Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-03
Surface Properties and their Modification

Hello, I welcome you all in this presentation related to the subject fundamentals of surface engineering and in this presentation we will be talking about the important surface properties and the general approaches which are used to modify the surface properties. So, as we have talked in the previous presentation that they are 2 important aspects related to the surface features 1 is the surface regularities which is quantified in terms of the surface roughness.

And the second is about the sub surface zones there are 4 or 5 sub surface zones apart from that there are number of properties of the surface which governed the way by which material loss from the surface takes place which in turn affects the life of the component and especially under the tribological conditions. So, these properties are like physical properties, chemical properties, mechanical properties and the dimensional properties.

We have talked about the physical properties and in this presentation we will be talking about the 3 properties that is the chemical properties, mechanical properties and the dimensional properties. And there after will take up the general approaches which are used to modify the surface properties, so first of all will be taking up the chemical properties of the surfaces.

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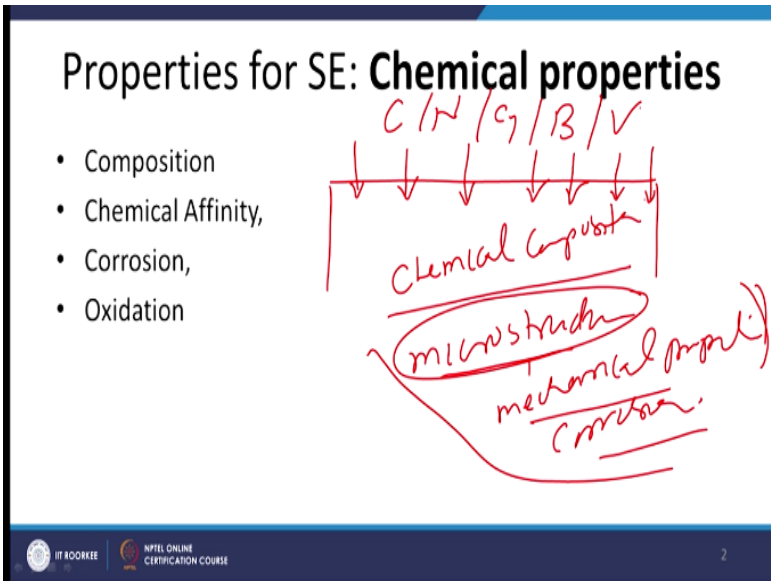

So, we know that all the surfaces will be made of the 1 or other kind of the metal system. So, chemical composition of the metal of which component is made is of the great importance. Because it affects the micro structure of a given metal and microstructure in turn affects the mechanical properties and sometimes even the corrosion properties of the surfaces are also affected.

So, what are the different constituents which are there in at the surface that will be governing the structural or meteorological properties and so mechanical properties or the corrosion properties. Chemical composition modification of the surface is one of the major category of the surface engineering where near surface layer composition is modified as per the requirement.

So, that the meterological features of the near surface layers can be adjusted to change the mechanical and tribological properties of the component as per requirement like carburizing, nitriding, cyaniding, boronizing, vanadizing are all these are examples where the near surface layer composition is modified through the controlled use of these elements to modify the chemical composition of the near surface layers.

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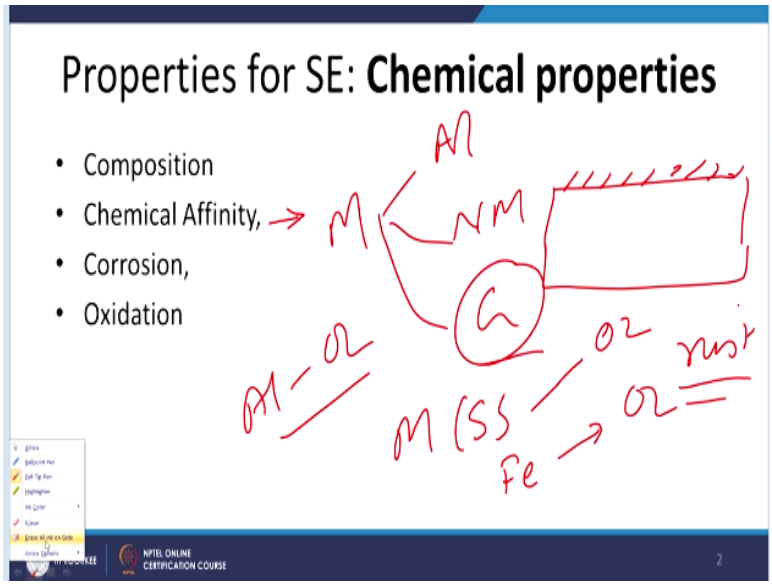

Another important aspect of the chemical properties is the chemical affinity, we know that all the metals will have some kind of affinity with the other systems which maybe of the like say metals or the non-metals or the gases. So, we can say metal to metal and non-metals or the gases, so most of the time like the gases which are present all around where the component is being used.

Sometimes these interact with the metals in favourable way but many times it does not happen, so like the application of the metals like stainless steel whenever it interacts with the oxygen it forms very thin layer of the chromium, oxide corrosion resistance of the stainless steel is thereby but like the iron simply when interacts with the oxygen it forms the rust or the iron oxide and adversely affects it.

As the same as true for the aluminium and oxygen interaction, so these are the interactions sometimes these interactions are favourable and many times it is not favourable and this kind of whether it is whether some kind of interaction or the affinity of the metal with the gases is favourable or not.

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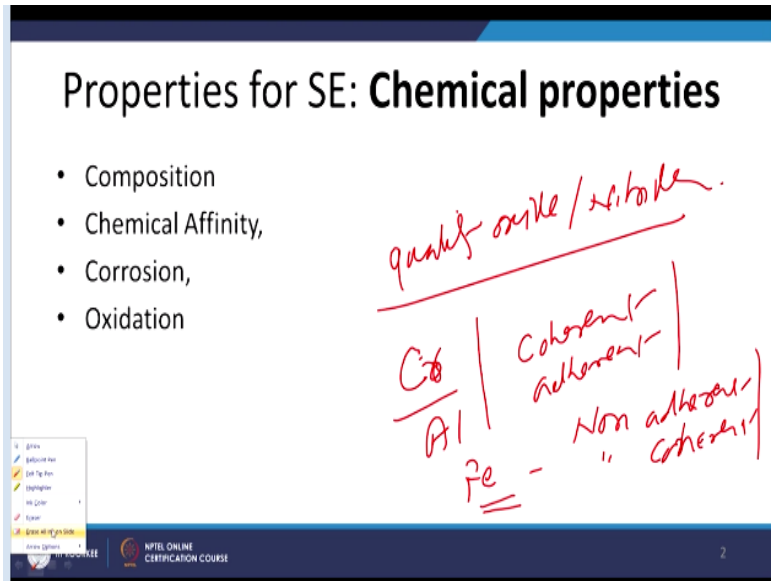

That also depends upon the quality or the characteristics of the oxides or the nitrides which are being formed at the surface. For example some of the oxides like the oxides formed by the chromium or the aluminium. These oxides are very you can say coherent and adherent. So they are a nonporous and they remain stick to the surface of the metal and thereby they offer the good resistance the further oxidation of the metals.

But, on the other hand metals of the iron whenever they oxides they it results in the porous and non adherent, non coherent oxides are form. So these are easily removed, so continuous formation of their oxides and removal also leads to the very fast rate of the material removal from the surface. So, depending upon the kind of interaction or the compounds which are being formed it may be favourable or it may be unfavourable.

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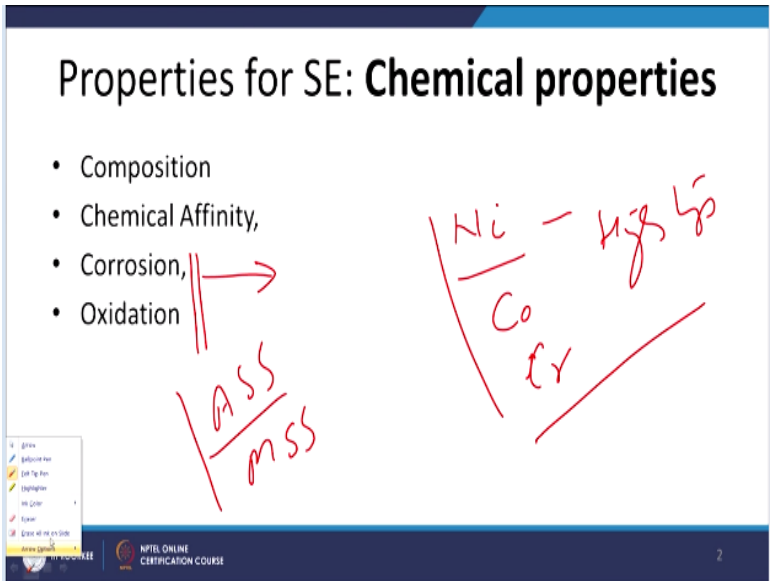

Like I have just said that the corrosion and oxidation both are the part of the surface properties or surface characteristics the way by which surface is respond to the surroundings in which the particular component is being used. So, like some of the metals show very good resistance to the oxidation even at a higher temperature. So Nickel or the Cobalt or the Chromium base systems are effectively used for the high temperature applications because of the good resistance to the oxidation.

Similarly some of the metals like austenitic stainless steel or even martensitic stainless steel where our good corrosion resistance is required in such kind of the metals are used. So, all the metals do not interact in the same way to the surroundings depending upon their affinity to the surrounding gases and the environment.

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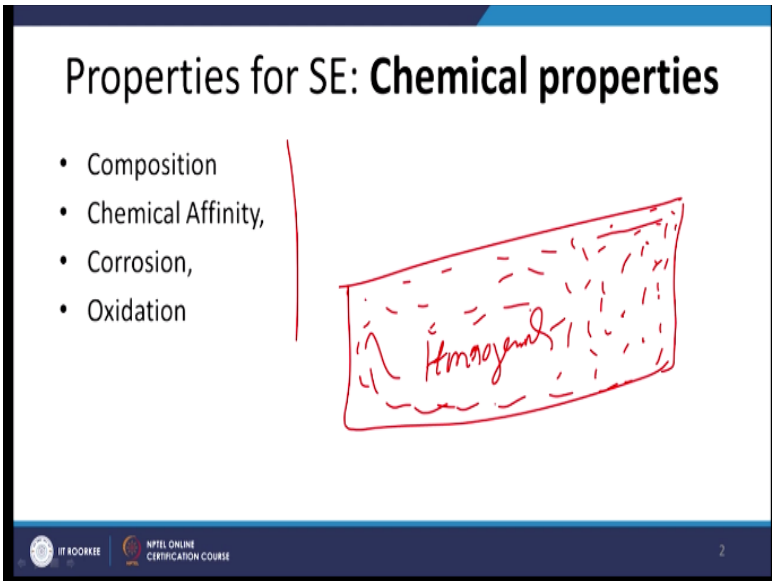

They are resistance to the material loss is influenced, so not just the chemical composition affects but the homogeneity of the chemical composition is also important. So it is required that whatever alloying elements are present in a given metal that is present everywhere, it is so there is no segregation and if there is a segregation then it will be leading to the formation of the easy galvanic salad which will be improving which will adversely affecting the corrosion resistance.

So, homogeneity of the chemical composition leading to the absence of the segregation or localised presence of the some of the elements that will further improve the corrosion resistance or the resistance to the oxidation. So, not just a chemical composition but the way by which the different alloying elements are distributed in a given metal system is also important.

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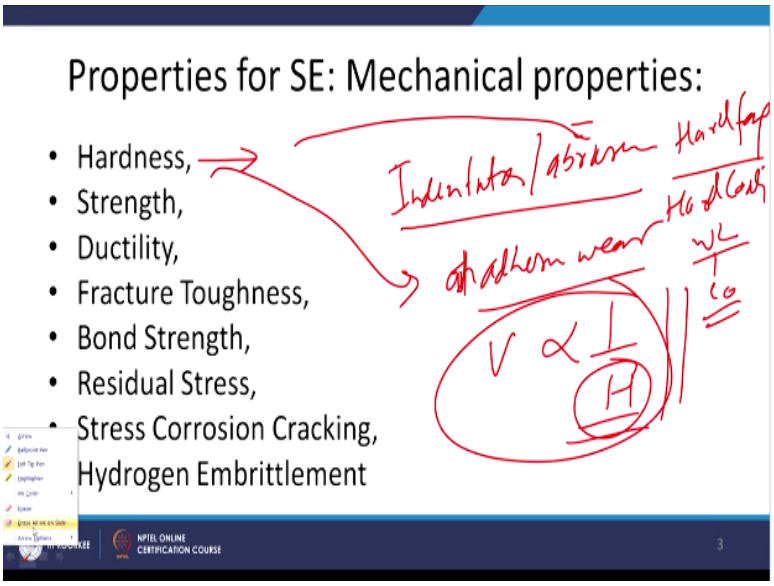

Otherwise it will adversely it will be adversely affecting the their resistance to the especially the corrosion or the oxidation. Coming to the mechanical properties they are various mechanical properties which are of the great importance especially for the wear under the adhesive, abrasive, erosive conditions. So, will be talking about the various properties like the hardness, hardness you know that hardness shows a resistance to the indentation or abrasion.

In general, so higher greater is the hardness greater will be the abrasion resistance that is very simple. But in addition to that higher hardness also leads to the good adhesive wear resistance and there is a famous archer's love which since that the volume of the material loss is inversely proportional to the hardness and this is for the adhesive wear conditions.

Although it does not hold good in on entire range of the conditions what is very classical law governing the adhesive wear resistance of a given metal and which relates it with the hardness. So, hardness is resist is define as a resistance to the indentation or the abrasion. So metals having the higher hardness they will be resisting the indentation very effectively as compare to those which will be having the lower hardness.

And that is why for the abrasive wear conditions normally the hard facing or the hard coatings like tungsten carbide in the cobalt matrix are applied over the surface. So, that it can effectively offer the resistance to the abrasion.

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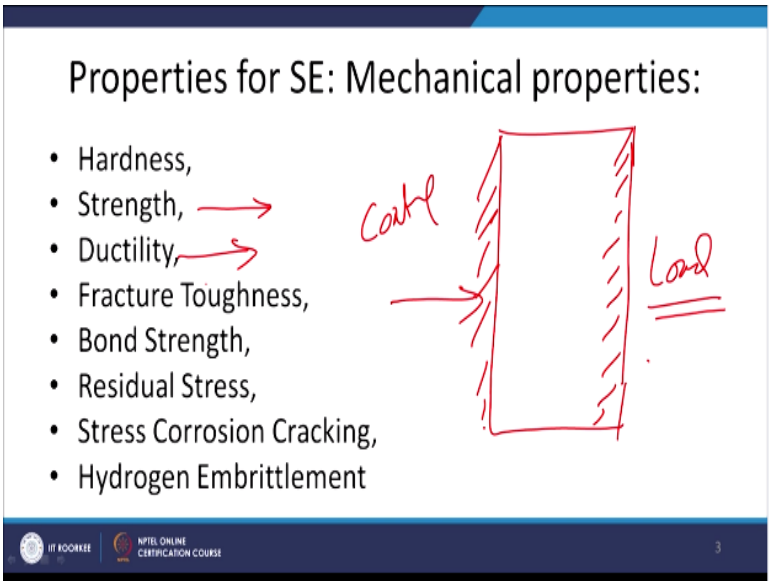

Strength is important especially for those conditions where it is suppose to take the load, you see if the surface has been modified by either applying the coatings or through the surface has been modified through the diffusion of the alloying elements it must be hard enough. So, that it can take the service loads and if it does not take the surface load then there maybe lot of then the load will be transferred from the surface to the underlying metal.

And it may lead to the formation of the like unimmunised at the surface or a localised surface layer deformation. Similarly the ductility is also important especially where the heavy loads will be acting onto the component during the service. So since the ductility resist the nucleation and growth of the crack effectively. So those metal system where there is a possibility of the surface layer deformation during the service and formation of them crack surface cracks it is then it is good to have the reasonably.

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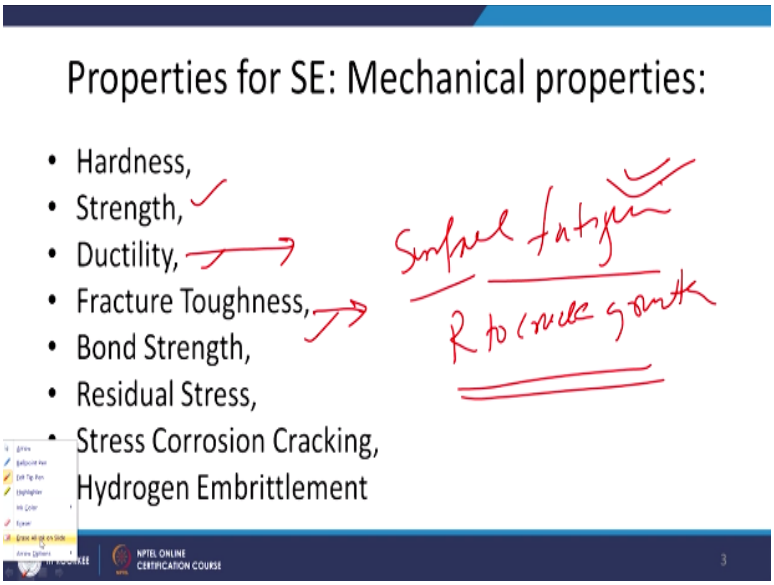

Then it is good to have the reasonably good ductility, so that it can resist the nucleation and growth of crack especially the conditions like surface fatigue conditions where a combination of the good, strength and ductility will effectively be checking the nucleation and the growth of crack fracture toughness is also important. Because it is shows the resistance to the crack growth, so surface fatigue or the fretting wear or the erosive wear or cavitation wear.

Wherever there is a continuous impact due to the busting of the bubbles or impact of the particles leading to the near surface layer, deformation development of the cracks and their subsequent growth leading to the removal of the material from the surface. So under those conditions strength ductility, fracture toughness properties will be playing big role in resisting the loss of the material from the surface.

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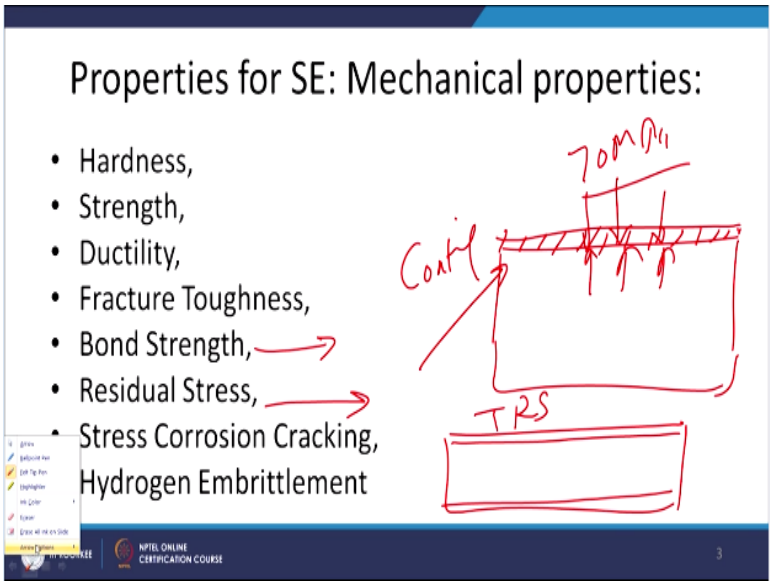

The bond strength is especially important for the coatings as accepted international factors whenever a substrate is modified through the application of the coatings. So, the coatings must bond with the substrate effectively with the required strength and this strength is must be greater than the 70MPA. Otherwise there will be tendency for peeling off or spalling of the coating from the substrate.

So, means our purpose of surface modification will be defeated if the coating is removed from the surface, residual stress is another aspect like if the surface layers are heated and then cool then sometimes this lead to the development of the tensile residual stresses. So, those processes where very localised heating at the surface followed by rapid cooling takes place under those conditions surfaces are under the tension while the sub surface regions will be under the compressions.

So, such kind of the residual stresses, presence of tensile residual stresses especially leads to the increased tendency of the crack nucleation and their growth. So the failure of the component maybe premature if the tensile residual stresses are present and therefore sometimes surface modification is intentionally carried out.

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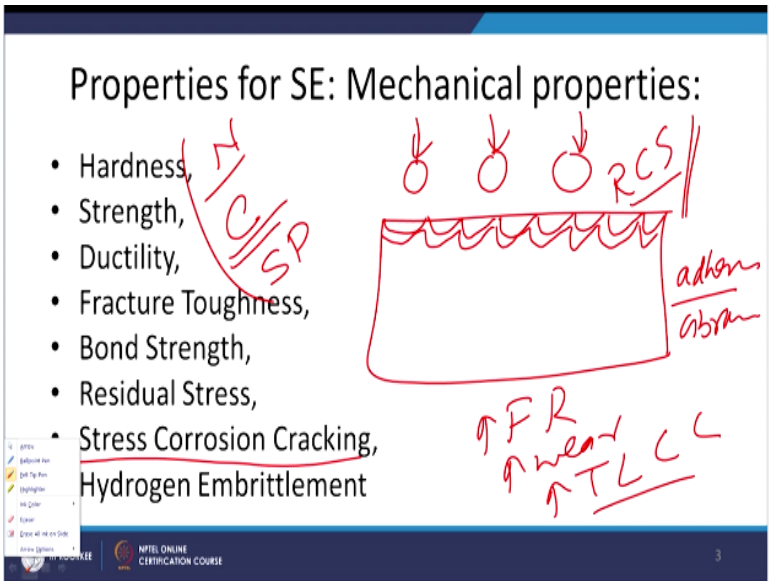

In order to have the residual compressive stresses at the surface, so the application of the surface modification approach like short peening onto the surface will be leading to the localised surface layer deformation plastically as well as sub surface will be subjected to the plastic deformation and this in turn leads to the development of the compressive residual stresses. So development of the residual compressive stresses improves the fatigue resistance, improves the wear resistance of the component.

And improves the tensile load carrying capacity of the component, so setting up of the residual compressive stresses to surface modification is another favourable aspect which is commonly achieved in the processes like carburizing, short peening carburizing even nitriding helps in developing such kind of the residual compressive stresses which help in improving the mechanical performance of the component as well as improves the resistance to the loss of material from the functional surfaces especially under the adhesive and abrasive wear conditions.

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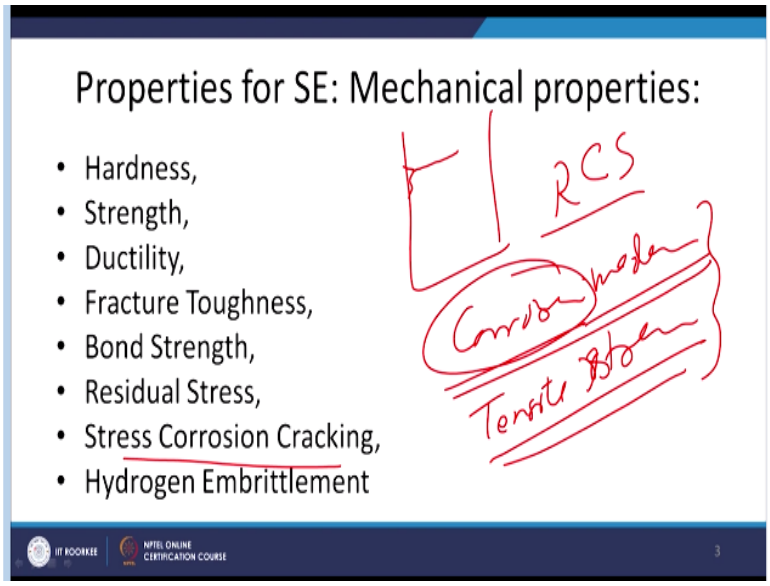

Then the stress corrosion cracking occurs under the condition of the corrosion media means in the metal system is sensitive to the corrosion and the corrosion medium and the tensile stresses. So, the metal sensitive to the corrosion media and tensile stress in presence of these 2 effects the metal system show very faster growth of the crack. So, first the cracks are nucleated in the zone of the higher stress concentration.

And once these cracks are nucleated then they will be growing at much faster rate and such kind of conditions lead to the much very premature failure of the component under the stress corrosion cracking conditions. So, development of the residual compressive stresses helps in reducing the tendency of the stress corrosion cracking.

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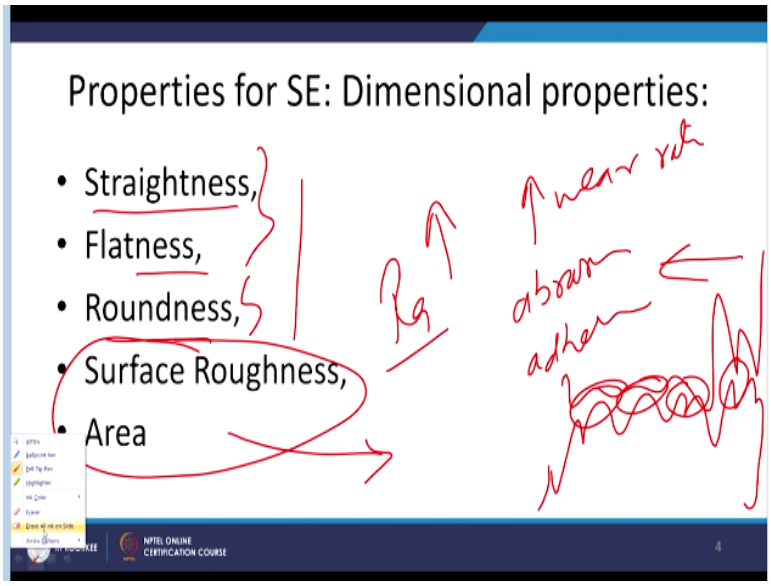

Now will be taking of the dimensional properties and try we will try to related with the resistance to the wear like straightness, flatness are important to have the smooth movement of the component during the service. Similarly the roundness of the component these are the surface properties or dimensional properties of the component which are made by the various manufacturing process.

And then they characterize to see what kind of the straightness, flatness and the roundness is present in the component which is meanwhile probably the 2 most important properties that affect the whereby it is material loss which will be taking place is the surface roughness that is Ra and the surface area. So, as for as surface roughness is concern so in general greater is the surface roughness higher will be the wear rate.

Especially under the abrasion and adhesion conditions, why because especially under the adhesion conditions when these peaks and valleys are very deep. So, the under the adhesive wear conditions very easy bonds between the peaks and valleys are formed which under the relative movement conditions easily lead to the removal of the lot of material from the functional surfaces.

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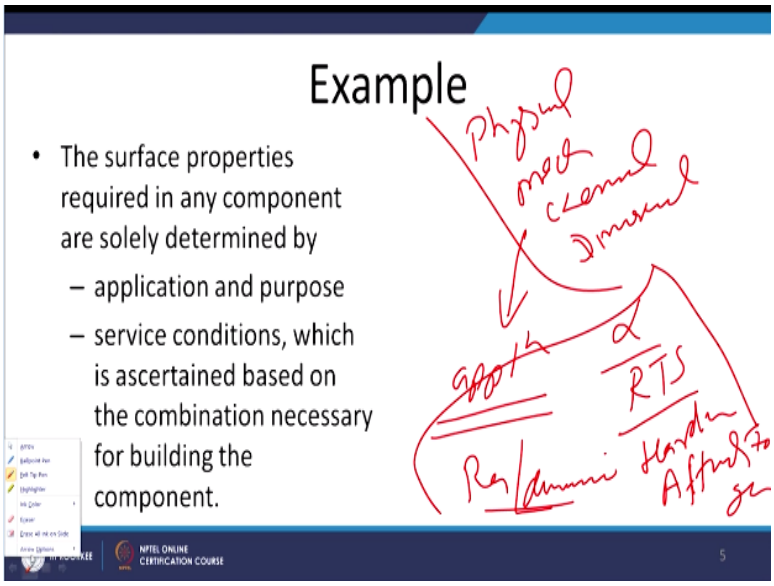

Similarly under the abrasive wear conditions, if like 1 metal which is very hard and it is interacting with somewhat smoother material which is soft, so one is soft and another is hard. So, hard metal when interacts hard metal having the higher surface roughness when interacts with the softer metals. So, these peaks which are present in the hard metal they will be indenting the soft metal and under the relative movement conditions between the 2.

One is scratch or these scratches are goose will be formed onto the softer surface and will be causing the lot of material removal by the abrasive wear mechanism. So, when the surfaces are rough especially hard surfaces if they are rough they will be abrading the soft surfaces very rapidly and will because in the greater metal removal rate. Similarly the kind of relations of exist in like if the surface area.

Since there are lot of combinations, there are lot of possibilities as per as the properties or avail properties which are to be considered for improving the wear resistance say these are the physical properties, mechanical properties, chemical properties and the dimensional properties. So, number of properties is available in each of the category of these properties.

So, for a given combination what kind of the physical, mechanical combination what kind of combination of physical, mechanical, chemical and dimensional properties which should have that will depend upon the application for which is being considered like which kind of the

thermal expansion coefficient which kind of resistance to the thermal softening has to be there, what kind of the hardness is to be there, what kind of the affinity of the gases with the affinity to the gases is needed.

And what kind of the surface roughness or the dimensions of the component are required. So, there is a lot of variability or difference in such kind of the combinations which can be chosen as per the applications.

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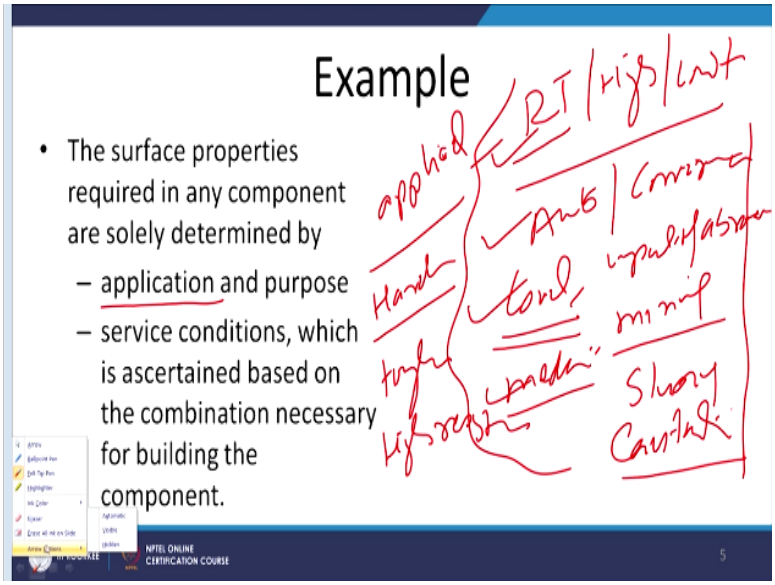

So, what is important here the application is very important like the component which is being considered for surface modification where it is being applied, where it is being used application is under the room temperature condition or high temperature or low temperature condition. It will be used under the ambient condition or in corrosion condition like petrochemical industry or any other condition, so ambient condition or the corrosion condition.

Similarly what kind of the load which will be acting, load is like in form of a impact of the abrasives like in the hydro power turbines which will be experiencing the impact of the sand particle or slurry, sand particles present at the slurry or a impact of the busting bubbles during the cavitation effect or impact during the excavation using the different excavators.

So, the load and kind of the medium across which it is coming like in the mining different kind of the abrasive mediums which will be there as compare to that where excavation is carried out and then the medium like as I have said the slurry is being used or like cavitation where particular kind of the fluid is flowing through the different kind of system.

So, as per the case means where the component is to be used what are the temperature conditions, ambient condition or to corrosion conditions, load, medium across which the component will be coming. We need to identify the suitable combination of the properties whether it is hardness is important or the toughness is important or the high temperature refractoriness or the high temperature resistance is needed or resistance to oxidation is needed what is needed actually that is to be identified.

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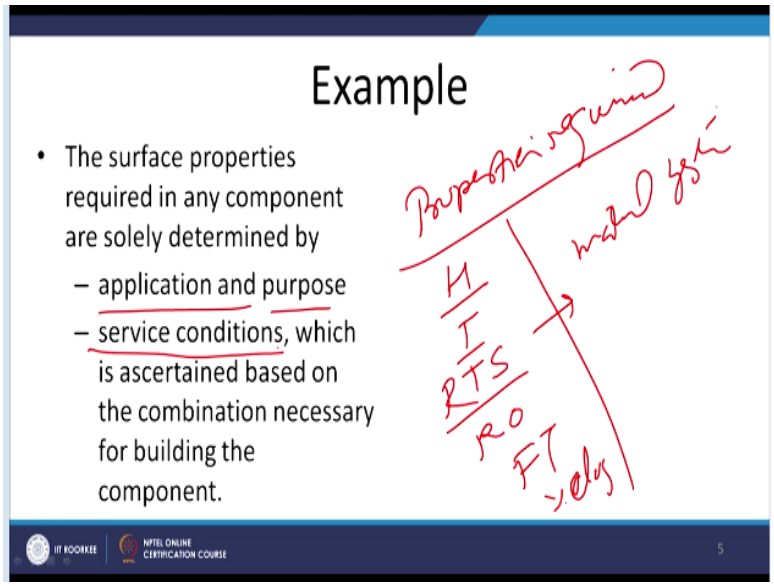

So, enlighten of the service conditions we need to 0 down on the properties required, a list of that is made. So, what kind of the hardness or the toughness or the thermal softening or resistance to thermal softening, resistance to oxidation the fracture toughness is needed what kind of the percentage elongation or the ductility which will be needed.

So, we need to prepare 1 list of the properties and accordingly we choose the suitable material system to be used for surface modification or will be making the modification in the composition of the surface of the component which is being considered. So, that we are able to have such kind

of the properties. So what we considered application and the purpose for which component is to be used based on that will be deducing the conditions of the service and the properties required for effective performance of the component under those service conditions.

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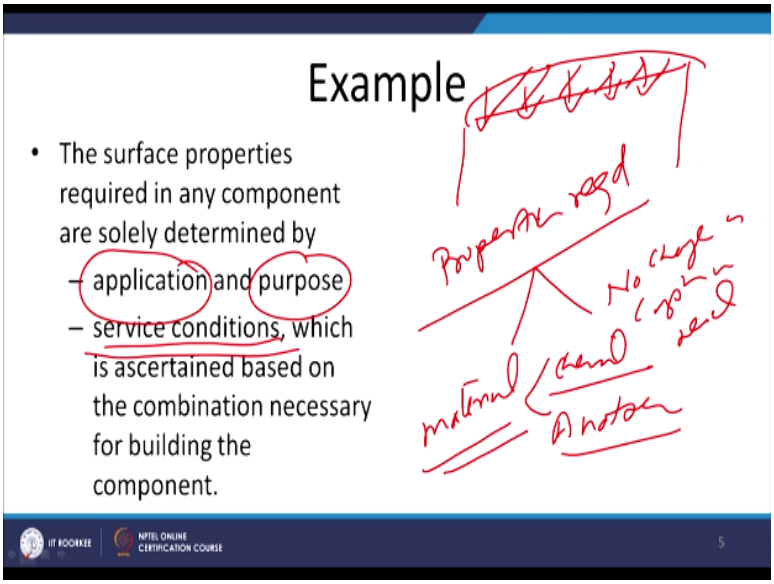

So, this is the another important aspect based on the application and purpose will be trying to identify the properties desired, based on the properties required this will be guiding us either if we have to modify the material present at the surface through the chemical changes or another material will be brought in. For example if this is the component, so just little bit modification of the composition will do the job or we need to put another kind of the material itself at the surface.

So, that kind of approach will be identified through the identification of the properties which are being targeted. So, the material is just composition or another material is to be brought in or no change in composition is needed at just little bit alteration in the surface properties or meteorological properties of the composition will do the required job.

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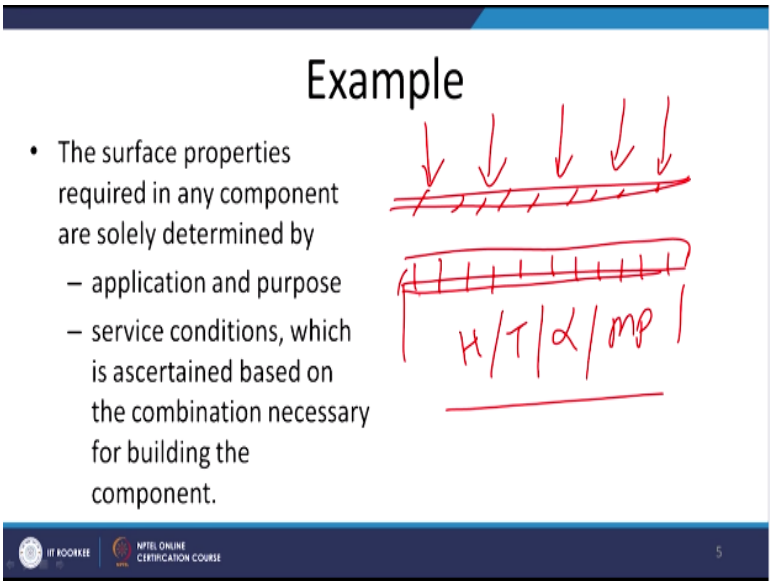

Just like that like this is the surface we just apply the plastic, we just apply the little bit external stresses. So, that surface layers get deformed and we have the required set of the properties. So no chemical modification in this approach or what we do, we will just do the localized heating of the near surface layers, so that the property modification at the surface takes place.

But which approach is to be used that will be governed by the extent of change in properties needed because the base metal will have 1 hardness, 1 toughness, 1 thermal conductivity, 1 melting point and likewise and what kind of change is needed at the surface that will govern whether we need to have altogether different kind of material at the surface or little bit modification in chemical composition will do the job or we need to do just the little bit metrological changes through the use of external force or through the use of heat.

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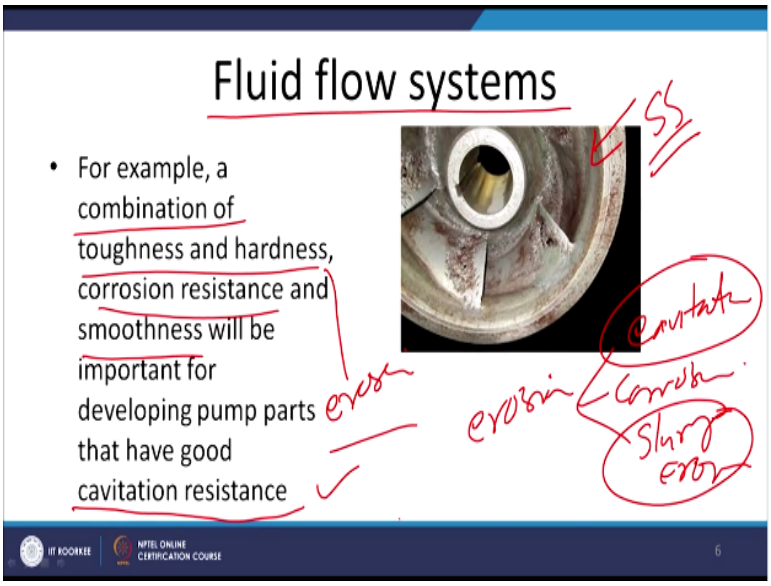

So, now as far as the property requirement is concern that can vary significantly as per the application which is being considered. For example for those systems where fluid flow takes place it is common do have the erosion depending upon the cleanliness of the fluid we may have just the erosion due to the cavitation when there is no sand particles are present with the fluid and when sand particles are present with the fluid which is flowing .

Like especially in hydro turbines then the slurry erosion can take place, the many times the fluid causes the corrosion of the component also with which at it is interacting. So, accordingly we need to select suitable combination of the properties. So, for example for a good combination of the toughness and hardness is needed to deal with the erosion which will be involving the cavitation and the slurry erosion.

And if the corrosion is also involved, then we need to select the material in such a way that it offers a good resistance to the corrosion as well. So, like for those systems which are used in chemical industries or petrochemical industry where the component or food processing industry where the components will be interacting with them.

The chemicals they are these are made of the stainless steel which offers somewhat better resistance to the corrosion as compare the simple structure steel or the common carbon or alloy steels. So, the properties like the toughness, hardness, corrosion resistance and it is smoothness

will be important for such systems where fluid flow takes place. So that it can take care of the corrosion if it is taking place or the cavitation or the slurry erosion. So the properties that we should have at the surface of a given component that will be governed by the application for which it is being developed.

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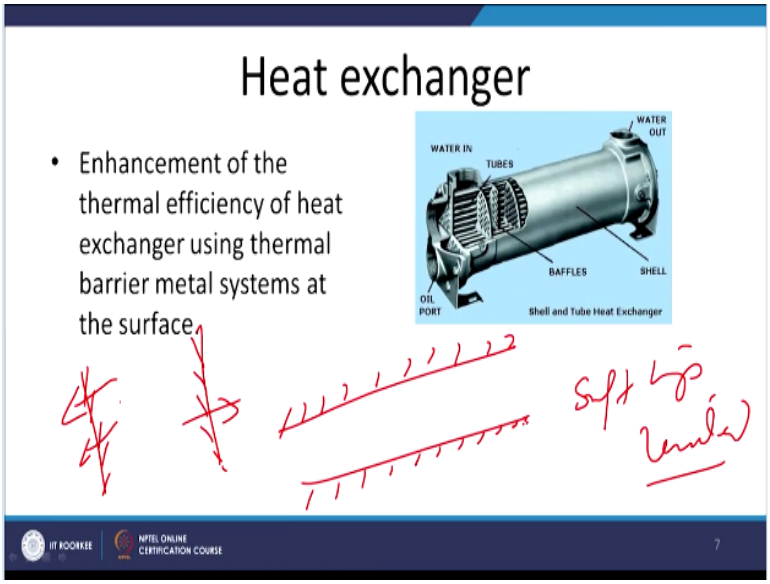

For example if in the heat exchanger if our target is to keep that the tubes are maintained within the same temperature limit and it is not exposed to a too high temperature. Then tubes maybe coated with the thermal barrier coatings in order to avoid any kind of the extensive use or sometimes it may also be required to conserve any kind of the heat loss from the system like I have given the example of the automobiles where inner surface of the cylinders maybe coated in such kind of systems which will reduce the heat losses through the surrounding.

And thereby improve the thermal efficiency of the system which is being considered. So, as per the case what we are looking for we want to improve the functionality and the performance of the component or we want to just control the tribological performance in terms of the reduced loss of the material from the functional surface, surfaces so that it can really perform for long.

Now I will summarise this presentation, in this presentation I have talked about the importance of the chemical properties, mechanical properties and dimensional properties with regard to the tribological aspects and also I have talked little bit about the way by which material should be

selected for a the given application, so that the suitable surface modification can be done, thank you for your attention.