Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-24
Functionality Graded Materials and other Materials

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and we are talking about the materials for surface modifications. So that functional surfaces can be design in such a way that they offer desired tribological life. In the previous presentation I have talked about the thermal barrier coating materials which are primarily used for reducing the temperature of the main component while outside temperature maybe higher.

At the same time they are also use to resist the material loss from the functional surfaces which are working at thigh temperature using the suitable combination of the material. In that one we have also seen that the thermal barrier coating materials may have significantly different properties from the substrate especially with regard to the thermal expansion coefficient and if the thermal expansion coefficient is significantly different.

Then under the thermal cyclic variation conditions it can lead to the spoiling chipping off or suppression from the substrate and therefore we use the bond coat in the line of the same in the similar lines if we need the material properties in such a way that 1 side it has a 1 kind of property while on the other side it has a another kind of property.

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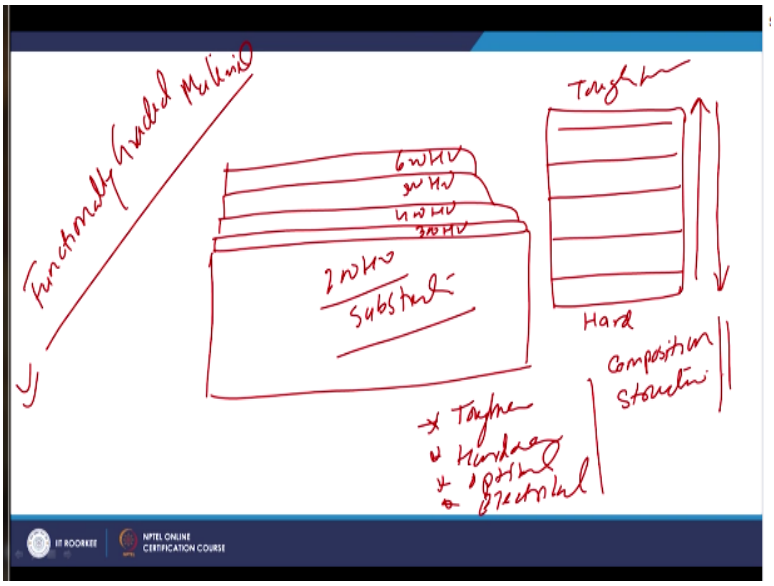

Then we need different kind of the material, say we want that material is very hard in one side and very tough on the other side. So this kind of due extremely different combination of the properties which are not available in conventional materials. So, to satisfy such kind of requirements the special category of the materials has been is being developed that is called functionally graded materials where there is a gradient in terms of the properties from one end to another.

Like say at the surface we want completely different set of the properties as compare to that of the substrate. So, we would like to have the properties at the next to the substrate or slightly different then at the surface then the further second layer is of the different property, third layer is offer the different property, fourth layer is offer the different property. So, what we try to do like if the substrate if offer a low hardness, we can say like 200Hv.

Then we will develop a layer of the 300Hv, 400Hv, 500 Hv, 600Hv, so means we are trying to have different layers of gradually changing properties and conventional materials are not of this kind wherein in the same material we have gradually changing values of a particular property and this kind of variation we may require in terms of the toughness, in terms of the hardness, in terms of the optical properties, in terms of the electrical properties.

So, if you want gradually changing properties from the substrate to the surface we need to have the special category of the material and that is what is called functionally graded material and such kind of the property variation where will have say for this combination will have increasing toughness this side and increasing hardness this side because the 2 properties are directly opposite to each other.

So, if we want to have the higher hardness then it will be done at the cost of the toughness and likewise for the toughness. So, this kind of the gradual variation is possible through the gradual variation in the composition, gradual variation in the structure of the material which is being developed. So, that the property required property variation can be achieved I will try to explain this in slightly different way say.

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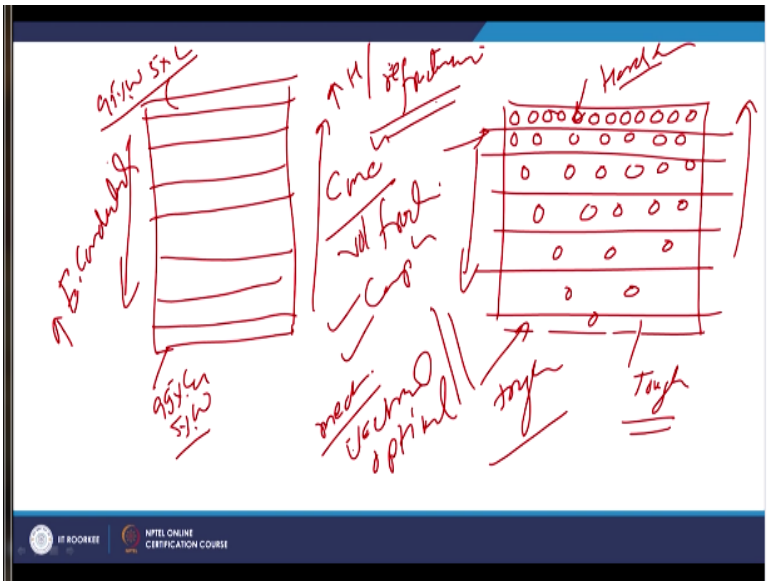

This is the one material and we are reinforcing this is the material which is soften ductile. So, this is tough material right and if we reinforce the higher fraction of the hard particle like ceramics are reinforced in very large concentration at the surface. And then concentration is gradually decreasing as we move below the surface then we will clearly notice the gradient in terms of the hardness and in terms of the toughness.

So, what we will notice in this case since the concentration or the volume fraction or the composition of the material is changing layer by layer and that is why there will be continuous

variation in terms of the properties. If the second phase which is being reinforced is hard and the metrics is tough then will be seeing here in this direction toughness is increasing and in this direction the hardness will be increasing.

And similarly we can develop the materials which will be having the varying composition and varying structures. So that required set of the mechanical, electrical or optical properties can be achieved. So that required function can be realised. There is an another example like in one side if you want the greater thermal conductivity and lesser effectiveness then this side we will have the 95% of the copper and 5% of the tungsten.

And on the other hand increasing tungsten concentration and reducing copper percentage at that top we may have 95% of the tungsten and 5% of the copper and such kind of the materials were certainly offer the in this case it will offer the increasing electrical conductivity and while in the opposite direction it will be offering the increasing hardness and increasing refractoriness. So, such kind of the gradients although possible through the controlled variation in composition are the constituents.

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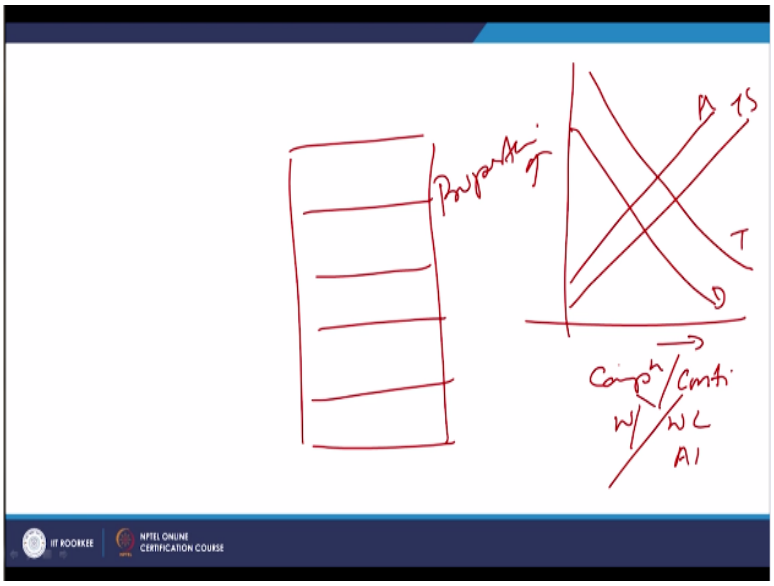

So, that the required combination of the properties is achieved and so that variation like say the composition or constituent variation if is plotted in the x-axis and the properties are plotted in the

y-axis. Then the varying composition like in this case tungsten or like say hard particles tungsten carbide if they are reinforced in the aluminium then what kind of variation will be getting.

We will see that hardness is continuously increasing tensile strength increasing on the other hand toughness and ductility is decreasing. So, such kind of the continuous gradient is possible by having in a material continuous variation in composition from the layer by layer approach this kind of variation in properties in very controlled way is possible for developing the functionally graded materials. There are variety of the materials which have been developed for making the surfaces which are wear resistant materials.

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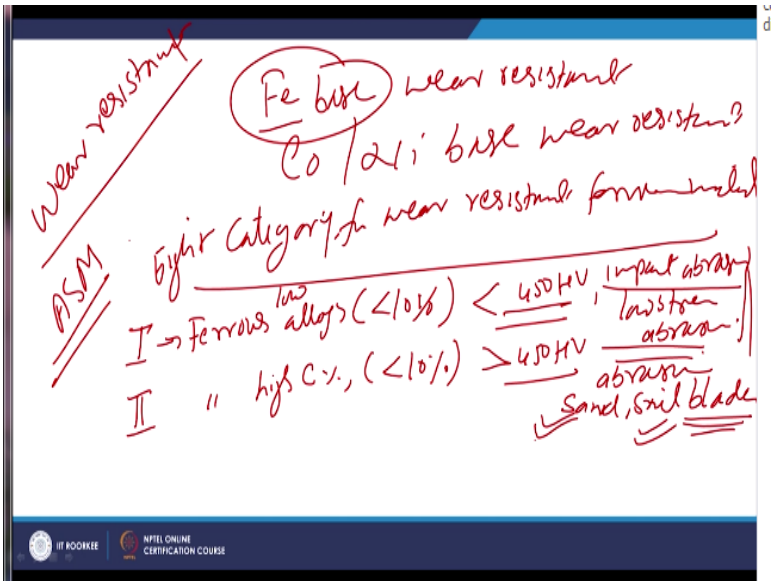

So, most of the developments have taking place around the development of the iron base wear resistant materials although the cobalt and Nickel base wear resistance materials also have been developed but those are for the special and specific applications. Since the most of developments have taken place for developing for making the wear resistant materials around the iron base alloys.

And therefore they are 8 broad categories according to the American society for metals there are 8 broad categories, 8 categories of the wear resistant materials. So, I will talk about each of the category one by one that what kind of the properties they offer and what for they are primarily used 8 categories of wear resistant ferrous materials which have been developed.

So, will be looking for the these categories one by one like the category 1 basically it is the ferrous category of the low alloy steel, low alloy ferrous category having the low alloys concentration alloy concentration is less than 10% and these offer the alloys having the low alloying concentration means that is less than 10% and offers the hardness lower than the 450 vickers hardness and these are primarily used are impact abrasion conditions means those conditions which are coupled with the impact and the low stress abrasion conditions .

Because it has lower hardness, so the toughness is good that is why these are better suitable for impact coupled with the abrasion resistant applications where good abrasion resistance and the impact condition is required and abrasion is of the low stress kind then there is a second category which is also the ferrous alloys and it has higher carbon content as compare to the first category 1.

But the alloying concentration in this case also is less than 10% but the hardness because of the higher carbon content is greater than 450Hv and because of this it is primarily used for abrasion resistant applications where like the sand, soil are to be handle using the blades. So blades are hard phased or covered with the category 2 wear resistant materials if they are to be used for handling or like in excavation or removing the sand and soil during the operation. Then such kind of a materials will be able to reduce the abrasive wear resistance effectively.

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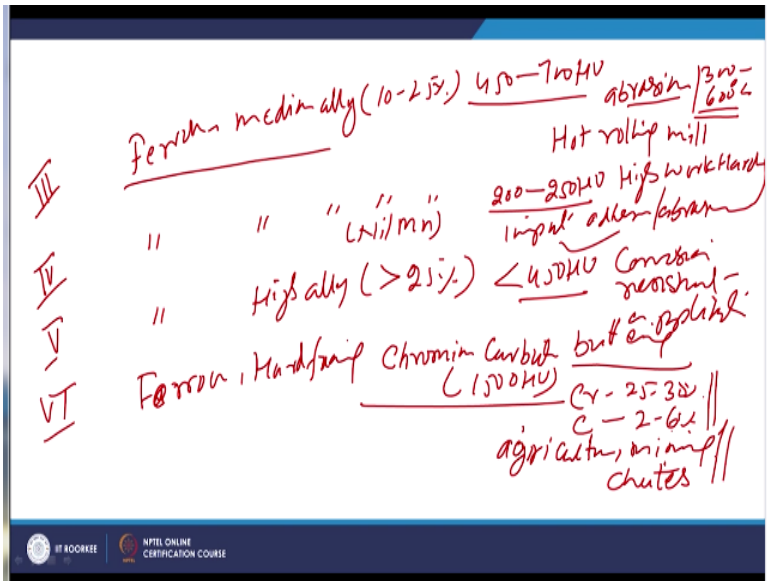

Then there is third category, in third category these are the again the ferrous based medium alloyed materials and these have the 10 to 25% of the alloying elements and the hardness is in the range of the 450 to the 700Hv. So, the hardness is on the higher side but these are used for the high temperature applications means abrasion under high temperature conditions like 300 to the 600 degree centigrade.

So, these kind of the conditions exist in the hot rolling mills, so since the hot rolling mills will be experiencing the abrasion under the high adhesion as well as abrasion at high temperature. So, in order to resist the material loss by wear under such conditions category 3 ferrous materials are used for surfacing. So, that the tribological life can be enhanced and the materials from the functional surfaces can be reduced.

And then we have the another category 4 which is also of the ferrous medium alloyed steel having 10 to 25% of the alloying concentration. But these are of very low hardness like 200 to 250Hv basically alloying of the nickel, manganese kind of the elements are used, these have the low hardness. So, initially their hardness is low but these offer very good work hardening capability and because of this work hardening capability these chutes for very good for impact adhesive and abrasive wear conditions.

So, these are used for such kind of the conditions were impact coupled with the abrasion and adhesion is involved. Then there is a fifth category wherein the higher concentration these are iron base and these are high alloy materials having the alloying concentration greater than 25% and these are these will be having the hardness less than 450Hv and these are used for corrosion resistant application and for the buttering purpose.

Then there is a category 6 and the materials which are primarily used for primarily these are the ferrous systems and these are used for hard facing. Primarily these consist the chromium carbide, chromium carbide which is of the hardness of like 1500Hv this is much higher as compare to that of the martensite and to realise this the chromium in this is in the range of 25 to 30% well carbon to form the chromium carbide it is found 2 to 6%.

So, these are high chromium and high carbon hard facing systems which are primarily used in the agriculture field, mining industry and used also in chutes where high abrasion is involved. So, mainly in the mining industry, agricultural industry and cement industry wherever the abrasion is the dominating such kind of the material systems are used.

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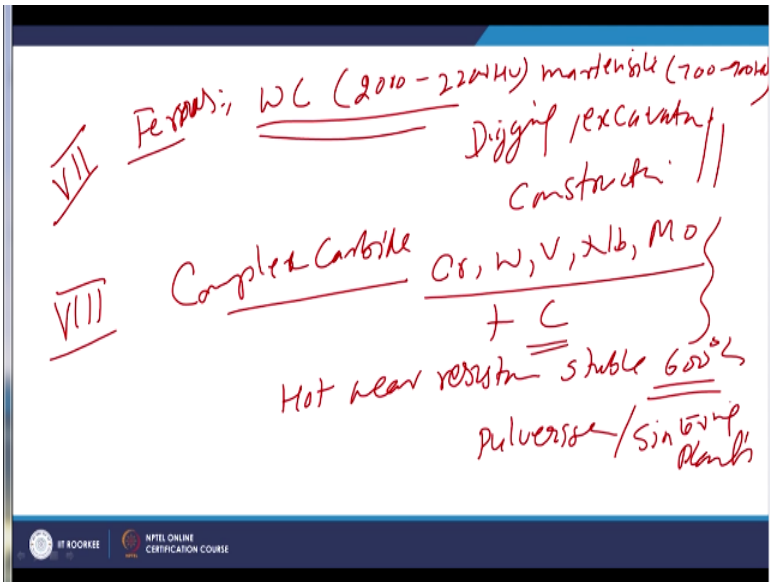

Then there is category 7 kind of the materials which are used for wear resistant applications these are also of the ferrous systems these have the tungsten carbide as a main element for enhancing the wear resistance capability the tungsten carbides offer the hardness to the tune of 2000 to the

2200Hv and these are designed to be in the martensitic metrics. So, martensitic transformation is common and these are enforced with the tungsten carbide.

So, they offer the good resistance to the abrasive wear condition, so martensite offers the hardness to the tune of 700 to 900Hv. So, martensite itself it is considered to be very good in terms of the wear resistance and when it is reinforced or when it highest the tungsten carbide then it offers very good resistance to the abrasion mainly in the components which are used for digging, excavation in the construction industry such kind of the hard facing materials are used.

And then the last one eighth category of the ferrous base systems which are used for wear resistant applications these are designed to have the complex carbides and which are these complex carbides are realised through the presence of the chromium, tungsten, vanadium, niobium and molybdenum elements coupled with the high percentage of the carbon.

So, they are stable carbides are formed and whenever such kind of the materials are developed means the iron base systems having the complex carbides they offer very good hardness or high temperature wear resistance. Because these complex carbides remain stable up to 600 degree centigrade without losing much of their hardness and that is why these are used for high temperature applications like in pulverisers and sintering plants.

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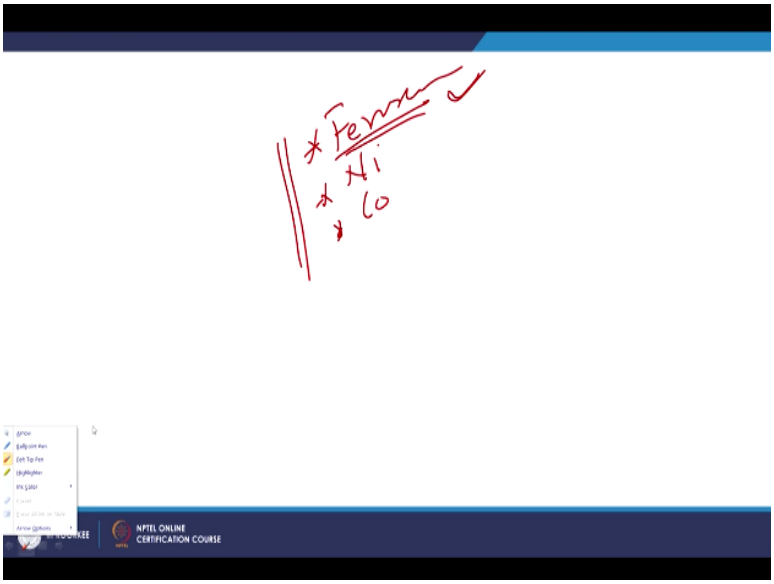

So, we have seen that there are 8 categories of the materials and which are of the 3 broad families which are primarily of the iron base family, ferrous base system but there are 2 other categories like Nickel base alloys and the cobalt base alloys. So, what are the different constituents different hardness what for these are used that is what we have talked about the ferrous base systems.

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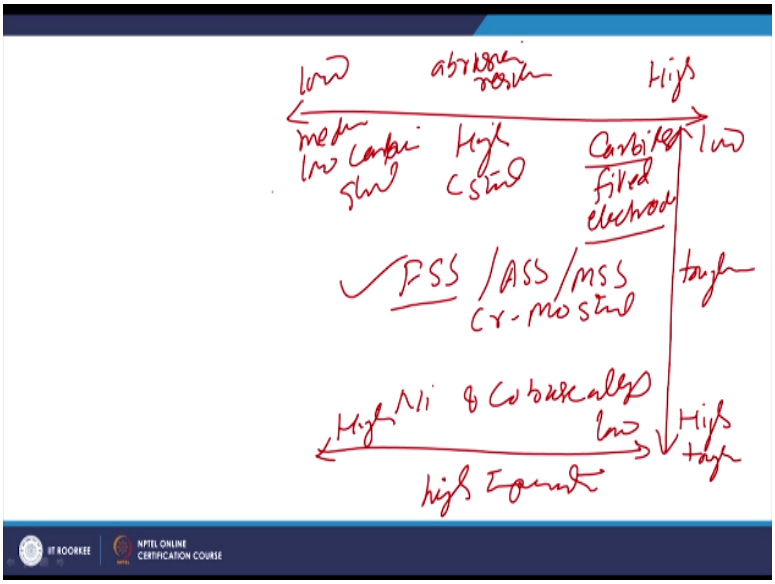

Now we will see how to choose the kind of materials if there is very wide range of the choice wide range of the materials are available for choosing with. So, there is a general guideline for the choice of the materials that is what I will be making here like say this is high toughness and this is high abrasion resistance, this is toughness and this is high temperature.

So, this side low, this side high, this side low, this side high, so there are low and high. So, what we will see high abrasion resistance and toughness is low because when abrasion resistance is high this they will have be having the higher hardness and when the hardness is high the toughness is low. So, this kind of situation is there when the carbides like tungsten carbide, chromium carbide filled electrodes are used.

They offer very good abrasion resistance but they offer the low toughness. On the other hand here we can use the low abrasion resistance and so like medium and low carbon steels, high carbon steels, on the other hand good combination of the toughness as well as the high

temperature resistance what will have like the ferrite stainless steel and austenitic stainless steel, martensitic stainless steel, chromium molybdenum steels.

And here high temperature like nickel and cobalt base alloys, so this is the category where they have high toughness as well as high temperature resistance, the medium toughness and medium abrasion resistance is available with the and good toughness is available with the ferritic, austenitic and martensitic and chromium molybdenum steels while on the other hand on the top we have abrasion wear resistance.

So, all these like high carbon steels carbide filled electrodes and the low and the medium carbon steels. So, this is the like say broad guideline for choosing the materials for various applications. Now here I will write some of the materials for variety of the applications like for abrasion conditions.

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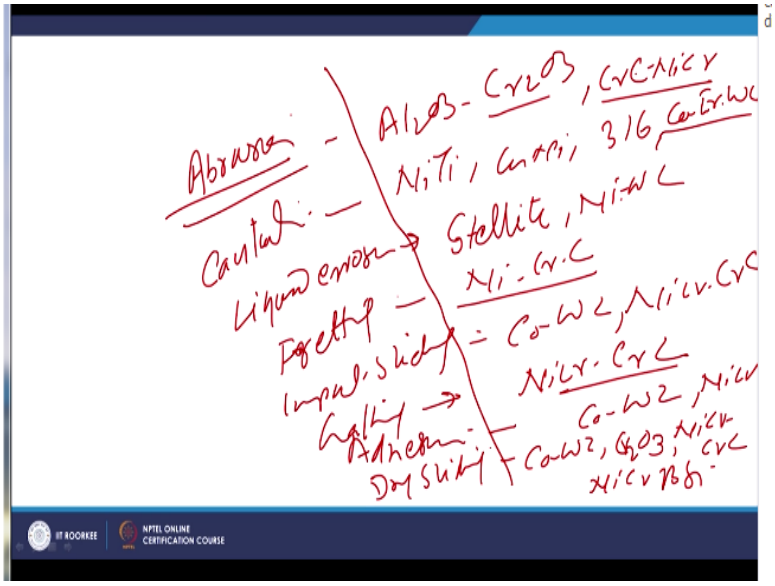

If the abrasion conditions are being experienced by the component then coating of alumina and chromium oxide Cr2O3, the chromium carbide and the nickel chromium systems are used and for cavitation erosion conditions nickel, titanium, copper nickel and 316 AiSi 316 stainless steel and cobalt, chromium, tungsten carbon systems are used for cavitation resistant applications for liquid erosion like in hydro turbines and pumps.

The stellite which are cobalt base alloys and Nickel tungsten carbide base composite systems are used for fretting wear conditions nickel chromium carbide systems are used and for impact sliding conditions sliding under the impact conditions cobalt tungsten carbide, Nickel chromium, chromium carbide systems are used while for galling conditions means the adhesive and the high temperature conditions nickel chromium, chromium carbide systems are used for adhesive wear conditions.

Cobalt tungsten carbide systems, nickel Chromium systems are used and for the dry sliding conditions, dry sliding conditions like cobalt, tungsten carbide, chromium oxide and nickel chromium carbide system as well as nickel chromium, boron, silicon systems are used. So, these are the as per the kind of the wear conditions which are being experienced the variety of the materials which are available can be used.

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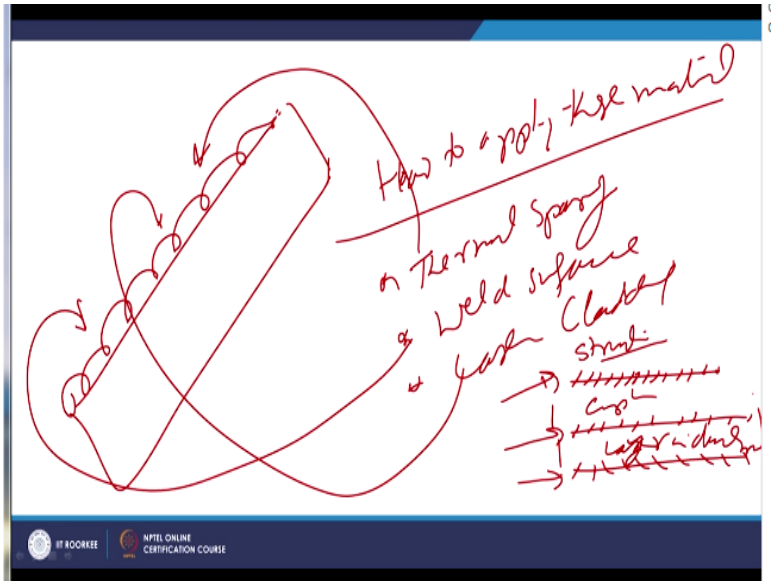

So, that the suitable wear resistance functional surfaces can be develop in order to resist the wear. Now how these materials will be applied, how to apply these materials for that variety of approaches exist and these includes like the thermal spraying, weld surfacing, laser cladding and likewise the list is endless. In all these cases we need to build up a layer of the suitable material on the substrate.

So, for this purpose we may use spraying, we may use weld surfacing, we may use laser cladding etc., but there are various other methods wherein we may like to modify just the surface structure. So, that required set of the properties are achieved we may like to modify the surface composition, so that required properties are achieved or we may like to build-up a completely different materials layer, so that required properties are achieved.

So, these are the 3 broad categories where just the structure is modified then the composition is modified and then third is a layer is developed. So, these are the 3 different approaches now in further lectures, now will be staring the different techniques which are used for modifying the functional surfaces. So, far we have talked about the different mechanisms that cause the material losses from the functional surfaces.

And we have also talked about the materials which can be used to resist the wear of the material from the functional surfaces. Now will see what are the techniques which can be used to develop the functional surfaces, which can resist the tribological conditions for enhanced tribological life of the component, thank you for your attention.