Nature and Properties of Materials
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Lecture 06
Mechanical Properties of Materials 3

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In the final series of mechanical properties of materials I have chosen 3 very important properties. One is the hardness where I will explain that how we do the qualitative testing as well as the quantitative testing of hardness and what is the relationship between hardness and strength which is very important in the design of a system. And then secondly I will talk about creep and finally I will talk about damping.

So these are the 3 important mechanical properties which we will cover in this final series. So 1st let us talk about the hardness. Now hardness by definition it is a measure of a material's resilience to localized plastic deformation okay.

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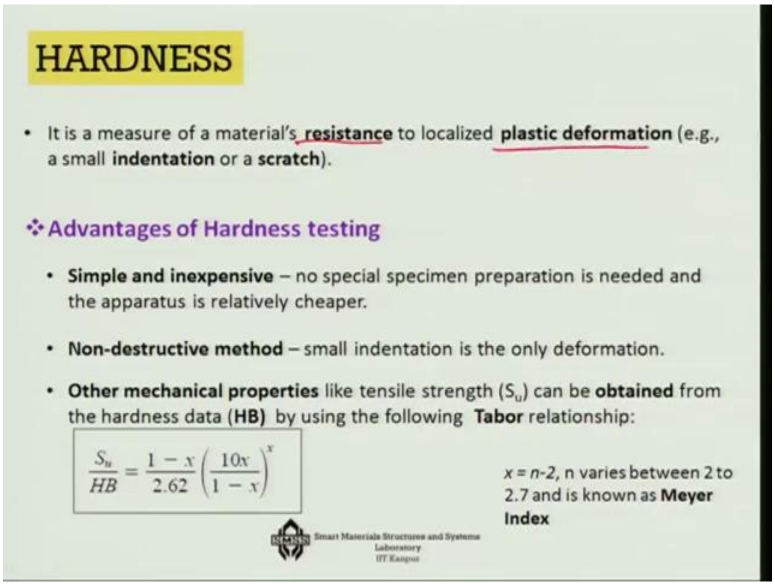

So for example, a small indentation or a scratch, so let me repeat so it is a measure of material resistance to localised plastic deformation example, a small indentation or a scratch. Now there are various advantages of hardness testing. 1st of all, it is a very simple and inexpensive test; it will not need a very special sample preparation. Of course for Micro hardness you will need, which we will talk about it subsequently.

But for simple hardness testing no special specimen preparation is needed and the apparatus is also relatively cheaper. So one can carry out the hardness testing you know in a relatively less expensive manner. Secondly, it is considered to be a nondestructive method because you are really making a very small indentation without really affecting the overall sample.

And finally, from the hardness test you could not only get the hardness, but also you can get some important information like say the tensile strength, okay. So this is a very important thing okay that can be obtained from the hardness data. For example, for metals there is something called a Tabor relationship okay in which if you know one of the hardness data in the brinell scale the HP data.

And then you should be able to actually use that data and then you can find out the ultimate tensile strength S u using this relationship where X is N - 2 and N varies between 2 to 2.7 and there is also known as the Meyer index. So such you know just an example that how you can further exploit the hardness data and find out you know certain important properties.

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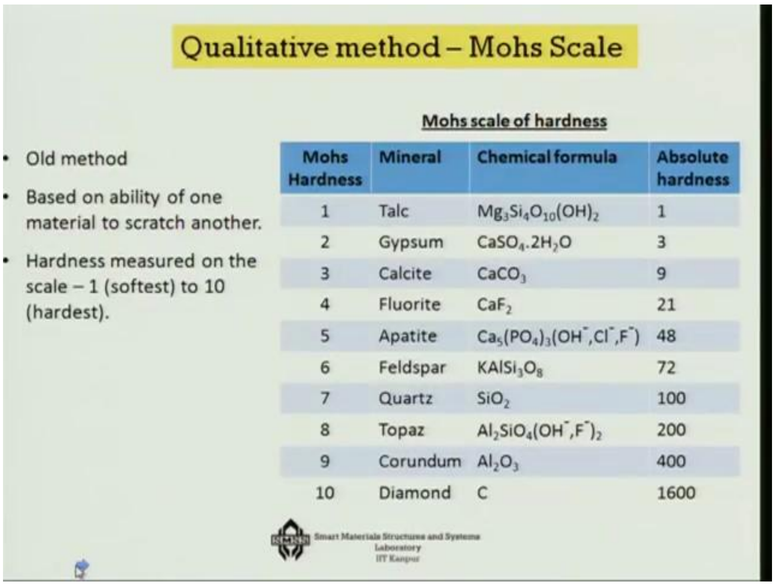

Now, hardness generally are the in a in a stage was used to be actually found out to a very qualitative method which we used to be mostly used by the geologists and that is based on the ability of one material to scratch another, okay. So in that scale the geologists use to consider Talc to be the softest material and it's absolute hardness keeping it as one. Then there you know various materials are used to actually scratch on Talc and that from the depth of indentation.

And the power of scratching and then the scratching of one over the other the ranking used to be done, so from that scale if you see that from a very low hardness to a high hardness, you are getting you know something like diamond has the highly hardness 1600. So that was a kind of a of course very qualitative way of you know determining hardness. It can only give you an idea of relative hardness one with respect to the other.

That suppose there are you are taking 2 materials and you are able to scratch material B with the help of material A and that would signify that the hardness of material A is more than the hardness of material B. So that was a very qualitative method in the Mohs scale.

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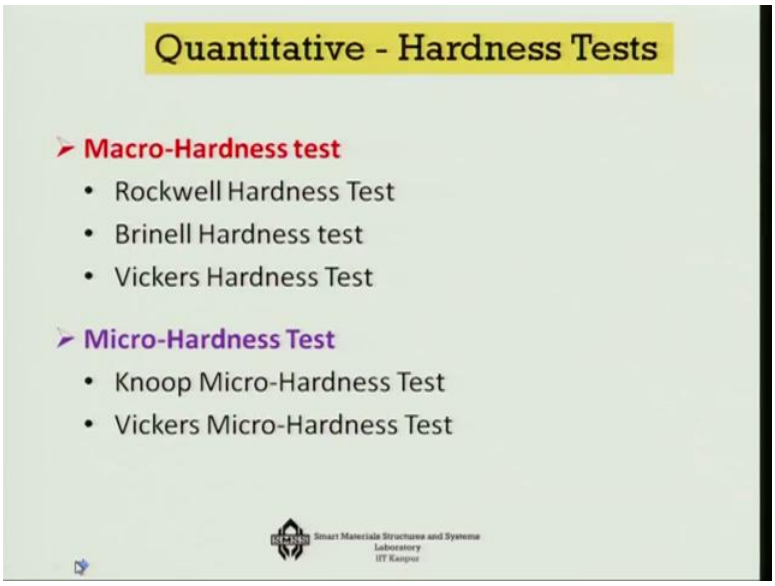

At a later stage, you know the quantitative hardness test started to get evolve and then there are basically 2 classifications of them, one is called the Macro hardness test where as I told you that not much of sample preparation is needed and the other group is called the Micro hardness test. Now in the Macro hardness there is there are many, but we have chosen Rockwell hardness test, Brinell hardness test and Vickers hardness test.

And in the Micro hardness test, the Knoop Micro hardness test and Vickers Micro hardness test. So total you know these are the 5 experiments that actually one can carry out in order to find out quantitatively the value of hardness.

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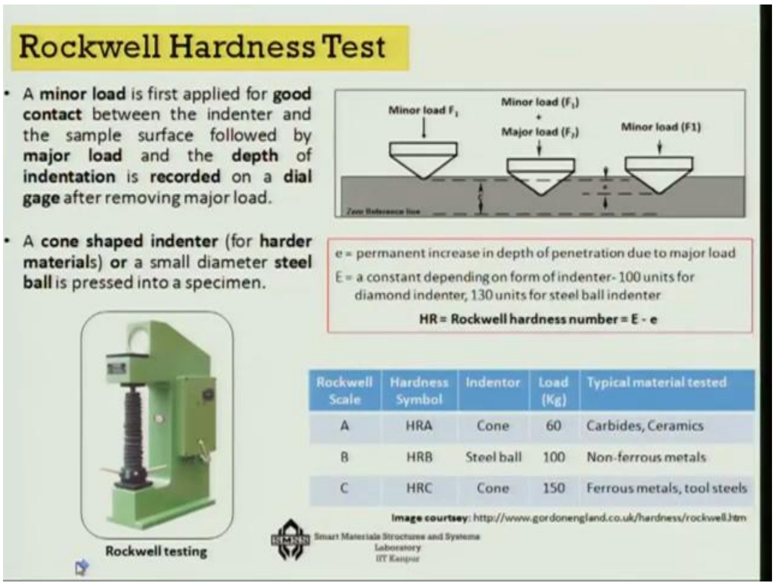

So the 1st one is the Rockwell hardness test. Now, the basic principle as I told you that resistance to plastic deformation that is same in all the cases, so only thing is that what kind of indenter you are using in terms of like this indenter if you look at it, the geometry of the indenter that actually varies from test to test.

So when we talk about Rockwell hardness test, 1st of all Rockwell hardness test employs 2 different loads, one is a minor load okay it is 1st applied for good contact between the indenter and the sample surface and this is followed by a major load and the depth of indentation is recorded on a dial gauge after removing the measurement.

Now here, the indenter is actually cone shaped indenter, which is used for harder materials and sometimes for steel balls for relatively less hard materials. And so the sequence if you look at it that you 1st apply the minor load and then you apply the minor plus the major load and then you withdraw the major loads, you have the minor load and then you withdraw all of them and then measure the depth of penetration.

Now suppose you know what the permanent increase in the depth of penetration due to major load okay is. So once you know that and then there is a constant E which depends on the form of indenter okay so for example, if you use diamond indenter, this is about 100, if you use steel ball indenter it is about 130, so then you can get HR Rockwell hardness number by actually simply subtracting this small e from capital E, so that is how you can get it.

Now in the HR scale you know there are 3 scales of Rockwell scale. One is scale A which is known as HRA and there the indenter is cone shaped indenter, the load is usually 60 KG, it is used for Carbides and ceramics so that means it is used mostly for ceramics type of systems. Then the B scale of Rockwell HRB where you use the steel ball indenter, the load is more here about 100 kg to create plastic deformation and then the typical material is used in the nonferrous metals it is used.

And then C, C is used mostly for steel, so HRC scale and then once again you use the cone shape 150kg load is use for ferrous metals and tool steels, so that is the Rockwell hardness tester okay. And this is a typical Rockwell hardness machine that you can see here that is a Rockwell hardness machine.

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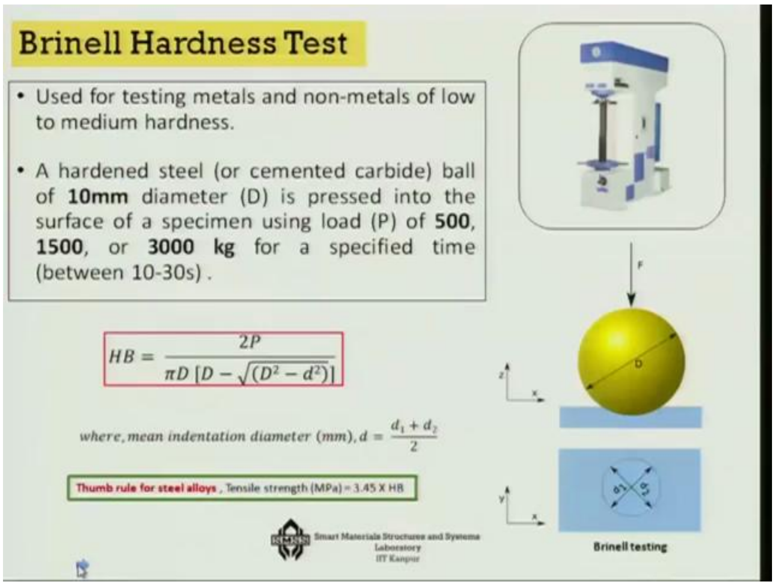

Now the other one that is also very popular is called the Brinell hardness testing. And this is used for also testing metals and nonmetals of low to medium hardness okay. So Rockwell hardness includes the ceramics also, whereas in this case it is most preferred metals and nonmetals of low to medium hardness. Now in this case however, the indentation is done not by cone, but by hardened steel ball as you can see it here by a hardened steel ball okay.

Sometimes it is cemented carbide ball of 10 mm diameter is generally capital D that is what is generally conventionally used, which is pressed into the surface of specimen using load P of either this load varies either 500kg or 1500kg or 3000kg for a specified time and the time is generally between 10 to 30 seconds, minimum 10 seconds up to 30 seconds. Now you know which load you are using, you know what the diameter you are using is.

And then all you have to do is that you have to find out this mean indentation diameter. That means, you know you get the indented shape and you calculate this diameter at 2 different points, D 1 and D 2 and then take an average of it so that is what is our D. And once you know D, you can use this formulation to find out the HB. And there is a thumb rule here and that is the tensile strength can be actually calculated directly as 30.45 times HB and that is usually used for steel alloys.

But as I told you earlier itself, couple of slides before if you remember that generally more generalized relationship is actually this one.

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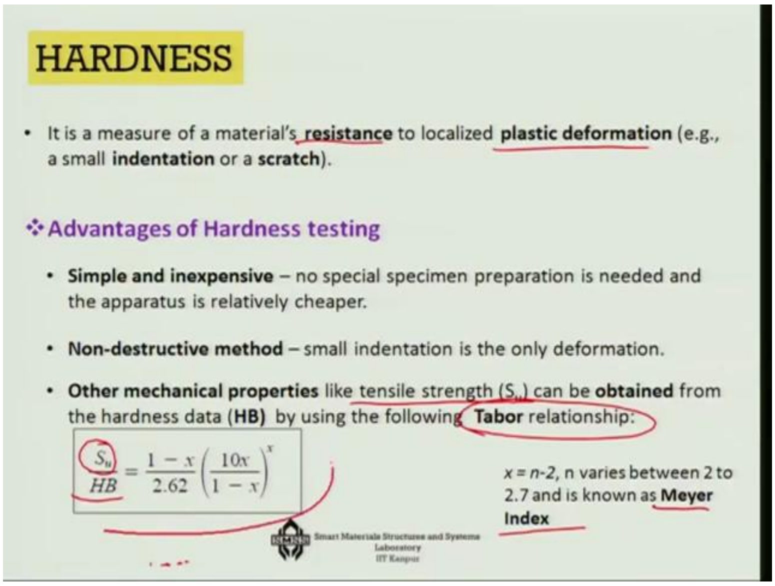

Which is used in terms of finding the strength for various types of materials, so this is not very material specific okay.

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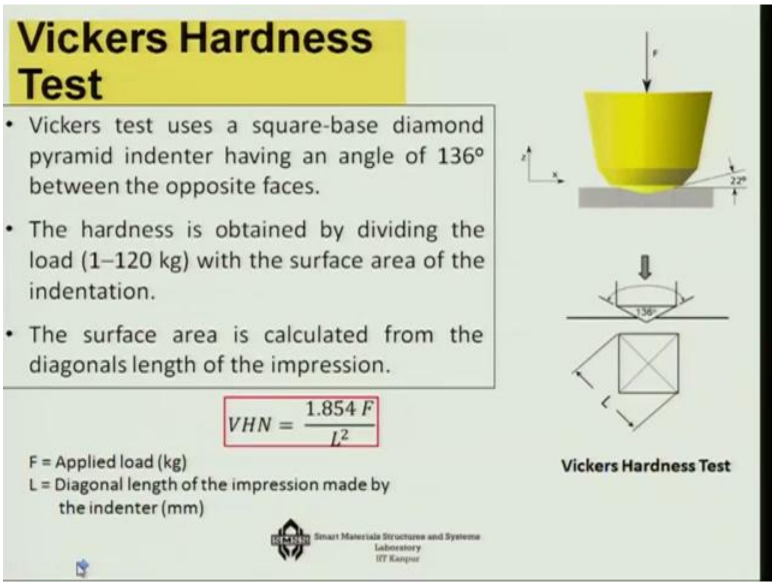

Now, we come to the Vickers hardness test okay. Here, what is the difference? Unlike this Brinell hardness test, the shape is different here as you can see that it is a square base diamond pyramid indenter and which is generally having an angle of 136 degree is between the opposite phases that is what is used in the Vickers hardness test okay. And in this case, the hardness is obtained by dividing the load which is generally 1 to 120 kg with the surface area of the indentation.

Now the service area is calculated from the diagonals you know of the length of the impression. So here, the impression is actually you know something like in this case it is a square type of an indentation unlike the circular indentation that you have seen for the Brinell case. So once you know this indentation size okay, then you know that and you know the force that you are applying.

So 1.854 times that and F is the applied load in kg then you will be able to get the Vickers hardness test. So that is how these 3 tests are used in terms of finding out the quantified value of the hardness data.

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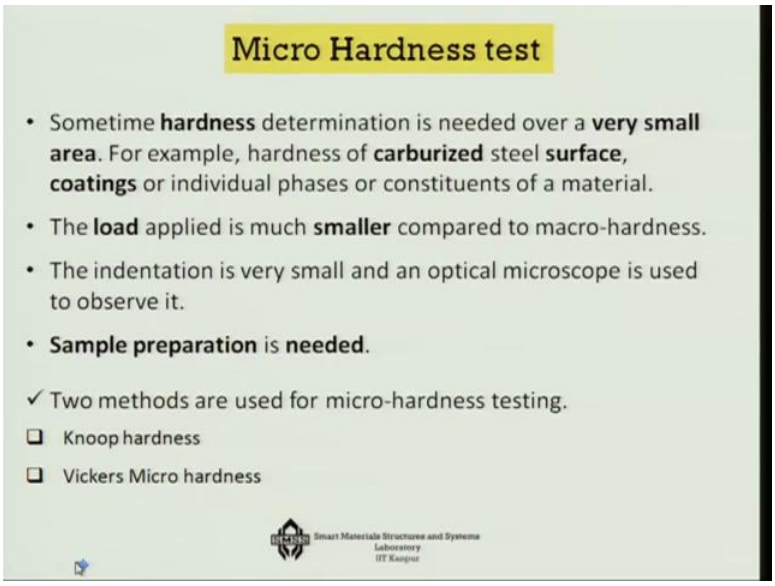

Now sometimes what happens is that this hardness is insufficient particularly when you will see that you make a very thin layer okay. So this kind of general hardness is good for when you have a single material. But many a times what happens is that we give a special surface coating on metals, okay. Let us say, when we actually work on things like suppose gears okay.

Suppose these are the phases of the gears which works against another gear okay so a smaller gear. Now so there is a continuous contact between the 2, so in this kind of surfaces you must give a special coating okay on the teeth of the gear. So you give a special very thin coating layer which is very hard, so that you know to save it from wear and tear.

Now this kind of very thin coating layers you cannot really see that how you cannot really use you know the Macro hardness test for doing that, you need a micro hardness test for doing it. So for such cases, you know the micro hardness test comes into picture and the important thing here that the load applied here is much smaller because the indentation thickness is very low okay.

Indentation itself is very small and sample preparation is definitely needed okay. So there are 2 methods that is used Knoop hardness and Vickers Micro hardness, let us go to each one them.

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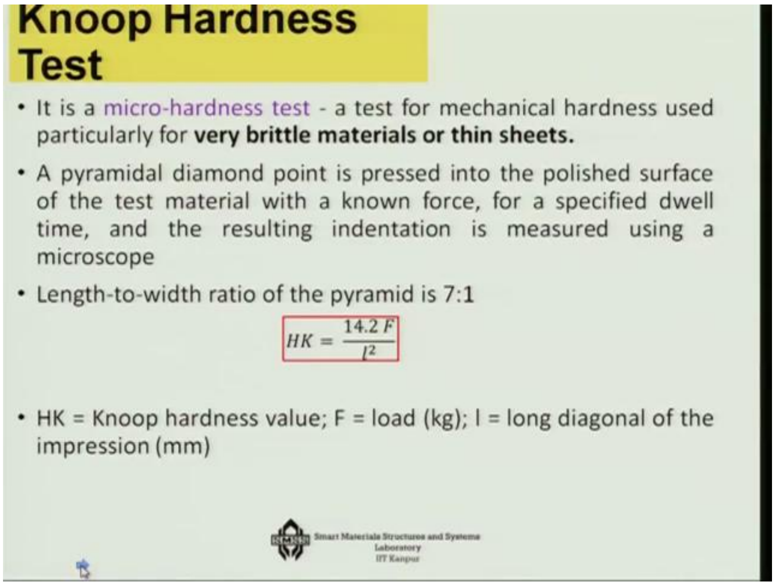

So in the Knoop hardness test, it is mostly used for very brittle materials on thin sheets okay. So here you use a pyramidal diamond point, okay which is pressed into the polished surface of the test material for a specified dwell time and the resulting indentation is measured using a microscope okay. So the length to width ratio of the pyramid is maintained as, 7 is to 1 okay.

And then you can actually find out the Knoop hardness value, where F is the load in kg and L is the long diagonal of the impression, so you can use this relationship in order to get the Knoop hardness value. So that is as you can see here that the load here that is used, F is load in kg, now that load is substantially smaller in comparison to the Macro hardness test. The other one is actually Vickers Micro hardness test.

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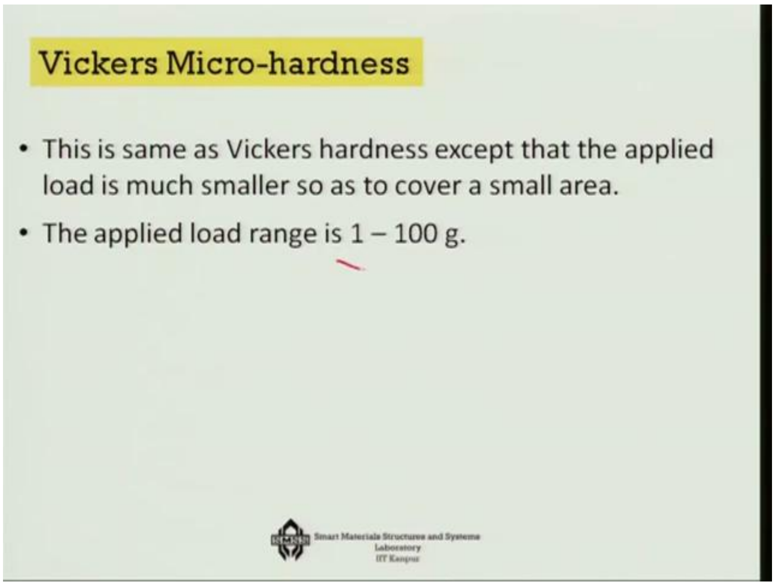

Here also you can see that the load range is 100g okay, 1 to 100 g. So that is the kind of a thing we are talking about when we talk about micro hardness test.

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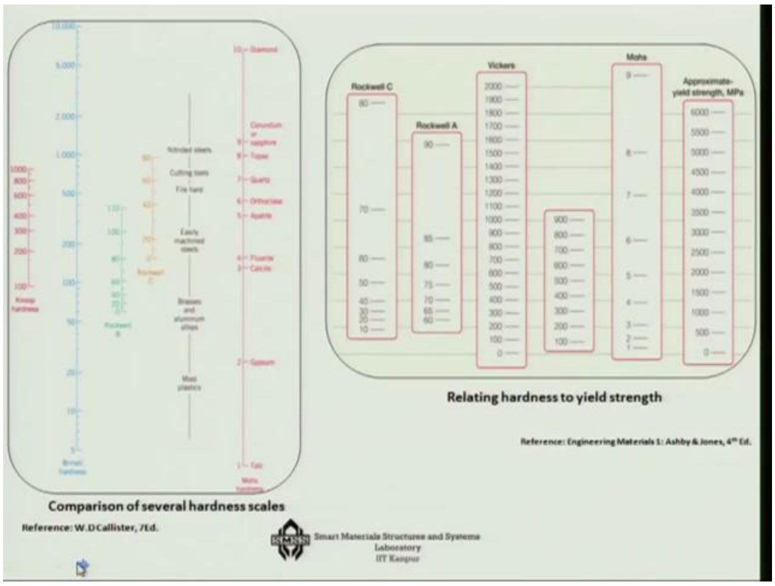

Now, this um you know slide gives us a kind of a very broad picture of 2 things. One is that suppose, I work with a something like a Brinell hardness okay. Then I can actually compare that what will be the performance of the same material in terms of Rockwell hardness or I can compare it in terms of Knoop hardness, et cetera or even the Mohs hardness. And the other thing is that, what is the general range of hardness that you can expect because the material science has advanced so much that most of them are fairly standardized now.

So for example, when you talk about the nitrite steel, so somewhere you know between 1000 to 2000 maybe 1200 or 1300 is the maximum value you can see in the Brinell hardness test. For the cutting tool it is somewhere like as you can see maximum value of 700 around that range, okay. And similarly you know for all other materials like for brasses as you can see that it is somewhere like 70 or so in the Brinell hardness.

So, even this particular slide tells us that where do we expect the values to come from that has been standardized. The other thing also that the formulation that I told you which is used for the calculation of the yield strength in this table which is from the in Ashby and Jones book, you can actually get this direct with this yield strength. For example, you get some value like 1200 and you go through this, you get Yield strength of something like 4000 MPA.

So, corresponding to each such values in the hardness testing machine, you can get an approximate Yield strength value, so that is a good part of this kind of a handy table okay. So, we have talked about the hardness next let us come to another important property that is what is called the creep okay.

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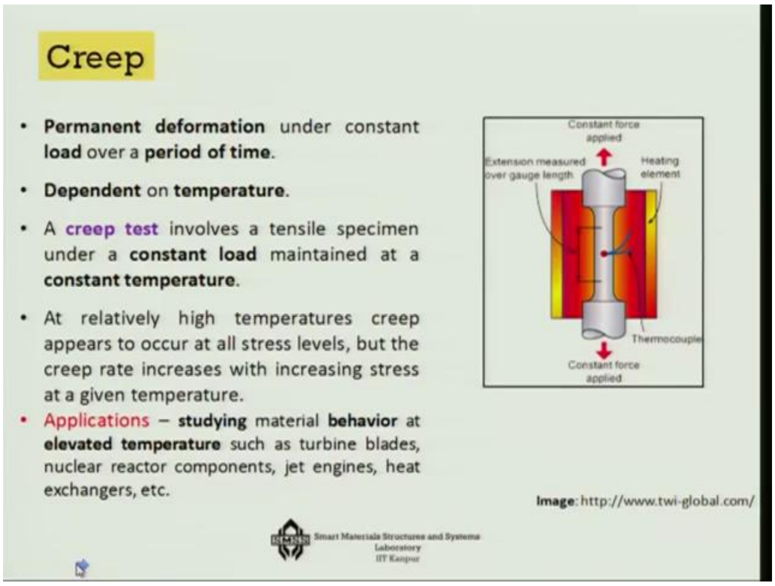

Now many of you I know might have experienced creep as a day to day experience for example, you use the nylon where for outdoor garments drying right. And you will see that you put a fixed tension, you fix your nylon wears and then you know you put your garments day 1 and after a month or so, you see that this whole thing is actually slacking and you know it is coming down more and more, it is getting lose. So why is this happening?

This happens because under a continuous load every material starts to get a permanent deformation over a period of time which is known as creep. Now creep has a very high temperature dependency. Naturally if the temperature is more, then what will happen that there will be as you are going closer to the melting point, you are getting a flow like behavior. So under loading, this effect of this permanent deformation will be much more.

And a creep test generally involves a tensile specimen once again in you know you can use a universal testing machine under a constant load maintained and a under a constant temperature, so that temperature important because as the temporary increases, the same stress level can actually create much more deformation in the system. Now, this is a very importantly case because its application is there in terms of supposed turbine blades which work at a very high temperature level or nuclear reactor component, jet engines, heat exchangers.

So those applications where there is a stress on mechanical loading at elevated temperature, creep is must okay. So that is what you know is the importance of the creep test. Now creep generally occurs in 3 stages okay. So the 1st one is the primary stage which is used for a smaller duration mostly transient and then there is a longer period which is known as a secondary stage and the creep rate is more or less steady in such a case okay.

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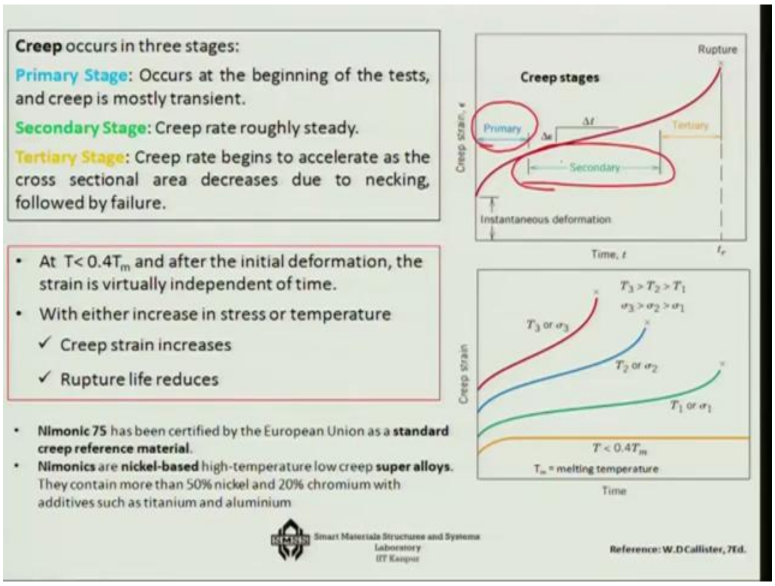

So you can get a slope, a continuous slope more or less at this stage okay and you can predict that how much it will be creeping in that time period. Then there is a tertiary stage okay, so that is you can see here with respect to time, beyond a particular time the creep increases actually exponentially as you can see in this picture. So that is you know that actually goes towards the failure.

Now at a temperature I told you that less than 0.4 of the melting point temperature generally after the initial deformation, the strain is virtually independent of time. But with the increase in stress or temperature, the creep strain increases and the rupture life reduces rapidly. Now to do all these things, we use a Nimonic 75 is E U actually European Indian standard as the creep reference material.

So any new material you want to test, you test it with respect to Nimomics. These Nimonic are basically nickel based super alloys okay and they contain about 50% of nickel and 20% of chromium with some additives such as titanium and aluminum. So with respect to this reference, you can actually measure that what the creep that is happening to the system is. Now here you can see that when the temperature is less than 0.4 T m, the creep is not so predominant okay the creep strain is almost constant.

But if the temperature increases okay or stress increases, you can see how the nature is changing, okay that means there is a study increase of the creep strain. So that is something that is you know that needs to be always studied with respect to a material. And there is a, I will not go into the details at this moment but there are various mechanical models that are used actually, a very common model is something like you know a spring, okay a material model and a dashpot combination in series okay.

So and the load is coming here okay, so this is a spring K and this is the dashpot okay. So imagine that you are applying a load F and how this system will be behaving, okay. So that is something that approximately kind of simulates the creep behavior of a system okay. Finally I will talk about damping, which is very important because as you know that many mechanical systems undergo dynamic molding okay.

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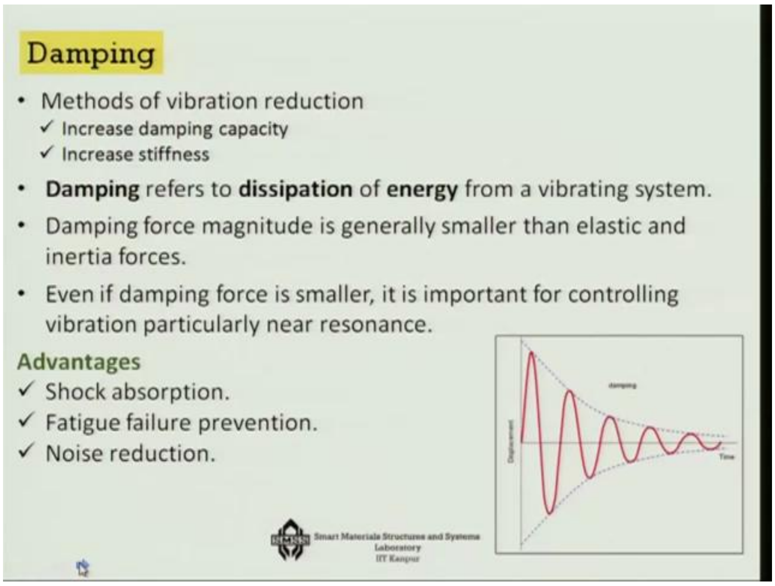

And also civil structures like which undergoes dynamic loading because of different reasons like a when loading or earthquake or maybe you know vehicles moving transport load, etc, so vibration is evacuated. Now there must be a material property which actually determines that what the level of vibration is or what is the kind of energy dissipation possible in the system.

Now, this method of vibration reduction actually there are 2 ways, one is the damping capacity and another is the stiffness. Damping specifically refers to the dissipation of energy from a vibrating system. So it is mostly the damping that is important particularly during the resonance of a system that means when the natural frequency matches with the excitation frequency, it is damping which plays a predominant role.

So the damping study is very important and that helps in terms of shock absorption, fatigue failure prevention, noise reduction, et cetera. So this is typically an under damp curve as you can see and this is actually under Viscous damping and you can see that the response is coming down exponentially okay.

So as the damping increases, this actually will be more and more and there is something we call the settling time that means in comparison to the initial value + - about you know 2 to 5% when the initial amplitude comes down to within say 2 to 5% level, we say that the vibration has actually damped down. So you know there are various ways in which we can actually quantify the damping.

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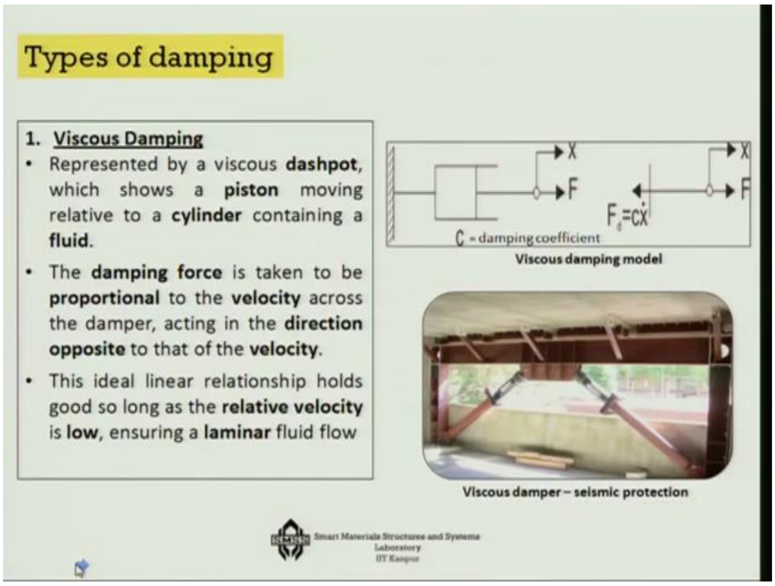

Now there are 2 important types of damping, one is called the Viscous damping and as you can see that like a seismic protection or in any door you will see that the door closer is actually a dashpot okay. So this dashpot is having actually a piston and a cylinder combination in the damping force here is considered to be proportional to the velocity across the damper acting in the direction opposite to that of the velocity.

So if the direction of force is this way okay and then the opposing force damping is coming as an opposing force okay, it is opposing the direction of the velocity okay. And so this is very important in terms of Viscous damping model.

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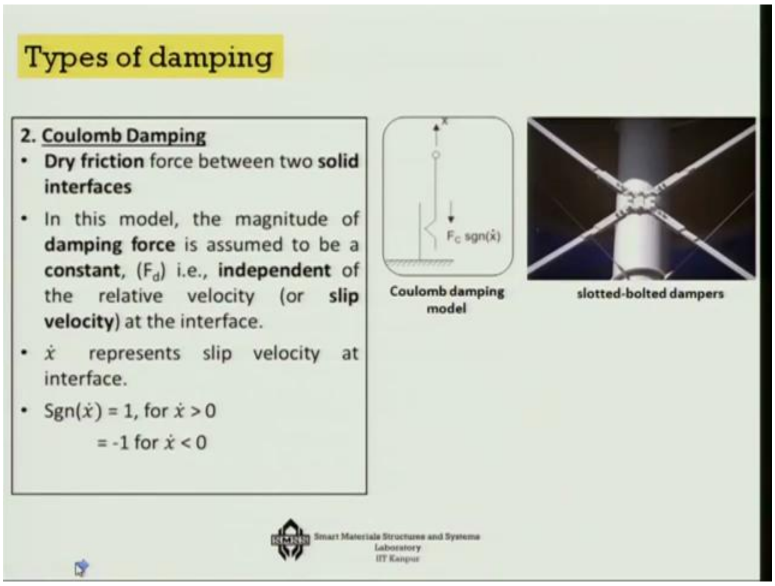

There is another type of a damping model also that is known as the Coulomb damping model, so which is basically dry friction force between 2 solid interfaces. Now in this model the magnitude of damping force unlike the last result is proportional to velocity, which means higher the velocity more is the resistance, in this case the damping force is assumed to be constant and that is it is independent of the relative velocity unlike the last case.

However, what happens is that there is a signum function that governs okay, so and the signum function is positive for positive velocity and negative for negative velocity okay. So that is how the damping force will change its direction, change its sign. That is for the Coulomb damping, so these are the 2 very important damping Viscous damping and Coulomb damping. Now how material properties are related to it okay.

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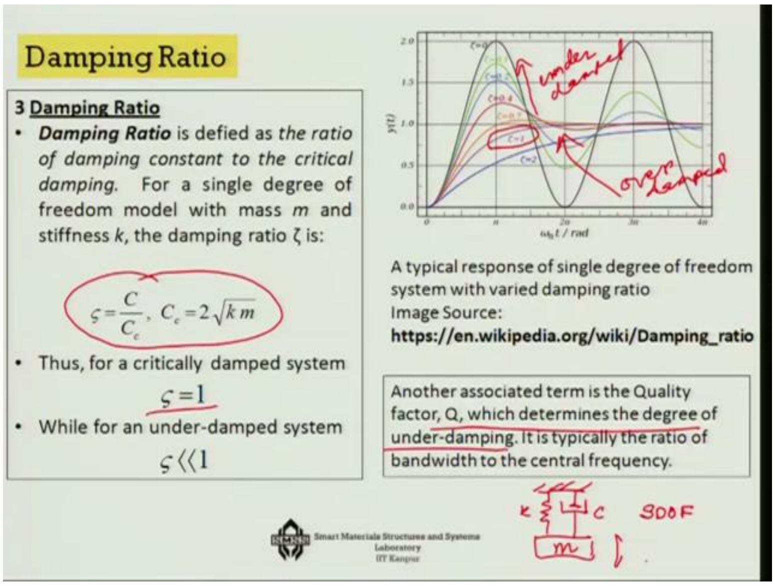

One important thing here is that what is the damping ratio? A damping ratio is basically the ratio of damping constant to the critical damping of a system. Suppose we consider a single degree of freedom system something like if you can draw it a single degree of freedom system, something like a spring here, a damper or a dashpot here and a must M okay, so this is called a single degree of freedom system, it can actually move only in one direction okay.

So in such a case, the damping ratio is Zeta is actually the ratio of C over C c, where C c is the critical damping called 2 root K M. And thus for critically damped system, the value of zeta is actually unity because C equals to C c. Whereas for under damped systems, Zeta is much less than unity like as you can see here that this is the case of a critically damped system. And all this where the oscillations are actually continuing our, other cases these are the cases of under damped system, so this is under damped okay.

And this is the one single case that is shown where Zeta value is greater than unity, this is the over damped case, which is not generally you would not see that practically, most of the cases it is actually under damped case and it is often important that what is the value of the Zeta at that corresponds to the under damped cases. In fact the quality factor Q also you know actually determines the degree of under damping.

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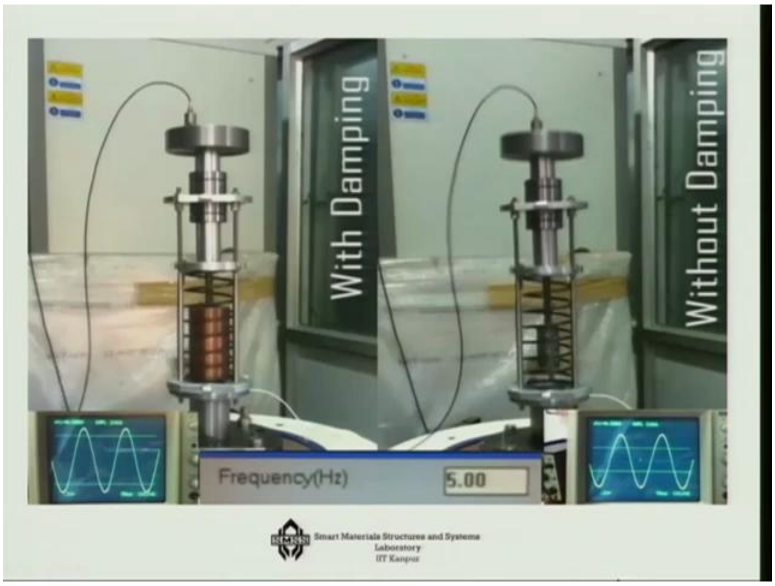

And which is typically the ratio of the bandwidth to the central frequency of the system. In the next slide I will just show you that how the damping changes the response of a system. So if you just look at this, that there are 2 systems I have shown here 1 is this is a system which is like a system which has a damper, it is like a damper which is in the form of a copper block here, which actually converts the oscillator motion inside the copper block there are actually magnetic blocks there.

And the magnetic blocks gets actually you know as it moves inside the copper block, it actually generates the eddy current and thus the vibration is converted to electrical energy in the copper block, so that is a you know kind of a damper okay. And then there is a this situation where there is no damper because you can see there is no copper block there and hence even if there are these magnates here as you can see.

This magnet actually has to create a electric field in order to create damping. Now let us see that how such a system would actually behave you know in terms of the oscillations. Look at the right hand side and see that how vigorous is the oscillation if you look at the top plate okay and you can also see it in the Oscilloscope. And if we look at the left hand side, you would see that most of the vibrating energy is getting transferred to electrical energy and hence you get much less vibration amplitude in the left hand side case.

So that is typically what you will see in the case of a say system which has a damper in it, in this case the specific damper is called the eddy current damper. And the frequency is of damping is around 8 Hertz okay, so it is between 7 to 8 Hertz level you would see it as you increase the frequency, you may come across a situation where this will be even more vigorous here okay um.

And on the other hand, you will see that with damper there will be hardly any you know as I told you that the damping is very important close to the resonance. So hence, you know whenever you will come across the resonance, we will see that the damping becomes you see a sudden decrease in the whole system. So that is kind of an example that how with and without damping a typically a system behaves okay. Now, let us go back to the quantification of the damping.

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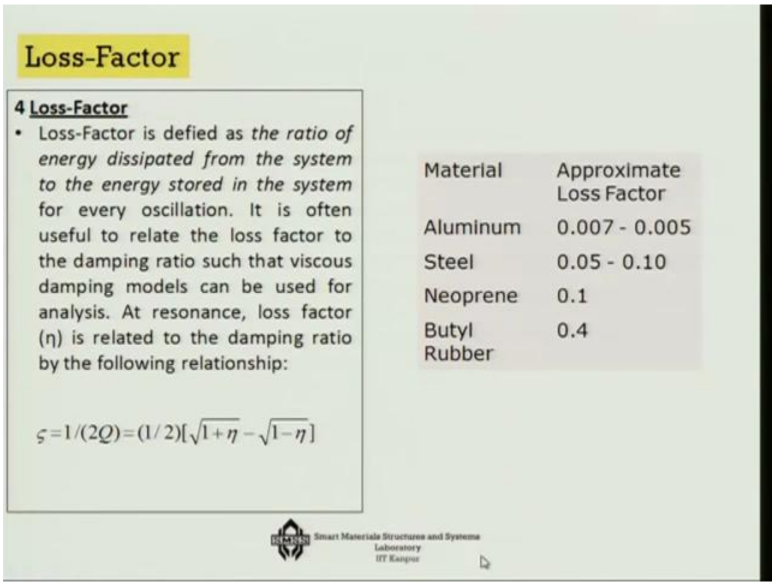

So while quantifying the damping, we have to talk about another very important factor which is known as the loss factor okay. And the loss factor is actually um defined in terms of the ratio of the energy dissipated from the system to the energy stored in the system for every oscillation, so that means you know if you consider that there is a under damped situation that means with respect to time, if you plot the response than the sponsor is in a cyclic manner.

Then however, the amplitude is coming down gradually so you find out that for one particular cycle, okay so let us say from this point to this ponit okay you have to find out what is the ratio of the energy dissipated from the system and what is the energy stored in the system. So that gives you the loss factor Eta and that is a material property. And this Eta actually related to both the quality factor and the Zeta by this particular relationship okay.

So even though Zeta and form factor Q are not directly the material property, but Eta is a material property because the more there is hysteresis for example in the material, the more will be this kind of energy dissipation. And this actually you know some material for example, aluminum you will see that the loss factor is much smaller in comparison to steel, so which means steel dissipates more energy inside it.

And if you look at rubbers which are generally used as damping materials, they have much higher right, like an order of magnitude higher of the loss factor. So that says that why we use rubber or Neoprene, et cetera as damping material unlike the metals. Generally polymers have much larger energy dissipation and hence the Eta is much more for the polymers. So that is um, you know the mechanical properties that we have discussed.

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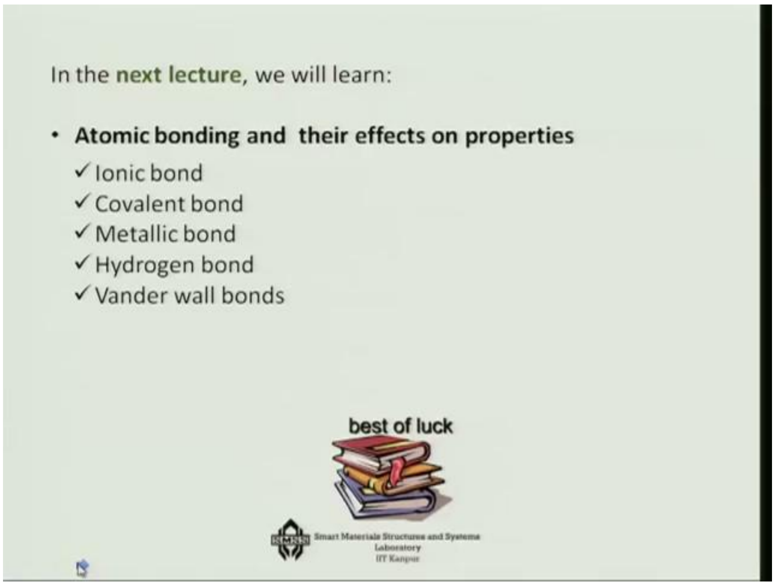

In the next lecture, we will now leave the mechanical properties. We will try to find out what is the source what is the reason of these mechanical properties and we will start that with the atomic bonding okay, so we will go to the very core issue of atomic bonding. And we will see things like ionic bond, covalent bond, metallic bond, hydrogen bond, Vander wall bonds. So that ones we understand some of these properties, we will be able to explain with the help of the atomic bonding, thank you.