Mechanical Behavior of Materials -I
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Lecture - 43
Hardness Testing

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Hey, welcome back last two hour course mechanical behaviour of materials. So, we have already discussed about the strengthening mechanisms and professor Sudhanshu Shekhar has also discussed with you about tensile testing. So, today what we are going to do? We are going to talk about other mechanical tests like hardness testing and impact testing etcetera. So, we will start with the hardness testing and then we will talk about impact testing.

So, let us talk about hardness test. So, what is first of all you know what is the hardness testing and why it is being used? We will discuss about that but let me begin with saying that you know in material science community and metallurgical community. People use a lot of this hardness testing. It is one of the most versatile techniques when you talk about measurement of mechanical properties and it is mainly measured on the surface.

So, let us talk about in details about hardness testing. So, what is hardness? So, it is a measure of materials response or resistance to localized plastic deformation. You already know what is plastic deformation so or say permanent deformation and basically, we do everything on the surface. So, hardness is typically measured on the surface. So, it is materials response or the resistance materials are going to give when you try to deform plastically the surface of a given material.

And that is how hardness is measured. So, there are three type of hardness we are going to discuss today. First one is scratch hardness then we have rebound hardness and then lastly indentation hardness which is one of the famous one what is most famous one among these three-indentation hardness.

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So, let me give you some introduction about hardness before we talk about all these hardness three different types of hardness. So, introduction two to three points about you know hardness. So, the first is that you see typically hardness is being used frequently by material scientist and metallurgical scientist because of the some of the reasons. The first is that it is simple and inexpensive. I should not say inexpensive relatively inexpensive. So, it is relative term.

So, if you compare to your tensile testing what professors are Sudhanshu Shekhar discussed you have to prepare a sample you have to use iridium etcetera. Then polish it then use tensometer etcetera so that is cumbersome although it is a very good technique it is slightly cumbersome. So, in that sense, hardness becomes much simpler technique to measure mechanical properties.

And second, the equipment what we use for hardness measurement is not that expensive so it is a relative term relatively it is slightly inexpensive. So, that is point number 1. Second, the test is non-destructive. So, now again compare with your tensile test there you are going to fracture the sample. Here in hardness test we are making indentation or say we are doing scratch on the surface of the sample.

So, you are actually not destroying the sample itself, you are actually giving a localized deformation on the surface of the sample. So, this test becomes non-destructive in nature. So, you are not actually fracturing or giving excessively deformation to the sample. So, this is the second point and third is you know it can give you an indication of the strength. That means you know if hardness is high, you know you can say that your strength is also going to be high.

So, it gives you an indication of the strength of the given material although you cannot directly calculate the value of the strength but it gives you qualitatively what could be the strength in the relative sense higher or lower. So, these are the three points you know why researchers use hardness a lot to measure mechanical property that to hardness. Again, remember it is the surface property rather than the bulk property, tensile test is your bulk measurement.

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So, now let us talk about the history how it has progressed over time. So, historical perspective so, the first hardness measurement let me change the colour in second year so it started in 1722 here. So, where it is related to the scratch in the surfaces and then in 1822 the development of Mohs scale happened and we are going to talk about this Mohs scale in couple of minutes. So, there you will see that there is a table of a ten-point scratch hardness table.

And depending upon the higher scratching ability you can guess what kind of mineral is present. Now after that John Brinell developed Brinell hardness in 1900 and then rebound hardness is around 1907. Then Rockwell hardness came into picture at around 1920 where we are going to talk about preload method. So, this Brinell, Rockwell, Vickers and Knoop all these are indentation hardness.

Mohs scale is related to scratch hardness and in 1917 you have this rebound hardness and then in around 1925 Vickers hardness testing method was developed and it became very famous. Now we are talking about instrumented hardness like nano indentation even in Vickers micro hardness you can measure using IIT instrumentation indentation technique. But we will focus on mostly scratching the hardness and then rebound hardness then Brinell, Rockwell and Vickers hardness. So, this is how I am going to talk about the progress of the (()) (10:03).

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So, let us start with the scratch hardness. So, the name itself suggests scratching, say scratch hardness so you are somehow scratching it scratching the material and based on that you are trying to understand what could be the hardness of a given material. So, here it is a Mohs scale and this is typically for mineral so this is the table here. So, we have Mohs hardness varying from 1 to 10 in increasing order like this and different minerals have been listed here.

So, one corresponds to say talc then four corresponds to fluoride and then 10 corresponds to diamond and we know diamond is the hardest one. So, 10 belongs to the diamond and the softest in this list is talc and I have also given you the chemical formula. So, it shows the table source what it shows scratch hardness of various materials minerals. So, it also tells you the ability of a harder material, a mineral to scratch a softer.

So, what does it mean? Suppose I take fluoride and try to scratch talc. So, fluoride can scratch start very easily and if I can see it, I know that fluorite is harder than talc. And if I do the opposite if I take tar and then scratch fluoride it is not going to scratch fluoride so we know that talc is softer than fluoride and that is what I wrote here, this table nicely tells you the which one is harder in mineral and which one is the softer material.

So, it gives you a scratch hardness of various material that is point number one. Now second you know it is this table can give you a it is a convenient way to help identify minerals. So, suppose you are going for a field trip and you found some minerals and you want to know which mineral is that you want to guess it. So, you can use this table to guess slightly yes you know which type of mineral it can be.

So, it is a convenient way to help identify minerals. So, suppose again you went to a field trip and then you know what is the scratch hardness of your fingernail it is around 2.5 so, you should use your fingernail it will be nearly say around 2.5 and if you take a steel nail it will be around 6.5 so, you are going to a field trip and you found some mineral and if you are able to you know scratch the mineral using your fingernail you know that the hardness scratch hardness.

Or Mohs hardness of that particular mineral is lower than 2.5 so and similarly if you are able to scratch a particular mineral say using steel nail but not using fingernail you should be able to know that the Mohs hardness lies between 2.5 to 6.5. So, basically you can use some common objects for which you know the hardness and then you can figure out what could be the Mohs hardness of a unknown mineral.

So, this is very important for mineralogists; they use this type of hardness a lot. So, this is one type of hardness which is Mohs hardness or scratch hardness.

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Now we will talk about rebound hardness. Now again the name itself is rebound hardness. What we are going to do? We are going to use the concept of rebounding. So, it is like you know you

are having a say ball, tennis ball and then you throw on the wall and then rebounds. So, it is going to come back and then you can measure how much distance it has covered while coming back. So, that is the same concept you are going to use when you talk about rebound hardness.

So, if you see here, I have a schematic so this is how you measure the rebound hardness you have a hammer which is typically of say diamond rounded tip or and it is a glass tube here and then you have a scale here so, this hammer is going to be released something like this so, this is situation number 2. And it is going to hit the sample so your sample is at the bottom here so, your hammer comes down it hits the sample and then rebounds back so it travels this much height.

Now you have to measure what is the rebound hardness and there are machines you do not need to do anything. This is the concept how it works how what is the principle of a measurement of rebound hardness. So, it measures the rebound height based on the scale and then it gives you a value and that value will be called as rebound hardness. So, the higher the rebound hardness higher is going to be the hardness of your given material.

So, the harder the material the higher the rebound. Suppose I have two material A and then another one is B for two material and I am doing rebound test. So, in one of them after rebound my hammer was here so this is my rebound height for say A and then in another one this is the rebound height for B h B. So, here h B is greater than h this means capital H B is greater than capital A where this capital H is your hardness or rebound hardness.

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And the small h is your rebound height so, this is how we measure the rebound hardness. So, higher the rebound height higher is your hardness of your material or alloy. So, one of the advantage of this type of hardness is that the machine what you use is portable and it is very easy to handle. So, that is one of the advantages. So, it is portable and easy to handle. So, this was about rebound hardness. So, we have covered scratch hardness that is the most steel and then the rebound hardness.

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So, now we will come to the third one, the most famous one as a material scientist or metallurgical engineer. We use indentation hardness. And you might have heard already about Brinell testing and because testing and Rockwell testing so we will talk about them one by one. So, what is the central concept when we talk about indentation values? So, let us understand it. So, again say we have two alloy this is A and the second one is B so two materials.

And say my indenter is of ball type and we are indenting both of them and I am applying a load of P constant load on both of them. So, we have two different alloys and then we are using ball indenter so this is your indenter ball indented. You see indentation hardness you have to indent it is like you know you have this nail and you are trying to pierce it. You are making indent on the surface so we have different type of standards for that like Brinell hardness, Vickers hardness and Rockwell hardness.

So, basically you have to indent the surface. So, you are applying a load P so it is going to go to some depth. So, suppose in alloy A it went up to a depth of say t 1 and in alloy B it went up to a depth of t 2 so now we know that t 2 is greater than t 1. So, by logic one can always say that B is softer than A because it has gone to a higher depth when we are indenting the surface. So, if it has gone to the higher depth B is going to be softer.

So, in the indentation what we do? We see the up top view of it so if I try to see the top view of say alloy A I am going to see a circle and if I try to see the top, we have alloy B after indentation I am also going to see the circle but it will be of larger diameter. So, if this diameter here is d 1 and it is here d 2 so we can write d 2 greater than d 1. See again remember it is a ball indenter so when you are trying to indent it you are going to get that if you see the top view you are going to see a circle.

And since t 2 is greater than t 1 you are going to see a larger circle in alloy B so if we have t 2 greater than t 1 so d 2 greater than d 1 where d is your diameter of indent impression. So, this is your indent impression both of them these two and t is your depth of indentation or indentation depth. So, finally you can write H 1 greater than H 2. So, this is a central concept of indentation hardness that we try to see the impression what is the impression of the indent you have made.

But in Rockwell we do not see the impression we measure the depth of the indentation so in Rockwell we will use the concept of say t 2 greater than t 1. And in other Brinell and Vickers we see the indent impression and then measure the diagonal length or say diameter of the circle which is the indent temperature and then finally we measure the hardness. So, this is the central concept of indentation hardness.

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$$\mathbf{BHN} = \frac{2P}{\pi D(D - \sqrt{D^2 - \alpha^2})}$$

So, in general the hardness we can write as load by indentation area and this is what we are going to use when we talk about Brinell and Vickers hardness. So, there are three types of indentation hardness which we are going to discuss in the class. So, the first one is Brinell harness second is Vickers and the last one is Rockwell. So, we are going to discuss these three Brinell, victor and Rockwell. So, let us start with Brinell first.

Brinell hardness testing. So, here we typically use 10-millimetre diameter steel ball so indenter in this case in the Brinell testing is steel ball of 10-millimetre diameter and typically the load what we apply is 3000 kgf, kilogram force kgf is kilogram force. But for softer material the load can be reduced but this is the standard 10-millimetre diameter steel balls and 3000 kgf. In some of the cases if your material is hard, you can also use tungsten carbide.

So, tungsten carbide can also use for hardened material and this is the setup so this is the Brinell hardness tester we have in our lab here at IIT Kanpur. So, we show this test to all UG students in our department so you place your sample here so you have anvil and then indenter is here on the top here so you can see this is your indenter. So, you place your sample and then you make an indentation then take out the sample, go to microscope and see the indent impression as I discussed just before.

So, this hardness measurement in this case can be given as a BHN which is Brinell hardness number and it will be given as 2P divided by pi D D - square root D square - small d square where P is your load and it is in kgf, D is your indenter diameter so here ball diameter which is typically we use 10 millimetre and then small d is your diameter of indent implication. So, since we are using ball indenter of 10 millimetre.

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$$\mathbf{d} = \frac{d_1 + d_2}{2}$$

So, suppose I have alloy or material and we are using ball indenter here something like this so, this is your ball indenter and this is your sample. So, ball intender is placed on the this, place here see the diagram I am marking here so, now if this is the side view and if you see the top view of it, you can see the indent impression now if I see the top view and it is going to be something like this. It is going to make a circle.

So, what we do? We measure d 1 and then along the other direction perpendicular direction we measure d 2 so we measure two diameter diameters d 1 and d 2 so here d 1 d 2 are diameters. So, diameter of the indent impression when you see from the top and you take the average. So, this will be average of d 1 d 2 so this d if you remember is here so, this will be d 1 + d 2 by 2. So, you know P because you are doing the test you know the ball diameter that is also given to you.

So, what you have to do? You have to use this indenter then take out the sample after indentation is done and then go to microscope see that of you are going to see a circle and then measure the dimension diagonal diameter along two perpendicular directions. Those will be d 1 d 2 take the average of those two and that will be d small d and then you can use this formula BHN = 2 P by pi D and you know D - under square root of D square - d square.

And then you can figure out what is the hardness in Brinell scale which will be given in BHN. So, here I am showing you one example which is for mild steel so load is 250 kgf so what you have to

do as I just mentioned you have to measure two dimensions. So, you can measure say d 1 along this direction and then d 2 along this direction and if you do that roughly d 1 will come out to be 1089-micron meter d 2 will come out to be 1080 these are rough numbers micrometre.

So, d average you can calculate that you can calculate you know what is P that is given to you that is 250 kgf so you can calculate the BHN number from this formula. Again, this D and small d will be in millimetre let me write both will be in millimetre and P will be in kgf. So, this is how you calculate the renal hardness number. So, especially when you use steel ball the brilliant hardness number is not going to be accurate when your material is very, very hard.

Because see you are using a steel ball there is a chance that your steel ball is itself deforming. So, if you are at your material is hard it is better to use Vickers which I am going to talk about. There we use diamond indenter and diamond itself is very, very hard. So, your Brinell hardness is not reliable at very high hardness values. So, that means harder material that is point number 1.

In all the hardness tests whether it is Brinell because or often your surface has to be smooth and you have to polish. So, basically when you want to do any hardness test you first polish your sample using conventional metallography technique and then use either of these three indentation matters depending upon your material. And then you can calculate what is the hardness value. Second, it is not very suitable for thin samples because of larger indented impression.

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So, the first disadvantage is that not reliable at high hardness value. Say greater than 400 also and the reason is because you are still a ball itself will start deforming, that is point number 1. And second point is not very suitable for thin samples, thin film etcetera or you know where your sample thickness is not that high d 2 larger indenter impression. So, this is what Brinell hardness is all about.

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So, now let us talk about Vickers hardness measurement. So, here what we are going to do? We will use the indenter is going to be diamond pyramidal. So, this is going to be your indenter. So, we are using diamond instead of steel ball when we talked about Vickers hardness test.

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And this is the indenter shape so this is your indenter here because indenter and if you see this so first of all you can see here your base is square shape. And if you take this particular surface and this particular surface the angle between these two it is fixed and that is 136 degrees. So, the angle in the diamond pyramidal indenter used in literal test the angle between the two opposite face is going to be 136 degree, again the indenter is made of diamond.

And if you indented your indenter shape, indent impression shape is going to be something like this at the bottom. So, what you do here suppose you have a material and you are indenting it using your diamond pyramidal indenter. And if you see the cross section now going to be looking like this so, this is your side view and this is your top view. So, finally you are going to get an indent impression which will be this from top view.

So, you polish the sample and then go to your in indenter I will show you the image of the indenter we have a machine we use here in our lab and then indented and then you measure what is this two diagonal length d 1 and d 2 and then you can take average that will be d 1 + d 2 by 2. So, there in the Brinell hardness testing we were measuring diameter of the indent impression. Here we are measuring the diagonal length of the indent impression so you measure d 1 and d 2.

So, I have machine set up so anyway so machine setup is the it looks similar but the only thing is your diamond indenter is different. Second, you are going to have a microscope attached to it. So, now they are different microscope, why? Because you want to see the sample surface before you make an indentation. So, you take the sample place on the anvil then use the microscope attached to the machine then see the surface where you want to indent.

Then bring the indenter on the surface and start your test and then remove the indenter. Now there are two ways you can measure this d 1 and d 2. You can use the same indenter same microscope

attached to the machine and then there you can measure d 1 in d 2 or you nowadays you know we have sophisticated machines and attached equipment so there are cameras attached to your machine and then camera can capture your image.

And then you have a computer attached to it where you can nicely measure what is your d 1 and d 2 and finally you can find out the average which will be your final diagonal length when you calculate the hardness.

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And the hardness can be given in the weaker hardness test is so we use H v when we call weaker hardness and it will be given again the formula remains same P versus area. So, here area is your pyramidal indentation area. So, that will be given as 1.854 P by d square so this is for your Vickers indentation where P is your load again in kgf kilogram force, and d is your average diagonal length this is in millimetre. So, this is how we measure Vickers hardness test.

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I have an example here so this is for aluminium it is for aluminium alloy say 7075 and then you are using 500 gf load so your load is given P is given as 500 gf. And this is your indent impression I was talking about before. So, what you have to do? You have to measure two diagonal here so one is going to be this one and another is going to be these two. We have to measure d 1 and d 2 and then find out what is the average of d 1 and d 2.

So, here if you try to solve it is going to be d 1 is going to be nearly say 75-micron meter and d 2 is going to be nearly about 74-micron meter. So, you can calculate what is going to be, d you know what is P you can calculate what is your H E and if you do that it will come out to be in this particular case the hardness will be 167 nearly. So, this is how we use Vickers hardness test to measure the hardness of a given material.

So, what is the advantage? So, one of the advantages I already told that when you use brittle you cannot go for very hard material because your steels are bulk and it is a deform. So, if you have a harder material, it is better to go for Vickers diamond indenter. So, that is the advantage when we

use Vickers hardness as compared to the Brinell hardness test. So, now last one is your Rockwell testing.

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So, now we will discuss about Rockwell testing. So, this is the setup we have in our lab here so you place again your sample then you have indenter on the top and then you make an indent on the sample. So, here instead of using microscope etcetera to see the indent impression it automatically gives you the value of the Rockwell hardness. So, here if you see the; scale on the top in this particular image that I have magnified.

And you can see scale C here and B here. We will discuss what is B and C but most famous B and C scales in Rockwell hardness. So, you can use this scale and this dial will give you the value of your hardness of the material you are testing. So, instead of measuring the d 1, d 2 you know diagonal of the diagonal length or the diameter of your indent impression Brinell test what we did here it will automatically give you the hardness value in the dial.

So, the indenter here we are going to use either we can use ball or we can use for tonospherical or say diamond cone we also say so that is something like this and this angle this particular angle is 120 degree. So, this is diamond cone.

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So, how do we do this test now? So, basically, we apply first of all something called minor load as I have shown here so, this is the schematic how your indenter is moving on the sample and this is another schematic corresponding to the top image and let me explain this. So, what we do? We first apply a minor load on the sample. One other advantage is that if you have some rough surface etcetera you know you are going to get rid of that effect.

So, you apply minor load of, F 0 and that corresponds to this particular point here so, this is your sample surface this line. So, you are applying the minor load so you attain some depth this particular depth here. Now what you do? You now apply major load on to the minor load so you

have minor load of F 0 and then major load of F 1 and total load of F which is equal to F 0 + F. So, you are going to reach to some distance here.

So, this corresponds to a depth at a load of F which is equal to F 0 + F 1. So, this is my total depth here at this particular point from the surface. Now what you do? You remove the additional test force of F 1 so you are removing the major load so you are removing here so, your indentation direction is shown by the dotted arrow. So, this is how your indentation direction is going to be with respect to time.

So, after you remove the additional test force F 1 your depth position is going to be this one c so the here you have c and here also you have c so, you all now you have only minor load of F 0 applied on your sample. So, what you do? You measure this distance e and this you use to measure the hardness of your material in Rockwell scale. So, if we use cone indenter the Rockwell be given as 100 - e divided by 0.002.

And if we are using ball indenter Rockwell hardness will be 130 - e by 0.002 so, depending upon whether your indenter is diamond cone or ball you are going to use two different formula like this so and that will be depending upon this value of e and again the Rockwell indenter gives you automatically the values.

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So, here I am showing you a table so this is for regular Rockwell. So, this is your Rockwell scale overall and this is for superficial. So, in there are two types of Rockwell scale one is regular Rockwell scale another one is superficial Rockwell scale. So, in regular Rockwell scale you are going to see your load value is high so here I have mentioned in this column the type of indenter and this is the scale and as I mentioned before B and C are the most famous one.

So, when we use B scale if you see if you remember the dial, I showed you before so there we had B scale and C scale. So, if you use B scale the indenter is going to be 1 by 16 inch steel ball and if you see scale it is going to be diamond cone with 120 degree angle. And in all the cases you are

going to have a minor load which is F 0 of 10 kgf here this F 0 value. Then we also applied major load on to the minor load that will vary depending upon the scale.

So, for a scale it is 50 for B 90 and C 140 and then total load is the summation of minor load and measure load which is given like this so, you have different scales in the regular Rockwell measurement. So, depending upon the material you would like to go for different scales but again the most famous are DNC. Now superficial came into picture especially when you want to do the hardness testing of say electroplated materials thin film etcetera.

So, here the requirement is that you do not want to go to very high depth so you need to reduce the load. So, if you see here in the regular one it was of very high load starting from 60 kgf it goes up to 150 kgf here in superficial it starts at 15 and stops at 45 kgf. And the scale name is given as a 15 and 30 and 40 and that indenter will be diamond cone and then when we have t then it will be steel ball.

And minor load is also reduced total load is reduced so minor load is also reduced from 10 to 3 when we have superficial scale. So, I have listed only some of them. You have many more in scale of say W, X and Y when we talk about superficial Rockwell scale. So, this is what I wanted to discuss about hardness testing especially the indentation one Rockwell, Vickers and Brinell.

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So, let me summarize the three scales. So, we have test I am going to list test here then what is the indenter this will help you in you know since I am going to make a table this will help you in understanding or you know capturing what type of indenter you using which type of test. Then here we are going to have shape of indentation side view top view. So, the first is your Brinell and what do we use? Indented in Brinell either steel ball or constant carbide ball.

And both are say 10 millimetre steel or tungsten carbide ball and if you see the side view of it is going to be spherical it is a ball so it is going to be spherical. And if you see the top view it is going to be circle and here, we will measure d 1 and d 2 so average is d and here your ball diameter is

your capital D so, this is one. Second is your Vickers here we are using diamond pyramid and that was 136-degree angle if you remember.

So, this particular angle here is so this is your side view. So, the opposite phase, the angle between the opposite two opposite faces is going to be 130, 60 degree. And if you see the top view going to be square and then you have to measure d 1 and d 2 so d is going to be d 1+ d 2 by 2. Now the last is your Rockwell. So, here we will use diamond cone 120-degree angle if you remember or you can also use steel balls and the size of the steel balls or spheres are 1 by 16, 1 by 8, 1 by 4, 1 by 2 inches.

And if you use diamond cone it will be so this is the side view and this angle was 120 and if you see the top view, it is a diamond cone so it is going to form a circle. And now if we have a steel sphere it is also going to form a circle. Here, we have two scales a Rockwell superficial and regular so 60 kg then 100 and 150 this was regular and then we had 15 30 45 this was superficial. So, we have discussed about Rockwell, Vickers, Brinell hardness test that is your indentation hardness. We have also discussed about scratch hardness and rebound hardness. Thank you.