Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-23
Thermal Barrier Coatings

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and in this presentation basically will be talking about oven and different type of the material, which is used for surface engineering of special category of the engineering components, like there are many components which are used in industry and which are expected to survive under the high temperature conditions.

So, the components used in thermal power plants or where in basically the ferritic stainless steel and the chromium molybdenum steels are used. And they are expected to perform at high temperature, normally this temperature varies from 500 to 650 degree centigrade and for the components which are performing at a high temperature it is expected that they will remain stable, they will not lose their mechanical properties, they will remain dimensionally stable.

And there would not be any material loss from the surfaces during their application or during their service. But sometimes it is observed that the hard flue gases or hot stream which is passing through those components causes the material degradation as well as high temperature rise also leads to their degradation.

So, what is required that if we can do something in order to reduce the material losses from the functional surfaces which are working or which are being used at high temperature or something can be done in order to reduce the temperature of the components which are being used at a high temperature. So, for that purpose especially 1 especial category of the material is used and which is called thermal barrier material.

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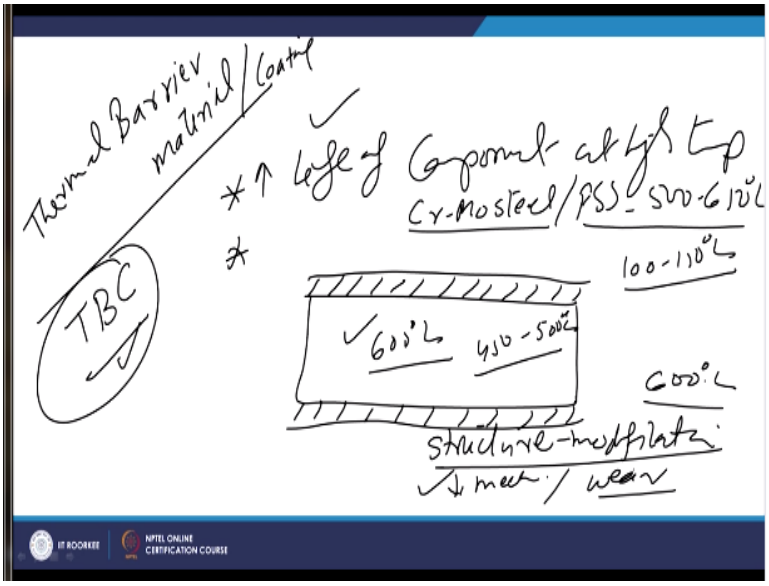

Mostly it is used in form of coatings and that is why these are called thermal barrier coatings. So, these coatings are primarily used to increase the life of components which are used at high temperature. So this temperature usually whatever is the working temperature application of the thermal barrier coatings helps to reduce the temperature of the component. So like say the materials like the chromium, molybdenum steels and ferritic stainless steels.

These are will be working in the range of 500 to 650 centigrade, so when these work at a high temperature there will be the micro structural in it is stability is there will be degradation in their mechanical properties and sometimes even the loss of material from the functional surfaces leads to the wear. So, in order to reduce such kind of the damages components used in thermal power plants and other engineering systems wherever these are used.

Application of such kind of the coatings helps to decrease their actual working temperature and which in turn makes the more stable and helps them to perform for long, another aspect related with this is that whenever there is a reduction in temperature will see the component working at in the temperature range of like say 600 degree centigrade.

So under the ideal conditions means under the stable conditions the entire component will be under the 600 degree centigrade and under whenever the entire component is expose to such a high temperature, it experiences the structural degradation structure modification . In case of the

steel it maybe in form of like say grain coarsening or formation of some kind of the carbides or depletion of some of the alloying elements from the functional surfaces.

So these kind of the structural undesired structural modification lowers their mechanical properties and another aspect is that hot flue gases if they are passing over the surfaces of such kind of components. Then reduction in hardness at a high temperature facilitates the material loss from the functional surfaces and which in turn causes the wear. So when these components are coated at the surface with the thermal barrier coating materials the effective component temperature is reduced.

So this reduction in temperature maybe to the extent of 100 to 150 degree centigrade, so means the same component exposed at 600 degree centigrade when it is coated with the thermal barrier coating material, it is effective temperature is reduced by 100-150 degree centigrade. So in this case means it will be reduced like say the temperature 450 to 500 degree centigrade. So if the component is being exposed at high temperature but it experiences lower temperature.

This in turn increases it is life, decreases the tendency for reduction and mechanical properties and reduction in dimensional loss due to the wear. So, all these tendencies are reduced to some extent.

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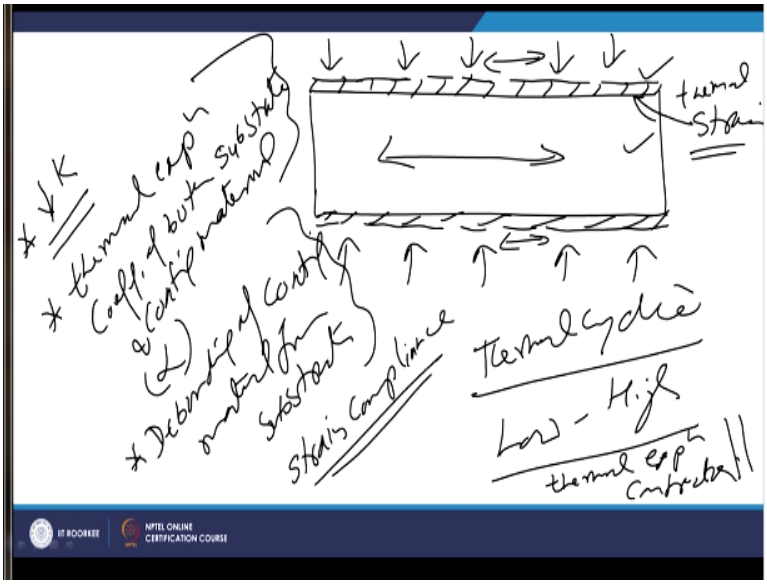

There are certain properties which are needed in material to work like thermal barrier coating materials. So as I have said that despite of being the component at high temperature for long the component temperature remains at lower level. And this is facilitated by the reduction in the heat being transferred to the component. So this kind of material has to be the material which is being applied as a thermal barrier coating material.

This should have the low thermal conductivity, this is the first primary requirement for any material to work like thermal barrier coating material, it should have lower thermal conductivity and since such kind of components will be working at a high temperature. So whenever there is shut down there will be reduction in temperature, so means this kind of components will be expose to the temperature variation during the service.

So the thermal cyclic conditions means the low temperature to the high temperature variation will be leading to the thermal expansion and contraction of such kind of component thermal expansion when it is heated and contraction when it is cooled. So thermal expansion and contraction due to the temperature variation will be leading to the thermal expansion and contraction of the coating material as well.

So it is important that the expansion and contraction of the main component as well as the expansion and contraction of the coating material, both magnitude of the both expansion as well as contraction of coating material occurs by the same magnitude. And for this and this will happen only if the thermal expansion coefficient of both the substrate and coating material are close to each other.

If the alpha value that is thermal expansion coefficient if these values differ significantly from each other then there will be the one material will be expanding more than other and this will put in lot of the thermal strain at the interface. So, such kind of the thermal strain on heating and cooling will lead to the de-bonding of coating material from the substrate.

So, this is the problem because if the 2 materials have the different thermal expansion coefficient on heating and cooling the thermal strain at the interface will cause the removal suppression,

chipping of the coating material from the substrate. So, the purpose of a planned thermal barrier coating onto the substrate will be defeated and therefore it is important that apart from the lower thermal conductivity of thermal barrier coating material it should have thermal expansion coefficient close to that of the substrate material.

And this situation or this condition is termed as the strain compliance with regard to the coating material properties. So, whatever strain is being induced due to the temperature variation that strain magnitude in the coating material should be same as that of the substrate material. So, that the thermal expansion and contraction mismatch between the 2. That is the coating material and the substrate is minimum and so this kind of this or chipping of tendency of the thermal coating material will be reduced.

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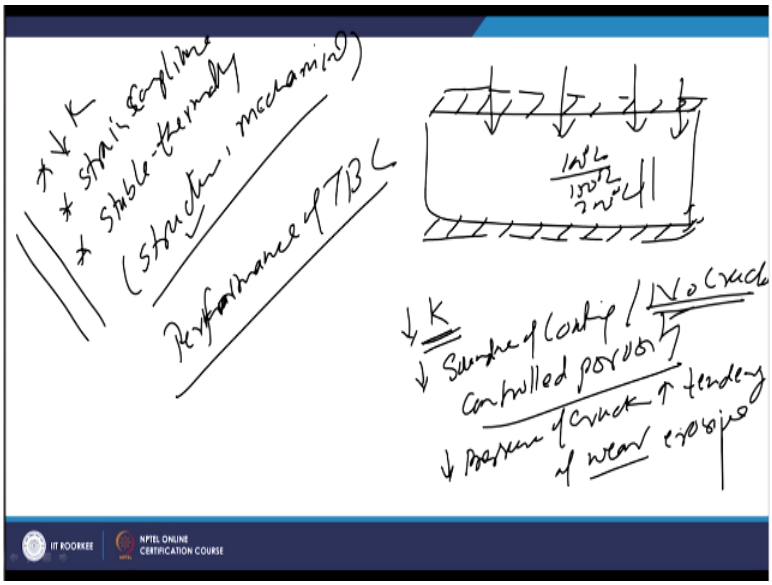

Another requirement apart from the lower value of the k and strain compliance condition where in thermal expansion co-efficient of the substrate and coating material both are largely same. Another important requirement is that the material is stable in many aspects like thermally stable thermally means at high temperature does not leads to the modification of the structure and it does not lose it is mechanical properties.

So, these are the 2 important requirements material TBC material must be thermally stable means at high temperature it does not it is structure does not get stabilise or it does not lose it is

mechanical properties. So, these are the 3 properties which are required in a material which can be used as a thermal barrier coating material. So, 1 is the strain compliant, 2 is the lower thermal expansion coefficient and 3 is the thermal stability.

So, that it does not get lost in form of oxidation or significant drop in mechanical properties like hardness and wear resistant. So, if these 3 characteristics are there then it will be able to perform it is function effectively. So, the as per as the performance of TBC is concerned, performance of thermal barrier coating material will be influenced by the extent up to which the drop in temperature of the substrate material takes place.

If the drop in temperature by 100 degree centigrade or 150 centigrade or 200 degree centigrade and this will be determined by of course the k value and the soundness of the coating means there should not be any crack, no cracks. Of course such kind of coatings are designed to have controlled porosity, so that the heat transfer from surrounding to the prime component of the main component can be reduced.

So, these are design to have the control porosity, these are made of the lower thermal conductivity material, so the transfer of the heat from the outside to the main component can be reduced. But if there are cracks which are through then heat will be able to easily transfer to the main component and further the presence of cracks like presence of cracks will increase the tendency of wear especially under the erosive wear conditions.

So, it is important that whatever coating is been applied that is by enlarge sound with regard to the presence of crack.

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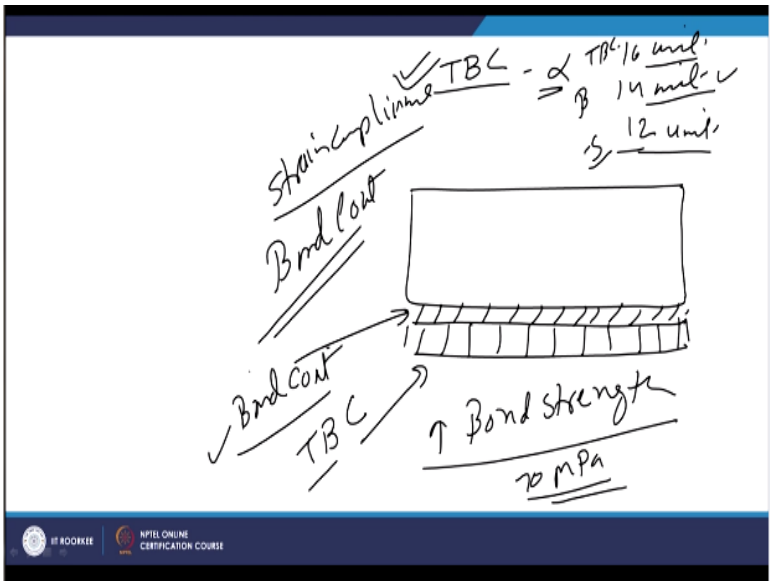

But it has been found that the thermal barrier coating materials if they have large difference in the in alpha value means if the steel is having the 12 units of thermal expansion coefficient and the material which is being used is having the like 16 units of the thermal expansion coefficient. So, this kind of the mismatch will lead to the thermal will lead to the tendency for the falling or chipping off of the coating material.

So, in order to avoid the chipping off tendency due to the greater difference in thermal expansion coefficient value it is suggested that the situation of the strain compliance is achieved through the application of the bond coat, bond coat will have the intermediate value of the thermal expansion coefficient. So, the extent of mismatch is reduced, say in that case the bond coat material will choose in such a way that alpha value for the bond coat material is in between the thermal barrier coating material and that of the substrate.

So, this is for substrate, this is for bond coat and this is for the TBC material, so this is how it is chosen. So application of the bond coat material first onto the substrate is normally soft material based normally made of the nickel-chromium kind of the alloys. And after the application of this bond coat the required thermal barrier coating material is applied onto the component.

So, first to deal with the strain compliance related issue for to satisfy this condition, the bond coat is applied onto the substrate and there after the thermal barrier coating is applied over the

bond coat and this kind of application helps to increase means application of the bond coat improves the bond strength means the strength with which TCB material will be held onto the substrate through the bond coat, it is required internationally accepted practices is that the coating should have enough bond strength.

Otherwise under the given service conditions are thermal fluctuations will lead to the easy palling or suppression or the chipping off of the coating material from the substrate and so the minimum required the bond strength is like 70MPa. There are methods for checking the bond strength that is the different issue. So, the bond coats are applied in order to avoid, in order to increase the bond strength.

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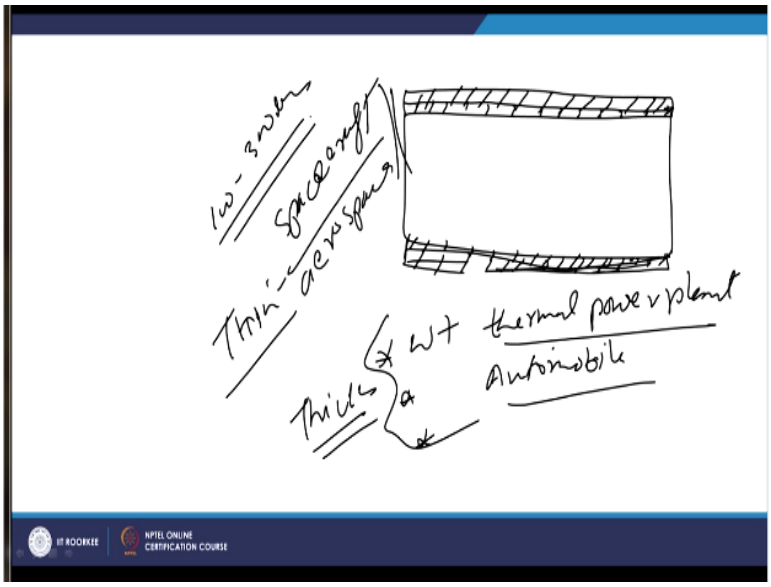

Now we know that the if the bond coat material if the TBC coating is very thin then the transfer of the heat from the outside to the substrate will be easier. So, in order to decrease the extent of heat transfer it is always favourable that the thermal barrier coating thickness is great. But since so the very thick coatings of the TBC materials can be applied in 2 situations where the weight is not a big issue.

So if weight of the TBC because the TBC coatings will be applied onto the substrate which in turn will be increasing the weight of the entire component as a whole. So, if a weight is not a major issue and thick coatings can be applied for reducing the heat transfer onto the main

component and this can be situation where like thermal power plants, this is one case and the second case is where in automobiles all the weight may weight is important.

But it is not that important as in case of the aircrafts and spacecrafts. So, for automobiles also like the coatings TBC coatings on in the cylinders help to increase the thermal efficiency of the engines there which in turn will help in increasing the mileage on the but in case of the spacecrafts where weight is important and aircrafts where weight is more important normally thin coatings are preferred.

So, for thermal power plants as well as for automotive applications of the TBC's thick coatings can be applied well thin coatings are applied onto the spacecraft wherever it is required and aero crafts means aero space application . Now this is one aspect normally thickness of these coatings is very small maybe like say 100 to 300 micrometer depending upon the kind of material which is being applied.

Now will look for the various materials and the kind of the thermal expansion coefficient and the thermal conductivity of the various materials.

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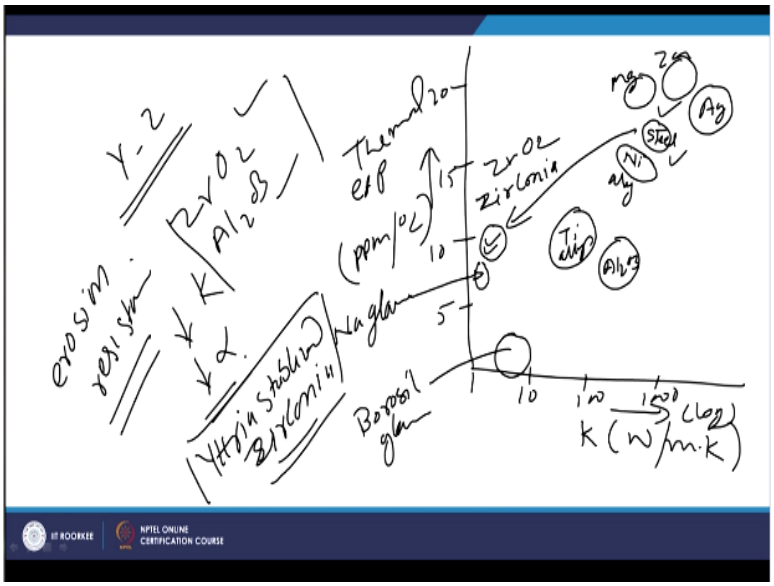

So, here like in x-axis if we mention thermal conductivity and what meter Kelvin in x-axis and in y-axis if we have like thermal expansion behaviour in terms of ppm/degree centigrade. So, here

like 5, 10, 15, 20 and in x-axis this is in log scale like 1, 10, 100, 1000. So, the one which is the most favourable is having the low thermal conductivity and lower thermal expansion coefficient is like this.

Here sodium glasses another one having the very low thermal expansion coefficient and somewhat higher thermal conductivity is like here borosil glasses. On the other hand one having very low thermal conductivity and little bit higher thermal expansion coefficient is this zirconia ZrO_2, then we have the titanium alloys Ti alloys, then alumina Al_2O_3 there after we have the Nickel base systems somewhat higher thermal conductivity as well as higher thermal expansion coefficient.

So, here we have the Nickel alloys close to this we have the steels then further on the higher side of thermal expansion coefficient we have Mg alloys and on the other hand we have the zinc alloys and very high means further higher thermal conductivity is in the silver. So, this is the kind of the mapping if the steels are offering the higher thermal expansion coefficient as well as higher thermal conductivity.

So application of the zirconia having very low thermal expansion coefficient and thermal conductivity which is suitable low thermal conductivity is the most suitable because of low thermal conductivity zirconia is most suitable material. So, in order to have the combination of the low k and intermediate values of alpha normally mixture of zirconia, aluminium or yttria stabilised zirconia or used for having the good control over the temperature as a TBC material.

So, yttria atria stabilised zirconia is the commonly used TBC material mixture of zirconia and alumina is also used for as a TBC material for erosion resistant applications. So, this map actually helps as why what are the materials which can be suitable to act as a TBC material for the steels or with respect to the materials.

So, offering zirconia is offering very low value of the k and lower value of the thermal expansion coefficient but this can lead to the zirconia can lead to the high thermal expansion coefficient

different situation. So, the strain compliance issues can be their which are delt with the use of mixtures of the various other materials.

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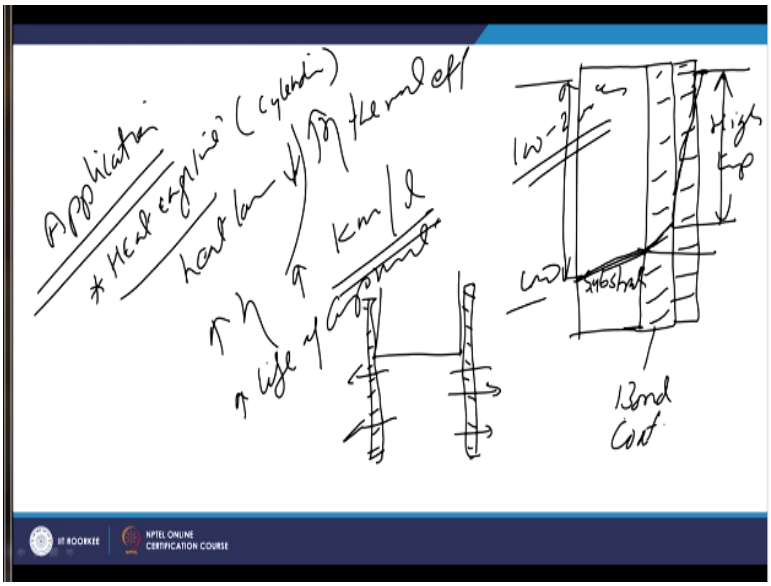

So, now schematically we will see the how the temperature variation can be observed, this is the substrate or the base material over this will be applying the bond coat like this, bond coat for good bond strength and however the bond coat the thermal barrier coating material is applied TBC. So, what we will see here that in the temperature this is the high temperature side where TBC has been applied.

So temperature is high and across that TBC there is sharp drop in temperature you see sharp drop in temperature like this. Then little bit further drop in temperature normally Nickel base systems are used which are of the lower thermal conductivity and then this is the low temperature side. So, what will see here is the low temperature side, this is the substrate little bit increase in temperature then further higher temperature in the bond coat.

And so we can see there is a clear gradient, this difference in the temperature from one side of the substrate to the other side of the bond coat of the TBC material this difference can be order of 100 to 200 degree centigrade depending upon the TBC material which is applied. So, maximum drop is offered by the TBC material then little bit help is also given by the bond coat and then there will be temperature gradient across the substrate as well.

So, this reduction in temperature is favourable with regard to the kind of degradation which will be controlled in the substrate material and which in turn will help in improving the mechanical performance of the component being expose to the high temperature, as far as the application is concern as per as the application is concern of the thermal barrier coating material is there, it is normally used in case of the heat engines or IC engines, so in the cylinders.

So, that the heat loss to the surrounding heat loss to the coolant is reduced which in turn helps to increase the thermal efficiency of the engine and increase in thermal efficiency heat loss is reduced thermal efficiency is enhanced. And increase in thermal efficiency improves the mileage and we are able to cover the longer distances for unique for per litre of the fuel which is being consumed and how it is applied say this is the cylinder and here are piston will be working.

So, the application of the TBC in the internal surface of the cylinder this will try to conserve the heat as maximum as possible and the heat loss to the coolant to the surrounding will be reduced. So, most of the heat is utilised for generating the power and the rise in temperature of the cylinder and the all the components which are nearby that will be reduced. And which in turn will also help in increasing the tribological life of the components which are being used.

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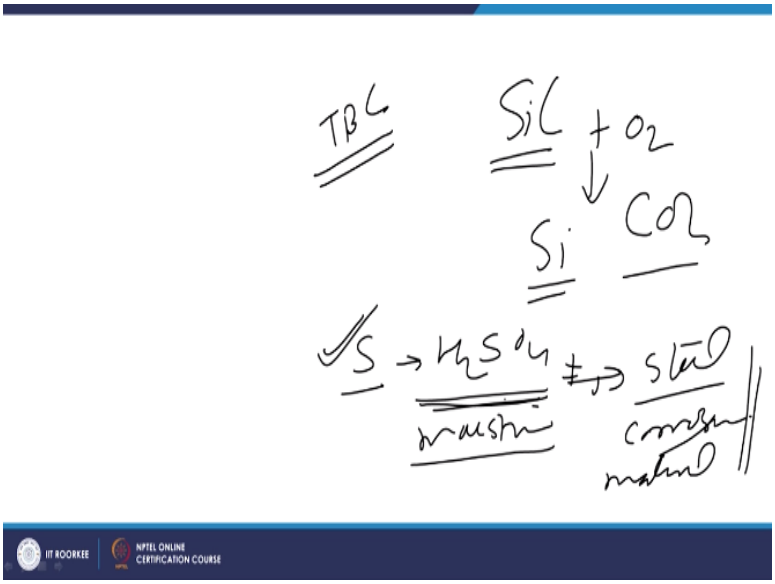

At the same time apart from this kind of thing some of the aspects are also to be seemed that the TBC materials are not damaged, some of the TBC materials like silica if it is used at high temperature reaction with the oxygen silica, silicon is left and it forms the Co2 or Co. So, this kind of the degradation can happen to the thermal barrier coating material at the same time like another observation is like in fuel.

If there is a sulphur, sulphur forms the H2SO4 after reaction with the gases and this H2 gases+moisture. So presence of moisture and presence of sulphur leads to the formation of H2SO4 and with the steel is H2SO4 causes the corrosion and the material damage and that is why we need to be careful that formation of such kind of the assets do not adversely affect the thermal barrier coating material.

Now I will summarise this presentation, in this presentation I have talked about the importance of the thermal barrier coating materials. And what are the properties of thermal barrier coating material should have and how these can be effectively utilised for increasing the life of the component and increasing the efficiency of the heat engines which are used, thank you for your attention.