Mathematical Modeling of Manufacturing Process
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Lecture no.#30

Mathematical Modeling of Manufacturing Process

Hello everybody, now let us start the next module, this module of mathematical modelling of manufacturing processes is that coating and additive manufacturing technology.

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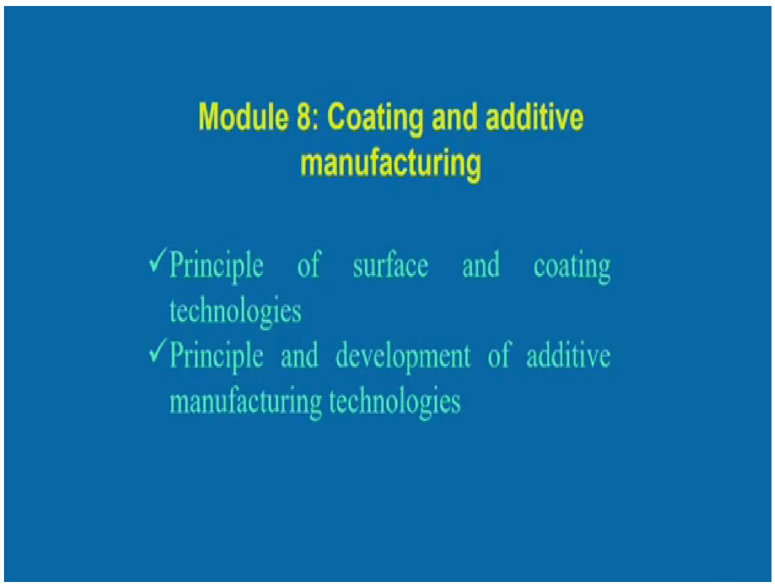

Actually, this coating and additive manufacturing of technology in this module, I just try to overlook the different technologies and what we can approach the mathematical modeling for the same, and how this mathematical modeling is actually beneficial.

Even if you go for some experiments, of course, to some extent, this, if we able to if we are able to to do develop this mathematical model, it will actually help to decide, certain range of the parameters so that is the beneficial of the mathematical aspect to study in a particular, and manufacturing processes. So first I will try to look into that principle of the surface and the coating technologies.

And the second part of this module is the principal and the development of the additive manufacturing technologies. So first part is a coating technology

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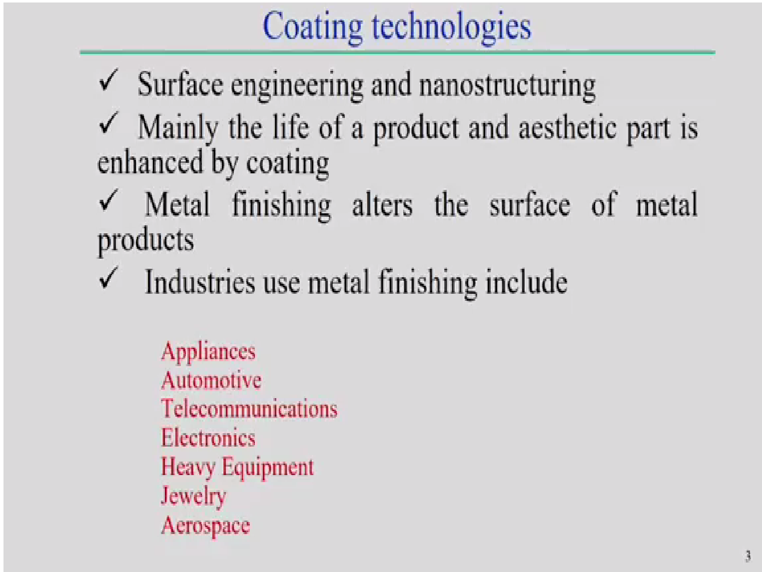

We know the coating technologies, we just simply understand that modification on the surface, either by changing the chemistry chemical composition of the surface, by, by some kind of the hardening methods surface hardening methods, or about the surface.

We can deposit, some secondary material, such that it protects the surface so that is the aspects of importance of the coating for a particular component so we can see the most of the manufacturing sector, the coating technologies are actually involved if we see the appliances, different appliances, there is must be some amount of the coating automotive telecommunication electronics heavy equipment.

Even jewelry, as the aerospace industry, or the that component, most of the cases we can found out that it is subjected to some amount of the coating of course the thickness of the coating varies the material of the coating varies and of course the different methodology of the coatings also exist in actual cases so we just started to look into that overview of the different coating technologies associated with the different manufacturing processes.

So, of course, the surfacing engineering, we need to understand the surface phenomena. And of course, sometimes the surface properties can be improved, simply by nano structuring and nano skills structuring the surface properties can also be improved, so basic purpose of coating technology is just to improve the surface properties, and of course, most of the cases this. We try to improve the surface property just to improve or enhance.

The, wear resistance characteristic of a particular surface. So, therefore, merely the life of the product so by introducing the coating on a particular surface the life of the product can be increased to enhance and sometimes we can bring some aesthetic, part by introducing the coating on a particular surface. Of course, metal finishing alters the surface of the metal products so metal finishing in the sense that if we introduce a coating.

It will actually or alter the surface of the metal products. So, that is, and we already see is already discussed that most of the industries are basically use the metal finishing process to get achieve the very good surface properties.So now in general surface properties of a particular material, we just, most of the cases.

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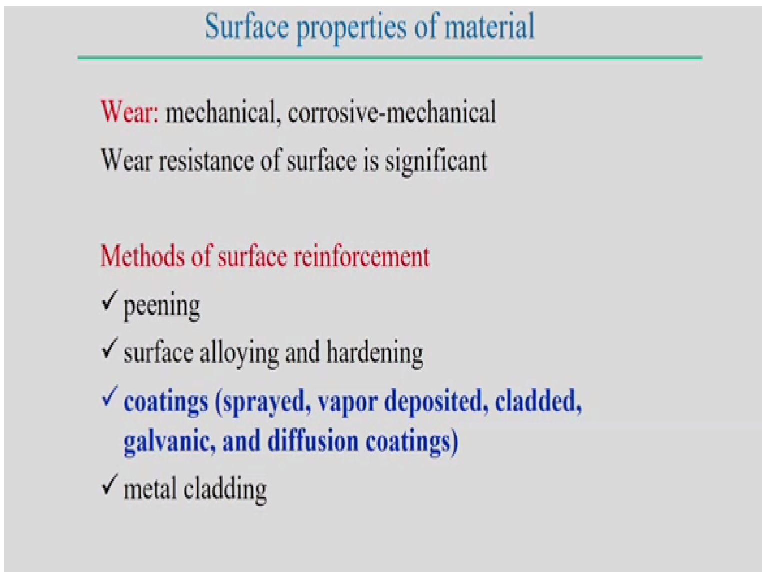

That aware of the wear. And that wear can be some mechanical means maybe between these two components so ware is the one important phenomena. And of course, sometimes that wear comes out because of the combined action of the corrosive and mechanical means.

So therefore, wear, the resistance of the surface is most important significant and that there are several ways to improve the wear resistance, out of which we can say that something is the peening a peening means is a simply hitting the surface by or hammering the surface that actually improves the surface properties of software hardness up to certain extent. And of course surface alloying, and some hardening.

If you follow some kind of the different heat treatment process also, we can induce modify the surface characteristic. And we are just introducing the carbon, carbon nitriding cyaniding these different kinds of techniques. So, we can introduce a carbons and nitrogen on the surface to improve the surface properties and of course, simply we hit the surface that that is called the surface hardening.

By surface hardening we can alter the surface properties, apart from that coating is also another alternative way to improve the surface properties. The sprayed vapor deposited these are the different coating techniques cladding also and galvanic and the diffusion coatings are normally used to, improve the surface properties, of course, metal cladding is another process. We have already discussed that different ways just keeping the powder on the surface.

And the powder is melt such that it becomes a part of this intricate part of the surface that is called the surface cladding or metal cladding, and we use cladding process just to improve the surface properties.Now surface, we are focuses on the surface coating. Since surface coating, if you look into that coating process can be developed in the different way .

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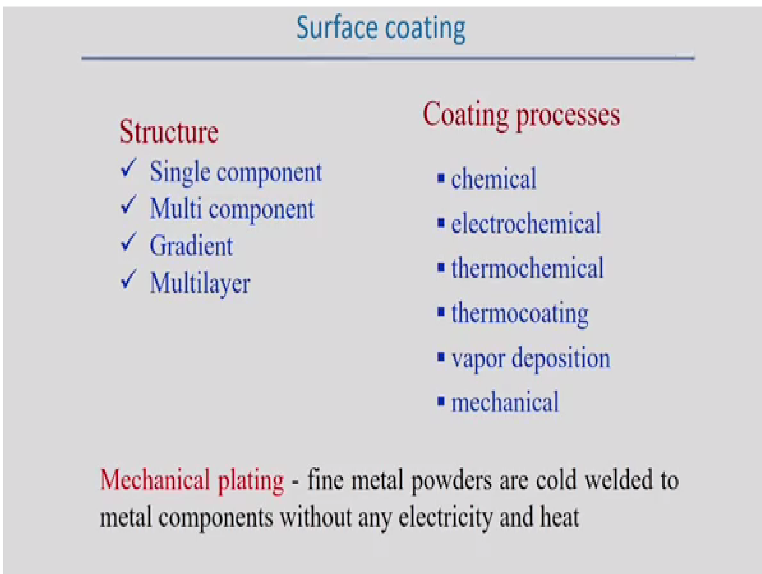

And the structures, may be single component, it is possible to deposit on the single component on the surface, a multi component different components, up to certain thing is different, we can introduce on the surface or gradient the different there is a gradient exist. The concentration gradient of the second component from top surface to the bottom. And of course, most of the cases coating coating induces a very small thickness in the micrometer level.

So, the thicknesses of the sudden thickness depending upon the application can be introduced on the surface, and of course sometimes multi layer coating is also applicable on the surface. So, different layer coating, so for different material can also introduce on the surfaces. Now in general, principle of the coating processes is follows that simply chemical reaction happens on the surface so that under some mounts.

Some elements can be deposited on the surface so it may be due to only the chemical reaction, or it may be electro chemical along with the appli chemical reaction. But that is that reaction can be accelerated, can be influenced by the electric field. So therefore, sometimes it can be of the thermomechanical process also thermochemical thermochemical process. And that thermochemical both here.

Thermal process, and maybe, with the addition of the heat, and the accelerate the chemical reaction on the surface and some elements can be deposited on the surface, or directly we use the thermal thermal coating. So we can use some kind of the heat source to make the coating on the surface, and sometimes in the, the substrate material we normally clears the vapor and the vapor actually deposited on the substrate material.

So, that is also possible. And, of course, some, in principle, the mechanical plating can also be used in the coating process. So mechanical plating is basically fine metallic powders are deposited on the cold welded. With the metallic components, but without applying any kind of electricity or without any kind of the heat. So it is follow the principle of the cold welding processes such that the metal actually deposited on the surface.

So these are called the mechanical plating so there are several principle we follow for a particular thickness of the layer on the surface, and in, specifically the surface coating technologies.
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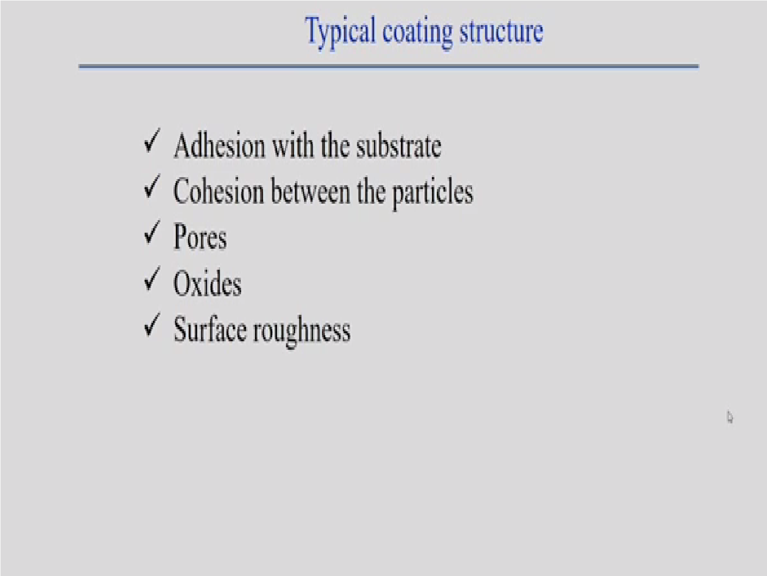

And if you look into the typical coating structure, we can see that addition to the substrate. Basically, over the, suppose this is the actual metallic surface, and the over the surface coating actually introduce in the different brain, a particular layer.And this, this layer is form, and of course we are having some particular surface finish.And of course the cohesion between the particles.

So, this cohesive force exists between the two particles, but additionally the subset, with this these particles coating was the follow the addition principle. One is adding with the actual work resurface and possible during this deposition of the coating some pores can also be possible to create and of course some oxides may also form. And because definitely most of the cases we apply some amount of the heat also.

And of course finally surface profile may not be smooth some surface roughness also exist so all these actually characteristic parameters. Normally follow if we see for a typical coated structure. Now, there are several coating processes. So, if you look into the different coating processes firstly the sprayed materials, so we can spray the material metallic in the form sprayed material in the form of the wire.

So we use the wire, and that wire is melt somehow and is spread throughout the surface, or we can use a powder metal powders and then with the application of the heat on the metallic powder, this metallic powder can be intricate part of the surface.

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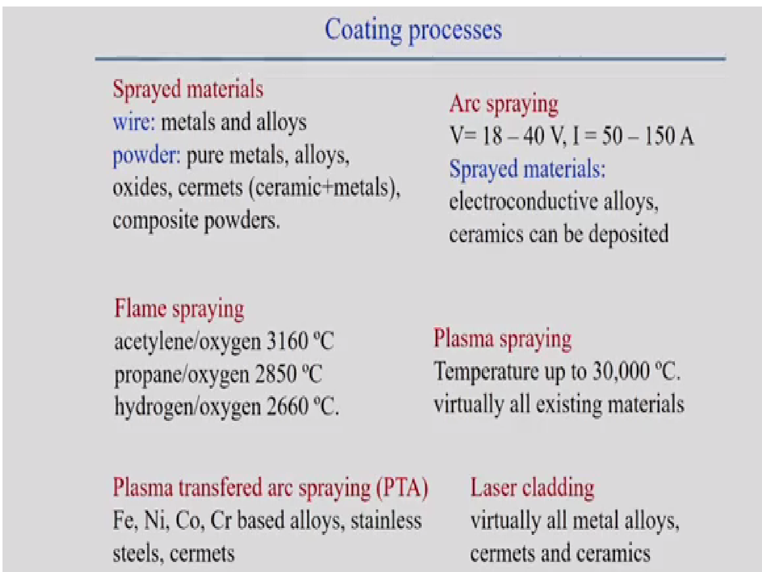

Therefore, wire in the forms of that we can use the metals, as well as alloy, both we can use in the form of a wire or powder or pure metals, alloy, oxides,cermets.

Cermets means ceramic+metals mixture of that, use that and of course composites powders, different from the powders can be deposited on the sprayed on the surface and then after that, we just simply heat in a controlled way. Of course it forms particular layer thickness of a coating. And of course, apart from that, we can use the simple flame spraying.

That means, oxygen/acetylene flame, we can use it and directly and propane/oxygen, hydrogen/oxygen combination. We just, we just, just use the flame to produce the coating on the surface. And of course, sometimes we can use the plasma transferred arc spraying. So plasma transfered arc spraying spring means we have seen that in discuss the in the welding process the plasma arc welding process.

So plasma arc welding process machine can also use the transferred arc spraying. just changing the cathode or anode process in this plasma or cooling process so therefore in the transport, are these powders can be used a few nickel cobalt chromium based alloy stainless steel and that can be deposited on the surface using the plasma transferred arc spraying methodology that was simply arc spraying cannot be used.

So maybe typically the voltage can be 18 to 40 volt and our current can be 50 to 150 amps. So in that cases sprayed materials may be conduct electric electro conductive materials, ceramics can also be deposited by using the simply arc appear on a particular surface. plasma spring also plasma spring but is of very high temperature of two and virtually all existing meterials can also be used.

Using the plasma spraying method, and of course laser cladding also one type of coating technology were all metals and ceramics can also be material all metals alloy and ceramics can also be used in a laser cladding method. So these are the basics of the different kinds of coating processes, but this we see the typical application of the coating processes.

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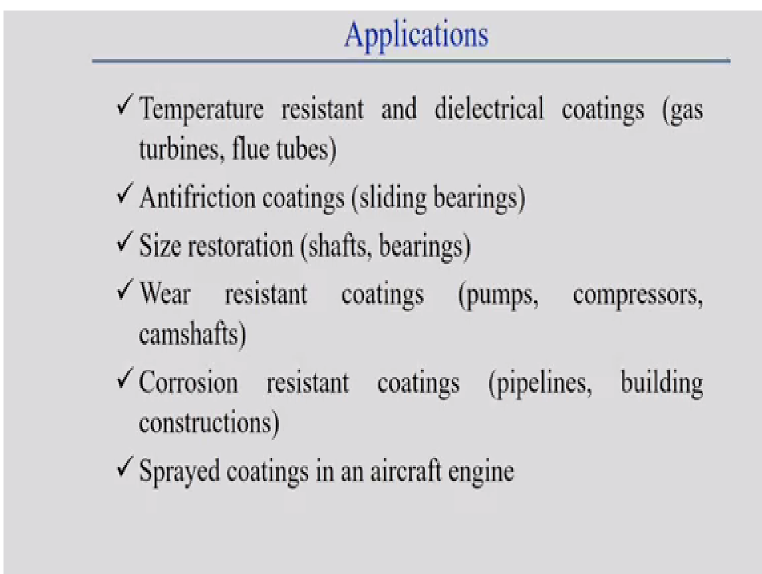

And switch will you see the temperature resistance coating we can use and dielectrical coatings we can use we can find out the gas turbine and the flue tubes both the cases we can find out this different types of the coating, having different purposes, and Antification coating normally using the bearing sliding ,bearing Antrification coating, helps in this cases the size restoration and can also shafts bearing.

To get the exact size sometimes coating can also be used here, and wear resistance coatings. We can use the pumps, compressor camshafts so we can find out the application of the ware resistance coatings. And of course corrosion resistant coatings, in a basically pipeline building construction, in that cases we can use that corrosion resistance coating also and of course sprayed coatings is normally used in aircraft engine.

So they are, we can see there is numerous application of the coating and almost all manufacturer except all, most of the product manufacturing product to some to improve the surface properties or to improve the surface quality, and most of the cases, we just take the help of a coating technology, of course, the metallic non metallic or different types of the materials.

And of course, the different form of the materials either were powder or other formats and different techniques of the coating techniques can be used. So here it is not exactly objective the, what are the different techniques materials and which process we can applicable, but rather I try to give some overview of this different coating processes, based on the application technology. So few coating technology one is the copper plating technology.

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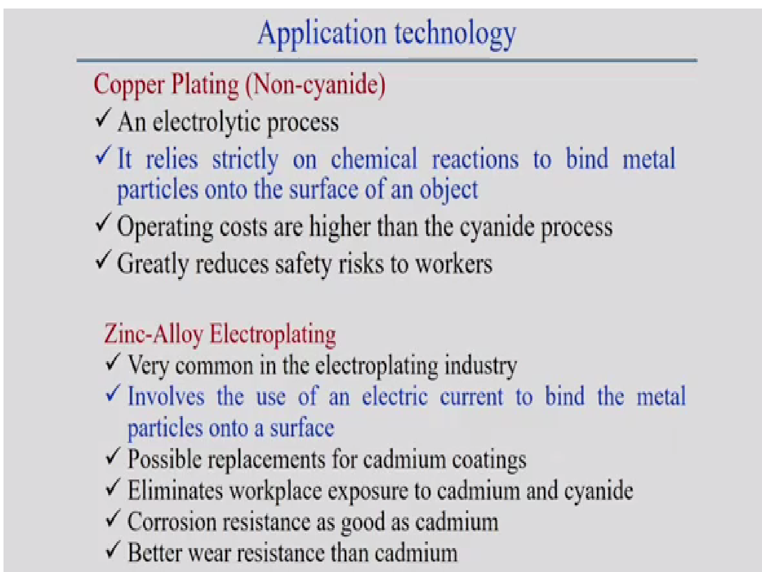

So copper plating technology. In this cases we use the, non cyanide because cyanide is basically not is the kind of health hazards. So therefore, non cyanide the development of the non cyanide could integration nowadays is mostly appreciated because it is a more environment friendly. So in that sense, the copper plating technology, put into place you use some electrolyte, and maybe the electrolyte we can use.

And of course, this, this electrolyte is basically strictly on the chemical reaction to build a metal particles. So such that chemical reaction happens and such that metal to bind the metal particle on the surface onto the surface of an object that is a in principle, but in simple plating process, we not necessary to apply any kind of the external heat or maybe not under the under the current also necessary.

So one is that such copper plating just simply use the electrolyte so during that reactor, and that electrolyte when chemical reaction and happens just deposited the metallic part on the surface, but operating costs as very high higher as compared to the cyanide process for cyanide process is very risk. it is not environment friendly in that sense.

So therefore we really did this is the safe. Safety risks to the workers, because this is copper plating is basically a non cyanide, non cyanide based process. So in that sense, it is the safety feature says more good as compared to the cyanide process. Similarly, other coating technology that is a zinc-alloy electroplating so zinc alloy electro here that we can use the electric current also, but at the same time, along with plating process.

So very common in the electroplating industry involves involves the use of an electric current. And that electrical current helps to bind the metal on the metal particles onto the surface. So, it is basically the possible replacement for the cadmium coatings that is also another coating technology but eliminates the workplace exposure to cadmium and cyanide.

So cadmium and cyanide is physically reduce the hazards. So therefore Corrosion resistance as good as cadmium, of course, this, we use a zinc-alloy electroplating the Corrosion resistance is basically a comparable, as compared to the cadmium, and of course, even better, wear resistant, as compared to the cadmium, so that is zinc-alloy electroplating

Now it is very common very common component electroplating industry says that in that industry, it is possible to avoid the cadmium or cyanide based plating technology. This is another application technology you can find out in coatings that is the iron vapor deposition of aluminum.

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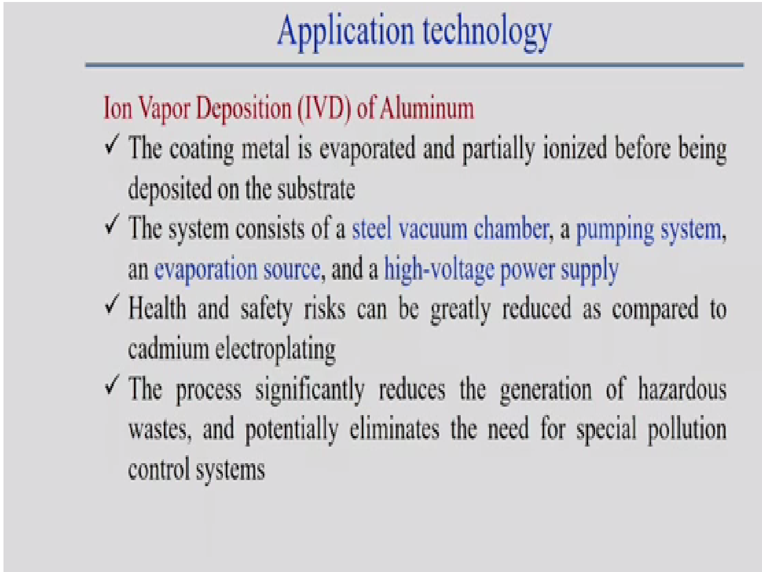

So in this cases the coating metal is evaporated and partially ionized, before being the deposited onto the substrate.

So it is evaporated and ionized. And of course this system one vacuum chamber, one pumping system, evaporation system and the high voltage power supply is required for this system, and in this case is the health and safety risks can be greatly reduce as compared to the cadmium electro plating. So we can always compare the cadmium electroplating technology

Because this process, reduces the generation of the hazardous waste, and potentially eliminates the need for the special pollution control system so that is the one advantage for the development of the iron vapor deposition of aluminum, as compared to the cadmium electroplating process, physical vapor deposition always one of the coating technology and the clean workplaces placed.

Basically, on the vacuum chamber and the chamber is basically heated and that plasma is created from an inert type of gas, such as argon, we can use and plasma is created on unit, gas argon. Now, the workplace is first plasma-etched is basically clean. To further clean the surface, and then the coating metal is then forced into the gas phase, by using the evaporation basically the coating metal is evaporated.

And that sputtering or the or iron plating normally happens on the surface, so therefore PVD results in the thin, very thin, very uniform, and much less likely to require machining after the application so very good surface finish because most most advantage of this technique is that it creates the uniform thickness throughout the structure. So therefore, PVD physical vapor deposition for titanium nitride coatings have already gained wide acceptance in the cutting tool industry.

So we can see cutting tool. The normal you can find out to improve the purpose of the cutting tool over this, the coating is normally used so titanium nitride coating which is very hard and useful on the cutting tool industry, and that that that normally happens is in the physical vapor deposition technology. Now there is another processes application technology of that chromium free surface treatments for aluminum and zinc.

So in this cases non-chrom chromium free surface treatments for aluminum is an organic conversation coating based on the zirconium oxide so in this cases there is chrom free surface treatments for aluminum and zinc for the aluminum and zinc surface, we can use a surface treatment using the coating, based on the zirconium oxide. So that is also one of the technology application we can find out.

And I think this is applicable more on the cutting tool industry also. So metal spray coating is also another coating technology the metal is basically heated by suitable heat source it is by resistance heating or burner, or maybe electric arc, and then supplied to the atomizing source in the molten form So in the molten form which is supplied to the surface. And then metal either metal melts in the form of wire or powder.

And then thermal Spraying of the metals are not typically replacement for the electroplating. It is having their own advantage, but it is, thermal spraying physically not substitute.For the,electroplating technology and both are equally important in the application industry, but we already discussed this thing,
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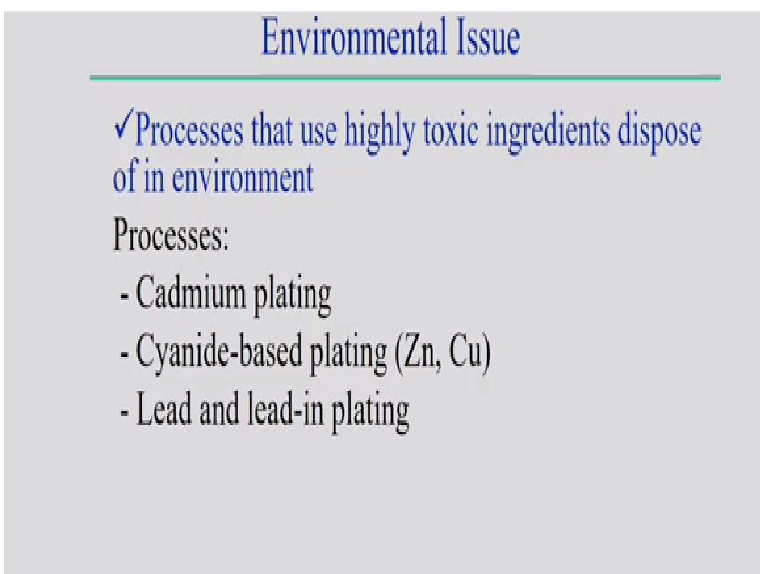

process that use the highly toxic ingredients dispose of in environment is an issue. And that is a sustainable manufacturing or green tech in the form of a sustainable manufacturing or green technology. So in that cases the processes can be cadmium plating cyanide-based plating and

lead and lead-in plating. All type of plating technologies just trying to replace with the other kind of the coating technologies because all this clears actually some issues to the environment.
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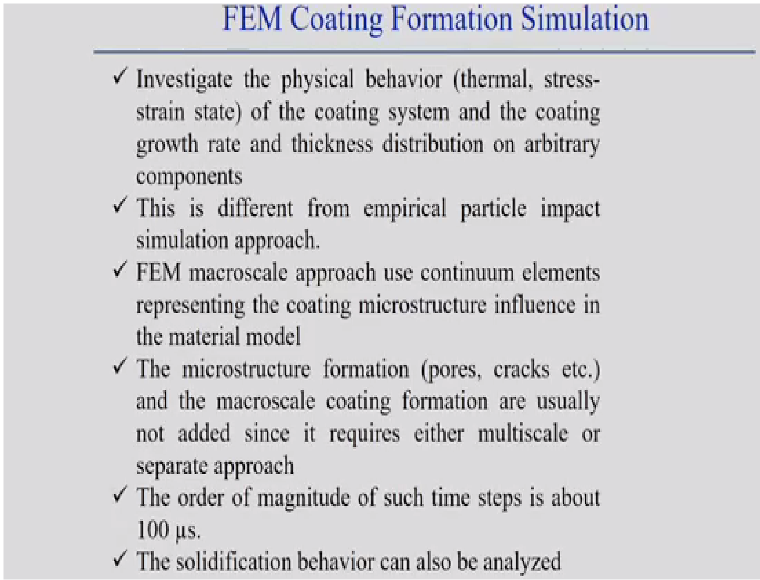

Now, of course, there is a different kinds of coatings technology we can see, but what we can do the develop the any kind of the mathematical model or finite element model for the coating processes. Just. we have some overview idea what is in general, we understand coating is basically the powder. Which is deposited on the surface or from the ware, we can deposit it on the surface, and that such that it is deposited earlier or deposited elements can be part of the original substitute material. So, therefore, investing is a physical behavior is possible normally in the modeling approach.

We normally use the thermal stress strain state of the coating system, and the coating growth rate thickness distribution on the arbitrary. these are the typical parameters or we can say the typical area, we can investigate by the development of the simple, heat transfer model or stress analysis model. So, stress analysis or thermal model. What do we develop using the heat conduction equation.

Because similar we can develop the thermal model. And of course, once you develop the thermal model. Consequently, it is also possible to develop this stress analysis model, such that it will be able to get the temperature distribution and any kind of the stress distribution on the coating surface on the in the coating system. Apart from that, since there is a continuous supply the metal to this substrate material.

So, there is a, we can estimate the growth rate, basically growth rate, what we just represents the rate of the solidification in case of the costing and the welding process of growth rate in that similar fashion we can it is possible to stimulate the growth rate. And of course, if we look into the mass transport during the system together, it can be possible to do uniform distribution or not, that kind of information, cannot be possible.

By developing the simple mathematical model. So of course this. This is different from the empirical particle impact simulation approach so particle impact simulation approach, means its a, this approach is simply. If this is the domain over the substrate material, what is coating is deposited upto certain layer so over is this layer. It is possible, or maybe whole domain.

It is possible to do the thermal analysis, as well as this stress analysis by using the the galvanification heat conduction equation for thermal analysis. And of course the constant. Relation between the strain state and thermal stress is generated from that point, we can estimate the stress, or is it in distortion level or not, you can simply estimate what we did the stress analysis and thermal analysis model, in case of welding process.

Now, apart from that, rate also this uniform thickness or from thickness,can also be estimated from the modeling approach, but this is different from the empirical particle impact simulation approach means that it is the other way the modeling can also be done by typically tracking the particles, and what is a simple tracking the particles so the particle is melting or not.

And what the momentum transferred by the particle to the domain. So in that approach, it is possible to do the modeling also but here we are not following that approach. Here we are following the simply a FEM macroscale approach and using continuum elements, representing the cutting microstructure influence in material model. so of course, when you try to do that stress analysis, we need to develop some material model also.

And we can incorporate the effect of the microstructure and the coating material. So the microstructure formation. For example, the pores cracks, just using the crack prediction of the crack in what is also possible to incorporate in the modeling approach. And of course, apart from that, macroscale coating formation are usually not added since it requires either multiscale or the separate approach.

So therefore, we need to link into the microstructure formation, and then microstructure formation is that a continuum whether solving the heat conversion equation that do scales are different. So in this cases the post formation, very microscale, we can, can do different microscale performance and then we need to go for the multiscale modeling approach.

Such that it will be combining the continuum scale, as well as the microscale phenomena. So therefore the order of magnitude of this time steps is also required in this cases deposition rate and look into that. Hundred microseconds in that range that time step for the simulation process. Of course the solidification behavior can also be analyze what we can do the solidification.

We will, in case of welding and fusion welding as it as a casting process.
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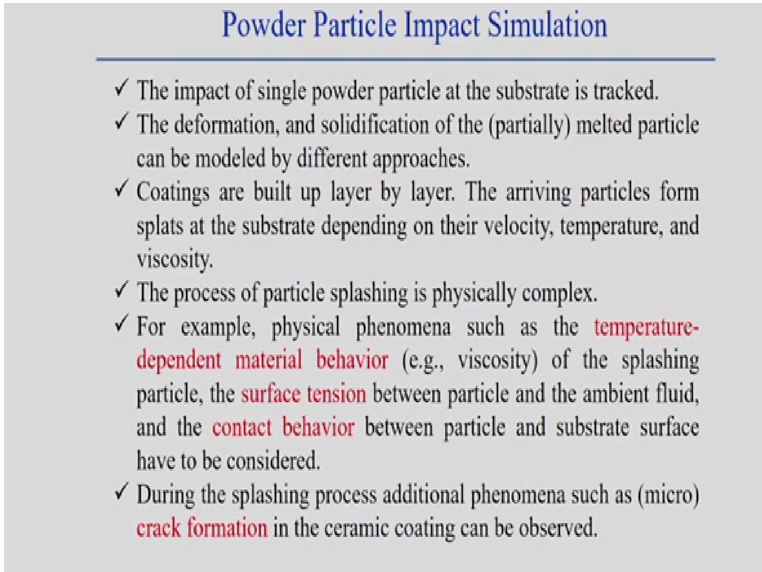

Apart from that, the powder particularly impact simulation also another approach in case of coating technology so in this case is the impact of the single powder particle on the substrate of material is actually tracked. So, what are the deformation, the solidification of the part partially of the melted particle, can we model by different approaches.

So definitely coatings have built up in this case a layer by layer. So therefore, the arriving particles from splats of the substrate depending on the velocity temperatures and viscosity. So then arrive particles to this domain, it depends all these parameters. So in that cases, it is possible to model a model to that approach so this process of the particles splashing is actually very complex.

So in this cases, for example, if we look into that the temperature dependent material behavior viscosity need to incorporate to look into the the particular particular. Then, surface tension pores between the particle and the ceiling gas or ambient fluid. That is also another important parameter need to concern, and of course, the contact behavior how the particle and contacting the substrate surface.

That contact behavior of the substrate is also another important. And behavior between the particle substrate surface. What we can represents the contact behavior that is becomes more complicated. In this approach so apart from that during this splashing process, additional phenomena such as micro crack formation. In the ceramic coating can also be observed so in this micro crack formation, the scales are different.

So then we need to change the scale also entering this. So therefore, then here also need to go for the multi skill approach to if you try to model. In case of tracking the particle, a particular particle. Now, based on the physical description of the particle impact we can get some information about this particle based impact simulation. Consider that arriving particle.

Assume that as a fluid with temperature dependent properties, since it may be in the fluid state or semi fluid state that is decided by the properties of this material. Or, if we decide the status of a particle accordingly we can assign that for this particular material. So most of the cases the numerical method to calculate the relevant fluid field quantities, it is basically flow filled this CFD computational strength.

Based approach and additionally volume-of-fluid method can also be used to simulate the free surface profile so an particle is projecting and free surface may not be flat. During this process so once it is not a threat. So in that most of the case we use the volume-of-fluid method to execute a predict the of his profile. So, volume-of-fluid method is a multi phase approach or two or more fluids exist in the calculation of the domain.

And do not interpenetrate in that cases. So therefore, a sharp interface may exist between the different pages is characterized by this method. In this method, physical problem modeling approach. So in this case, particularly impact the particular forms one fluid in one phase one fluid should be considered as one phase, and the ambient gas, another phase here process depend the second phase.

So there fore interaction between the two different phase two to phase flow may be important to consider for this kind of the simulation. See particle can be tracked and the impact behavior deformation clattering, cooling, solidification we will can also calculate this is on the physical low so therefore we see this approach becomes more complicated and of course.

We need to consider the several aspect, when you try to track that particular particle, and how it behaves on is interact with the surface material so we need to consider so many physical phenomena.for that if we try to develop this mathematical model of the coating technology So this just overview of this different approach in the mathematical modeling approach of the different coating technology.

So this is all about the overview of the different coating technology normally fall in the manufacturing processes, and of course, in in a very sort of brief that how what a, we can model of this different coating technologies. So thank you very much for your kind attention.