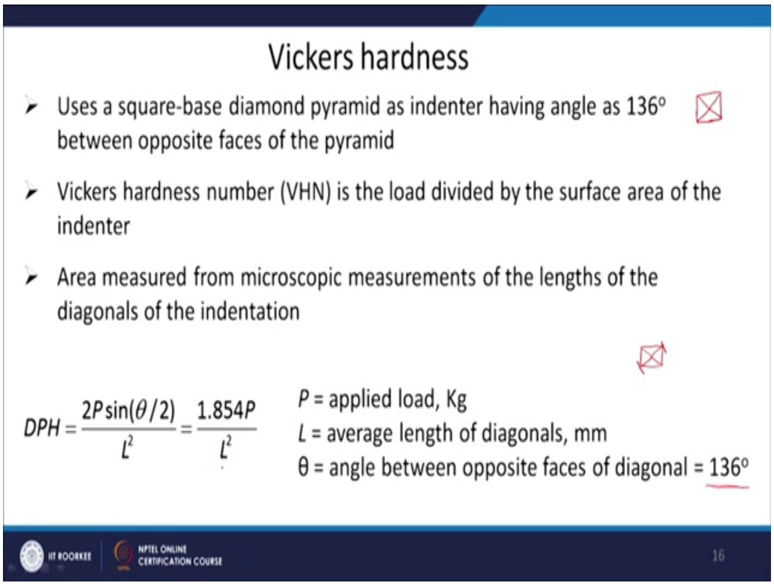

Which uses a square based Diamond pyramid. So, instead of cone, now you have a pyramid a square base pyramid.

So you will have basically a square base of the pyramid will be like this and then, you have ok. If I look from the top it will look like this the angle is around 136 to the degree between opposite phases of the pyramid. Vickers hardness, VHN is the load divided by surface area of the indenter. So, area measured from microscopic measurement of the length of the diagonal of the indentation. So, in this case the indention indentation which we do is of very small size. So, we have to see it through some microscope that what is the size of the indenter?

So, we do not want to alter the surface too much. So, that is why we use Vicker and Vicker hardness test to create a very small indentation on the surface of the sample ok. And that can be seen only through a microscope that what is the size of this indentation.

So, the Vicker hardness number value can be find out by an relationship like this ok. So, where P is your applied load; L is the average length of diagonal. So, you will have on impression like this in the material because you have introduced the indenter.

So, what is the length of this diagonal that will give you the and this L; theta is angle between opposite faces of diagonal which is what we are taking as 136 degree ok. So, if you put 136 degree here theta by 2; it will be I think 68 science six of 68 and multiplied 2, will give you this factor 1.854.

So, I can be once I know the indenter angle, I can replace this by value like this depending into P divided by L square ok. So, this will give you the Vicker hardness which kind of does not change the surface too much ok; you will be you have to see this indentation through the microscope.

So, these are the three hardness values or hardness measurement, I have just wanted to introduce you to you to you because one of the very important ways to find out the mechanical properties of the material quickly ok. So, you do not have to keep on doing the tensile test every time. And then, you can find out the candidate material for which you want to do detailed mechanical property measurement ok.

So, with that I would like to thank you for and we will discuss the Electrical Magnetic Properties and Composite Ceramics and Polymer Composite, in the coming lectures.

Thank you.