Surface Engineering for Corrosion and Wear Resistance Application

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Lecture - 41
Thermal Spray Deposition – I

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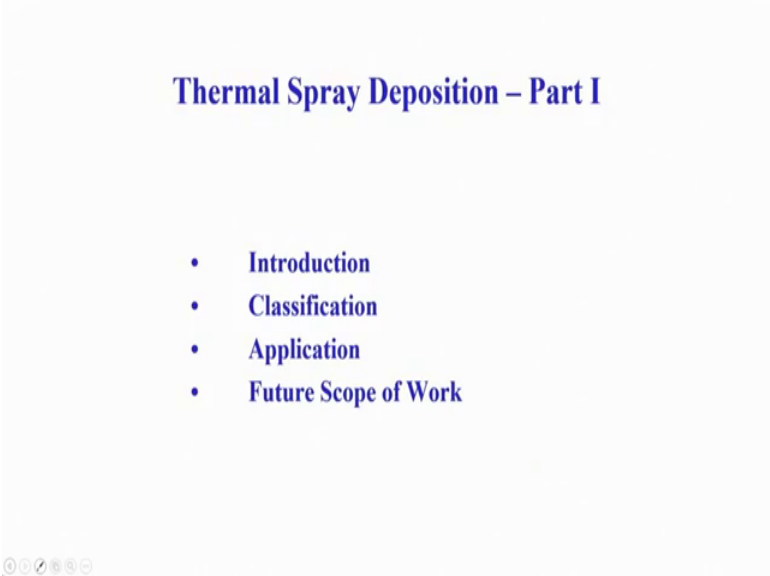

Welcome to the topic on Thermal Spray Deposition, this particular topic will be covered in four talks lecture number 41 to 44. So, thermal spray deposition in this particular talk I will discuss about the introduction of this particular process, then classifications applications and finally the future scope of research.

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Now, if you talk about thermal spray deposition it is nothing, but a kind of category of processes in which material is heated to a state of molten state and then spread over the surface of another substrate to create the coating.

So, this particular technique is in between weld overlaying and hot dipping; in hot dipping you melt the material and subsequently you deposit it by leaping the substrate into the molten metal. On the other hand in weld overlaying you basically apply high power heat source to melt the material and subsequently apply on the sub surface of the substrate.

And thermal spraying is a kind of versatile technique which can take care of deposition of the low melting material as it hot dipping as well as high melting point material as is weld overlay. So, where again the material is melted and subsequently it is coated onto the surface of substrate by the process of spraying.

This particular technique is very easy and it is versatile in nature, so as you are depositing it by spraying there is very less distortion of the substrate, there is a very good bonding at the interface, but bonding is not as strong as in weld overlaying or maybe in hot dipping. Because the mechanism of bonding is basically mechanical interlocking, there is very little decision at the interface.

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So, usually this particular technique is a versatile technique as I mentioned because this technique can be applied for a wide range of materials may be starting from polymeric materials to high melting ceramic material. And deposition speed is very fast, there is negligible heat affected zone the process is very much environment friendly, there is superior coating properties, lower substrate distortion and much more economical as compared to that of high end processing like laser or electron beam processing and it is capable of deposition on heat sensitive materials.

So, this process is a very much unique process and but you have to choose the process parameters as well as process technique in terms of heat source carefully. So, that you get the desired coating onto the surface of the substrate.

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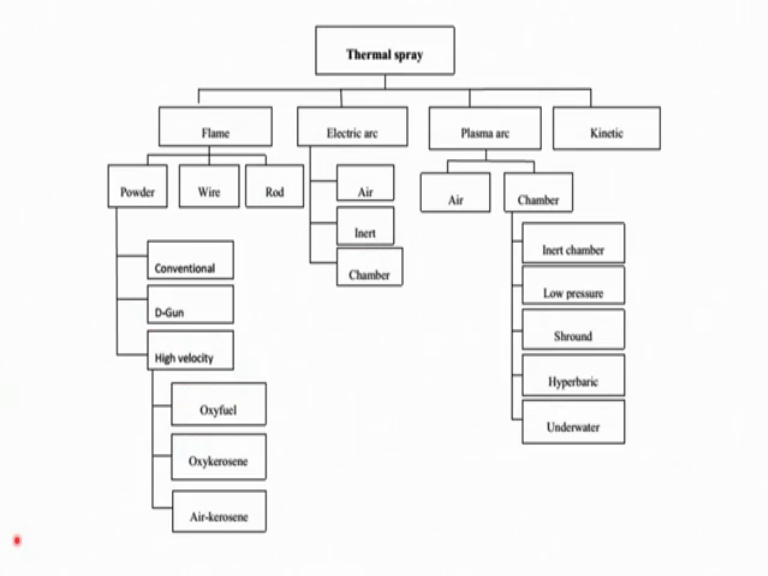

Now, accordingly different varieties of thermal spray deposition techniques that are available, if you just quickly go through the techniques or maybe classification of thermal spray deposition techniques you can broadly classify into four categories like; flame spray deposition, electric arc spray deposition, plasma spray deposition and kinetic deposition kinetic spraying process.

So, as the name implies in flame spray deposition you use oxyacetylene flame as the source of heat, electric arc you are using you use electric arc a source of heat, plasma arc you use plasma arc as source of heat. On the other hand in kinetic spraying you do not use any high heat source for melting purpose this is basically it is also called cold spraying process because material is in the form of un molted set user your may be semi molten state you avoid the overheating of the powder, so that there is degradation of the powder.

So, this particular kinetic spraying technique is mostly applied for deposition of polymeric materials or nanostructured materials where there is scope of a degradation of the microstructure because of heat. Now, if you talk about different sub classifications under flame strain you will find that the sub classifications are based on the way you are using the precursor material, it may be in the form of powder, it may be in the form of wire or it may be in the form of rod.

And if it is in the form of powder then there may be conventional flame spraying or detonation gun flame spraying or high velocity oxyfuel flame, then again under high velocity category there are again sub classification like oxyfuel oxykerosene or air kerosene depending on the kind of fuel you use for burn efforts of heat generation by burning.

So, you will find that the powder spraying may be in the form of conventional or detonation gun how you are producing the, how you are igniting the this oxy acetylene fuel and high velocity winds velocity is very high above the sonic velocity. So, again your fuel might be different depending on the kind of heat you need for the generation of the heat as well as for the development of the coating.

On the other hand, it may be in the form of wire or in the form of rod, if it is in the form of wire or it is in the form of rod then it has to be only under conventional category because under detonation gun or high velocity category you do not use you cannot use wire as the precursor material for deposition.

On the other hand rod when you use as precursor there also it has to be conventional flame spraying. Then if you talk about electric arc spraying this may be your electric arc spraying or inert electrical arc spraying or maybe chamber spraying where you use special chamber for development of the coating and under plasma it may be their plasma air plasma spraying or maybe chamber plasma spraying.

So, in air plasma spraying you do plasma spraying operation, you do spraying in normal environment where there is a environment only air in the environment. On the other hand in chamber plasma spraying you can use inert chamber, low pressure chamber, shrounding chamber, hyperbaric chamber or underwater chamber depending on the kind of material you are going to deposit onto the substrate.

And kinetic spraying is basically cold process where you do not heat the powder and you basically use very high velocity for spraying operation and as a result of which kinetic spraying is a very safe process, but can only be applied for low melting point materials coating. So, these are in general classifications of thermal spray deposition techniques.

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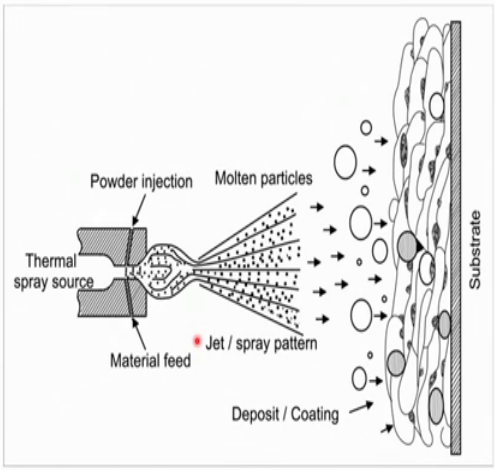

Principle of thermal spray deposition technique schematically

Now, if you quickly go through the technique in details you will find that how the technique is how the spraying is done, this is typically the spray torch where you basically can use any heat source for heat generation. And in the torch you basically you inject powder and powder particle size usually is 45 to 60 micron and if it is too low a dimension like if it is a powder particle size is submicron, then there will be problem of agglomeration of particles there is problem of flying of the particles.

So, usually most of the heat based process used the micro sized particle of the order of 45 to 60 micron particle dimension and if you are interested to use nano sized particle for spraying purpose you have to agglomerate it and subsequently spray dry and make it with the particle size of that level. Certainly nano size particle does not mean that powder particle size is nano dimension it is the grain size or crystallite size is nano in dimension.

So, your particle nano size it may be nano size, grain size your particle particles that is the grain size or crystallite size may be nano sized or micro sized, but actual particle size should be in the level of 45 to 60 micron and should be flowable. So, that particle is actually fed or injected near to the tip of the flame and then it is melted and with the help of high velocity that high velocity oxygen or high velocity, inert gas or high velocity nitrogen it is propelled and subsequently spread over the surface of the substrate.

Now, if you quickly see the parameters in this particular process, parameters are that nozzle to substrate distance, the velocity of the spraying and the kind of heat source you are using for spraying as well as the powder particle size. So, these are the parameters which play a very important role in determining the microstructure as well as that composition distribution of the coated layer and subsequently its properties.

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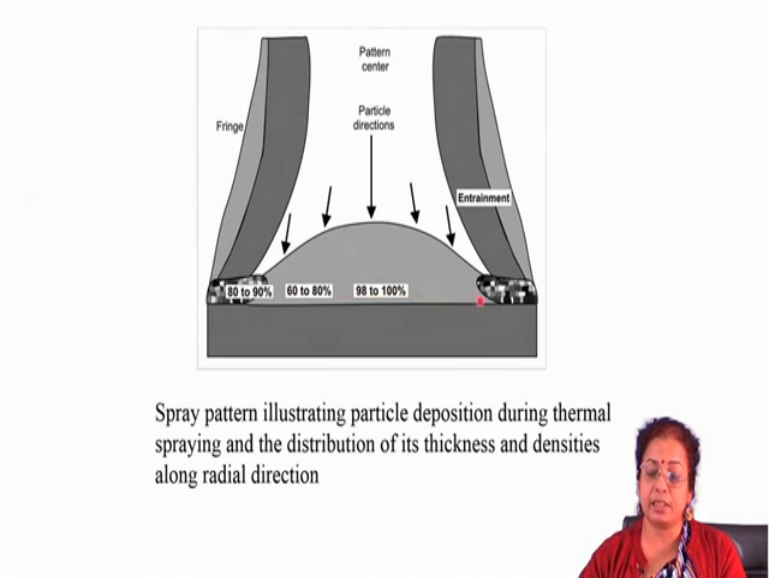

Now, if you quickly go through the coating thickness and how the coating thickness and properties of the coating varies with this distance along radial direction you will find that in the middle of that particular nozzle the distance is maximum, coating rate is maximum it is highly dense, but as you go along the radial direction you will find that the coating density decreases and also thickness decreases.

So, you should have a kind of overlapping of two tracks, so that you get uniform thickness all throughout the substrate of the material. So, it is very much important that you have several cracks in the coated material in the coating and all in between two cracks there has to be a little bit overlapping, so that you get dense coating with uniform thickness.

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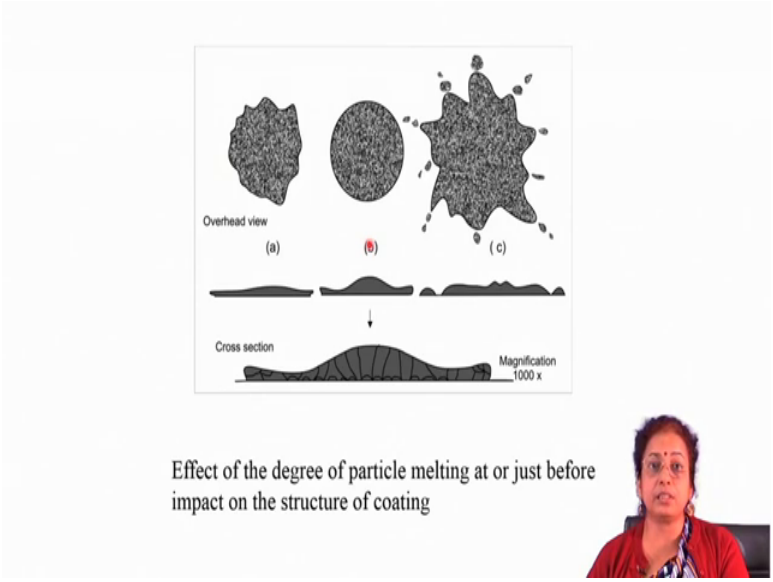

Now, if you quickly go through the particle effect of particle melting before it forms the coating you will find that if it is particle is not molten state, then naturally you will find that it is spread over the laid over the surface with the minimum thickness because just whatever test substrate to whichever part of the particle is actually in molten state there touches the substrate and then get overlaid over it. But inner part which is not molten that part cannot stay any flies away.

On the other hand if it is in molten state then naturally it falls perfect coating as I shown in the as I showed in the earlier slide that thickness is maximum in the middle and it is minimum along radial directions. On the other hand if it is over melted, then naturally you find that the vertical you get lot of splat kind of structure and serving in regular thickness all throughout the; all throughout the direction and you will find that there will also be lot of roughness which is created because of the coating.

So, it is very important that you apply appropriate heat, so that the material gets melted and subsequently spread over the surface. But again as I mentioned you that there are a large varieties of thermal spray deposition technique, like in kinetics spray you get totally we use totally cold particle to get spread over the surface of the substrate.

So, in that case we are use cold particle to get spread over the surface of the substrate, there you have to apply very high velocity. So, that it get impresting and subsequently

that you get very high density coating with strong at a which is strongly adhere to the surface.

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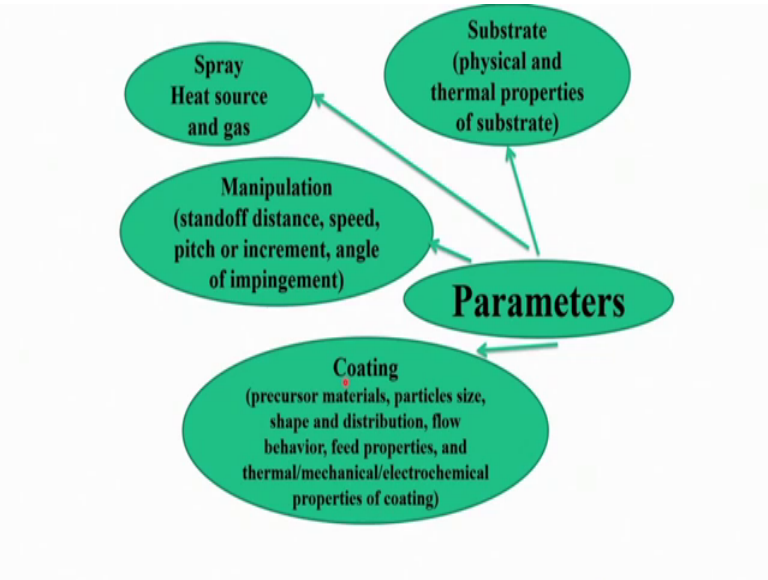

Now, coming to the main parameters you will find that there are four main parameters which play important role like; if you talk about the coating parameters naturally which material are you using for coating, what is the melting point of the material then particle size of the material, then shape and distribution, its flow behaviour in which form the material is taking whether it is in the form of powder or it is in the form of wire or it is in the form of rod.

So, what is the flowability of the particles, what is its thermal mechanical or electrochemical properties of the material which you are using these are all parameters play very important role in determining the quality of the coating.

So, this is a coating which you are going to develop for a specific application. So, naturally which kind of material are you going to coat it is to some extent known to you, if you are interested to coat the material for wear resistance application usually we use termites or maybe composite as the coating material or you can also use hard fist powder as coating.

So, naturally you know that which kind of material has to be there for a specific wear resistance application. For example, if it is high stress wear then you have to use some

very hard particle which is tough enough, if it is low stress wear then you can the particle can be hard only ceramic particle will work.

If it is for example, corrosion resistance application then you can use some coating which is highly inert or maybe you can also use highly noble in nature on the other hand if it is very much that particular environment is not really shows, so I have received then you can also think of polymeric coating.

So, coating material choice is very important and that is the first thing which you should do prior to choosing this particular a particular technique because which coating material you are going to coat onto the surface of the substrate that dictates the coating technique you should apply. So, all coating techniques as I mentioned here these are not applicable for all kinds of coating.

For example, if you are interested to coat ceramic materials you have to opt for the plasma spraying technique. If you are interested to coat low melting metric materials for example, zinc aluminium, then zinc aluminium or maybe tin coating then you have to opt for; you have to opt for that flame spraying technique as that technique for coating.

If you are interested to develop that very thin like nanostructure coating. So, you have to look for the is that either is vof or may be kinetic spraying as the coating technique. So, which technique should you apply for coating? It depends completely on the materials which you are choosing for coating and naturally your precursor for the which form the coating has to be it again will vary. If it is only simple flame strain it can be in the form of powder it can be wire, it can be in the form of rod. If it is plasma strain, then it has to be in the form of powder, if it is kinetic spraying it has to be in the form of powder.

So, your form of coating is also the in which form the coating has to be that depends to some extent on the technique which you are using for coating purpose. And then flow behavior of the coating is very important, it has to be highly flowable if it is not highly flowable or if it is and if it gets a agglomerated very quickly then there may be the non uniform deposition all throughout.

The feeding properties is also very important how nicely it can be fade and certainly thermal mechanical or electrochemical properties of the coating, they basically dictate the thermal mechanical or electrochemical behavior of the coating which you are

developing. Then second important parameter is a substrate, so substrate parameter is also very important because what is your substrate is very important depending on the kind of substrate you are using you have to choose the technique.

If your substrate is having very low melting temperature, then you should not use the very high melting temperature coating material for coating purpose, then there will be chance of degradation at the interface or you cannot really apply different coating techniques like plasma spraying for coating purpose you have to use flame spraying for coating purpose.

So, plasma substrate nature is also very important like physical and thermal properties of the substrate and what kind of property (Refer Time: 16:40) you need on the substrate that also is very important. So, for what is your substrate that pays very important role because ultimately you are going to tailor the substrate to a large extent by coating. So, we substrate you are using that basically dictates which coating techniques you should apply.

Then manipulation; manipulation is also very important because that also gives you information about the coating strength and also the quality of the coating roughness of the coating, like standoff distance, speed of the manipulator, pitch or increment, angle of impingement these are the parameters which are very important because these actually again dictates the quality of the coating.

Quality of the coating mainly, these manipulation parameters particularly it determines the roughness, it determines the strength of the coating, it also determines the microstructure of the coating as well as defect density of the coating. Then finally, the spray heat source and gas which you are using, so depending on the naturally it is nothing, but it gives you information about which coating technique you are using, which spraying technique you are using for spraying purpose.

And as a result of which it gives you kind of direct information about the quality of coating to a large extent. So, these are the process parameters which you need to choose as well as optimize for getting the base property in the coating.

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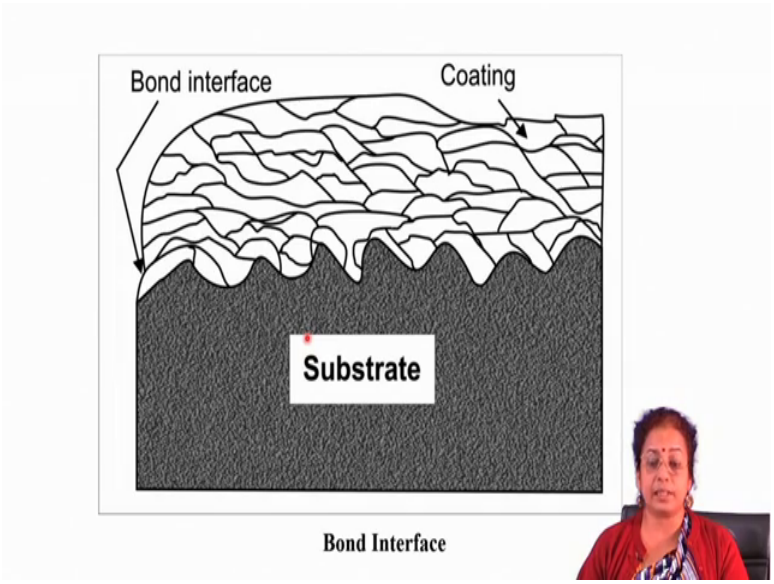

Then enough if you think of the interface, then you will find that usually at the interface if you check carefully by a scanning electron microscopy, you will find that at the interface there is impingement of the particles. So, interfaces it is important that this particular particle scan can or may be the semi solid or solid or liquid particles should get ideally impinged in the substrate surface and if it cannot impinge, if there is gap or if it is incomplete impingement then naturally you will find that you would not get adequate strength in the interface.

So, for getting adequate strength and properties of the coating it is essential that the particles get impinged at the surface of the substrate very nicely to have the proper bond strain because mechanism of bonding is usually the mechanical interlocking. So, it is important that you prepare the substrate prior to the coating very nicely, so that you have very nice grooves on the surface of the substrate. So, usually this particular moving is done by sword blasting operation or sandblasting operation.

So, when you do sandblasting depending on the particle size of the sand you will get different kinds of group formation on the different size of group formation on the surface of the substrate. So, because of the group formation this helps in anchoring the solidified melted or maybe semi solid particles to get impinged into the surface of the substrate. So, it is important that surface should be properly treated prior to spraying operation.

So, usually the pretreatment technique as I mentioned you they may be of two steps first step is your solvent decreasing, to clean all the grizzly layer or may be dirty layer which are present onto the surface of the substrate and second step is sandblasting operation. So, sandblasting is very much helpful and is a kind of mandatory pretreatment step prior to plasma spraying operation prior to any thermal spraying operation.

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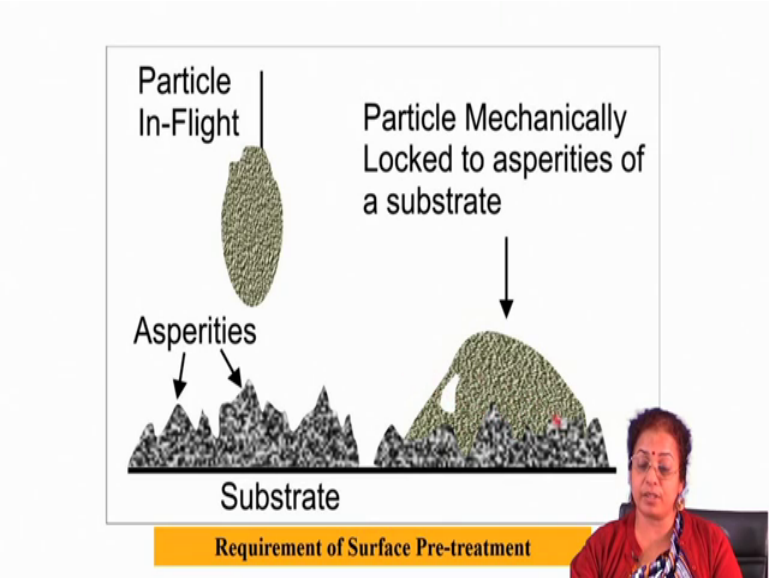

So, as this figure mentions that if there are asperities on the surface of the substrate naturally you will find that it get impinged in very nice thing and get locked to the molten material gets locked onto the surface of the substrate. But it is desirable that asperities are regularly in dimension, so that degree of wetting is maximum and you get very nice wettable coating onto the surface of the substrate.

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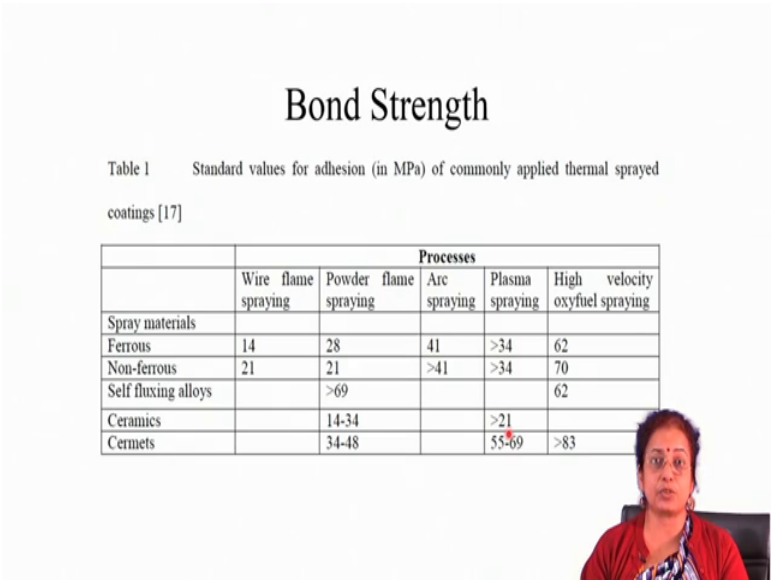

Now, if you quickly go through the bond strength, so of these thermal spray deposited layer you will find that bond strength; obviously, varies with the technique which you are using like in wireframe spraying of the say for example, if you talk about ferrous material coating. So, on by wire flame spraying you get around 14 MPa, powder feed flame spraying powder flame spraying you get 28 MPa, on the other hand if you use arc spraying you get 41 MPa, plasma spraying you get higher than 34 MPa and high velocity oxyfuel getting you get 62 MPa.

So, if you compare the coating bond strength of different material you will get some clue, you will see that non ferrous materials you get higher bond strength than ferrous material in most of the cases except for few cases actually where you get almost similar bond strength. And again you will find another interesting thing which you find is that, you get maximum bond strength when you do high velocity oxyfuel spraying as the proper coating technique.

So, they are actually you will get the maximum density can be maximum bond strength can be as high as 85, 80, 90 MPa. So, the reason behind the fact is that when you just go on spraying with a very high velocity you get high degree of mechanical interlocking and as a result of which you get very high coating; very high coating bond strength.

It also depends on the kind of material you are coating like ferrous materials you will get a little lower bond strength when you do wire flame spraying, when you do just non

ferrous material you get a little higher bond strength. So, bond strength is more or less of same order, but depending on the kind of coating technique you are using you will find that the bond strength also vary or varies a lot.

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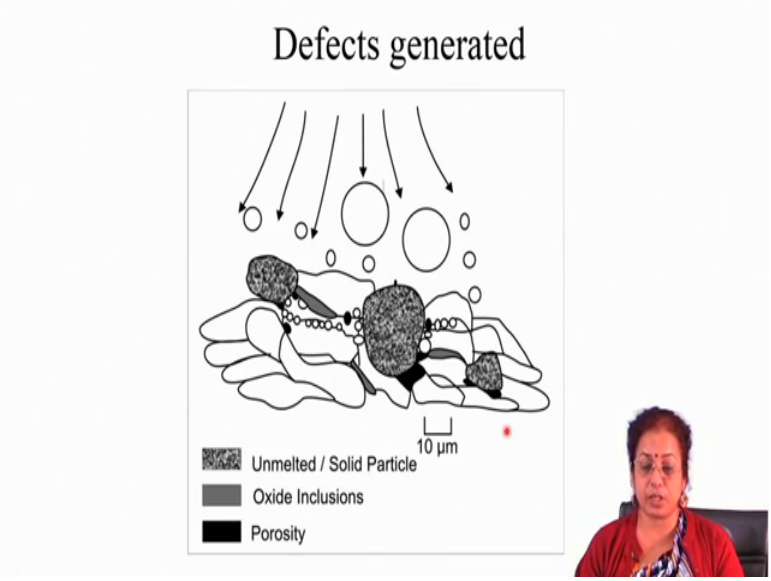

Now, one of the important problem associated with the thermal spray deposition is that, there are lot of defects which are generated in the structure because of the thermal strength process. Because as I mentioned you during thermal spraying you basically melt them powder or maybe in heat the powder in the state of molten or semi molten state and subsequently spray over the surface of the substrate, then you will find that after spraying there is a generation of coating.

So, if you think see the if you see carefully or maybe think carefully the reason behind the defects generation you will find that, the reason behind the defect generation is a oxide particles because this is carried out in open environment. So, a lot of oxide particles that there are so which create trouble.

There is also another source of defects that is know that blow holes which is because of the gaseous material which you are using that get stuck, they are get trapped in the coated layer when it is molten state and naturally when it solidifies then naturally the gas cannot come out. So, it remains in the form of the holes actually, remains in interacting.

So, and also sometimes the unmelted solid particles are also impinged in they are also present in the coating, oxide inclusions porosities these are the sources of defects or different types of defects that you observe in the coated product.

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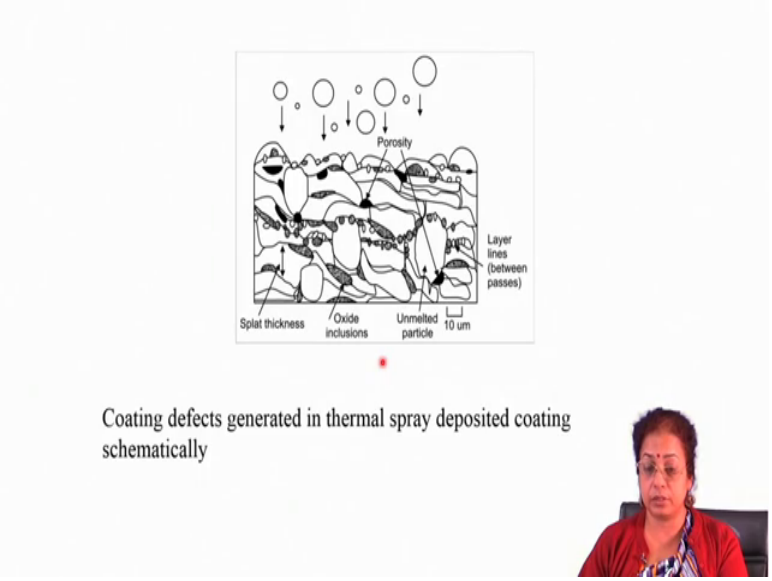

So, this is again the same sets of defects are shown here like oxide particles are there, oxide inclusions are there, some unmelted particles are there, then layer lines are there, then splat thickness also is important because from the splat thickness you get ideas. Splat thickness depends on several factors, like it depends on amount of heat input, amount the particle size of the melt, it depends on the rate at which it is flowing.

So, splat dimension is very important or splat thickness is very important because splat thickness actually gives you information about the coating dimension and depending on the splat thickness the cooling rate also varies because thinner the splat thickness higher will be the cooling rate and finer will be the microstructure.

But thicker is the splat thickness you will find that there will be more chance of coating effect or segregation effect and there will be more less rate of heat flow or rate of cooling as a result of which there will be chance of microstructure coarsening. So, splat thickness is very important.

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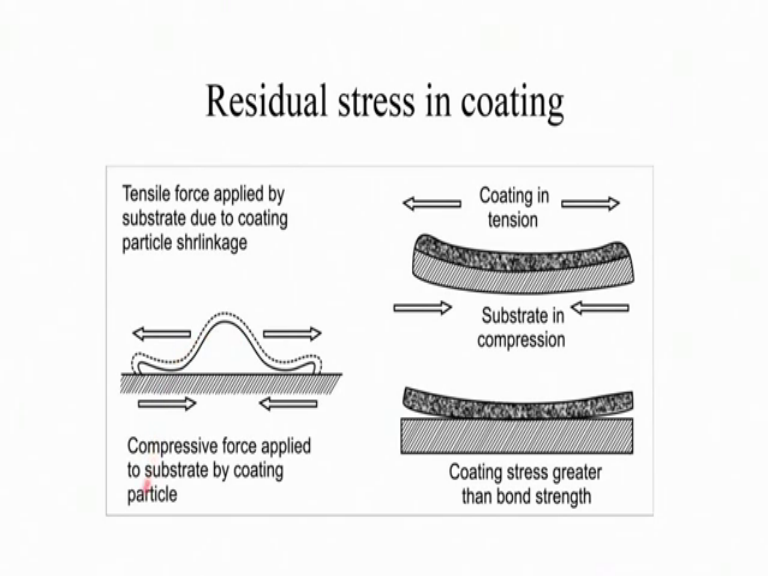

So, these are again some of the that the defects which are generated into thermal spray deposited layer. And finally, another important defect which is very much associated with thermal spray deposition is the residual stress. So, residual stress is generated because of the fact that usually whenever you are doing spraying, then that sprayed coating or coated material is cooled at a much faster rate.

So, that particular faster rate of cooling creates trouble because it introduces lot of residual tensile stress in the coating and not only that you will find that depending on the material which you are using, there may be differential quenching there may be differential quenching rate actually. And also because of large difference in coefficient of thermal expansion you will find that the maximum stress is introduced at the interface between the coating and that of substrate.

So, because the this particular stress which is generated or residual stress which is introduced by thermal spraying is proportional to that of Young's modulus of the coating material is proportional of that thermal expansion coefficient differences and also it is proportional to that of the dt that is a thermal gradient.

So, higher is the Young's modulus, higher is the coefficient of thermal expansion differences, higher will be the stress arrested within the component. So, usually you will find that after the coating is over if the coating thickness is very high, then there may be the coating with coating actually which pours out and it is important that you should

optimize the thickness. So, that there is no chance of spoiling out of the coating because of the residual stress arrested during coating process.

So, this is about the thermal spray deposition, so in summary I can say that thermal spray deposition is very important technique for the deposition of wide range of materials and, but you have to be careful in choosing the proper deposition technique and also you have to be careful to choose proper process parameters.

So, that you get rid of the residual stress which is arrested in the coated material after thermal spraying. And sometimes therefore, residual stress relieving you or you can also go on stress relieving operation where you heat treat the sprayed part at a little higher temperature. So, that stress whatever stress is introduced is released and you have to be also careful to reduce the different kinds of defects which are introduced after the thermal spray deposition process particularly the defects like porosities, then low holes and also the inclusions particles.

If it is reactive material you can also go on doing this thermal spray deposition in a closed chamber where you get rid of all atmospheric contaminants. And process parameter selection is very important and also depending on the material you choose the proper technique.

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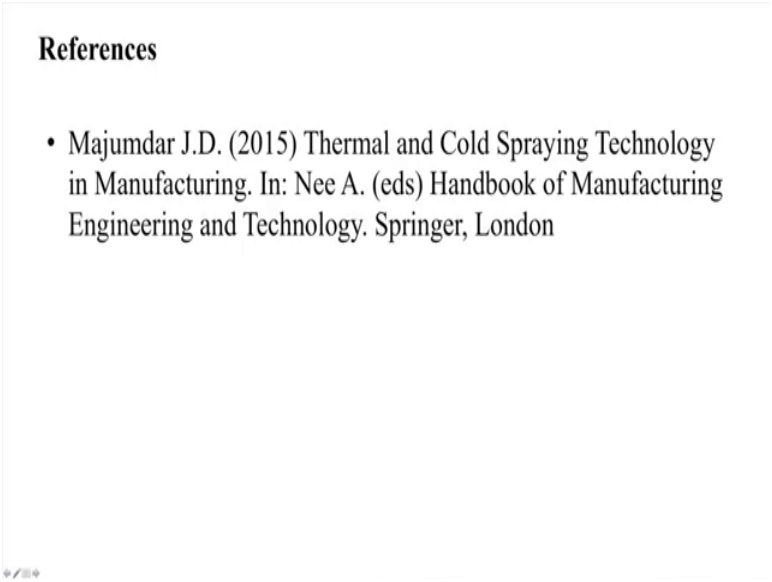

So, that you get proper adherence at the interface with the proper surface finish and good quality coating on the substrate of your choice for the desired application.

Thank you very much.