Chemical Engineering Principle of C V D Processes
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Lecture No 09
C V D of Coatings

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Good morning, welcome to this lecture in the course on Chemical Engineering principles of C V D process. In the last lecture we talked about C V D processes for depositing metals on services, on surfaces.

So we talked about metal C V D using inorganic precursors as well as metal C V D using organic precursors. It is also known as M O C V D, metal organic C V D. And we just started discussing C V D of coatings.

Coatings are a special category of C V D films because they have requirements that are different from other C V D films. Primarily C V D films are very thin and they are put down on very critical, sub micron dimensional surfaces in order to provide certain functional properties such as conductivity or resistivity and so on. But C V D coatings are very different in the sense that they are much thicker.

Typically the coating must be of the order of microns rather than nanometers and therefore it is the conditions for

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C V D of coatings is very different from

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the conditions for C V D for other types of films. Now when we talk about C V D processes for coatings, they are the same as any other C V D processes.

If you remember in one of the first lectures, we described 3 or 4 methods or types of reactions to make C V D films. Decomposition, reduction, oxidation, and substitution slash exchange reactions. So the same types of reactions

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can also be used for C V D process, for C V D of coatings.

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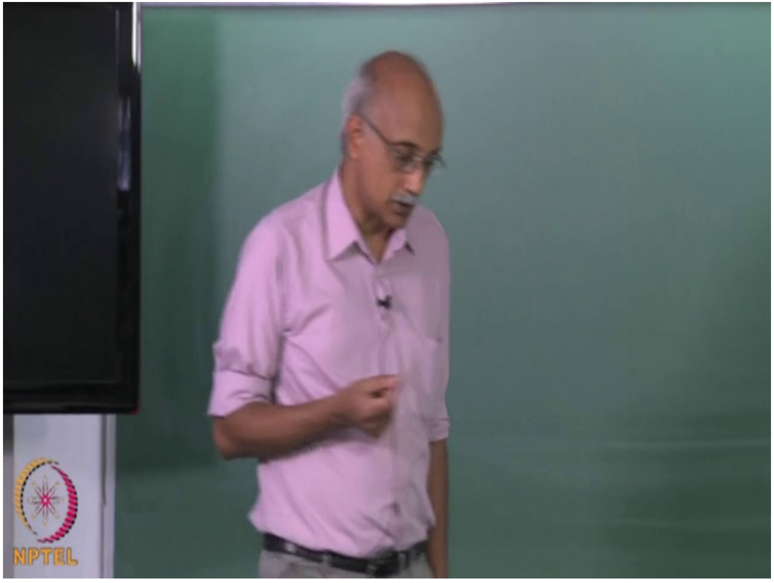

For example you can take

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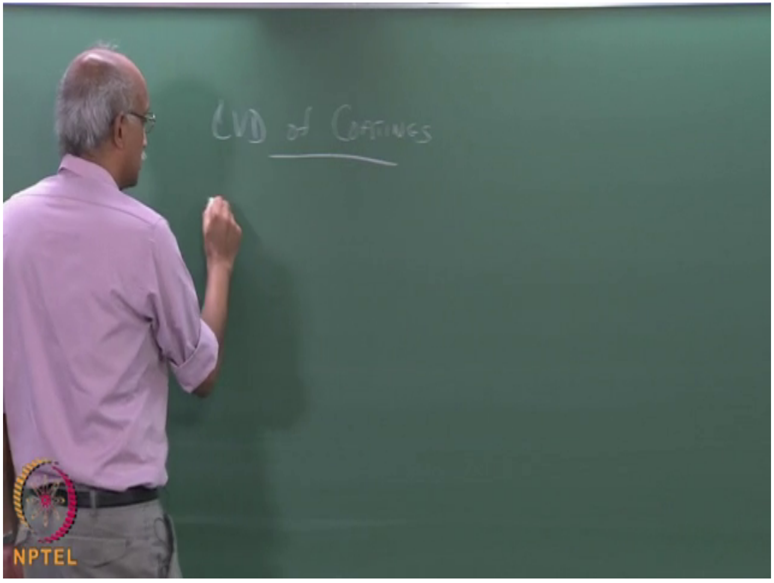

a compound like N i C o 4 and use that to deposit Nickel solid plus 4 C o. So this is a decomposition C V D reaction to get

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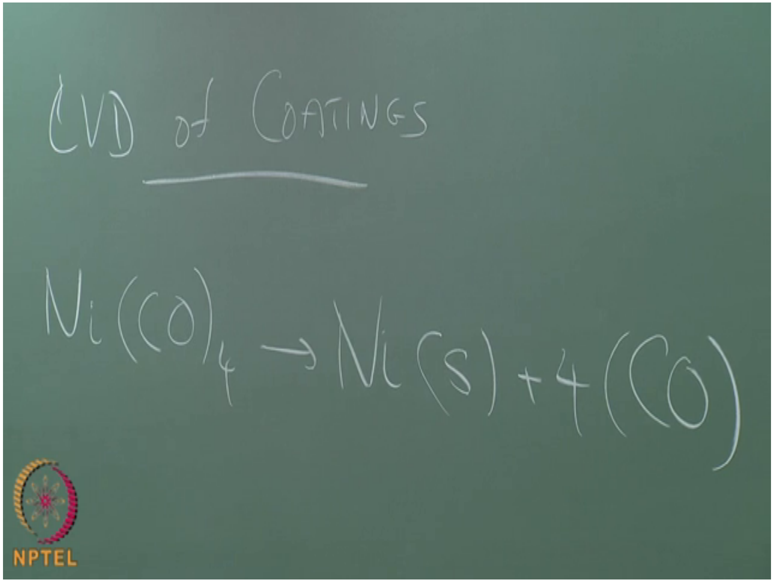

a nickel coating. Another example of such a process could be, if you want to actually make a tungsten coating then you would, as we saw the other day, you can actually use either W F 6 going to W plus F 2 which is a decomposition reaction or W F 6 plus S i H 4 which can also lead to a tungsten deposition

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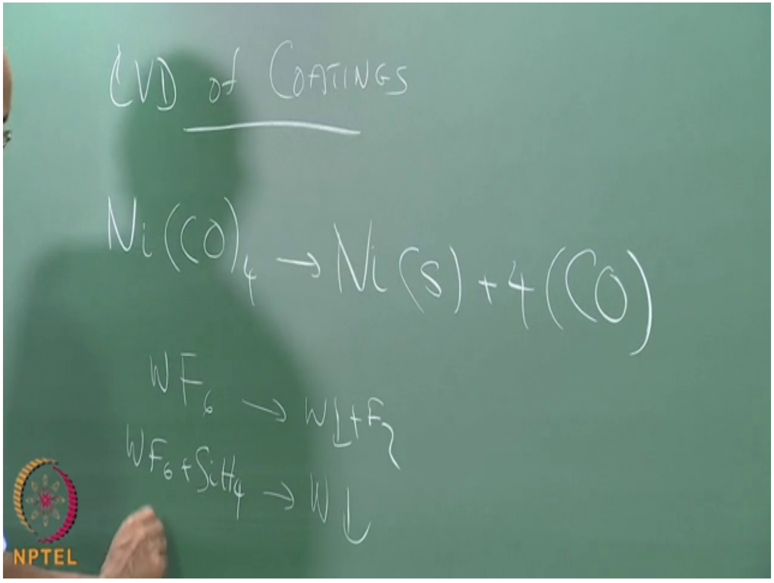

CVD of COATINGS

$Ni(CO)_4 \rightarrow Ni(s) + 4(CO)$

$WF_6 \rightarrow W\downarrow + F_2$

$WF_6 + SiH_4 \rightarrow W\downarrow$

or you can also do W F 6 plus H 2 going to W plus H F.

Now actually,

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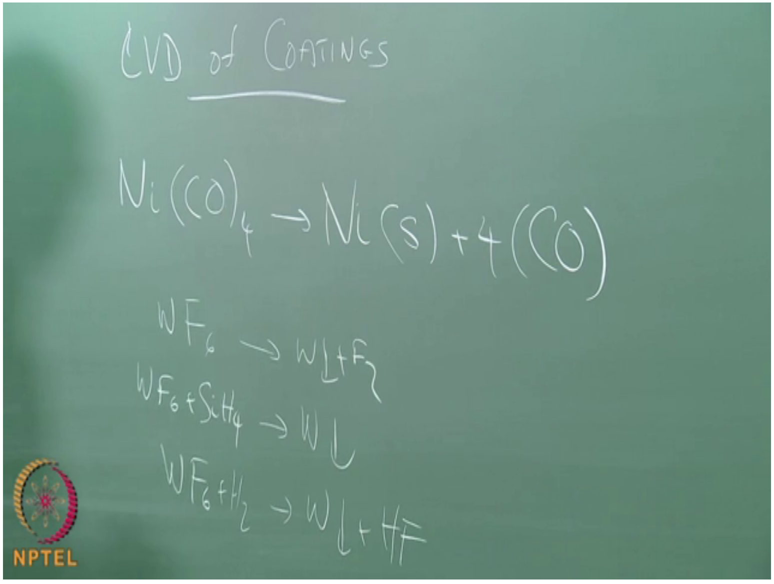

CVD of COATINGS

$Ni(CO)_4 \rightarrow Ni(s) + 4(CO)$

$WF_6 \rightarrow W\downarrow + F_2$

$WF_6 + SiH_4 \rightarrow W\downarrow$

$WF_6 + H_2 \rightarrow W\downarrow + HF$

tungsten can be deposited therefore by all three kinds of reactions. This is a decomposition reaction, this is a reduction reaction and this is essentially a substitution type of a reaction. And so the C V D processes for coatings, in terms of the types of reactions are no different from C V D from other films but as I mentioned earlier, the primary difference is in the characteristics of the films that you are trying to obtain.

They are much thicker and they have more emphasis on the physical properties rather than on their electrical or functional properties. And similarly when you talk about designing the C V D reactor the critical parameters are the same as for any other C V D system.

So the critical parameters would be the substrate temperature, the temperature distribution in the reactor, the operational pressure, the flow rates of the feed, the flow rate of the carrier gas, the flow rate of the reactant species, the concentrations of the reactant species, the reactor geometry, the flow dynamics and you know, the controls over the input, controls over the operating parameters, controls over the exhaust and

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pre-treatment of product stream prior to venting into the atmosphere and so on.

So again the design principles for C V D reactors for coatings are essentially the same. So what makes C V D

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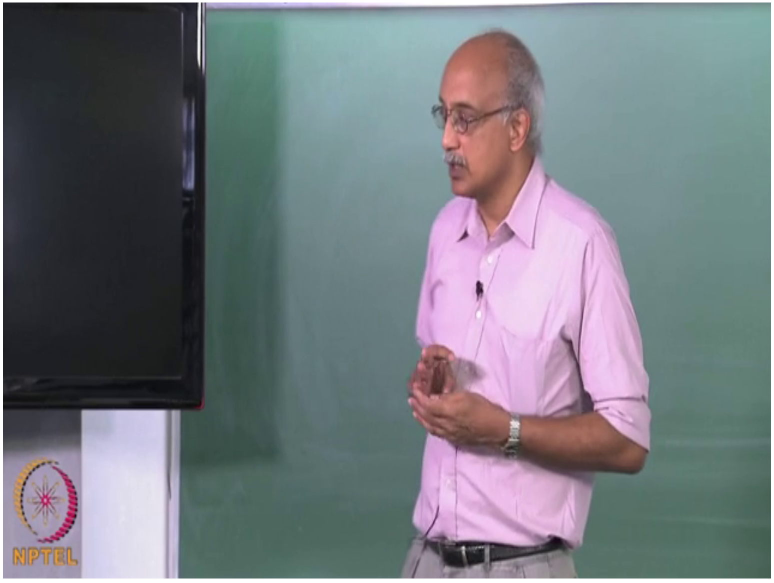

of coatings unique? What is really different about it? The primary difference again is the fact that, there are some conflicting requirements on C V D coatings that have to be satisfied. They do have to be much thicker than a C V D films that you normally deposit. The problem is that as you make the coating thicker, adhesion or delamination issues become more and more difficult to deal with.

When you have a substrate of some kind and you try to put down a coating on top of it,

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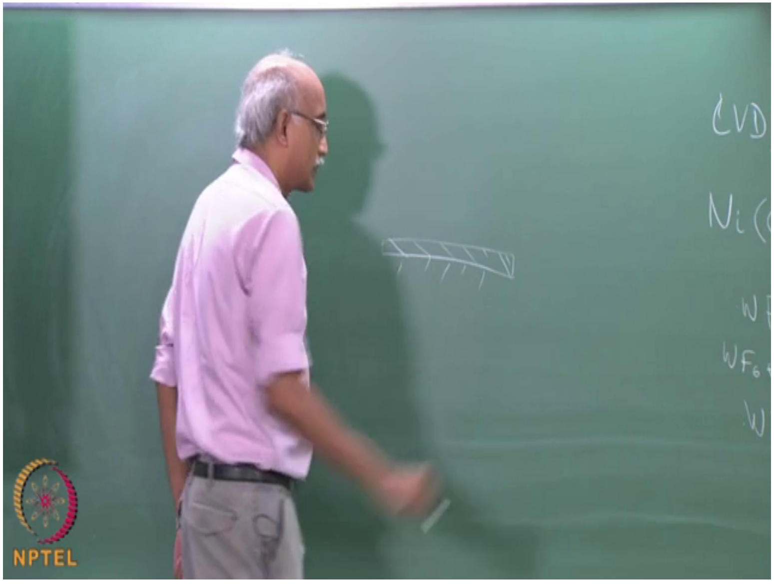

clearly for the most part, the coating has a very different chemical composition and physical structure compared to the substrate that is underneath. That is the reason you put it down as a coating, right? But the problem with that is when you go from here to here, there is a very, very short transition in properties right at the interface.

All of the sudden you get this huge change in chemical composition, in physical properties, in structure, in hardness, in density virtually every imaginable parameter when you go from the coating layer to the substrate layer. And what that introduces is stress. So the biggest problem with C V D coating is the build-up of stress at the interface between the coating and

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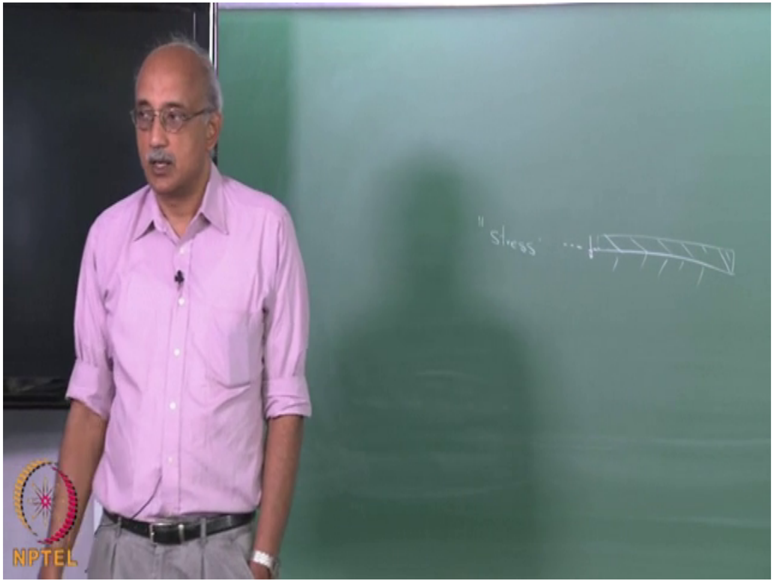

the substrate.

If you can relieve the stress adhesion will improve. Part of the reason why the C V D coating or actually it applies to coatings that are put down by other process as well, but especially C V D coating is that the film is ready to, kind of detach from the substrate, you know, at the slightest excuse. So you have to provide an environment which will promote the adhesion of that coating layer to the substrate.

So what are some of the techniques that are used for relieving the stress? The first is reducing thickness. Try to achieve your end effects

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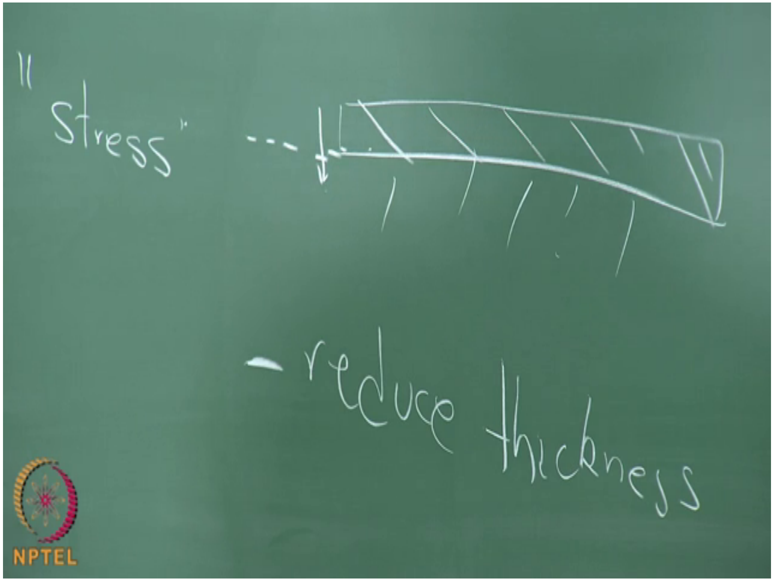

with as thin a C V D coating as possible. The thicker the coating, the more the likelihood that it can disengage from the substrate as well as if you have a thick coating you can also have delamination within the layer itself.

So one layer of the coating can actually detach from the next layer of the coating. So intra-coating adhesion also can become an issue. So make the coating as thin as possible. The second is to increase the radius of curvature.

Even though C V D

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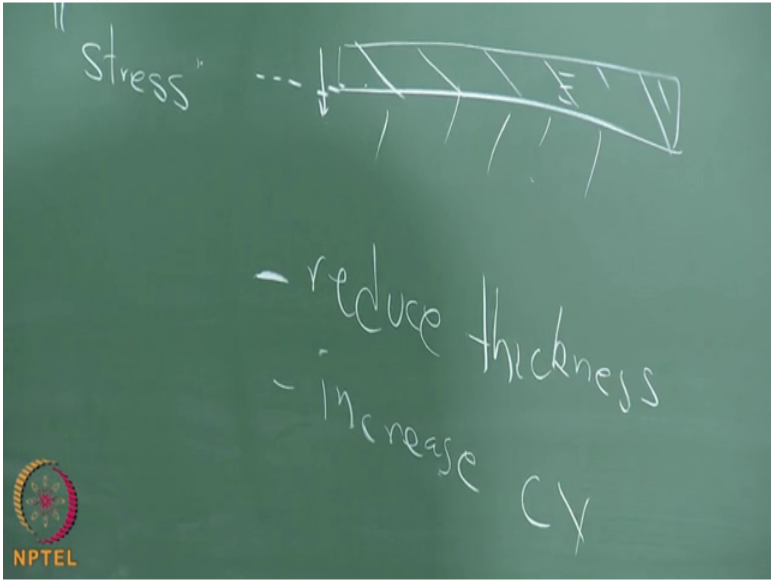

is much better than other coating processes in terms of being able to follow the contours of a body, a smoother or more curved surface is easier to coat than one that has very sharp transition points. So you can make it easier for the coating to adhere to the surface by making the surface, by reducing the number of abrupt geometrical transitions in the, in the body of the substrate.

The third technique that you can use is to actually match the physical properties, match the physical properties of the coating

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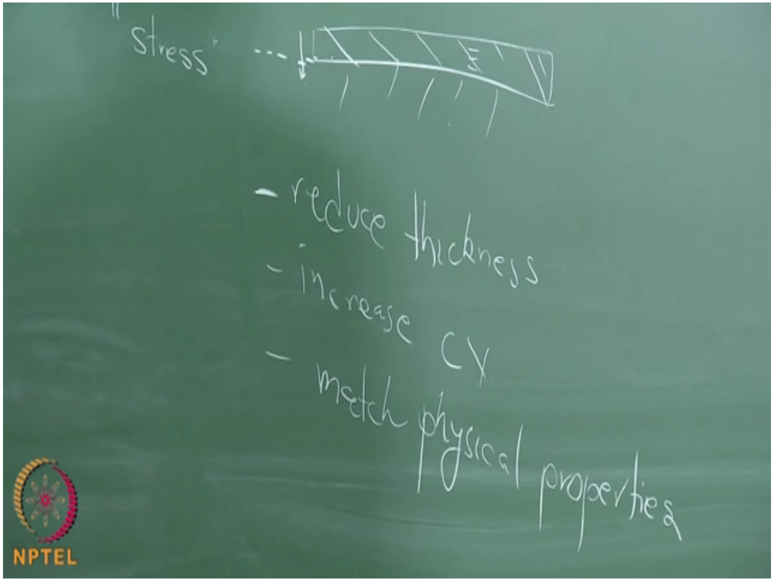

to those of the substrate. The closer they are, obviously the less would be the stress that is built up due to the transition.

So particularly properties such as conductivity, thermal conductivity, coefficient of thermal expansion is very important one because as the substrate coating goes through various cycles, what causes delamination to happen frequently is the difference in coefficient in thermal expansion.

So one of the most important parameters to try and match is C T E, coefficient of thermal expansion particularly when the coatings are being used for high temperature environments.

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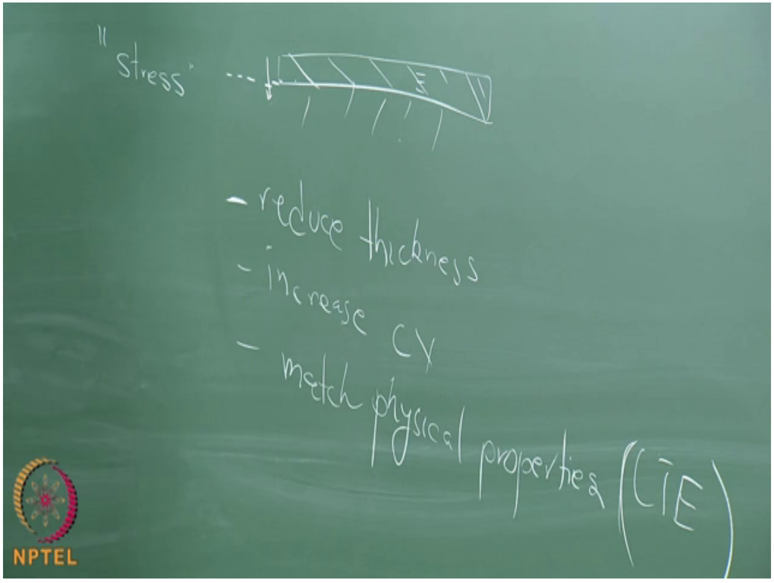

Now sometimes it may not be possible. You may have a metal substrate on which you are putting down a ceramic coating. You really cannot match the physical properties.

Then a suggested method to handle that is instead of having this very short transition where the property may suddenly drop like this to a much lower level or a much higher level, you provide a smoother transition. So you provide certain intervening layers which will make that transition much smoother.

So instead of, across the thickness of the film, instead of getting this sort of behavior you try to smooth it out and get a more gradual transition. The way you do that is that in a C V D film, you deposit various layers with different compositions and

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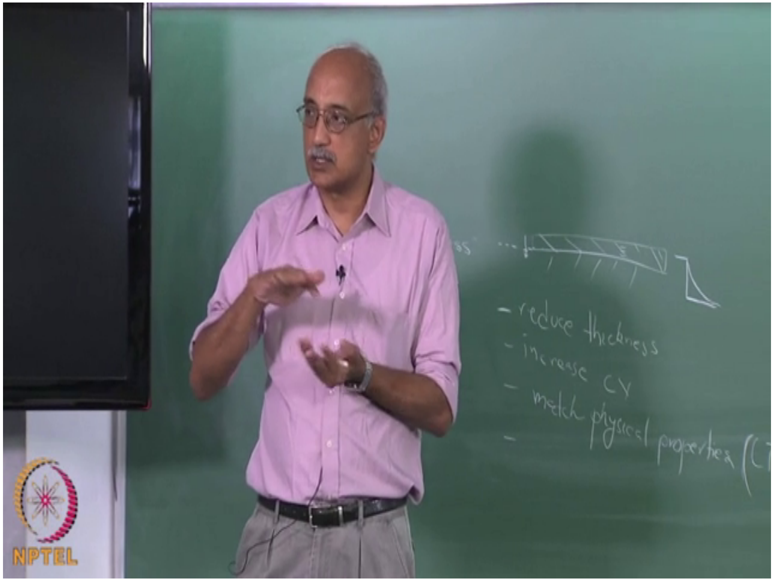

physical properties.

The layer that is closest to the substrate should most closely mimic the properties of the substrate and then as you move away from the substrate, you can slowly start increasing the departure or the deviation of the properties from the substrate properties themselves.

And so this is frequently resorted to, again to reduce the stress. The other thing that you can do to reduce stress is to essentially have the coating itself

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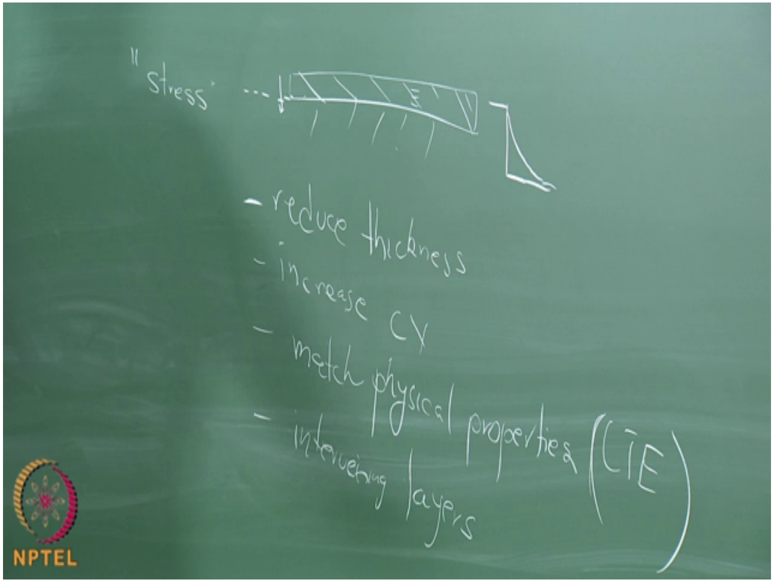

diffused into the substrate. So when you have this diffusional coatings again it provides for a smoother transition. So within the metal itself or the substrate you will have a transition zone where the properties will change slowly from the properties of the coating to the properties of the metal.

This also promotes adhesion because once the coating material, coating element has actually penetrated into the substrate material the interlocking is much stronger. So it helps in both ways. It helps the mechanical interlocking between the coating and the substrate. And it also makes the gradient much, much shallower as you, as you coat the substrate.

So these are all things that you can do, and of course there is also the post-processing typically post-baking.

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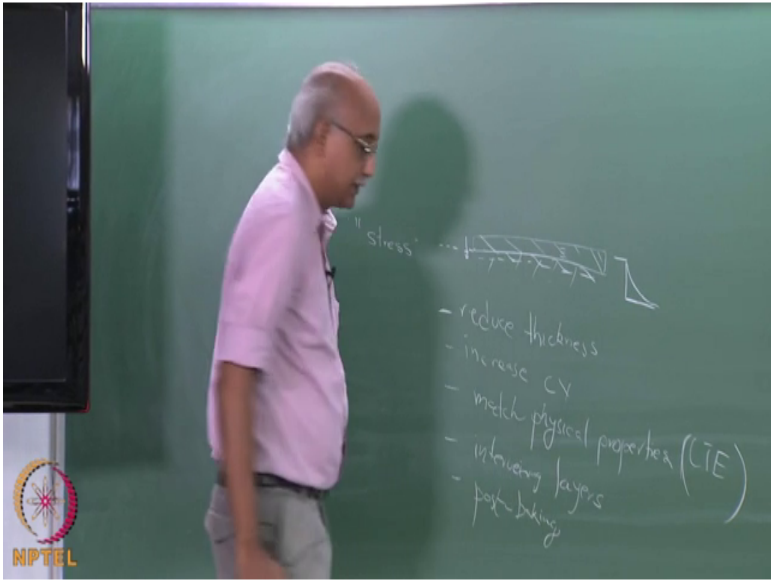

This is important to control the structure of the deposit. Because it turns out that one of the major differences between the coating and the substrate is the morphology and structure of the coating and how that differs from the morphology and structure of the substrate.

So for example, if you are trying to do, again a, let us say, a metal coating on top of the semiconductor, the metal will have properties that, well, the metal layer that you deposit depending on the deposition conditions can be a very amorphous structure or it could have a more rigid structure to it. Now in terms of stress it turns out in principle, an amorphous structure should introduce less stress because it is more accommodating as far as the stress distribution is concerned.

You can imagine that if you have two very rigid bodies getting them to stick together is more difficult than if you have one of the bodies being much less rigid than the other. It can actually deform in a sense. And therefore provide better adhesion and also more surface area for adhesion. When you have either two deformable surfaces in contact with each other or one rigid surface and a deformable surface in contact with each other, the contact area which is really what controls the adhesion is larger to begin with and tends to increase over time.

Because the two surfaces as they contact each other will continuously deform over time until they reach a steady state. So what you will find is the adhesion forces are actually at their lowest at time zero and then with the passage of time, the adhesive forces will increase to a certain value and then they will stabilize. So matching the structure is also important and that can be done by post-processing.

For example if you have an amorphous substrate and you are trying to bond

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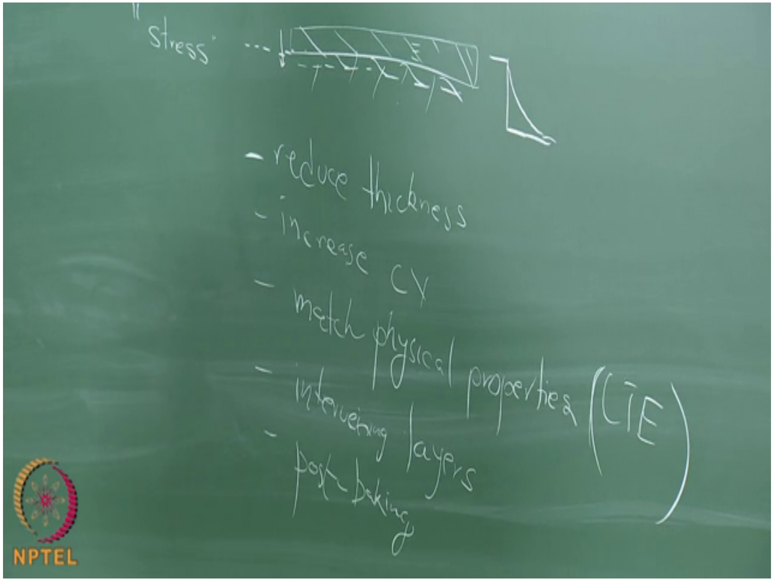

an amorphous film you probably do not require a post-baking. However, if you have a substrate that is rigid and the film that is amorphous that is Ok for time zero to get adhesion to happen but then once the film is bonded to the surface you want to control its structure to provide the necessary physical properties. So you can resort to things like annealing in order to improve the properties of the C V D coating.

Now typically the properties that you look for in

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a C V D coating are, you know things like rigidity, hardness, density,

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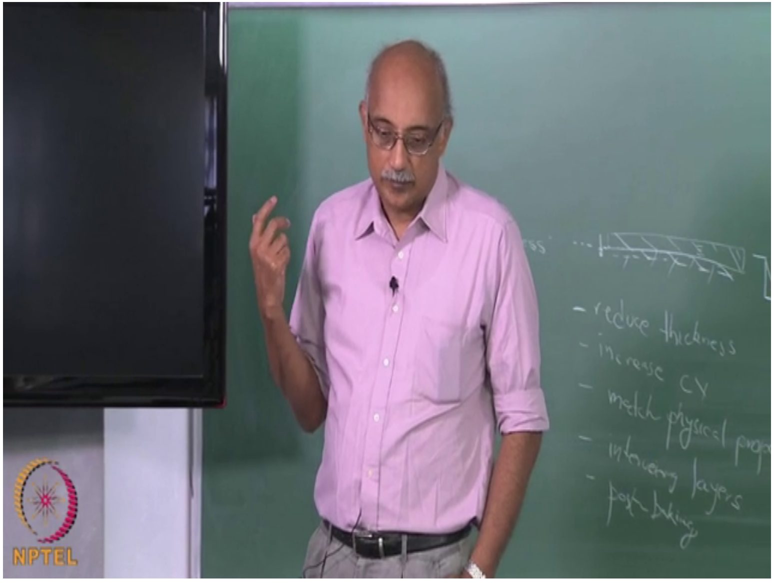

ability to withstand thermal cycling, frequently these coatings are used in high temperature environments but it is not just the high temperature, it is also the fact that temperatures can frequently cycle between low and high. And it is really this thermal shock that can create damage rather than continuous exposure to either a high temperature or a low temperature environment.

So ability to survive in aggressive environment in general, whether it is high temperature or high pressure or highly reactive environments; that is one of the hallmarks of a good coating.

Coatings also have to provide good resistance towards diffusion. They are frequently used as diffusion barrier coatings.

So this may be a barrier against even water vapor diffusion, if you are trying to protect something from moisture permeation or it could be protection against diffusion of corrosive vapors or toxic vapors. So diffusion barrier coatings are another widely applied usage of, of C V D coatings. Of course classically erosion resistance and corrosion resistance have also been associated with coating materials.

So there are variety of coatings that can be deposited for all these different processes and the C V D process again is sufficiently flexible that you can achieve virtually every one of these coatings using a C V D process.

Actually the history of C V D coatings, those go back to the 1950s. The aerospace industry was actually the first one to use coatings as a diffusion barrier. It was developed back in the 1950s by the US Aerospace industry which by the way has been responsible for many innovations, you know. People talk of clean rooms used for semiconductor manufacturing. But clean rooms were actually invented by the Aerospace industry and, to make the rockets and the space components and similarly they also invented C V D of coatings.

The process that they used was something called pack cementation. So this is in the aerospace applications. And again most the application was diffusion barrier coatings in this case.

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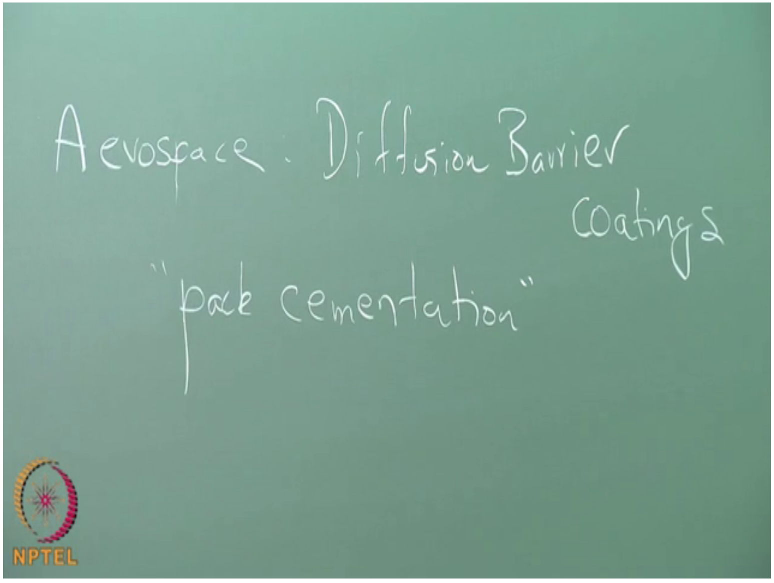

Aerospace : Diffusion Barrier Coatings

"pack cementation"

Pack cementation is actually sort of a variation on a conventional, commercial C V D process. What it refers to is, let us say that you have a metal on which you are trying to deposit some kind of a protective coating.

In pack cementation, what you do is you take that reactive metal that you are trying to deposit and grind it into a powder, put it into essentially a vessel or a chamber in which the substrate is also located, the substrate on which you are trying to do the coating, introduce a gas, an inert gas as a carrier gas, typically argon was used as a inert gas and you also introduce appropriate reactive gases typically H C l, H 2 and so on.

Now, and then you kind of pack, pack all this into a container and you jack up the temperature to 1000 degrees plus. So what happens is that the reactive gases will flow through and they will react with the metals that you are trying to coat and because of the elevated temperatures, they will form the gas phase vapors of the metals.

So for example, if you have aluminum in the, as the reactive metal it will react with chlorine in the H C l and it will form aluminum chloride for example.The halides that you are forming will then flow over the substrate that you are trying to coat and they will deposit aluminum as a film, right. So it is kind of, everything is happening inside a vessel.

Unlike the classical C V D process where the preparation of the precursor happens outside the C V D reactor and then you feed the precursors in the C V D reactor where the coating takes place. Here everything takes place in one reactor so to speak. You are generating the vapors in situ and you control the transport phenomena inside this reactor in such a way that the reactive vapor species that are formed are directed to flow over the substrate that you are trying to coat and the film deposition happens within the reactor itself.

So typically some of the coatings that are formed using this technique are aluminum, the process is called aluminizing, boron which is boronizing, carbon carbiding, nitrogen nitriding and so on. The Aerospace industry wanted to do it this way because essentially they do batch processes. I mean, they do not make a lot of components in a year, unlike for example the semiconductor industry where they are trying to pump out a million wafers in a year, in aerospace you may make only one of each in a year.

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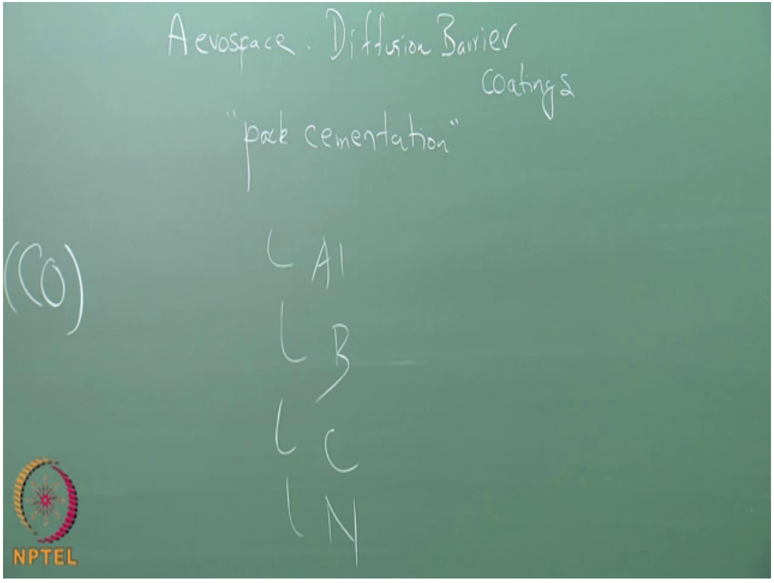

So you really need a good batch process that is well-controlled where you can take time but make sure that you do it right. So the primary disadvantage of this technique is that it is a batch process, it is slow and it is not very energy efficient but it will give you very repeatable and reproducible results because everything is being kind of being done in one place. So you have, you can control that, the whole process very well.

So this pack cementation was invented back in the 50s, and then in the 60s,

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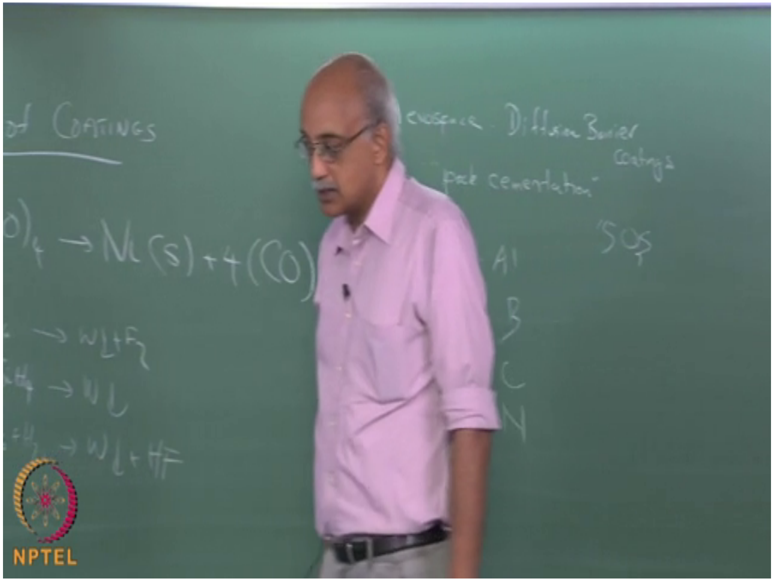

the second commercial application of C V D coatings was for tools, tooling components, tool bits. Because tools tend to wear easily. So you need a coating to prevent wear and chipping of tools. You also need to reduce friction between sliding components and there again you can use a coating to improve the frictional characteristics between mating surfaces.

And the third problem is what is known as galling. Galling is where you have two metals that are of somewhat comparable hardness and they slide on each other; they both tend to lose material. And they actually tend to stick to each other because of deformation. As I was mentioning earlier, as two contacting surfaces deform their contact area increases and therefore they have a tendency to stick together. So galling is a phenomenon that happens because of this wear of a surface which then promotes sticking of two sliding components.

So all of these issues can be addressed by doing a C V D coating on top of the substrate. For example if you have a tungsten tool bit, you can coat over it with tungsten carbide. Or if you have a titanium tool, you can coat over that with titanium nitride.

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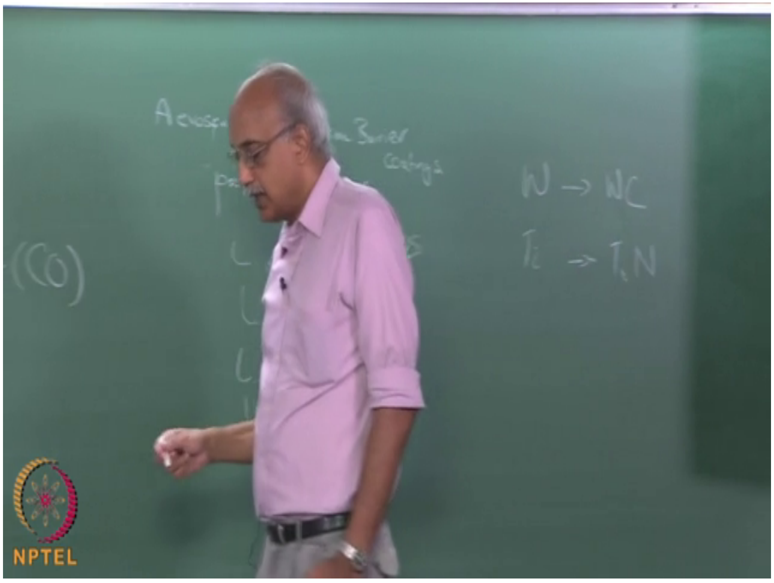

So carbides, nitrides and carbo-nitrides T I C N is another popular

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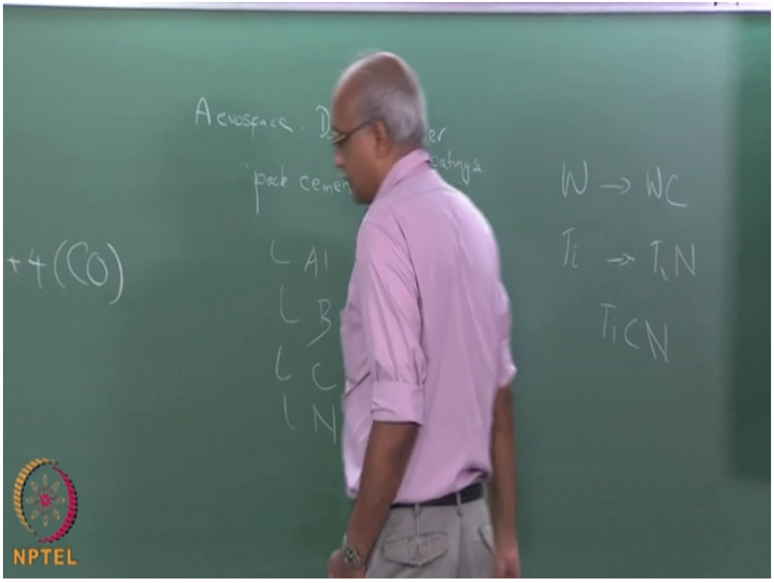

coating material for tools and actually, you know there is a fairly large variety of these types of coating materials.

They all have increased hardness compared to the base material that they are trying to coat. So for tools especially the primary requirement for the coating that goes on top is that it should be significantly harder so that galling does not happen but at the same time, it should have good frictional characteristics and wear characteristics.

So there are some very specific functional properties that these coatings should have and it turns out that a C V D process that is typically run at a low pressure hot wall C V D is typically employed to deposit these types of coatings on the substrates.

Another application for, the third commercial application for C V D of coatings was actually erosion prevention coatings. This became important when, particularly in power plants where you are burning low quality fuels such as coal. You have a lot of these ash particles and other inorganic materials that survive the combustion process which then get into the product gas stream and then they start flowing over surfaces that have immersed.

And as it happens, if you have sufficiently large particle that, that impacts the surface at a certain angle, you can have fairly severe erosion of the surface. So you need to coat these materials with erosion preventive coatings. Now these are usually ceramic coatings, alumina, silica and again some of the carbide and nitride coatings have good properties for erosion mitigation.

But in addition you also need to have the same coatings, need to also have thermal barrier properties, because again in power plants and also in gas turbines the product gas streams can have temperatures in excess of 1500 degree Centigrade because they have just come from the combustion process. So depending on the temperatures that are obtained particularly if it is an adiabatic process, combustion temperatures can be of the order of 2000 Kelvin.

So the coatings not only need to be erosion resistant but they also need to be able to withstand high temperatures and actually a fairly reactive environment. Because of the high temperatures and the fact that you have a variety of organic and inorganic species in the gas stream, there will be a tendency for the combustion product gases to try and react with the surface and so you have to essentially provide a chemically inert surface as well in order to resist any interaction of the vapors with the surface.

So the second and third applications for C V D coatings are tools and erosion protection coatings in power plants, boilers, turbine blades etc. The fourth application

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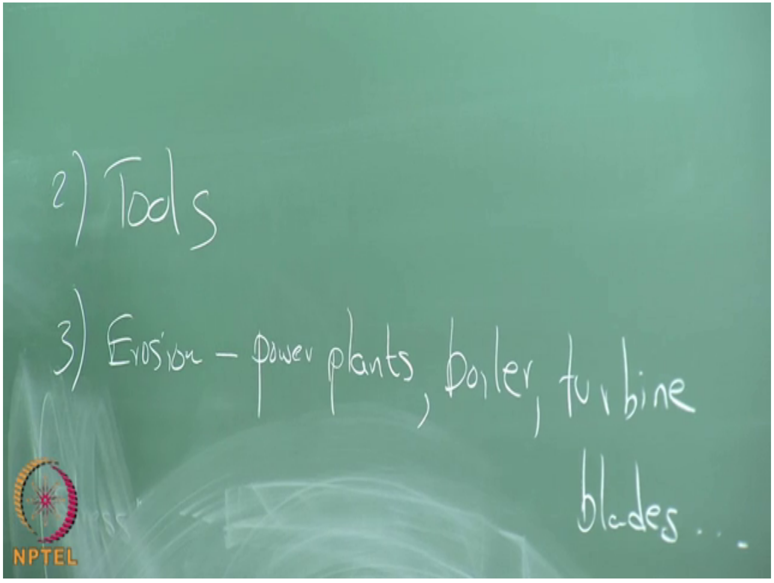

2) Tools

3) Erosion – power plants, boiler, turbine blades . . .

and which is probably the most important one is corrosion protection coatings.

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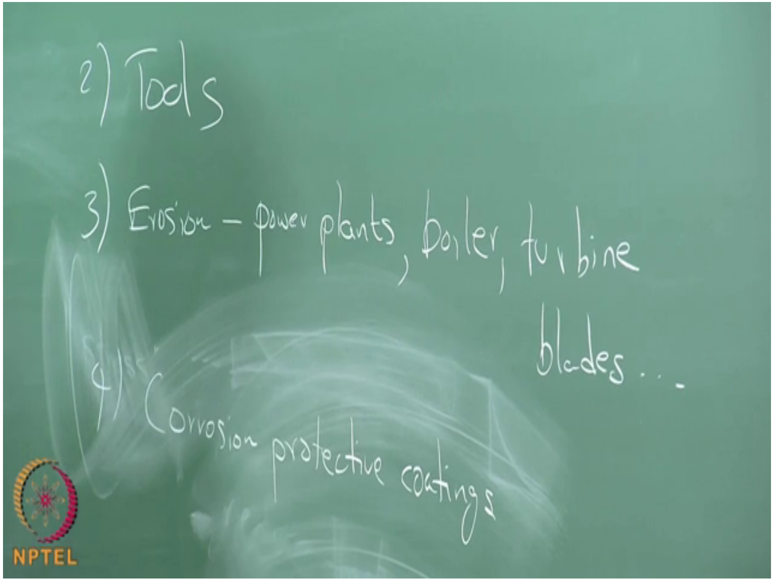

2) Tools

3) Erosion – power plants, boiler, turbine blades . . .

4) Corrosion protective coatings

In terms of potential value, this application far exceeds all the others because it has been estimated that just in the US alone, the annual losses due to corrosion in various industries exceed something like 500 billion dollars.

So corrosion protection in various environments is a very critical application. Now in order for protection from corrosion, there are different strategies that you can use and certainly coatings are a way to do it. But act/actually in this particular instance the coating is not the smartest way to do it. The reason is that you know, when you do, I mean, when you talk about corrosion the types of coatings that you can have organic coatings, inorganic coatings and ceramic coatings right?

Organic coatings are typically bio-compatible, environmentally friendly but they do not survive high temperatures very well and they do not survive chemically reactive environments very well. So they do not really work when you are talking about particularly high temperature corrosion prevention.

The second, you know, inorganic coatings and ceramic coatings can provide the thermal resistance and the chemical resistance and so on but they are expensive processes and they are not environmentally friendly. The processes that you have to use to put down these coatings can result in the discharge of very harmful chemicals both in the liquid discharge as well as the vapor discharge.

So a preferred method is actually to put down the material on the surface, a very, very thin film of it and allow it to again penetrate the top portion of the surface that you are trying to protect so that just the surface that is exposed to the outside environment has certain properties that are superior to the bulk of the material.

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For example again in gas turbines you know the stators and the rotors

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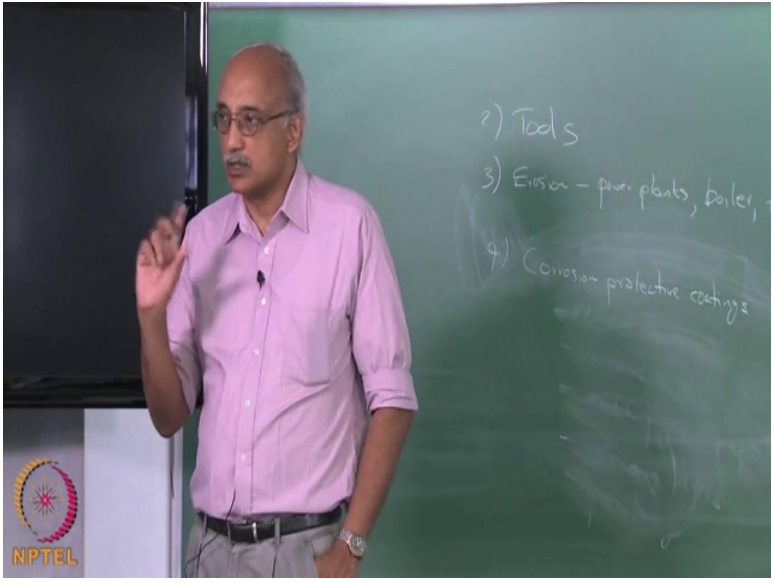

are typically made of stainless steel. Now stainless steel is good for most types of corrosion protection. However stainless steel does not provide you with absolute protection particularly at elevated temperatures and in highly reactive conditions.

The primary reason is the stainless steel manufacturing introduces impurities. And it is these impurities that really initiate the corrosion and then it quickly spreads. So even though you may have stainless steel as your substrate material you have to provide additional protection to it and especially if you start using the less expensive steel alloys this becomes even more important.

And in fact if you look at the turbine industry in general they do use steel alloys rather than stainless steel alloys in order to minimize the cost. But they have to immediately deal with corrosion. So the lifetime of these steel components can be quite low. So what you really have to do is to use what are known as super alloys.

So the super alloys are also steel alloys but with certain additives like chrome and nickel which provide additional protection against corrosion as well as erosion, folding, slagging and so on. The problem is the super alloys are extremely expensive. So if you want to construct an entire turbine blade out of a super alloy, you are talking about thousand times increase in the cost of the turbine which is not acceptable in order to get your process economics.

So what we do is you C V D instead and deposit the element that is going to give you that extra protection such as chrome, nickel and so on as a top layer, on top of the steel substrate and design the conditions to allow it to penetrate into the steel to a sufficient depth in order to provide the protection properties you need.

So essentially you are only turning the top layer of the steel into a super alloy. The rest of it can stay as a low cost, commercial alloy material. So it is kind of a smart way to achieve what you are looking for. Because when you think about it, if your concern is mostly with surface exposure and surface phenomena there is no point in trying to improve the material throughout the cross-section. You only need the enhanced properties at the surface where the material is encountering the environment.

So it is very, giving very localized protection. So this corrosion protection coatings are typically metallic coatings, again iron, chrome and nickel are the most commonly employed metals in this application and they are deposited as a thin surface layer and they are allowed to diffuse into the substrate.

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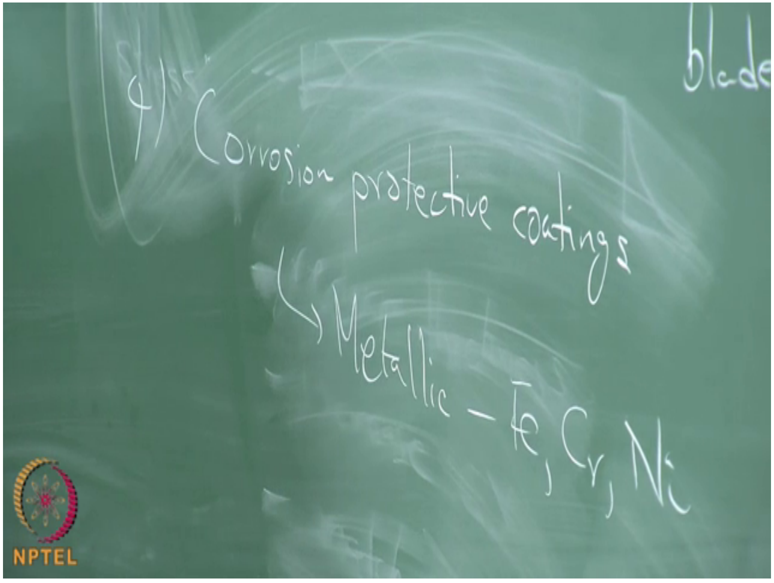

blade

4) Corrosion protective coatings

↳ Metallic – Fe, Cr, Ni

Now as we saw in the last class

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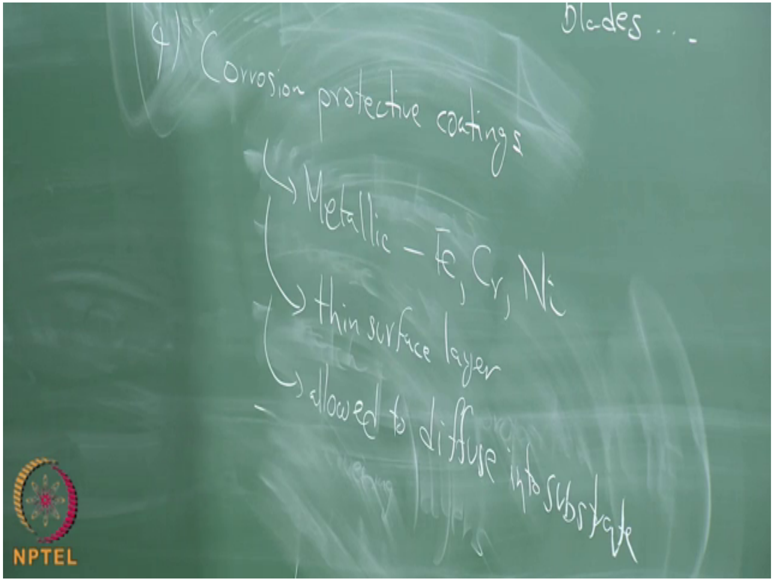

Blades . . .

4) Corrosion protective coatings
↳ Metallic – Fe, Cr, Ni
↳ thin surface layer
↳ allowed to diffuse into substrate

when we were talking about C V D of metals, there are well-established processes. There is metal C V D; there is M O C V D which are very effective in depositing metal films on surfaces. The only problem is that, typically again these work on small substrates you know, but in the case of turbines we are looking at very large surfaces that need to be coated.

So this technique is these techniques are not very appropriate for coating of large components such as turbine blades and so on. So the process that is used in this case is one that blends some, again a very classical chemical engineering process which is fluid bed with C V D, so it is called fluidized bed C V D.

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FB-CVD

0:34:16.7The way this works is, you prepare a bed of the coating material and you fluidize it. You fluidize it using again using a carrier gas such that may be, inert, inert gas or it could be hydrogen or it could be nitrogen and along with the carrier gas you also introduce certain reactive species such as chlorine or H C l or H F and so on.

And then you essentially prepare this bed and you fluidize it using this mixture of carrier gas, inert gas and the reactive gases and as the fluid passes over the bed with the metal particles, the metal particles will react with corrosive gases and form halides.

So for example C r will form C r C l 3 and then the, these gases now the halides for example are flown over the substrate that you are trying to coat. So it could be a turbine blade, it could be a stator, it could be a boiler tube whatever it is that you are trying to protect will be laid in the path of the product gases from the fluidized bed C V D and as they encounter the substrate they will break down and deposit the metal on top of the substrate. Now that is the first step.

It allows you to deposit a layer on top of the substrate. But the key thing in doing corrosion protection using F B C V D is the second step which is to provide sufficient time as well as conditions in order for inter-layer diffusion to happen. You want the film not only to be at the surface but it has to be sub-surface as well.

You know in any substrate you have essentially three layers. There is a bulk, the sub-surface and the surface. So the C V D coating has to be able to penetrate at least into the subsurface region and you can actually control its depth of penetration by controlling things like time of exposure, the pressure.

Essentially the higher the pressure the more you can push the material into the, into the substrate so by using the lower pressure you can reduce the depth of penetration. And you can also control it by turning on and off the reactant gases that are flowing in. So as soon as you figure that you have sufficient protection or sufficient thickness of this protective layer formed, you can turn of the flow of the reactive gases and prevent the film from forming.

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So this process of F B C V D in combination with a post-process

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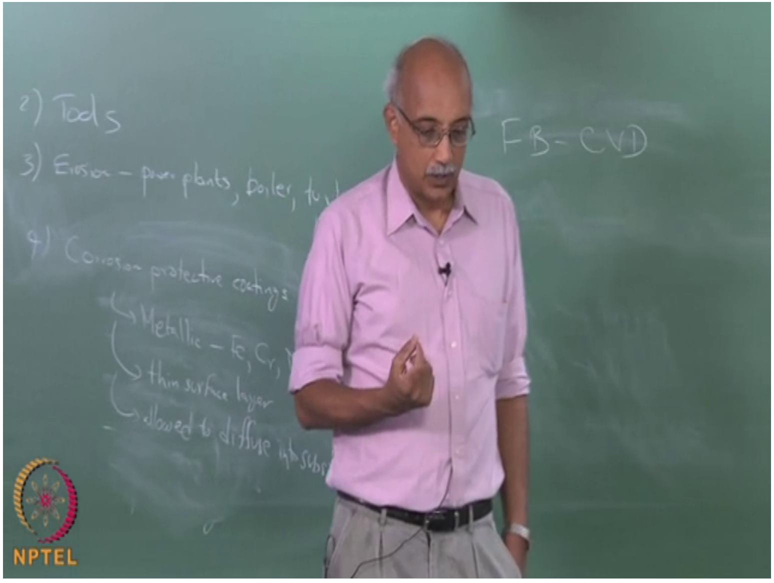

can provide excellent control over corrosion protection of surfaces using a C V D process. So this is now frequently employed in the turbine industry especially to put down inexpensive corrosion protective layers on top of the pre-existing substrate.

So you will see an interesting transition, you know. If you look at a turbine blade, you know it looks like this. And you cross-section it, the bottom most surface will simply look like a steel. The topmost surface will look like what is known as a super alloy which has the most enhanced corrosion protection

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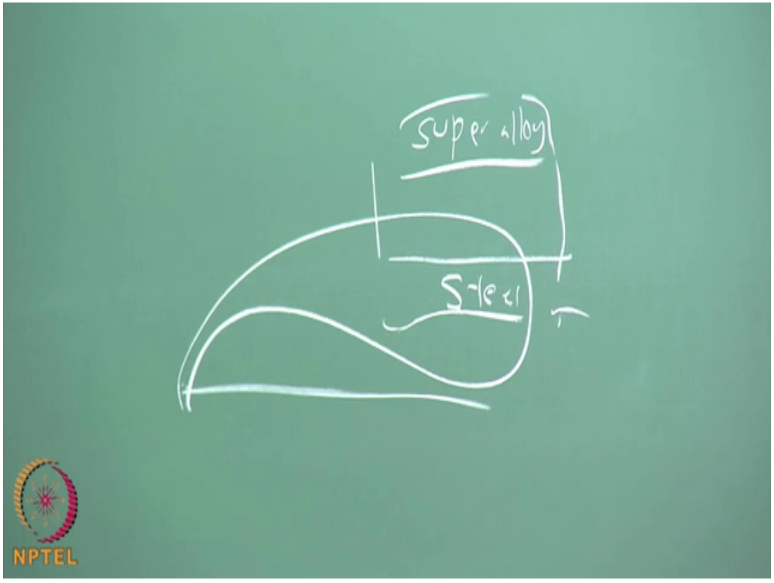

properties and in between you will see a transition zone

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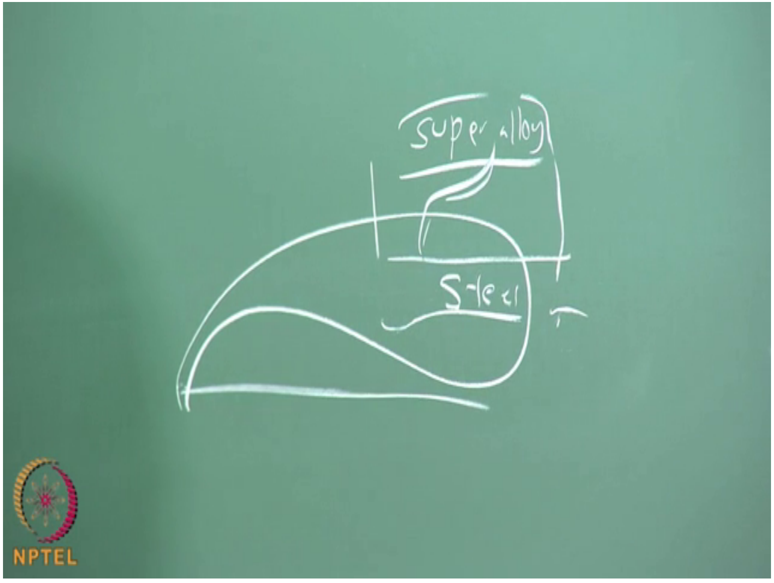

where the properties of the substrate will slowly change from the low cost steel properties to the high cost super alloy properties.

Another application of C V D coatings is on top of polymers. There are frequently applications where the substrate has to be a polymer but the surface has to have enhanced properties beyond what a polymer can give. Typically these are used in biomedical type of, medical devices especially, especially medical inserts that go into the human body.

For various reasons, these inserts have to be made of a chemically inert material like a plastic but it must have sufficient surface resistance to things like chemical reactions and also diffusion in and diffusion out. You don't want impurities in the plastic to come out and pollute the human system and at the same time you do not want the plastic to be degraded too quickly by something that may be diffusing into it from the human body.

So that is one example. But you know the plastics are used in many demanding environments because of the lightweight characteristics. So any time you talk about propulsion, payload, you know space applications, rocket launch, if they could they would make the entire rocket out of plastic, right because it is the weight of the rocket is what you are constantly fighting when you are launching.

So plastics are a highly desirable material and rubbers also. So all classes of polymers are very desirable in terms of certain properties but they do have one issue that a plastic surface can easily wear. It can be easily be abraded, it can easily be eroded. It cannot be corroded so much but physical damage is quite possible. So it certainly makes sense to put down a coating on a polymer and it is very difficult to do because plastics by definition are low surface energy materials.

And so adhesion tends to be poor if you put down a coating and also the chemical reactivity is also not very strong. And so conventional coating processes do not work very well. And even conventional C V D processes do not seem to work too well. It is very difficult go to get a C V D film to bond on to polymers. And also you cannot use high temperatures because most plastics will degrade. Most polymers will degrade at high temperatures.

So what would you suggest; if you wanted to use a C V D process for coating polymers what would be an appropriate process? Plasma enhanced C V D because that can be done virtually at room temperature and the plasma itself

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will have multiple uses. It will provide the energy

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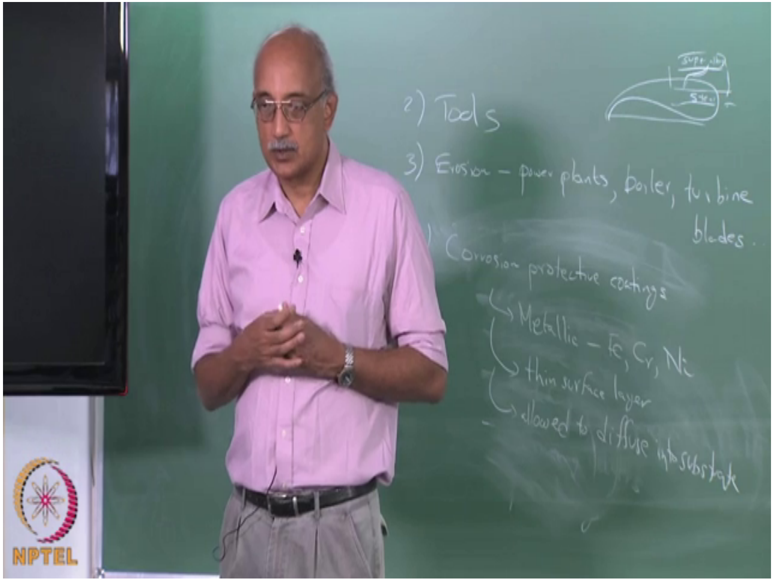

to, to improve adhesion. Plasma can also energize the vapor phase molecules plus it can actually, while you irradiate a low surface energy surface with plasma, you can increase its surface energy.

So you can take a polymer and increase its surface energy by exposing it to the polymer. You can almost make it behave like a metal

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in terms of surface energy characteristics. So plasma C V D for coating of

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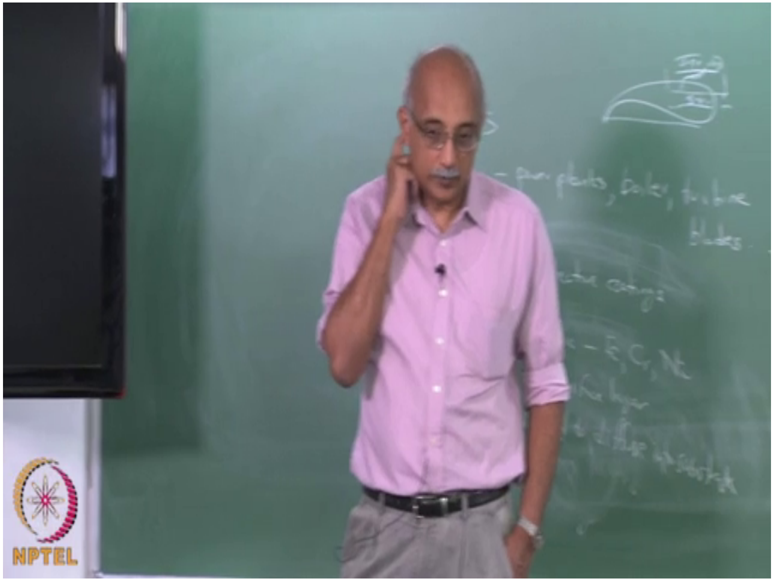

polymers and this can be a variety of polymers. You can coat everything from poly ethylene to poly propelene to polystyrene, nylon, P E T anything can be C V D coated but you do have to do it in a P E C V D reactor and not in low pressure C V D reactor or a atmospheric pressure C V D reactor.

The other benefit of plasma enhanced C V D is in addition to coating substrate that are, you know, large continuous surfaces, you can even coat fibers. So for example textiles, textile fibers can be coated using the plasma enhanced C V D process. And that can sometimes be very important, again when the textile has to have certain properties.

For example in many applications that involve electronic components, electrostatic discharge can kill the device. So you have to provide a static dissipative kind of environment for manufacturing and one of the places where static discharge can happen is the human body, particularly the clothes because that is where the static forces can build up.

So what they do is these garments, they actually put down some coating on the fibers that are used in these garments to improve the conductivity. Therefore make it difficult for static charge to build up. So that is a classic example of where you take a polymer surface and you coat it with something and you make, and you change its conductive properties.

And similarly if somebody has to go into a very high temperature environment. You have to provide sufficient thermal barrier protection. And for that you need again these types of coatings. So you can coat fibers, you can coat fibrelles, you can even nano-fibers essentially by using plasma enhanced C V D as the coating process.

So there are some very interesting applications of C V D that are used in the coatings industry ranging all the way from large surfaces on which you are putting down microns thick coating to micro or nano applications where you are putting down very, very thin coatings on very, very tiny surfaces and the amazing thing is C V D as a process is sufficiently flexible to allow all these different types of coatings to be realized.

Ok so let us stop our discussion at this point. In the next class, I think we have kind of discussed most of the basics of C V D in terms of applications. The one aspect that we need to cover is the properties of C V D films and how would you evaluate them but the next few lectures, we will primarily concentrate on the transport phenomena involved.

But before we do that I also want to look at a couple of more examples of C V D. I mentioned in the very first class I think about non-conventional C V D processes for example, such as those that happen in tungsten filament lamps or in high temperature corrosive environments.

So we will also take a little bit of time to discuss those processes and then we will begin to focus on really the core of this course which is the transport phenomena and the chemical engineering principles involved. Ok, any questions on what we have talked about today?

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(Professor – student conversation starts)

Student: Sir, Teflon coating 0:45:29.9, that also comes under this type of category?

Professor: Well, I was actually talking

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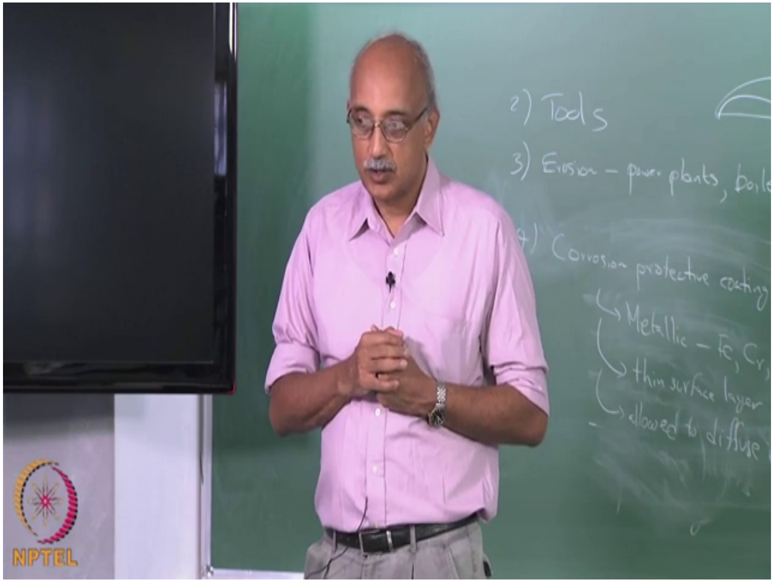

about coating of Teflon with the metal. So it is kind of the reverse process. Teflon coating on metal surface, I mean, you do not need C V D to do that. You know, basically there are other processes that are available but when you are trying to coat a polymer that is actually lot more difficult.

(Professor – student conversation ends)

Because you have to do that without damaging the polymer. And so, and sometimes you have to do that as well because there are many Teflon devices particularly again in biomedical applications that require metal coating. That is why C V D is helpful. Coatings of metals with plastics is not that difficult to do. I mean there are many different processes that can do it

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with less complexity than a C V D process, yeah.

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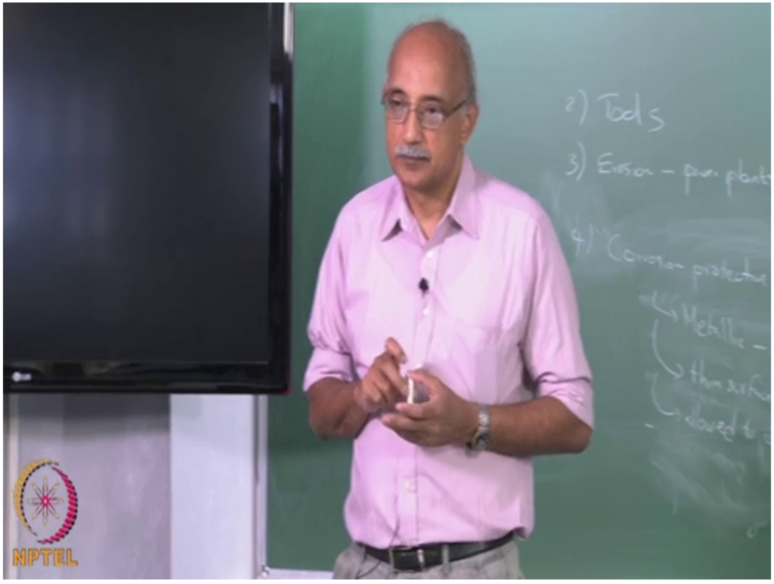

(Professor – student conversation starts)

Student: And powders are used

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for, to we need to have a free-flowing property for that powders, 6 by 200 micron size powders. For that

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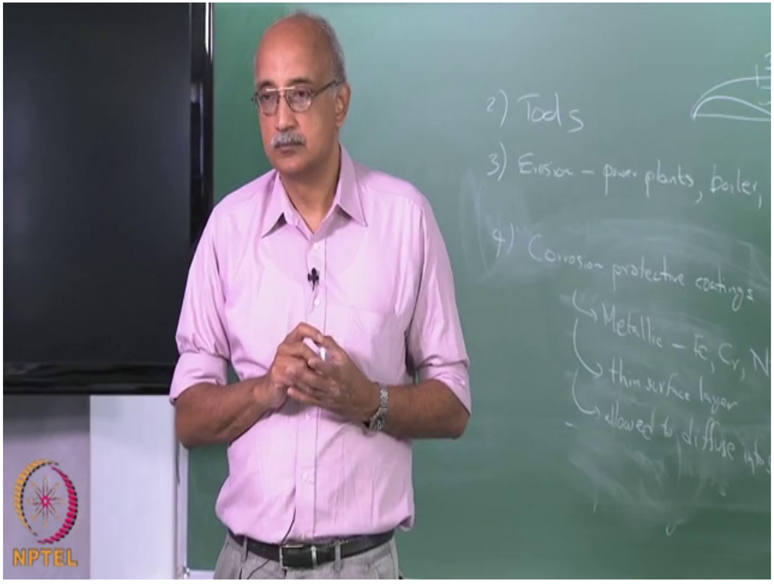

case

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we also, by C V D technique or...

Professor: Yeah,

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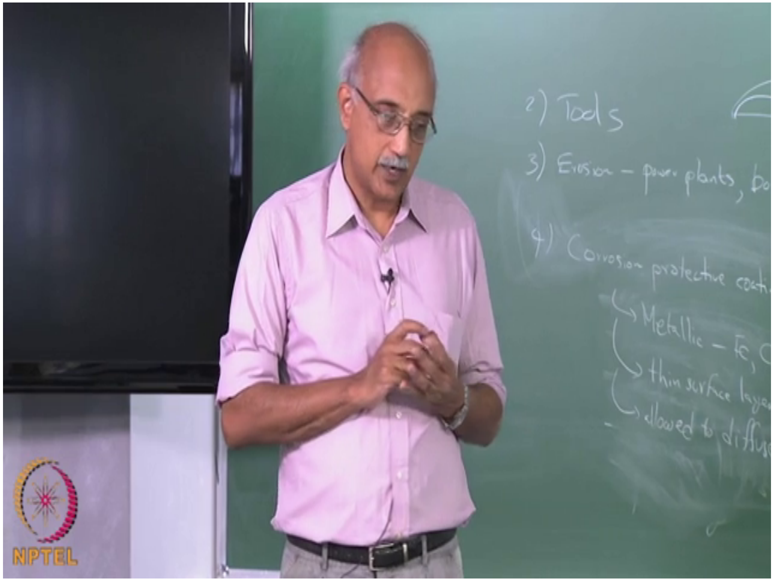

I mean C V D has an advantage that it coats not only continuous surfaces but it can also coat individual particles. So essentially the surface energetics will favor the formation of the film around each particle surface and so if you have powders and if you want to coat them with a C V D film, it is actually in many ways, it consumes less energy to do that than to coat a continuous surface because a particle by definition is more reactive than a, you know, film. So I think that should not be

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too hard.

(Professor – student conversation ends)

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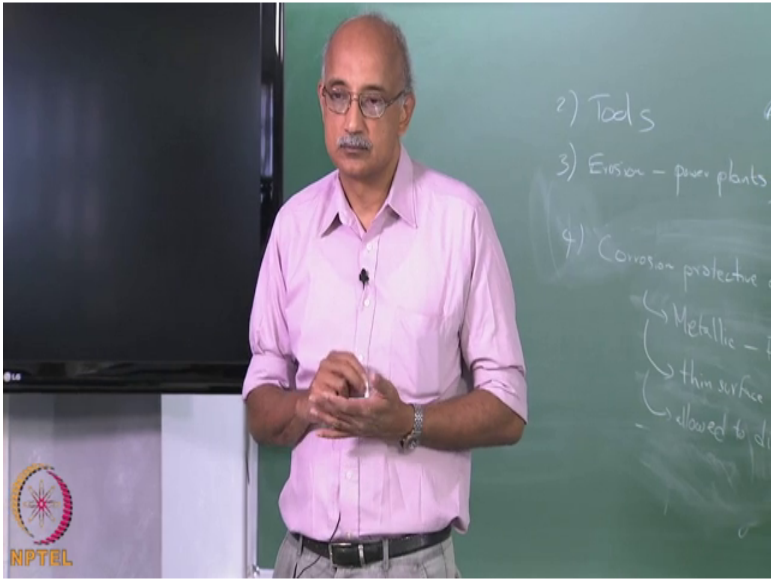

Ok so I will see you at the next lecture then.