Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-22
Metal Systems

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and we are talking about the materials for wear resistant applications and in the previous presentation we have talked about the different material properties which play a big role in governing the rate at which material will be removed from the functional surfaces and these properties help in selection of the suitable material for enhancing the tribological life.

In this presentation basically we will try to see the different metal systems which are available and which are used for developing the wear resistance surfaces through 2 various approaches of surface engineering. So, we will try to see what are the various options as for as metal systems are concern or available for modifying the surfaces suitably for enhancing the tribological life.

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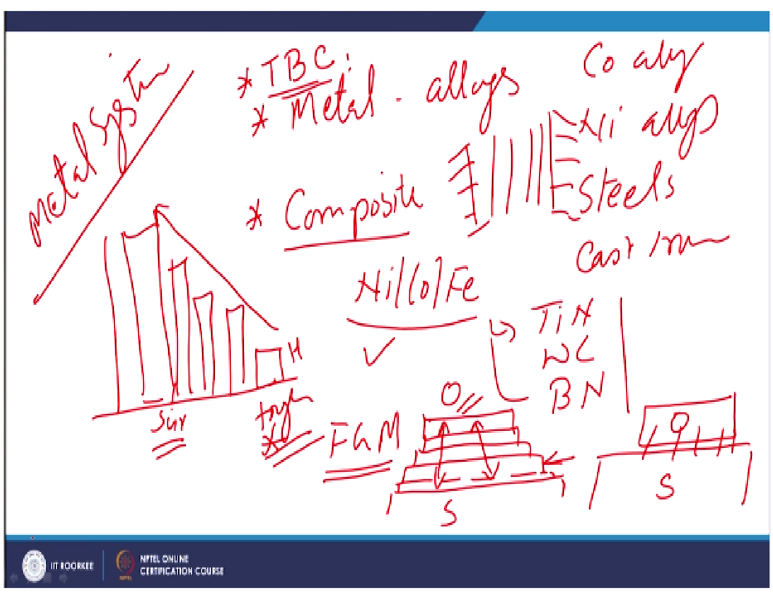

So, here if we go there are the options are the metal systems which are available, metal systems wear resistance metal systems. So, 1 is like simple metals which are basically alloys, these maybe in form of like cobalt alloy or Nickel alloy or various types of the steels cast irons etc., all these are alloys. Then we have the composite materials where in the soft matrix like Nickel, Cobalt, iron is reinforced with the hard constituents maybe in form nitrides, carbides, borides.

So such kind of the hard ceramic particles are reinforced in the soft matrix in order to have the combination of contradicting properties like combination of the toughness and high hardness. So, such kind of the benefits are exploited by using the composite materials, then there is another category of the metal systems which are like functionally graded materials, in functionally graded materials so for what we have talk like we will use metal A with certain kind of the properties which is applied over the substrate.

In order to have the engineered surface with required properties but there can be huge mismatch between the substrate and the overlay or the coating or the material being applied over the substrate. So this kind of the mismatch can be a problem, so in order to reduce such kind of the issues the substrate is applied first of all with 1 layer of the material having the composition close to the substrate then slightly different from the substrate further different from the substrate.

And likewise continuously changing compositions and finally we have a material which is actually to be applied. So, this will be close to the overlay material which is to be applied and this substrate and in between we have the different layers of gradually changing compositions. So, this is what is achieved, so functionally graded material means the different property the different layers will have the different set of properties.

And there is a particular gradient, for example if we want very high hardness at the surface and at the surface and very good toughness at the substrate or we can say if we want very high hardness at the surface and we want the toughness at the substrate surface. So, between the 2 will have the different layers which will be offering the different degree of the hardness or the toughness like this.

So, hardness for this is minimum and hardness will keep on increasing until it reaches to the required hardness at the surface. Similarly the toughness will be in opposite order means the hardness increasing, toughness will be decreasing. So, we will try to have such kind of the materials where 1 side is having 1 type of property and another side is having another type of property and in between there is a continuous gradient with regard to the properties that is what is called functionally graded material.

And there is one more category apart from the functionally graded material that is the thermal barrier coated materials. So, alumina and zirconium or zirconia is very commonly used material for this purpose what is the application of this like this.

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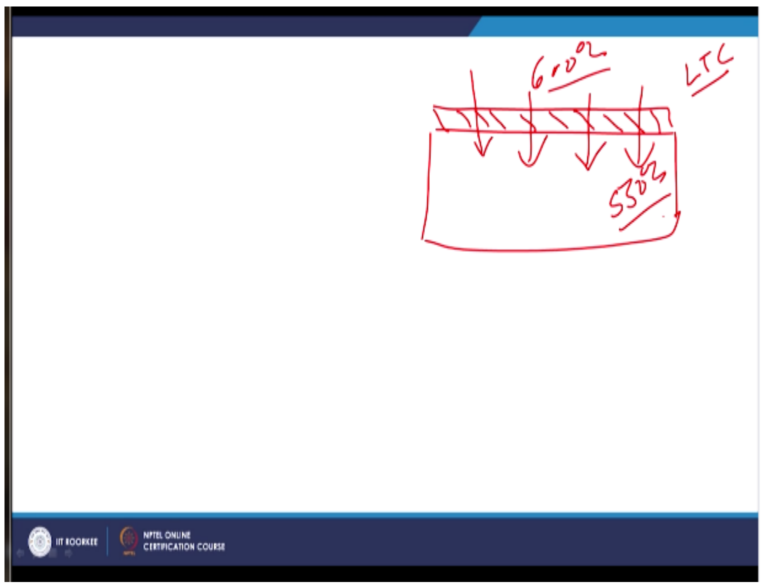

If you want that this surface will be exposed at high temperature like say 600 degree centigrade but we do not want the rise in temperature of surface above 550. So, the surface will be coated with such kind of material which will reduce the transfer of the heat from outside to the substrate. So, it will be applied with the low thermal conductivity metals and application of low thermal conductivity materials will reduce the transfer of heat from the surrounding to the substrate.

And thereby it will be reducing the temperature by it 50 degree or 100 degree centigrade that is the kind of difference which is normally achieved when thermal barrier coatings are applied. So, application of thermal barrier coatings will be increasing the capability of the component which is standard to high temperature while maintaining the component actually at lower temperature, so will be talking little bit about the thermal barrier coating materials also.

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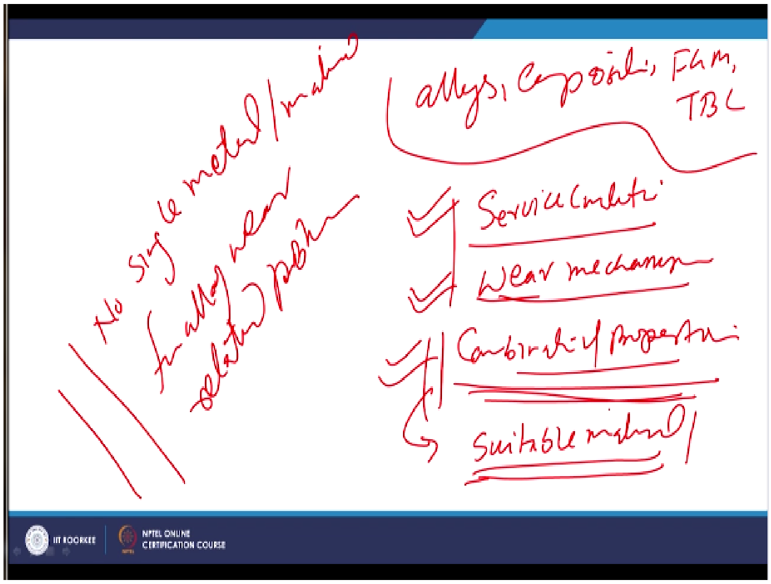

Now as far as the choice of the materials like the alloys or composites or the functionally graded materials or the TBC's which one is to be chosen for from that will depend upon the kind of the service conditions which will be experienced by a component during the service or these service will be determining the wear mechanisms responsible for material loss, in light of these things will try to see what combination of properties we should have in material surface.

So that the material degradation or material loss from the functional surfaces can be reduced, so those combination of the properties need to be identified and in light of these combination of the properties will be selecting the suitable material. So, whether will be going for alloys, composites functionally graded materials that choice will be govern by the kind of properties that we are looking for.

And which kind of the material can offer the properties required properties using the lower investment in terms of the processes cast and materials which are to be applied for modifying the surfaces using such kind of the materials. So, as per as so there is no single metal or material for all wear related problems why because the different service conditions different wear mechanisms requires the different combination of the properties.

And such kind of the combination of the properties will be available with the different metal systems and that is why we need to use variety of materials for variety of applications. And therefore we say there is no single material for all wear related issues. So, what we need to do we need to consider the service conditions analyse the service conditions and identify the operational wear mechanisms. Then identify the properties that we should have and accordingly we can select the suitable material for a given application.

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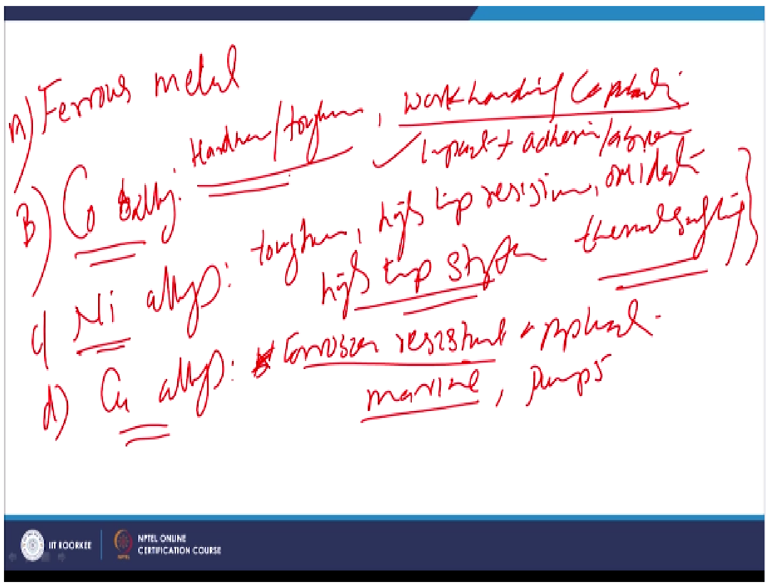

Now what are the options which are available normally there are broad group of the metal systems like ferrous metals is 1 category then for B we have Cobalt base cobalt alloys then C nickel alloys and D we have the copper alloys. These are the broad categories of the metals which are normally used for wear resistant applications. So if we see here the copper base alloys are normally used for the corrosion resistant applications.

Like the components of marine, components or those components which are used like pumps, they are normally made of the copper base alloys because they offer good resistance to corrosion, nickel offers very good toughness, very good high temperature resistance and resistance to high temperature resistance in terms of the oxidation and thermal softening. So, these are the positives of the nickel base alloys high resistance to the high temperature oxidation or resistance thermal softening.

And good toughness even at the lower temperature at the same time it offers the high temperature strength. So, these are the properties which are required for good resistance of the material for the tribological conditions then will be choosing for the nickel base alloys, cobalt base alloys on the other hand they are of very good hardness and toughness combination, another important aspect is they are very good in terms of the work hardening capability.

So, they are good for those wear conditions were like adhesion with the impact or abrasion with impact. So impact coupled with the adhesion and abrasion such kind of the material systems offer very good resistance to the abrasion and adhesion coupled with the impact. So for these conditions will be using the cobalt base alloys, cobalt base alloys offer very good combination of the hardness and the toughness.

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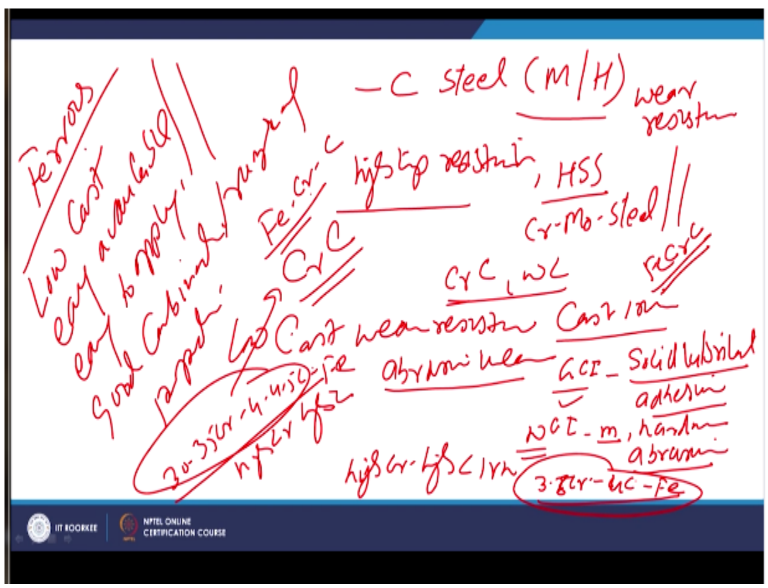

Now the most common ferrous metals which are extensively used most common metals which are used for wear resistant application is the ferrous metals. So, ferrous metals are very low in terms of the cost easily available and easy to apply. So because of these features these are extensively used and offers the good combination or the range of properties**.**

Like there is very wide range of the metals which are used as per as the ferrous metals are concern, it includes like carbon steel, simple carbon steel like medium carbon and high carbon steels are used simply where high hardness will do the work. So, for simple low cost wear resistant application medium and high carbon steel is selected, no alloying elements. On the other hand if we want that okay some high temperature resistance, high temperature hardness is required.

Then why not to go for high speed steel or chromium, molybdenum steels, these will be offering good resistance to the softening at high temperature. Then these metals reinforced with the hard particles like chromium carbide, tungsten carbide, further offer very good resistance to the high temperature. Then there are simple for low cost wear resistant materials include cast irons, cast irons are hard and brittle.

But they are very good under the abrasive wear conditions a very good abrasive in abrasive wear conditions. So, there are various types of the cast irons. For example there is a grey cast iron GCI the present in grey cast iron x as a solid lubricant. So, this solid lubricant works very good under the adhesive wear conditions. So, like lath guide ways or those applications where we want the good adhesive wear resistant at low cost.

So, grey cast iron is very good, white cast iron which primarily has the molten site with the other phases offers extremely high hardness and because of this we good get very good abrasive wear resistance certainly these are not good for the impact conditions because high hardness leads to the brittleness and that increases the wear especially under the like cavitation conditions or a solid particle erosion conditions or the abrasion coupled with the impact under those conditions why cast iron is not good.

Now there is one more improvised and improved version of the irons is the high chromium, high carbon iron. So, what we have there are various variants like we may have 3.5% chromium or like 4% carbon balance iron. So, this is 1 and there can be possibility of 30 to 35 % chromium then 4 to 4.5% carbon balance iron, so these are high chromium and high carbon irons.

So, there is a lot of difference when the chromium is less and for a given quantity of carbon we get the very fine mixture of the chromium, iron chromium carbide which of is the good resistance to the wear, adhesive wear as well as abrasive wear. But when the chromium content is high then it leads to the formation of the chromium carbides and chromium iron, chromium carbon carbides in big in form of big polyhedral shape particles.

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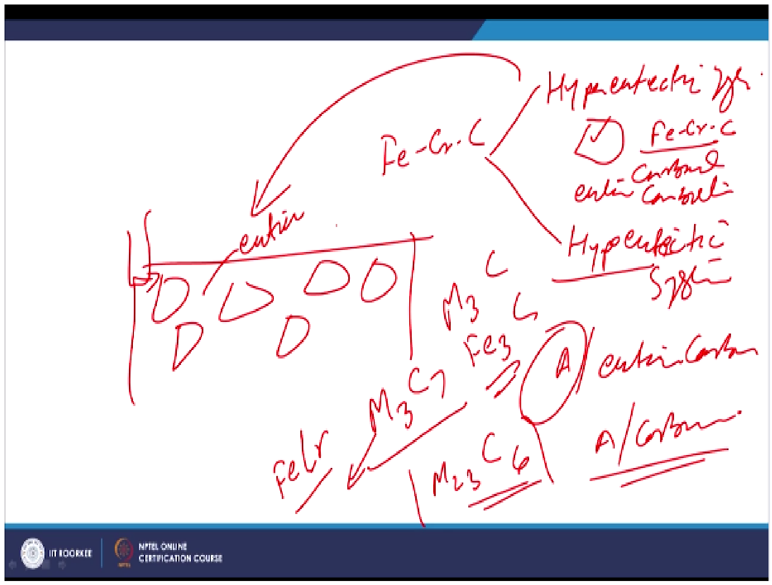

So, basically the in iron-chromium-carbon systems we have the hypoeutectic system and hypereutectic system where the big primary polyhedral shape iron-chromium-carbon-carbides are form apart from the eutectic carbides. So eutectic carbon and in case of a hypo eutectic systems basically we have the austenite and the eutectic carbides.

So, eutectic carbides basically austenite+carbide mixture, so in and the matrix is of the austenite in this case basically we have the big primary carbides of the iron-chromium-carbon. So, in a metrics having large primary chromium-carbide or inter-metallics of a chromium, iron and carbon and carbide particles these are known as M3C7, where M stands for iron and chromium combination.

There can be M23C6 this is another variant of the carbide or M3C is also which is basically iron-carbide. So, various types of the carbides are formed in case of the hyper eutectic we have this situation, so under the abrasive wear conditions hard particle were moving they it is path is effectively restricted by such by presence of such primary carbide particles.

And in the metrics we have the fine eutectic fine mixture of the eutectic having the austenite+ and the carbide or maybe ferrite+the carbide measure depending upon the kind of the chromium and carbon which is present in a given metal system. Now this was the story behind the iron-chromium and carbon systems. Now if we take a simple iron-carbon systems like in simple carbon steel.

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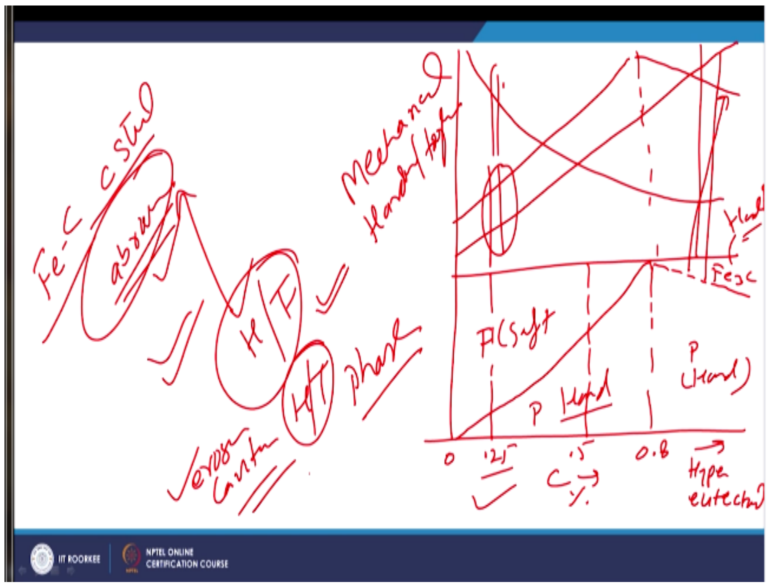

So, how does it will be leading to the variation in wear resistant we know that the chromium the carbon content in steel directly affects the phases present in the steel. And say 0% carbon, 8% carbon in the x-axis. So, there is the if we increase the carbon content there is increasing fraction of pearlite and decreasing fraction of the ferrite. So, this is the ferrite % and this is the pearlite %.

So, pearlite percentage will be increasing and it will become 100% at the eutectoid point at 0.8% and the ferrite will become 0 and further higher content of the carbon will be leading to the presence of the pro eutectic Fe3C that is the siemen type and the pearlite percentage % will keep on decreasing after that. So, too high since the iron-carbide is harder than the pearlite and pearlite is harder than the ferrite.

So, increasing percent of the pearlite will simply be increasing the hardness and when the iron-carbide is starts appearing in the metrics then it will be increase in the hardness for that. So, if we see this is about the phase variation as a function of the carbon content. So, for low carbon steel ferrite is dominating up to like say 0.25, the pearlite is less and ferrite is more for medium carbon steel or let us say the for medium carbon steel 0.5 to 0.25, 2.5.

The ferrite is less and pearlite is more, so further higher hardness and pearlite is higher means 100% for 0.8% carbon and thereafter pearlite percent is starts decreasing and iron carbide is starts appearing. So, since this one is soft this is hard and this is hardest as for as the this is hard this is the pearlite zone and this is hardest. So, increasing friction of the hard phases will be changing the mechanical properties accordingly.

And we know that hardness, toughness both will be going in opposite way. So, if we just see initially the hardness then hardness will keep on increasing. Because after this even after this hardness keeps on increasing because presence of the iron carbide is starts appearing or is iron-carbide is starts appearing after the above the 0.8% carbon weight and this is the side of the high per eutectoid steel and below this we have high pole eutectoid steel.

On the other hand the toughness decreases very rapidly, so hardness and toughness both go in both show opposite strength as per as the strength is concern, the strength will be increasing continuously up to eutectoid point there after starts if they starts decreasing and this activity through the presence of the iron-carbide above the 0.8% carbon. Since the hardness and toughness are the 2 important properties or 2 big properties which will be governing the various wear mechanisms and the rate of the material removal.

So the carbon content directly affects the mechanical properties and so there wear behaviour, if the abrasion is the only wear mechanism then will be focusing on the hardness and if it is coupled with the impact kind of thing like in solid particle erosion or cavitation then we need combination of both hardness and toughness and for that properties need to be selected or carbon content has to be selected in such a way that it has a combination of both.

If we want just a very high hardness then low carbon content systems are selected, so that sorry if we want very high toughness then low carbon content in steel with a low carbon content is selected. If you want just high hardness and steel with the high carbon content will be selected.

So the choice of the steel and the steel with proper kind of the carbon content that will be governed by the kind of application. The kind of properties which are required and this intern will be dictating the kind of carbon content we should have in given steels.

So, this is how we can relate the steel composition with the various phases and the mechanical properties and accordingly we can relate that which kind of the material which kind of the composition as per as plain carbon steel is there should be selected for improved tribological life of the component for a given situation. So for abrasion we want hardness, for cavitation and erosion conditions we want combination of hardness and toughness. Similarly for adhesion also we want good combination of the hardness as well as toughness.

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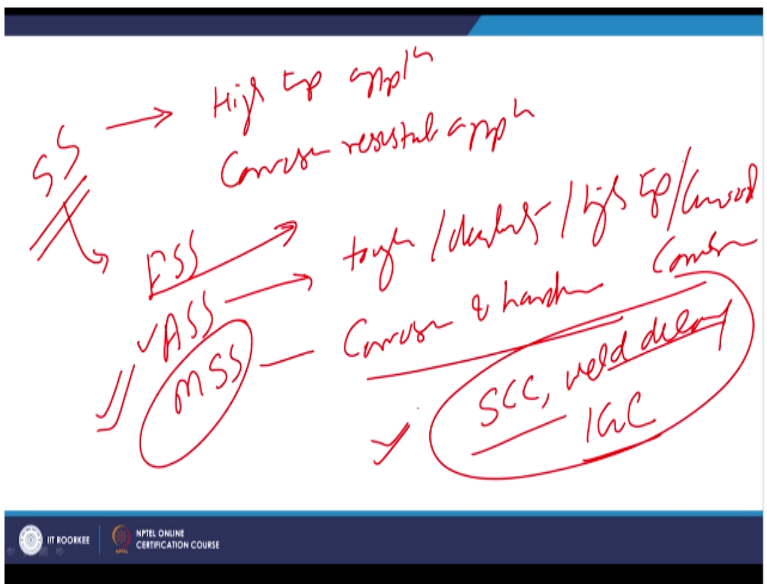

Now there are few other unique kind of the metal systems and their role is identified in a particular way. For example stainless steels, stainless steels are mostly used for high temperature applications, corrosion resistant applications. So these are the conditions then will be choosing the material accordingly again there are various categories in a stainless steel will have ferritic stainless steel, austenitic stainless steel and martensitic stainless steel.

If you want that surface is engineered for corrosion resistance as well as good hardness, then will be relying heavily on the martensitic stainless steel. If you want the good corrosion resistance and reasonable toughness and strength then ferritic stainless steel is selected. And good toughness, ductility, high temperature resistant and good corrosion resistant then will be using the austenitic stainless steel.

So, we need to see what are the service conditions, what are the properties which will be important for given set of service conditions and then accordingly will be choosing the suitable kind of the metal systems. And if it is not selected properly then it can lead to the various issues like stress corrosion cracking in case of the stainless steel if the metal is not properly processed it can lead to the weld decay, this is another corrosion problem or inter granular corrosion.

So, these are the issues which are observed and which also frequently lead to the failure if the material is not processed properly. So we may be applying these metal systems judicially in order to see that these kinds of the issues do not arise. Then we have another kind of the metal systems which are in the nickel base systems.

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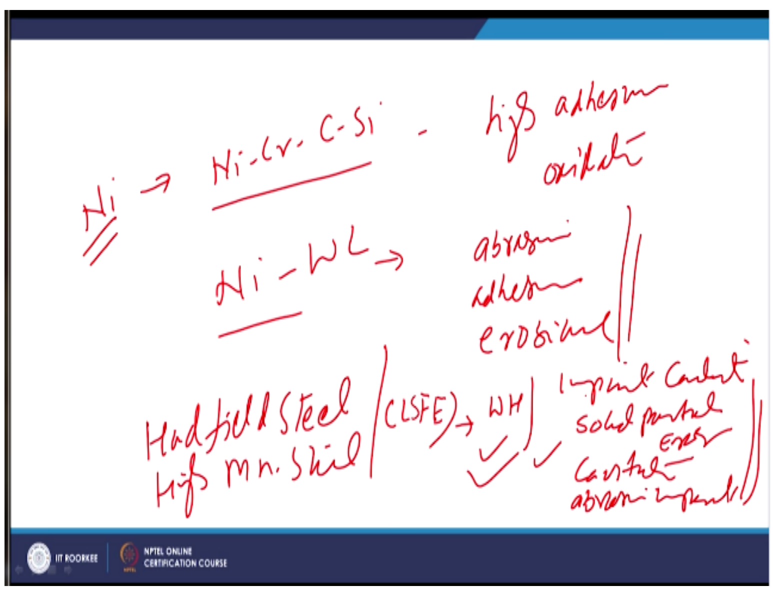

We have the nickel-chromium-carbon-silicon, this is 1 system which is normally used for good high adhesive wear resistance and high temperature oxidation resistance, nickel-tungsten carbide kind of systems are used for group at abrasive and adhesive wear resistance as well as these also work very effectively under the erosive wear conditions like solid particle erosion conditions.

Then the 2 very commonly known materials like had field steel and high manganese steels, these are the 2 metals which have the low stacking fault energy. So these metals show very good work hardening tendency under the impact conditions like surface solid particle erosion, cavitation or abrasion coupled with the impact. For these conditions had field steel and the high manganese steel work very effectively.

Because the good work hardening tendency make the surfaces harder and stronger which effectively restricts the loss of the material from the functional surfaces by these wear mechanisms because of the improved hardness. Now I will summarise this presentation, in this presentation basically I have talked about the various metal systems which are available for engineering the surfaces.

So, that the tribological life of the component can be improved and these metal systems include like iron base systems where in we have a carbon steel, alloy steel, stainless steel and various types of the irons like white cast iron or grey cast iron and iron chromium high chromium and high carbon iron. Then we have nickel base alloys, cobalt base alloys and in steel categories we have had field steel and high manganese steels.

So, as per the service conditions we need to analyse the properties required for reducing the metal removal rate or the reducing the wear rate. So, that suitable kind of the material can be selected for engineering the surfaces, so that the tribological life of the component can be improved, thank you for your attention.