**Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations**

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**Lecture-58**
**Characterization of Modified Surfaces: Soundness and Mechanical Properties**

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and we are talking about the different techniques and methods used to characterise the modified surfaces. We have talked about the characterization of the depth or thickness of the modified a layer. And also we have talked about the two techniques of assessing the soundness of the modified zone. We will see the two more techniques of the assessing the integrity and the soundness of the modified layers.

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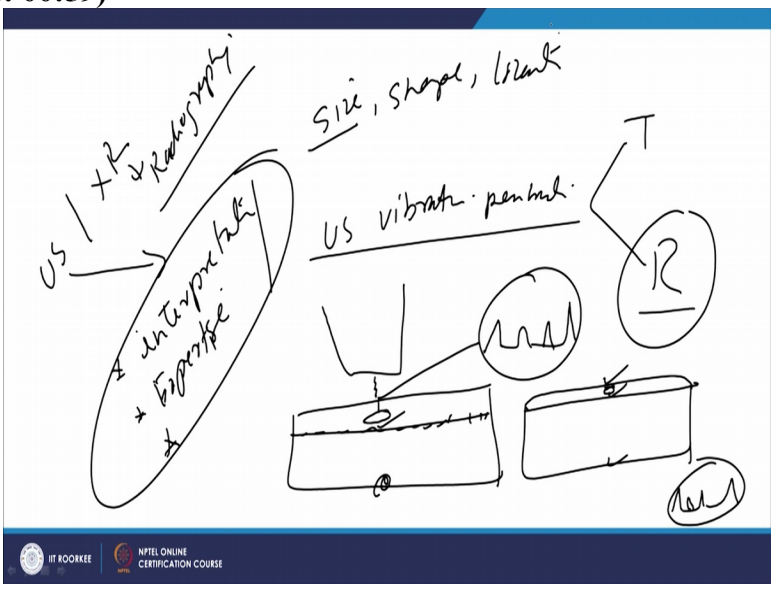


These are the ultrasonic testing and X-ray testing which is also called like radiography testing. So, the basic principle of the ultrasonic testing we have already talked that the ultrasonic vibrations can penetrate the metals and whenever they come across any medium or interface due to the change of the medium then these vibrations are reflected. So, basically there are two approaches one is the transmission approach and another is a reflection approach.

The reflection approach is the simple one for assessing the soundness of the modified layers. Because in this case the vibrations are reflected whenever it comes across any interface whenever the change in medium place. So, like say there is a defect in modified zone this is the coating substrate interface and if it is having the defects whenever vibrations are transmitted. So,

obviously will be getting one peak from the top surface and then as soon as it comes across the defect we get another peak.

And then we make not get any further peak if the defects size is very large but if the different sizes limited then we make get; that the last strong peak from the; we may get one additional from the interface and the last peak from the another side of the substrate surface. So, in this case so what is happening normally in case of the; like if the on the substrate the coating has been applied when they are three interface is 1, 2 and 3.

In that case will be having the 3 peaks 1 from the top, 1 from the interface and one from the bottom so, but if the defects are present in the coating itself then will be getting one additional peak. So, these are; these method is simple to apply but interpretation about the presence of the defects is difficult and it needs expertise to handle to use this method for assessing and of course we can keep the record of but there is no such physical record of the things.

As the record will be there that at particular location what kind of the peaks were observed and how this can be interpreted with regard to the presence of or absence of the discontinuities. So, these are the two limitations but it helps effectively to check the size, the shape, locations wherever the discontinuities are present.

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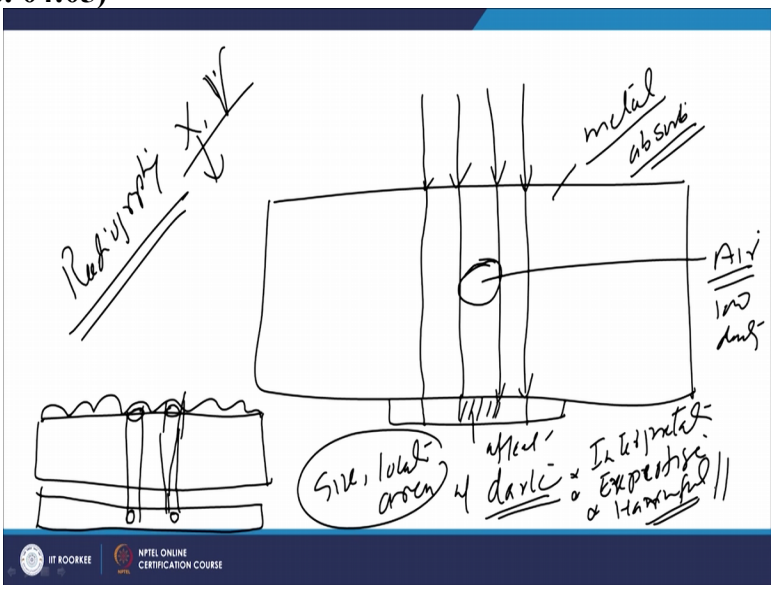


The radiography is the another method radiography is the another method which can use the X-rays or the gamma rays is mostly the X-ray method is very simple and very easy as compared to the gamma rays which is primarily used for thicker sections of a very heavy sections or assessing

the soundness of the heavy sections. So, the property of these radiations is used in case of the soundness assessment is that these radiations actually can penetrate the metal.

Like say the X-rays are being applied or gamma rays are being applied on to the component whose of soundness is to be checked? So, whenever these can penetrate but whenever these penetrate these are observed also. So, the penetrations whenever penetration takes place metals absorb these radiations. So, the magnitude of these radiations reaching other side is reduced if we put one sensitive film to the radiations then that is affected.

Now you see if there is no discontinuity then the extent of effect on this film of these radiations will be uniform in all the areas of the film. But if there is any discontinuity like this, so whenever there is there is a discontinuity then there will be air or there will be low density material which will be able to absorb less of these vibrations. So, there more amount more magnitude of these radiations will be reaching to the, another and affecting the film more severely.

So, at that location in will be will be getting the significantly different colour and shade as compared to the other areas so this is the concept which is utilised in case of the X-ray. So, if this is this a component or the substrate and it is applied with modified layer. And if it is having the discontinuity at the interface over there is discontinuities are present at that location will be finding the greater means the dark spots.

While other areas it will be lighter because at these locations more amount of the X-rays will be reaching as compared to the other zones. So, where were the whatever the areas of the film that are less affected due to the more absorption and more soundness of the metal they will be less affected. And wherever the discontinueties are present the radiations are will be effect will be absorbed less these X-rays will you absorbed less and so the film will be affected more severely and at that locations will be having the dark spots.

So, the size location area of the dark spots will indicate where the discontinuities what size of discontinuities are present. But to us; to precisely identify the location of the discontinuities we need to take; we need to perform the X-ray testing of the component from the two and three directions so that precisely the location size of them discontinuities can be established. But there are certain limitation in this method again making the interpretation from the radiographs interpretation of the radiographs is difficult.

It needs expertise to read this radiographs. At the same time it uses the harmful radiations in the form X-ray and Gamma rays we need proper protection to protect the human being from this radiations. So, this is how we can say that the four techniques which are used for assessing the soundness of the modified surfaces.

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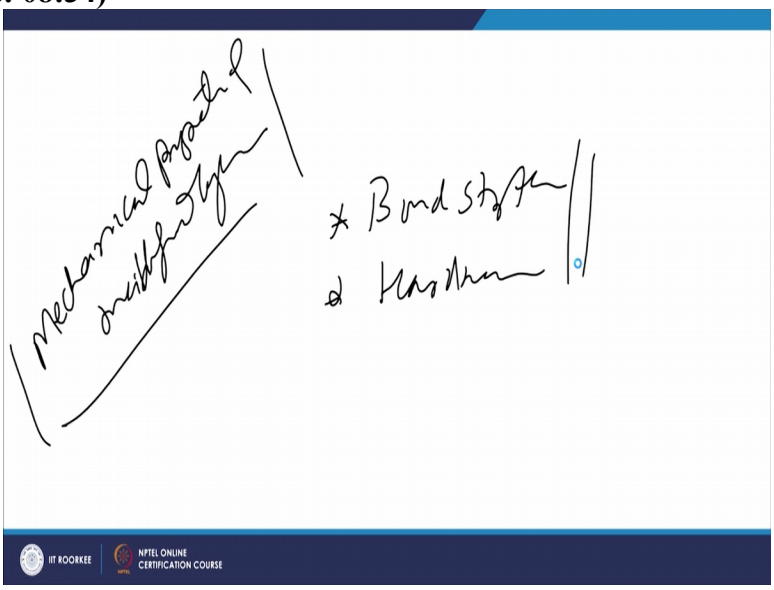


Now I will talk about the mechanical properties of the modified layers basically there are two properties which are extensively investigated of the modified layers. One is the bond strength and second is the hardness and these two properties help us to make the inference about whether the modified zone will be able to perform effectively under the service conditions are not. So, I will be talking about the importance and the need of assessing the bond strength in what condition is important.

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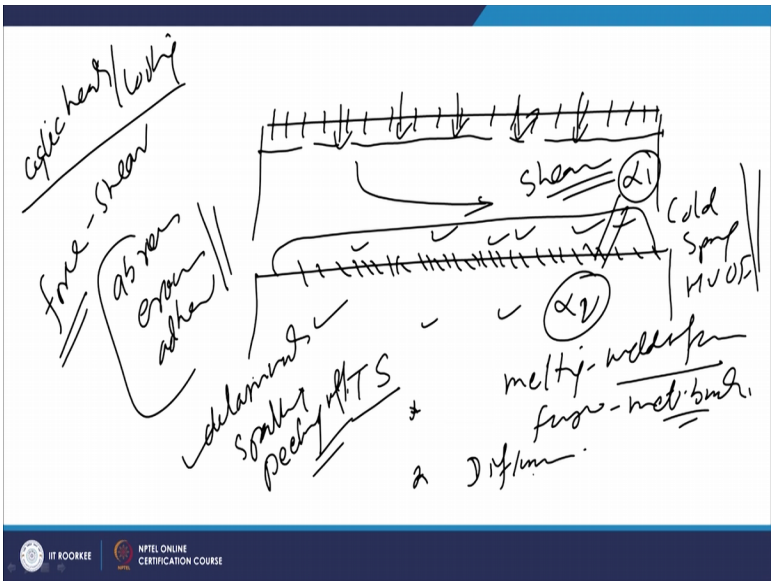


We know that the surface modification is carried out by various approaches. So, in case of the surface metallurgy modification approach there is no question of the bond strength because just the surface microstructure is modified through the control heating or the deformation. In case of the surface compositional modification also we just introduced the required alloying elements at the surface through the diffusion.

So, the modified zone is also metallurgically bonded and very much part of the substrate itself again there is no question of the bond strength. But in those methods that is where wherever the mechanical interlocking of the modified layer between the modified layer and the substrate is used like in thermal spraying processes where either melting is absent or just the mechanical interlocking is facilitating the bonding between the coating and the substrates.

So, definitely in those cases where there is melting like in weld surfacing or so if there is a weld surfacing then there is a fusion of both filler as well as the wings of the substrate and the good metallurgical bond is created in those cases. Similarly there is no issue of the bond in case of those diffusion based processes, but if in case of the in case of thermal spray processors where primarily the bond is taking through the mechanical interlocking.

Then like in cold spray process and HVOF process, the bonding between the coating and substrate becomes crucial why because under the normal service conditions when the load acts on to the functional surfaces is shear stresses are induced on the surface of the component due to the friction. And under the effect of the shear stress during the abrasion, erosion or adhesion there will be tendency for removal of this layer of the coating due to the delamination or spalling

are called peeling off or removal of the coating or the layer applied substrates due to them limited bond strength.

So, this is one reason where the application of the force leading to the shear stress generation in the coating and then there is spalling or delamination from the surface of the substrate. But there can be another reason behind the removal or separation delimination of the coating from the substrate and that is cyclic, heating and cooling. Since the layer of the metal which is applied will have the different thermal expansion coefficient then the substrate.

And these two are significantly different thermal expansion coefficient of the coating material and the substrate material are significantly different than during the heating and cooling they will be expanding and contracting by the different magnitudes and because of that there will be tendency for debonding, decohision or the delamination of the coating from the substrate.

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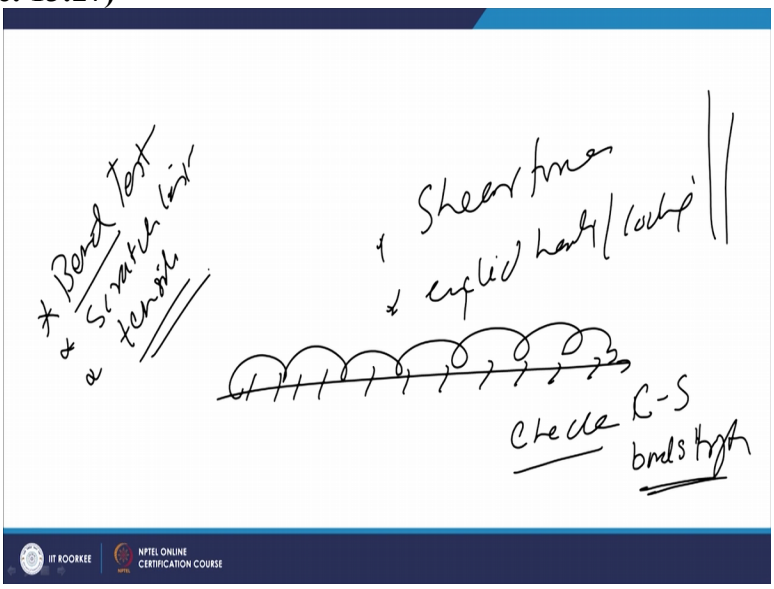


So, these are the two main factors one is application of the shear forces under the cyclic heating and cooling especially due to the differential thermal expansion coefficient can lead to the removal of the coating from the substrate. So, it is important to have that the coating is very formally bonded with the substrate. And that is why we need to check the coating substrate bond strength and therefore for checking the coating substrate bond strength.

There are three methods which are used one is simple in directors that is called bend test second is called scratch test and third is the tensile test. So, will be talking about the basic principle of these three types of the tests

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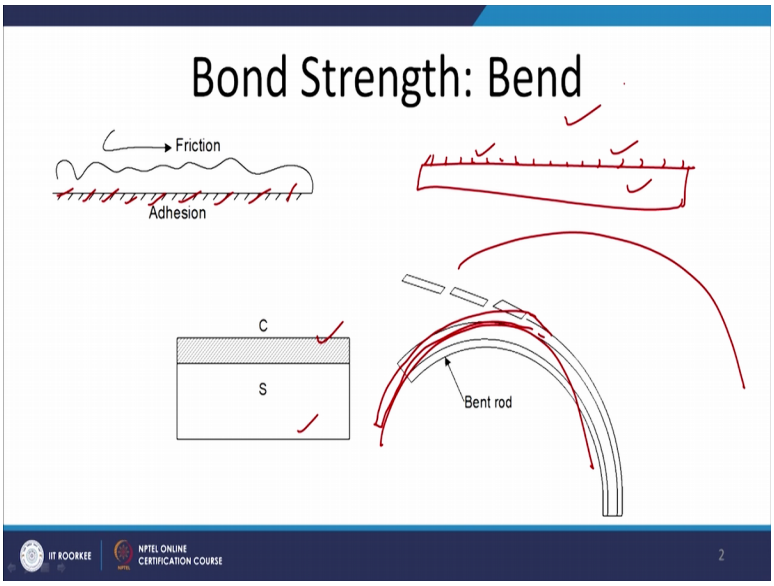


So, this is what has been explained in the like during the due to the shear forces if the forces are acting on to the shear force acting on to the coating then it can lead to the delimination from the surface of the substrate. In case of the bend test like this is a coating applied on to the surface of the substrate so the sample coated or the substrate coated, coated substrate will be subjected to the bending.

So bending of the substrate having the coating in suitable form block will be leading to the bending of the substrate as well as coating and will keep on bending until we find either the cracking on the coating has started or the coating has started to delaminate from the surface of the substrate. So, like say if the bending we continue until we find that removal of delimination of the coating from the surface of the substrate has started.

And this kind of the bending will continue until we find either cracking or delimination of the coating from the substrate in case of the bend test this very simple test .

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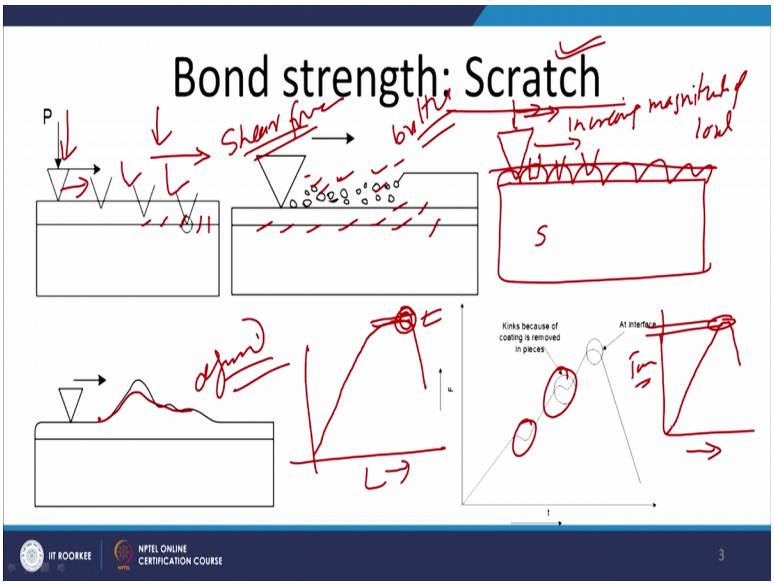


So, greater is the angle of the bend greater will be the bond strength that is how the indirect indication or the idea about the bond strength is obtained. Next is the scratch test method in case of the scratch test like say this is the substrate having coating like this. So, we apply one indenter, so, indenter is applied and it is moved indenter is applied with increasing magnitude of load so when it is moved the magnitude of the load is increased.

So, indenter basically will be penetrating deeper and deeper and deeper when we are moving the intender load magnitude is increasing like this. In moving the indenter load magnitude is increasing and because of this intender is going deep and deep and because of and so because of this situation like the movement of the intender coupled with the increasing load sets in the shear force in the coating.

When this magnitude of the force reaches to such an extent that the interface remains that that the interface remains intact but the material of the coating itself tends to get break that means the interface is still intact and but the coating is weak. This and when the coating is weak, coating maybe brittle, so in that in case when the coating is brittle will you finding the removal of the material due to the movement of the intender leading to the development of a scratch and it will be finding the fine brittle particles.

The sketch will be formed by removing the material of the coating in form of fine brittle metallic particles ore fine particles of the coating material. If the material is soft and ductile in that case it will get piled up and it will get deformed. There are two different behaviours which will be shown as per the nature of the coating material. So, if we see the relationship between the

distance being moved by the indenter and the force which is being applied for the movement of the indenter?

So, the length which is being moved and the forces which is acting on to the intender. So, this force will keep on increasing with the increasing length increasing length of the indenter which is being covered and there will be a situation when it will reach to the maximum force and thereafter start decreasing abruptly so, this maximum magnitude of the force which the coating can sustain before a removal or separation from the interface that will indicate the maximum magnitude of the force that the interface can sustain.

In this case we are applying we are developing 1 scratch using the shear force and increasing magnitude of the shear force which is being applied through the indenter and will try to see what magnitude of the force can be sustained by the interface. And this is also an indirect method which will be indicating the kind of the force shear force which can which coating substrate interface can withstand higher is the magnitude of the force greater bond strength that will be assume to be.

So, here if some coating is removed in form of fine pieces that will see some kind of the deviations in this form otherwise if otherwise it will keep on going straight and then again suddenly it will start coming down with the increasing length of the indenter the force magnitude will keep on increasing. So, this magnitude of the force will be indicative of the bond strength. And if this division is starts much earlier than that will indicate that coating substrate bond strength is weaker.

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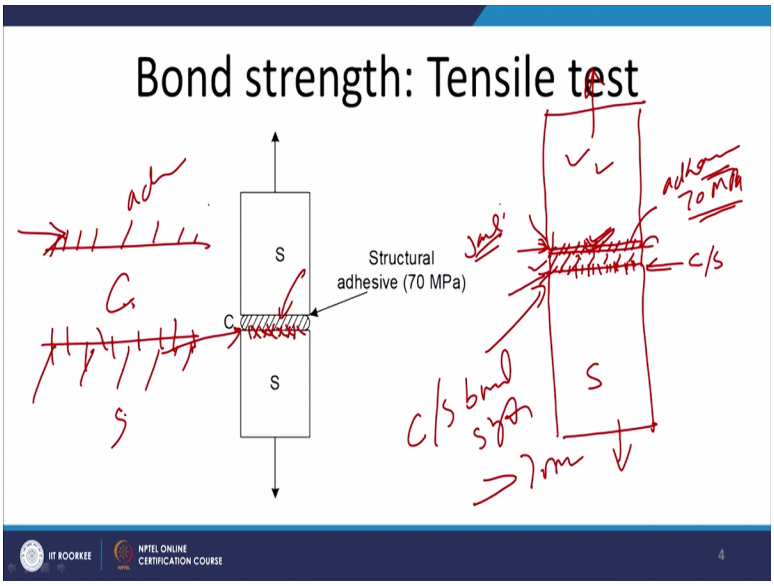


There is another indirect request method of the bond strength testing in this case like say this is the substrate and having the coating. So, we want to check the basically the coating substrate interface is strength, strength of this zone we want. But there is no direct measurement method so what we do will apply another structural material of the same as that of the substrate. And it will be joined with them coating itself using suitable adhesive.

Adhesive having the joint strength of 70 MPA was this joint is formed of this structural element. So, what we have basically 1 substrate then coating and then another you can say the structural element made of the substrate material itself. And there we have one joint another so this is one joint adhesive joint between structural element and the coating. And then there is one you can say the interface between the coating and the substrate.

Then we apply that tensile test and based on the location of the failure will try to access the bond strength. So, when the tensile test is performed and if the failure is taking place from the structural element and the coating interface bond admission from the adhesive joint which will indicate that the coating substrate interface is stronger than the adhesive joint which indirectly indicates that coating substrate bond strength is greater than 70 MPA.

So, if the failure location is this means that coating is coating substrate bond is stronger. If the failure is taking place from this location in that case it suggests the at coating substrate bond strength is weaker than the 70 MPA. So, the failure location basically if the failure is taking place like this is the coating this is the adhesive and this is the substrate. So, if the failure location is this means that the coating substrate bond strength is greater.

And the failure location is this which means that the coating substrate bond strength is lesser than the 70 Mpa. So, this is the indirect test method of the bond strength assessment.

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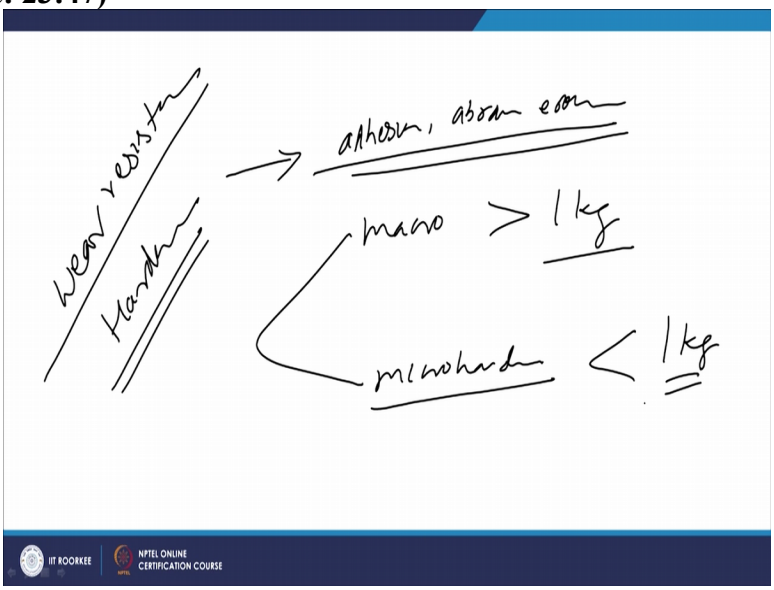


Apart from the bond strength another important property which is used for checking the wear resistance of the material is the hardness. This hardness indicates significant mechanical behaviour of the modified zones especially the resistance against the adhesion or abrasion, erosion. So, it is important to check the hardness of the modified zones. Basically there are two approaches one is called micro hardness and another is called micro hardness.

For the macro hardness basically we use higher value hardness of the load so for the macro hardness load magnitude is greater than 1 kg and for micro hardness load value used is less than 1 kg this is the broader distinction.

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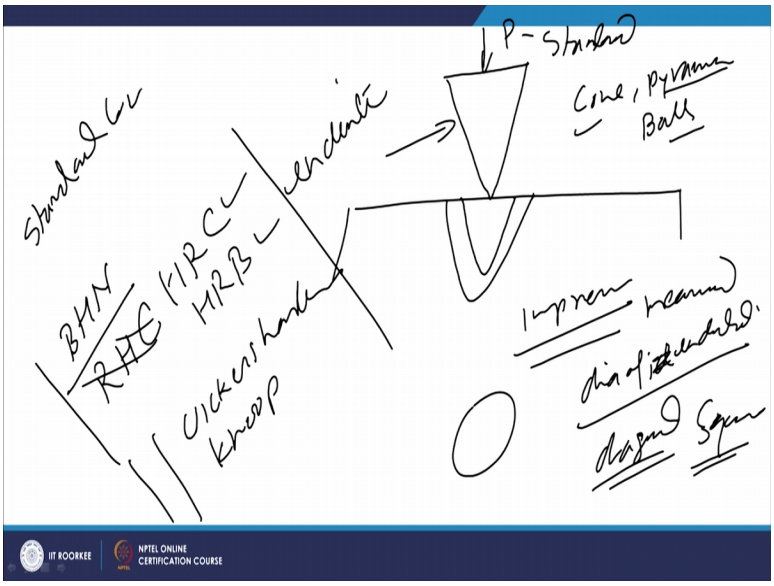


The basic principle of the hardness testing is simple where one had indenter of particular shape it may be in form of cone, pyramid it may in form of ball is used and one standard load is applied on to the modified surface and we will try to see how the surface of the modified surface is being affected because of this indenter. So, this is called indenter we apply one standard load and try to see how it is being affected.

Affected means what kind of what is the kind of impression being formed this impression is measured. Impression may in the form of diameter of the diameter of the indentation at the surface it may be the diagonal of the square shaped impression being formed in case of the pyramid or it may be the diameter in case of the conical shape impression being formed in case of conical indenter.

Now depending upon the hardness test there are variety of the hardness test like Brinal hardness test, Rockwell hardness test which is like a HRC or HRB these are the two common scales of the Rockwell hardness which are used for measuring hardness and then the two common hardness which are used for the micro hardness testing or like Vickers hardness test and Knoope hardness test these hardness test methods use the different value of the standard load and the different types of the indenters.

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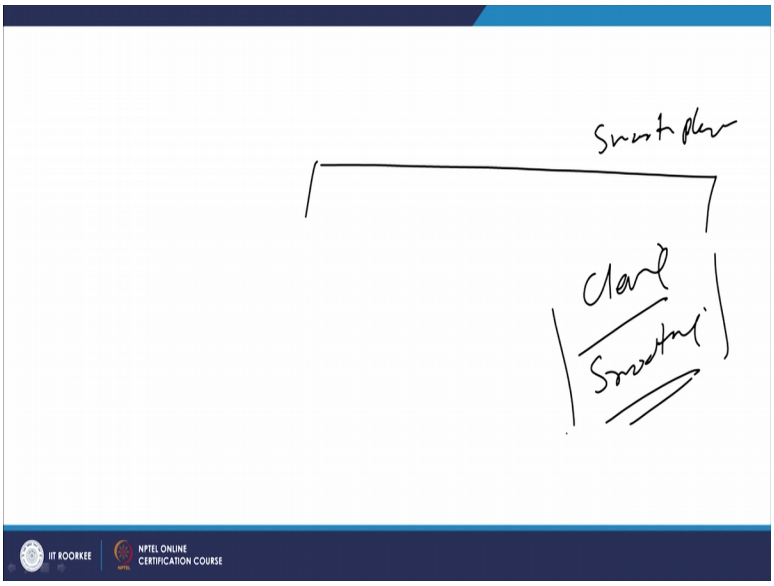


And there is one more like whatever the surface whose hardness to be checked that must be smooth, plain and free from impurities like oxides. Because if the oxides are present oxides may be harder for softer in so accordingly it will be decreasing or increasing the size of impression and that indirectly be giving the wrong value of the hardness. So, cleaning and smoothening of the surface whose hardness is to be checked is important

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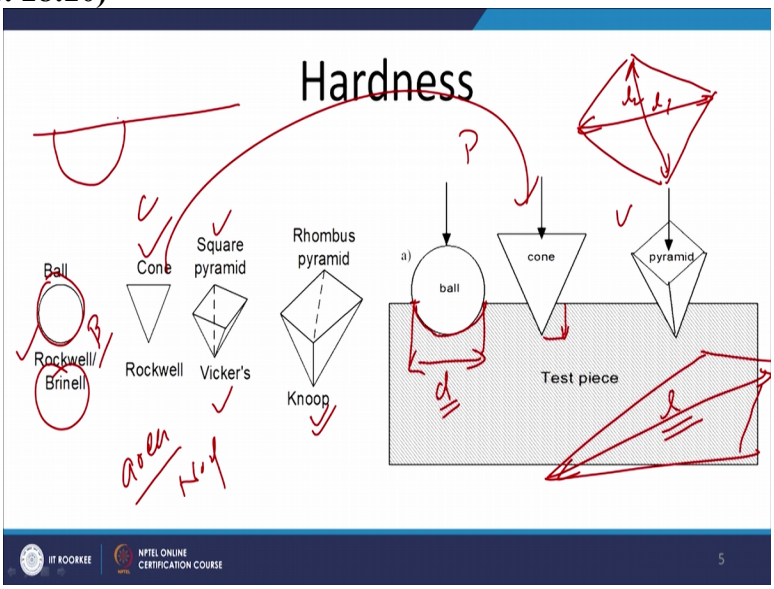


Considering this one if you see there are variety of the indenter which are used in different hardness tests like the ball, steel balls are used in case of the Rockwell hardness test for B scale and Brinell hardness test. Then cone is used in case of the Rockwell hardness test for C scale. Vickers hardness test uses the diamond in square shaped pyramid as indenter and Rhombus shaped pyramid is used for the Knoop hardness test.

And as I have said we apply standard load as per the test method and try to see up to what extent the intender has affected the sample and in this case like say the Brinall hardness test or the Rockwell B scale hardness test we measure the diameter of the indentation at the surface. In case of the cones which are used in case of like a Rockwell hardness tests on the C scale we normally measure the depth up to which the indenter has affected the work piece.

In case of the pyramid which is used in case of the Vickers's hardness test and the Knoop hardness test like square shape impression is formed in case of the Vickers's hardness test average of the diagonal length is used to characterize the Vickers's hardness value against the given standard load. While in case of the Knoop hardness test a typical geometry of this kind is formed and where we measure this length to characterize the knoope hardness value.

Micro hardness and macro hardness tests are different with regard to the area or you can say the number of the micro constituents which are considered. Since the micro hardness test is performed using the large size intenders and the heavy loads as compared to the micro hardness test. So, the macro hardness test like a Brinal Vickers hardness test provide give the more representative hardness values of the material which is being considered while in case of the micro hardness test which is primarily used for checking the hardness values of the individual constituents.

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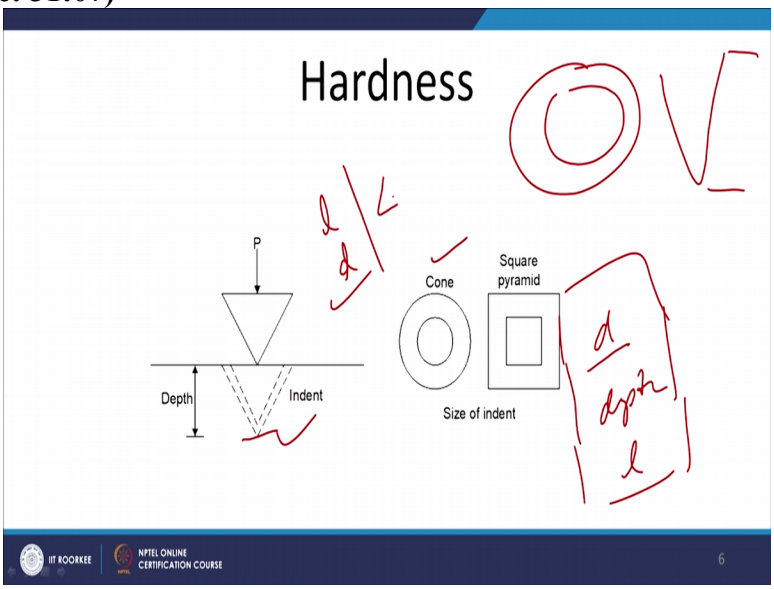


So, this is how it is done in case of the cones we measure the diameter of the impression which is in case of the cones are like in Rockwell hardness test on C scale image are there like this. So,

this will be indicating now there is one more important for a given diameter of the ball or for given depth of the indentation for the soft material we get the greater size of the indentation and greater depth of the indentation as compared to that of the hard material.

So, hard materials will be showing the smaller size of the indentation as compared to the soft materials. So, depending upon the diameter or the depth of the indentation which is being achieved are the length of the diagonals which is being achieved it will be indicating the hardness. So, this dimensions either the average length of the diagonals are the length of the diameter if these values are less than the hardness of the material against the given standard load will be higher.

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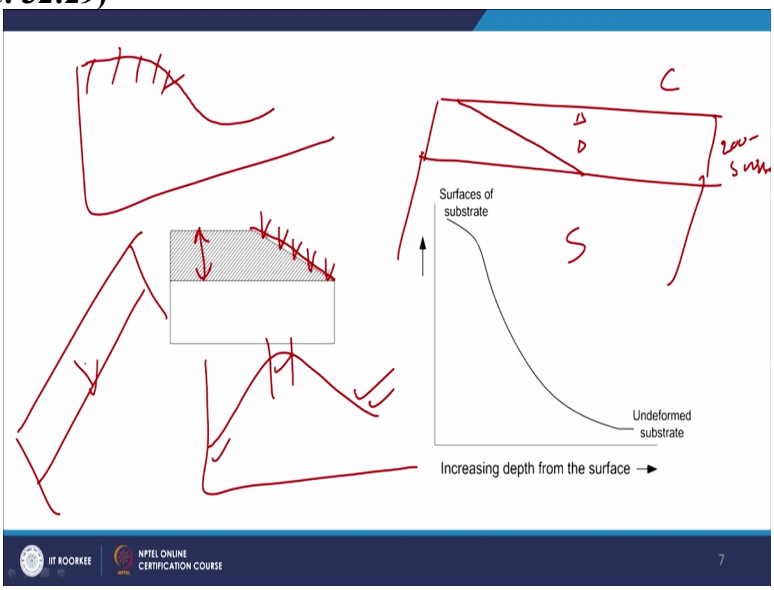


So, now there are certain methods like if there is modified surfaces will be like this is a substrate and this is coating. Since this coatings are very thin these coatings are very thin like maybe 200 to 500 micrometre. So, putting the intender in such a thin coatings will be difficult, so to measure the thickness variation from top to the interface what we do we make a slant surface like this. This may be 5 degree or 10 degree and then so we get the much wider length.

So, if this is the thickness when we prepare the sample from the slants surface we get much greater length and then indenters are put at the different locations to measure the variation in the hardness from the surface to the substrate. So, we will find that the surface is having the greater hardness and then hardness is somewhat decreasing. So, the surface at the top surface you get much greater hardness then at the interface due to the dilution possibilities.

But in case of the flame spread coatings you find the hardness variation of this kind maximum hardness at the middle and the less hardness at the top and the interface. So, depending upon the process which is being used like in case of the carburizing and nitriding we may get the maximum hardness at the top and then hardness value will keep on decreasing as we approach towards the interface.

So, depending upon the surface modification approach being used for modifying the substrate the different kind of the variation in the hardness values can be achieved. Now I will summarise this presentation, in this presentation basically I have talked about the two techniques of assessing the soundness of the modified zones one was the X-ray technique and another was the ultrasonic technique.

And both these help us to assess the internal discontinuities in the modified zones. In addition to that I have also talked about the techniques used for evaluating coating substrate bond strength and also and what are the various techniques which are used for measuring the hardness values. As I have said different loads, different intenders are used for measuring the hardness as per the kind of the thickness of the coating we can use suitable technique we can use the micro hardness or we can use the micro hardness testing methods. Thank you for your attention.