Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-02
Surface/Sub-Surface Regions and Properties of Importance for Surface Engineering

Hello, I welcome you all in this presentation related with the subject fundamentals of the surface engineering and as we have talked that the surface properties affect the performance of the mechanical components significantly because many times the failure is triggered from the surface. So, it is important to understand what the surfaces are composed of and therefore in this presentation basically will be talking about the various aspects related with the surface and subsurface features.

In surface engineering we target on the 2 aspects 1 is improving the surface characteristics and enhancing the surface properties. So, that the life of the component can be improved and it can perform the required functions in much better way and in sometimes surface engineering is also used for increasing the functionalities and capabilities of the component. So that it is able to deliver the required function.

Basically any surface comprises the 2 aspects 1 is the features which are present at the surface and the second is about the subsurface features.

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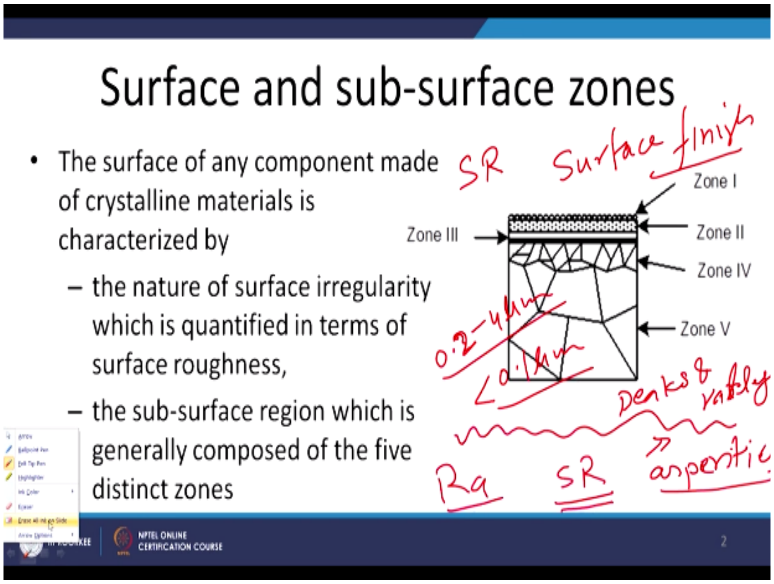

So, as for as the surface features are concern what we will have like any mechanical component which is made by one or other manufacturing process like casting, welding, forming, machining etc., it will have some kind of the irregularities present at the surface. These irregularities present at the surface are normally quantified in terms of the surface roughness and surface roughness is normally characterised their number of methods to characterise the surface roughness like stylish based is 1 method.

And there are number of non contact base methods nowadays which are use to characterise these ups and downs present at the surface which are known as surface regularities in form of like in say surface asperities. These surface asperities are also termed as the peaks and valleys present at the surface. So these height and depth of these peaks and valleys are characterised in terms of the surface roughness.

And Ra is one of the most common parameter which is use to characterise the surface roughness and normally the machined component of for the surface roughness in the range of like say 0.2 to 4 micrometer while the polishing and finished surfaces offer the surface roughness even less than 0.1 micrometer. So, polishing and super finished methods are used for improving the surface finish or reducing the surface roughness.

Surface roughness indicates the extent of ups and downs are present and inverse of this is characterised as a surface finish. So, greater the surface roughness lower will be the surface finish or the smoothness. So, we know that the extent of ups and downs is peaks and valleys present at the surface significantly affect the friction and wear behaviour of the component.

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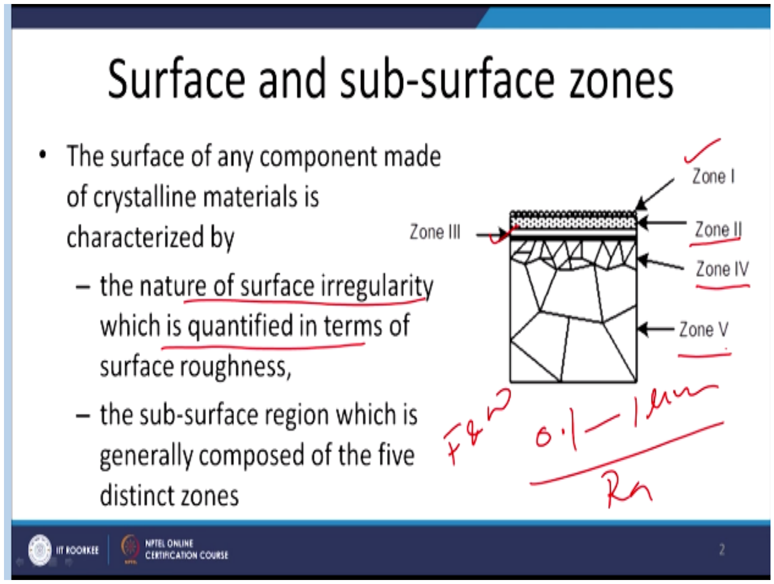

Because although there is an optimum combination very high surface roughness or very low surface roughness both result in higher friction. While the optimum level of the surface roughness results in the good combination of the wear and friction resistance. So, in general since it is very difficult to achieve very high degree of the surface finish therefore efforts are always made to reduce the surface roughness.

So, that reasonable required degree of the surface finish can be achieved normally in the range of like say 0.1 to 1 micrometer in terms of the Ra as a roughness parameter. So, this is one aspect like presents of the surface regularities and their quantification in terms of the surface roughness is one aspect of the surface features or surface characteristic. The second important aspect is the sub surface features or sub surface characteristics.

So, in general any surface comprises 5 different zones at the surface and near surface zones or near surface layers. So, there are 5 different zones which are normally present in all components mechanical components made of the crystalline material produced by the conventional manufacturing processes. These are termed as zone 1, zone 2, zone 3, zone 4 and zone 5. Now will look into these zones, so one by one what these zones will be comprising and what kind of a effect will be there in these zones.

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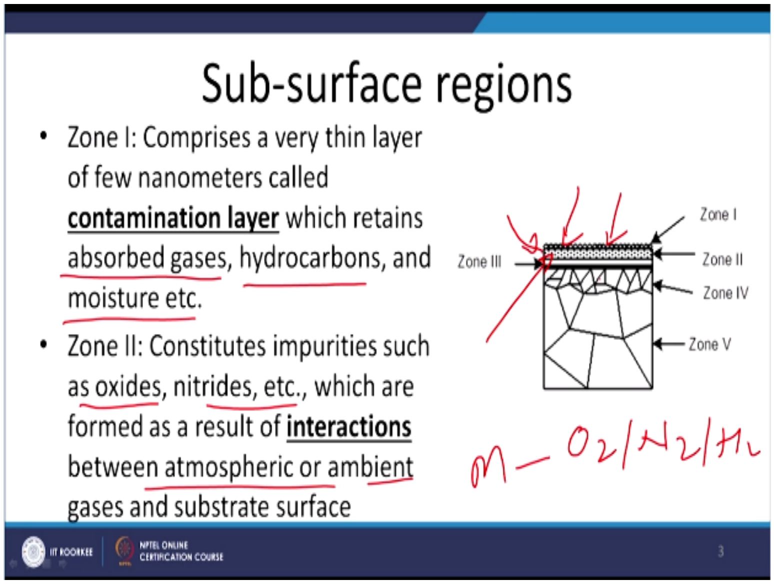

So, the zone one that is which is present just at the surface it basically it is very thin zone which is of very few nano meters. And this zone is a composed of a like absorbed gases hydrocarbons and moisture. It is very thin and this is also called contamination layer and this zone maybe damaged or maybe removed with the application of the pressure and the heat very easily and effectively the second zone is made of it is next to the contamination layer is the zone which comprises basically oxides, nitrides which are formed due to the interaction between the metal of the surface.

And the surrounding gases like oxygen, nitrogen, hydrogen etc. And these interactions will be resulting in the formation of their oxides so, the interaction of the metal with the atmospheric gases are the surrounding material or surrounding gases whatever is present that will leading to the formation of this zone. Like formation of the rust through the iron oxide formation is one of the typical examples for this kind of the zone.

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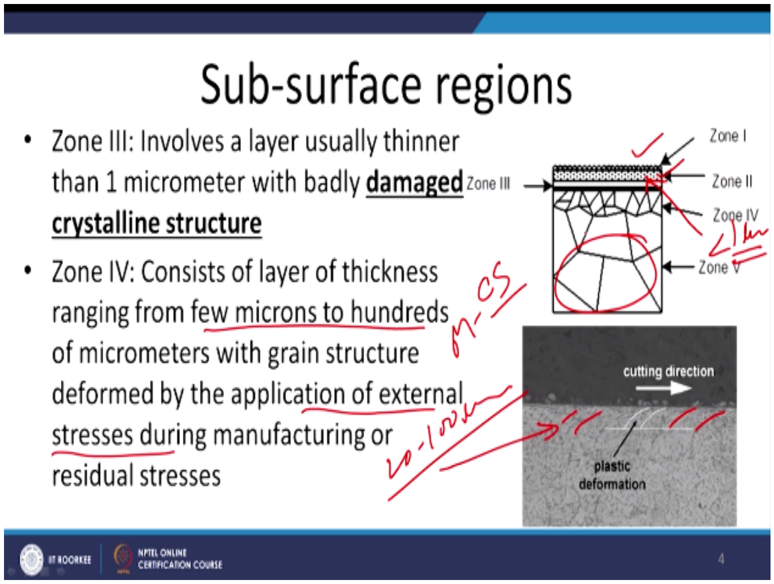

And the third zone is damaged zone we know that most of the metals will have the crystalline structure and this crystalline structure involves the regular arrangement of the atoms in one particular order and whenever metal is subjected to the mechanical processes for sizing and shaping or some other kind of the processes then like say the shot pinning or any other process used for improvement a very thin zone which is formed next to the oxidised or nitrides which are present in the second zone.

So, after the first zone there is a second zone and next to the second zone we have a very badly damaged zone which damaged zone means the crystalline structure is damaged and this zone is also very thin it is less than 1 micrometer and there after we have a 1 region which will be experiencing in the lot of deformation or a strain due to the somewhat more plastic deformation of the near surface layers.

We know that the most of the materials when they are subjected to the processes like machining to get the desired size and shape the near surface layers will be experiencing some kind of the deformation like this one typical example where the surface has been produced by the machining process and near surface layers will have some kind of the will be experiencing some kind of the strain.

This zone maybe very thin like a 20-100 micrometer but this deformed zone is always there in especially in the machine component. So, the zone 4 is this zone where the plastic deformation is will be occurring to such an extended there is no damage to the crystalline structure. But the plastic deformation can be seen from the orientation of the grains as well as change in the shape of the grain or maybe hardness of that region will also be different due to the work hardening effect.

So, the zone 4 consists a layer of a thickness ranging from the few micrometers to the 100, 100 of the micrometer with grainy structure deformed. So, the grain structure grains with the shape of the grain is deformed and this may happen due to the application of the external stresses during the manufacturing or the development of the residual stresses, so this is the zone 4.

And the fifth zone is basically the zone which is the which will be mainly of the base metal or the unaffected metal which has not been damaged in anyway due to the effects of the temperature or by the mechanical forces being used during the manufacturing process that will be leading to the formation of the zone 5.

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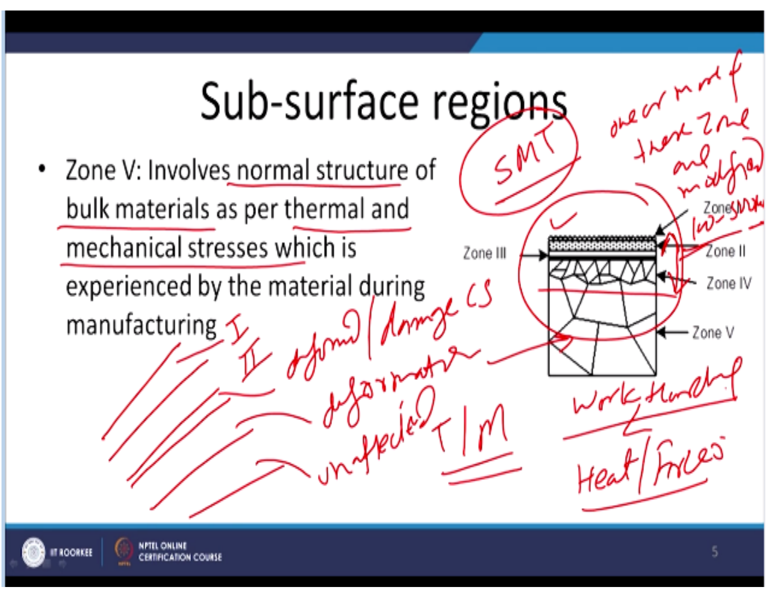

So, the zone 5 involves the normal structure of the bulk material as per the thermal and mechanical history or the stresses experienced by the metal during the manufacturing. So, this is how we can say there are 5 zones those the zone 1 is of a absorbed gas or the hydrocarbons or the moisture then we have a oxidised zone, the zone having the oxides and nitrides then very thin layer of the badly deformed or damaged crystal structure.

Then there is a deformed zone where there is a change in orientation of the grains and the fifth zone is basically the unaffected zone. So, since there are lot of techniques or the processes which are available for modifying the surface properties, since all these 5 zones will be forming the features which are closely associated with a surface and subsurface zone. So, whenever the surface engineering techniques are or surface modification techniques are applied 1 or more of these zones are modified or altered.

Like application depending upon the extent of the effect of the surface modification technique means the depth up to which the surface characteristics are affected that will be changing these zones as per the kind of process of the surface modification being used like few modification processes they will be working, they will be affecting the zone 1 and zone 2 only which are very thin, few will be affecting the zone 1, 2, 3.

And few will be affecting zone 1, 2, 3, 4 also, so depending upon the extent of effect because zone up to 4 this maybe of like say depending on the process the zone may vary from 100 to like say 500 micrometer, if the machine component is very badly machine, if I have used machining is performed, this zone the zone 4 maybe verified and fine finishing will be leading to the very thin zone of the zone 4.

So, maximum the depth from the surface like 40, 50 or up to 100 micrometer in case of the finished processes or the polished surfaces will be leading to the further thinner zone of these further finer thickness of all these zones. So, the point is here whenever the surface modification is carried out 1 or more of these zones are modified during the surface modification process.

So, the surface engineering or modification will be involving the modification of these 1 or these more of these zones. Now one more important thing as per the kind of approach which is being used whether the heat is being applied or the forces are being applied during the surface modification as per the extent of effect of these aspects, the different kind of the changes will be occurring like application of the heat maybe leading to the removal of these absorbed gases or the moisture.

And hydrocarbon even the thermal decomposition of the oxides present at the surface layer can also take place similarly the mechanical forces use of mechanical forces can lead to the very large scale damage to all these zones which are present at the surface. And leading to this significant the deformation of the surface, and near surface layers leading to the significant work hardening effect increasing the hardness and so the mechanical properties of the component.

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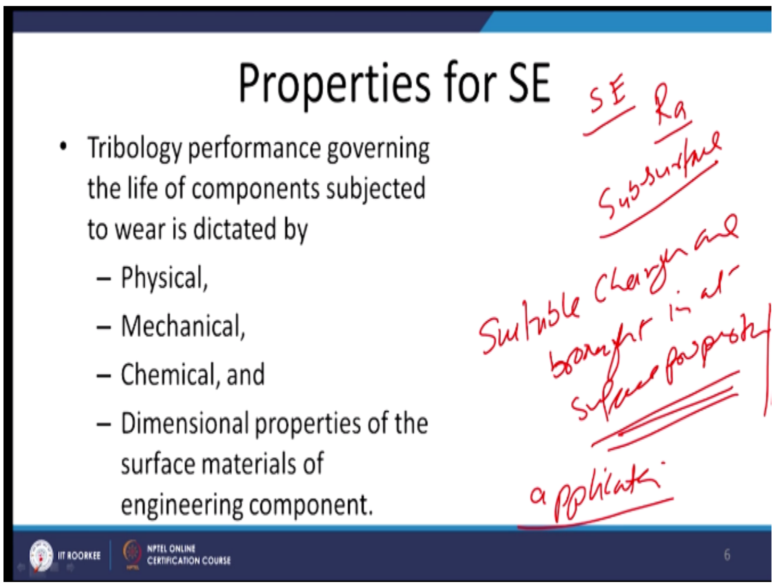

Now so as you have seen that the each surface will be composed of the 2 aspects, 1 is like the features which are present at the surface in terms of the surface roughness Ra or in terms of the kind of a the sub surface zones which are present below the surface . So, we need to for improving the performance of the mechanical component it is required that the suitable changes are brought in the metals, brought in the properties of the surface suitable changes are brought in at the surface properties.

So, now which kind of the changes we should being in that will depend upon what we are looking for and what kind of changes we should have means what properties we should have at the surface after the modification that will be governed by the application. Because application of the surface for a particular situation will determined what kind of conditions it will be experiencing.

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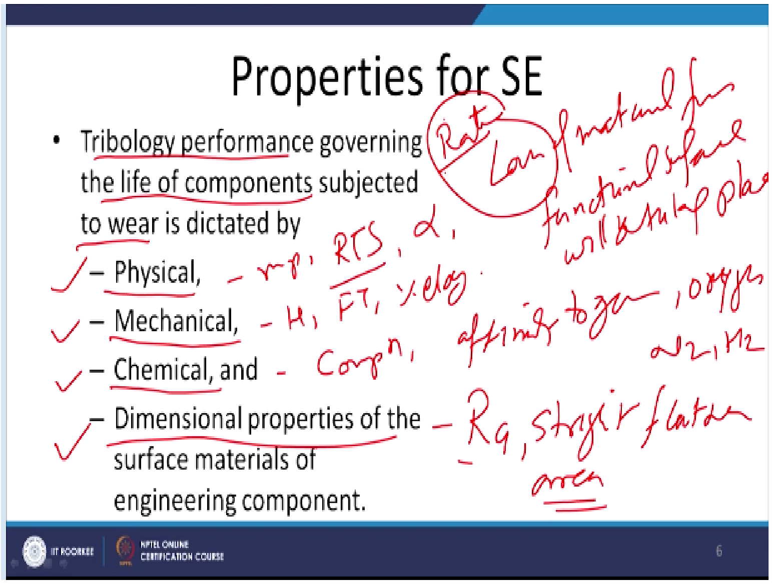

And accordingly the properties it should have that will be dictated. So but in general if we see the performance tribological performance in terms of the wear resistance of a mechanical component is influenced by these following 4 groups of the properties. So, the tribological performance which is affecting or determining the life of the component under the wear condition is dictated by these 4 group of the properties.

The group 1 includes the physical properties which maybe in terms of like the melting point are resistance to thermal softening or it may be in terms of the thermal expansion coefficient similarly the mechanical properties like hardness or the fracture toughness or the percentage elongation. Similarly the chemical composition will also have the chemical properties will have composition or affinity to the gases which are present are like in form of oxygen or the nitrogen or the hydrogen how quickly.

And how the given surface of a given material reacts with the gases which are present all around or the environment in which component has to all and the dimensional properties primarily it is the surface roughness like straightness, flatness and the like the area of which will be under the which will be exposed during the surface. So, these are the 4 broad categories of the properties that will be determining the way by which the loss of material from the functional surfaces will be taking place.

So if the properties are dictating the combination of surface properties like physical, mechanical, chemical or dimensional property combination for a given component is such that the rate of material loss is very limited or very low.

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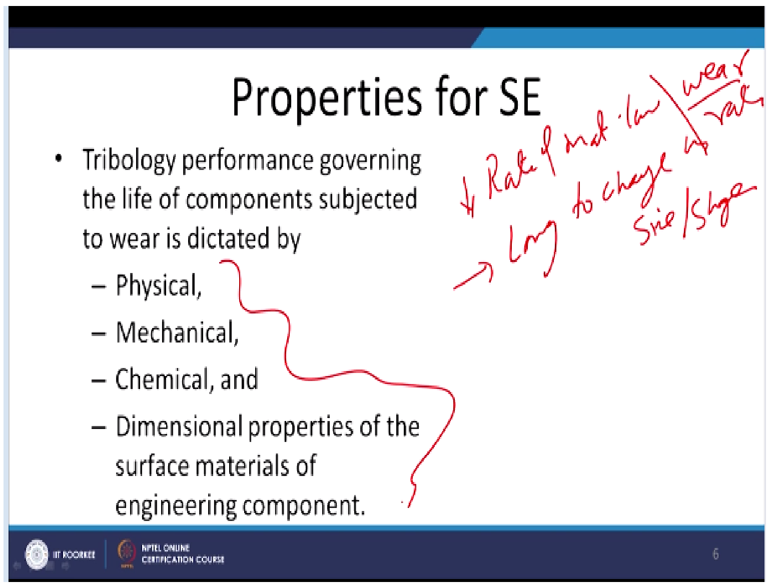

The rate of this loss is very less than means the low rate of material loss indicates that it will take long to have any significant change in size and shape of the component. So components will continue to perform for long and will result in the longer life of the component under the different service conditions the different operational wear mechanisms will be present and as per the operational wear mechanism different combination of the physical, chemical, mechanical and dimensional properties will be required.

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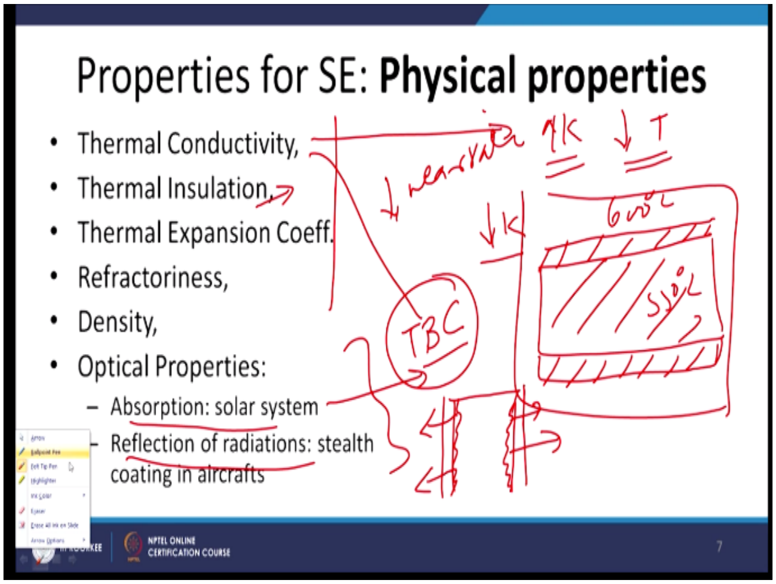

So, first of all will be looking into the physical properties and the way by which is the physical properties can affect what are those physical properties and the way by which they can affect the surface performance. They are 2 types of the physical properties 1 is which are primarily used which are primarily designed in a particular component in such a way that it reduces the wear rate.

But there are certain properties like optical properties absorption, solar system this and the reflection of the radiations, I will talk in detail about these later. First of all what will see that the thermal conductivity. Thermal conductivity will be determining how fast the heat will be transferred from the region wherever heat is being generated due to the frictional effect in tribological system.

So, high conductivity high k means the first greater ability of the material or more effective transfer of the heat from the region where it is being generated to the other zones. So, increase in k reduces the temperature of the functional surfaces where heat is being generated, so the metal is able to retain it is properties more effectively and component is able to perform more successfully, many times it is required in reverse way where low conductivity metals are used like what we want a component is to be those components which are to be used at a high temperature like surrounding temperature is 600 degree centigrade.

And what we want this component temperature should not exceed 550 degree centigrade. So in that case will be covering this component using the low thermal conductivity metal system. So the heat is isolated means this component is isolated from the high temperature conditions and this low thermal conductivity metals will be reducing the transfer of heat to the main component. So, that it can run under the safe temperature conditions and for this purpose only thermal barrier coatings are used.

So, that is what we can say thermal insulation. Thermal insulation will be used for those cases where either heat we want to preserve or we want that a given component is not exposed to a much higher temperature. So, the heat is not transferred at to the component and this is facilitated by the thermal barrier coating. Similarly in the heat engines where we want that more and more amount of the heat is preserved and less heat loss takes place.

So, in a surface of the cylinders maybe coated so that the heat losses whatever heat is generated by the combustion of fuel that is preserved and not much loss of the heat to the coolant or to the external bodies takes place it will performing 2 functions heat will be preserved and the surrounding temperature of the cylinders and the pistons are whatever the components which are in contact with the high temperature zone they are capped within the safe temperature limit. So, it can be useful to have both as per the need.

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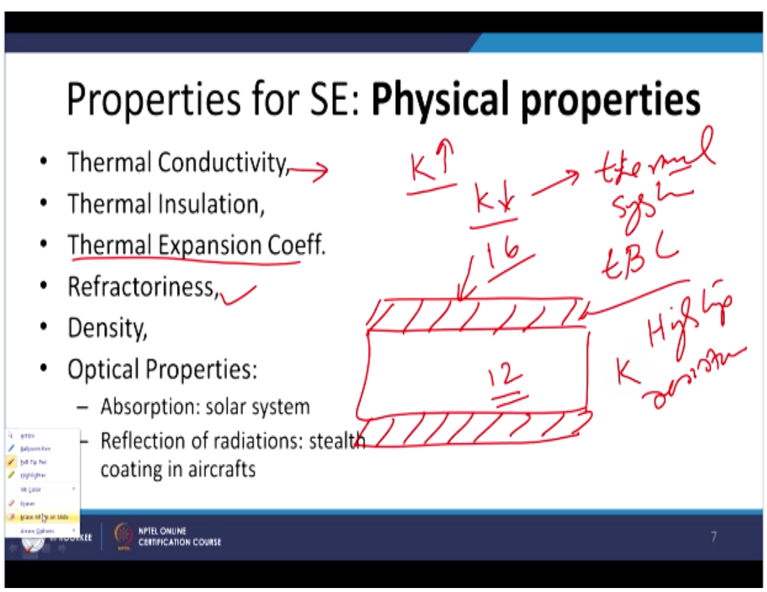

We may require so for improving the functional team, improving the tribological line we may use high conductivity metal systems as well as the low conductivity metal system. So, low conductivity metal systems are used for improving the thermal efficiency of the component of the thermal systems and thermal barrier coatings tBC these are called tBC.

And high conductivity metal systems where high thermal conductive metal systems when it is required that it is transferred very effectively from one zone to another, thermal coefficient will be effecting especially where the component is coated with the coating material like this like in surface engineering development of coating and development of layer is one of the common approach.

So, if the base metal is having the k value same close to that of the coating material then coating will be able to sustain the thermal cycles very effectively. But if there is a large mismatch like 12 units of the base metal and 16 units of the coated material then under the thermal cyclic conditions due to heating and cooling the coating may is fall off or peel off from the surface.

So, removal of the coating from the substrate will be losing the function of the surface modification and the purpose of surface modification will be repeated. So, it is required that the thermal expansion coefficient of the material which is being applied in form of the coating or in form of a the overlays that is almost matching with the base material properties, refractoriness is important especially for the conditions where the metal is being applied is able to retain the required properties at high temperature.

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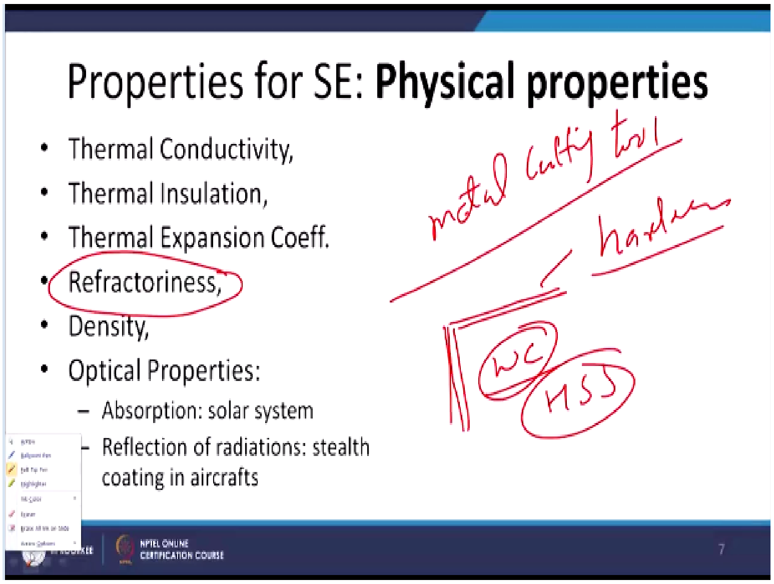

So, high temperature resistance this is important especially the coatings which are used for the in the metal cutting tools for surface modification like variety of the coatings are used over the like this is the tool can be made of tungsten carbide or made of the HSS, so the surfaces of such kind of the tools are coated with the such kind of materials which can retain their hardness at high temperature.

So, because hardness is important during the metal contain lot of heat is generated and that heat will be softening the tool materials as well as the material whatever is present at the surface. So, if the coating is applied on these materials then that coating should retain it is hardness to perform the desired functions successfully and that is why as for the application it is important that the selected material is having the required refractoriness it does not melt it does not thermally softened, it retains it is hardness even at a elevated temperature.

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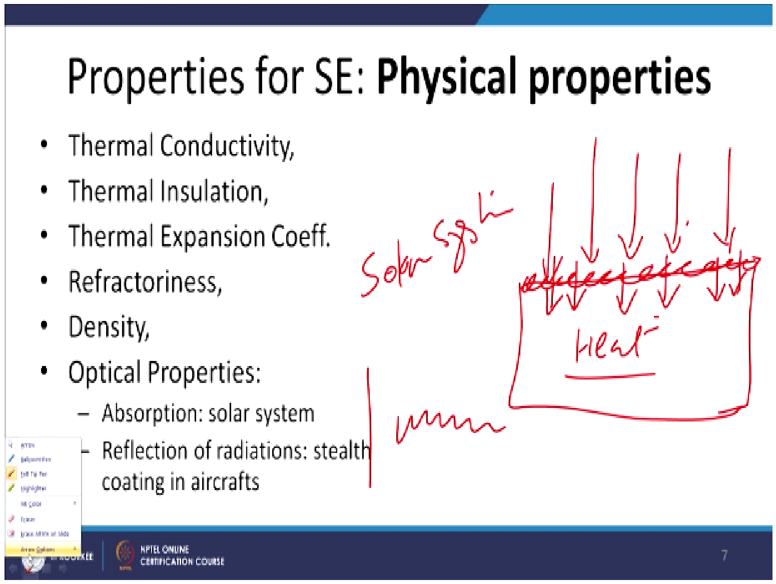

So, that is how the refractoriness also place an important role, then coming to the electrical sorry this optical properties are used in both ways for absorption as well as for reflection for improving the absorption and for enhancing the reflection. For example like we use lot of solar systems where the radiation coming from the solar will be falling onto the surface.

So, part of it is reflected because all the metals will have some kind of the reflection capability and because of this reflection heat mean whatever energy is coming from the sun is not absorbed fully and lot of energy is reflected in form of the radiations back. So, coatings are develop onto the surface in such a way that absorption capacity of the surface to absorb this radiations which are coming from the sun can be enhanced.

And once this is absorbed in greater amount then it will be more effectively converted into the heat which is being used for over s for useful purposes. So, one application of the optical with regard to the optical properties is application of such kind of the coatings are generation of as kind of surfaces which will be enhancing the surface absorption of the radiations, roughening of the surface also has to improve the absorption that can be another way of modification of the surface for improving the absorption.

And the reflection of the radiation, we know that every country wants to safeguard it is boundaries from the enemies.

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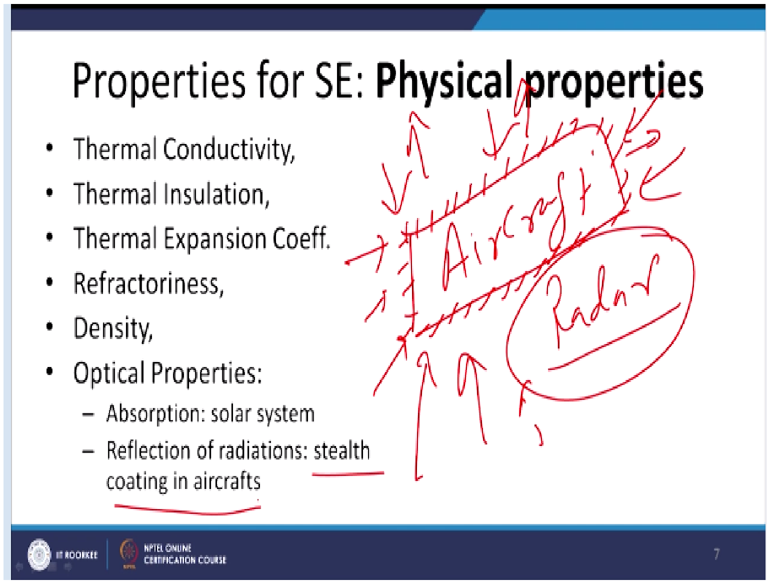

And for that purpose like air force uses the aircrafts, aircrafts their technologies electronic technologies where even if visually if aircraft is not visible it can be strange to the use of the suitable radars. So, radars what they do they send the radiations and based on the reflections the object is recognised and it is position, size, shape etc. is identified.

So, the technologies are very old where the radars are used to identify what is which object and where it is. So, what is being developed is the aircrafts are being coated with such kind of the stealth coatings that these coatings reflect the radiations falling onto the aircraft by the radars which are trying to detect the location and position of the aircraft, so if the radiations are coming from the radars they will be reflected back by such kind of the coatings.

So, stealth coatings basically help to reflect the radiations being applied through the radars to detect to the location of the aircraft and such kind of the coatings help non detection of the aircraft. So, it can be used for spying purpose by the different countries and so stealth aircrafts are being developed for this purpose, so that the NV is not able to detect the location and position of their aircrafts.

So, this say is about the physical properties here at now I will conclude this presentation, in this presentation basically I have talked about the characteristics of the surface and the zones which are found at the subsurface zone in the subsurface region and at the same time what are the properties of importance which can affect the tribological life of the component, thank you for your attention.