Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations
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Lecture-50
Surface Modification Techniques: Flame Spraying

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering and you know that we are talking about the thermal spray processes which is one of the approach for developing a layer of the suitable material for improving the tribological performance. In the last presentation we have seen the basic principle of the thermosphere processes and there is one more aspect related with the thermal spray processes.

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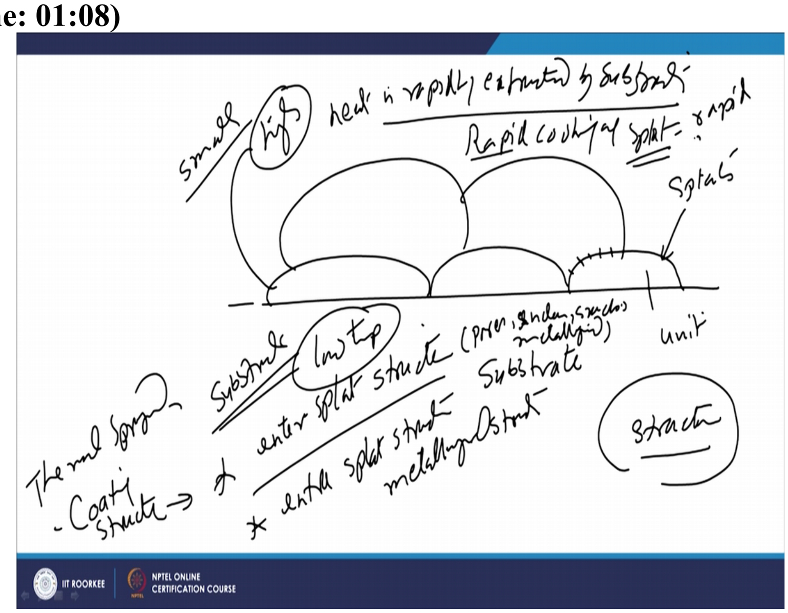

That the coating which are formed will be before will be produced one by one by development of this is splats over the surface of the substrate and these are the splats which are deposited. So, as per the particle velocity and their mass the different splats one over other will be deposited. So, if we see each splat is one unit. So, each splats will have own structure, while if we see the splats and splats are in contact with contact with each other at particular surface and this one is called inter particle, inter splats space or inter splats surface.

Inter splat structure this is another aspect there can be pores, there can be inclusions, there can be other defects there can be cracks or there can be simple metallurgical bond. So, there are two aspect as far as the structures of the coatings structures are concerned or you can say thermal spray coating structure that two aspects, one is the inter splat structure and intra or within splat structure and both needs to be seen separately.

There in the inter splat structures there can be pore,s inclusions, cracks or simple metallurgical structure. While in case of the intra splat structure there will be metallurgical structure. Now these are the two aspects which need to be seen separately. Now one more thing is the mass of the substrate is very high, it is at low temperature. So, mass is high and low temperature and the temperature is low.

While the particle mass is very small it is very less and the temperature is very high. So, because of this contract as soon as the particle impinges with the surface of the substrate the heat is rapidly extracted by the substrate from this particle. And this in turn causes the rapid cooling. Rapid cooling of the splat which is in the either in the semi solid state or the completely molten state and this in turn causes the rapid solidification of the splats.

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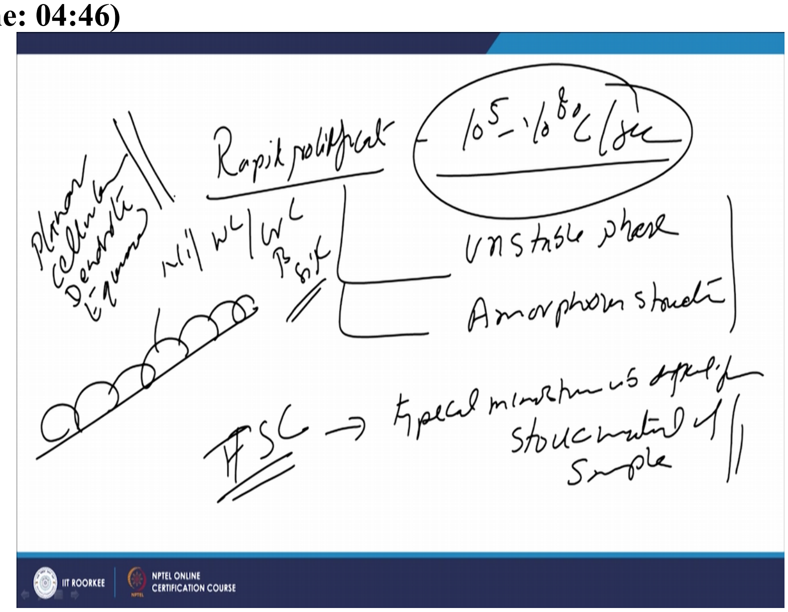

And the rapid solidification of the splats and the rapid solidification of the splats can occur in the range of 10 to the power 5 to 10 to the power 8 degree centigrade per second, so these cooling rates are very high and which in turn leads to the formation of the unstable phases even amorphous structure which is not crystalline. So, these will tend to get stabilized as soon as the farther rise in temperature of such kind of the coatings takes place.

And because of this we do not find in the flame spread coatings on thermal spray coating the typical microstructure is different the typical from the from the stock material of same composition which may be in form of like say the rod or the wire. So, different microstructure is really very difficult to recognise that which constituents belongs to which type of the particle. Like say in the coating we have large number of the splats deposited like this.

So, there can be there this so there can be nickel there can be tungsten carbide there can be chromium carbide, boron and silicon carbide etcetera. It is very difficult in the flame spread coatings to identify which constituency belong to which particle. Because here we come across very high cooling reads the semi molten or the complete molten state and even just or even the cases even just softening is taking place.

And that is why we do not get that the common structures in the flame spread coatings which are like maybe in form of planar structure or cellular structure or are dendratic structure or equax structures. These are the most commonly observed structures in the conventional conventionally solidified structure castings or the welding and therefore the identification and distinction of the various micro constituents in case of the flame spread coatings are become difficult.

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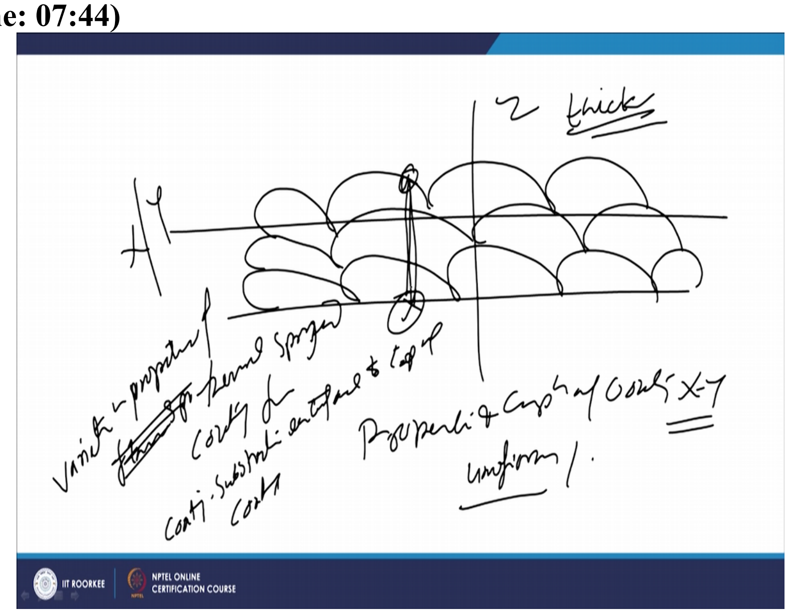

There is another aspect related with the flame spread coating characteristics that is like the splats are deposited on the surface of the substrate like this one layer by layer one over other this manner. So, if we take any section like this is one section obviously in the in the so, there may be three different directions one is the Z direction that is across the thickness direction and length and width the direction which we can say as XY direction.

So, the properties and composition of the coatings in XY direction that is in a particular plane they become by and large uniform and variation is variation in terms of the hardness another properties is very limited but if we see the variation across the thickness like changing from our variation in properties if we study from the interface to the top of the surface. Then we find lot of variation in properties of flame of thermal spread coatings from coating substrate interface to the top of the coating.

So, from the interface that is this coding substrate interface is this and the top of the coating and there will be lot of variation in terms of the properties and composition. So, heterogeneity exists in the thickness direction while in XYZ direction or at particular plane of the coating the variation in the composition as well as properties is very limited.

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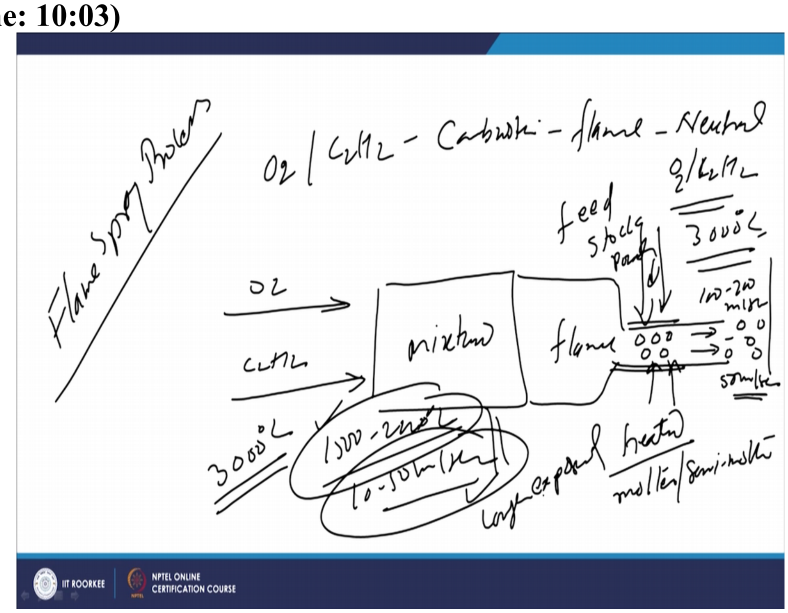

Now we will see the one typical thermal spray process it is called flame spray process. So, we have in this process of flame using the oxygen and acetylene this mixture is burnt combustion takes place and flame is achieved which is mostly we use the neutral flame using the equal proportions of the acetylene and oxygen which generates around the temperature of the 3000 degree centigrade. So, for this purpose we have to feed oxygen we have to feed acetylene in a particular chamber where these gases will be mixed.

Mixture of the places will be obtained and then these will be burnt. So, a flame is achieved and this frame will be coming out of the nozzle and here we feed the feed stock in form of powder. So, feed stock is fed in form of powder in the flame. So, here the powder particles of the material which is to be applied on to the surface of the substrate they will be entering into the flame which is at 3000 degree centigrade and same moving at 100 to 200 metre per second speed.

So, this will be now first of all these will be heated to high temperature so that they can either be brought to the molten state or semi molten state. And then these are when these particles are there in the flame they will be accelerated towards the surface of the substrate. So, the acceleration will be increasing the particle velocity like say maximum up to 50 meters per second. And then this will be impinging the surface of the substrate to develop the coatings. So, in this process as we know the temperature is around 3000 degree centigrade that is maximum temperature.

While the particle temperature is limited to like 1500 to 2000 degree centigrade while the particle velocity is very limited like 10 to 50 meters per second. So, because of this; in this case the particle velocity is limited, flame temperature is a limited. So, low temperature of the flame is favourable with regard to the reduced thermal damage of the feed stock material. But the limited particle velocity will be permitted the long exposure of the feed stock materials within the flame.

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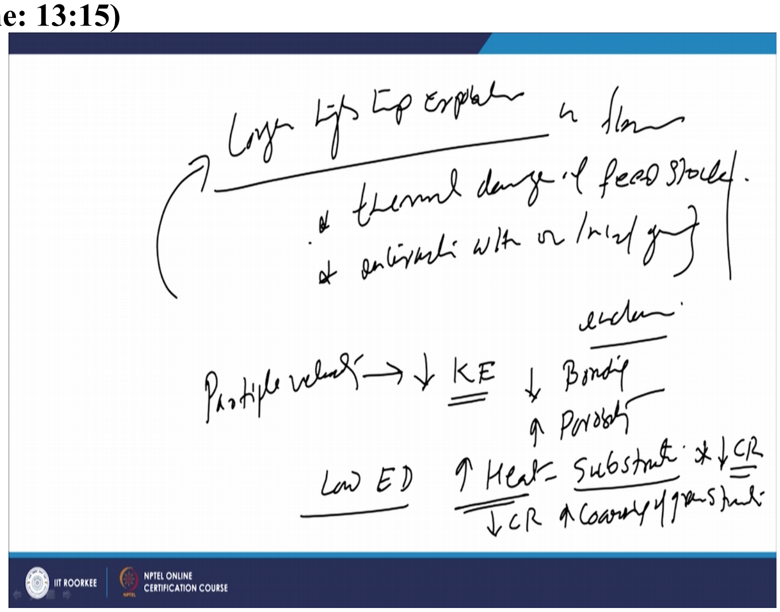

So, as we have seen it longer high temperature exposure of the feed stock material in the flame will be leading to the thermal damage of the child feedstock material of this is one which may be informed decomposition of the tungsten carbide particles are the chromium carbide particles or their interaction with the oxygen, nitrogen and other gases which are present in the flames. This will be leading to the formation of inclusions.

Further the particle velocity and this why this is happening while longer time of the exposure at high temperature because of the limited particle velocity limited particle velocity will also be leading to the reduced kinetic energy of the powder particles at the time impingement and which in turn will be leading to the reduced coating substrate bonding. Bond strength is limited so there is a possibility of a falling of that delamination of the coating from the substrate and high porosity.

And we know that the flame which is obtained through the combustion of acetylene and oxygen is a low energy density process. So, we need to be; in this process with a lot of heat to the substrate. Substrate gets; there rise in temperature of the substrate as well. Rise in temperature of the substrate during the thermal spraying will be causing the resolution and distorted related issues one.

And the second it will be leading to the reduced cooling rate of the flame spread coatings. So, reduction in the cooling rate of the flame spread coating will be leading to the coarsening of the grain structure. So, the coarsening of the grain structure is undesirable aspects will be getting the reduced and the poorer mechanical properties.

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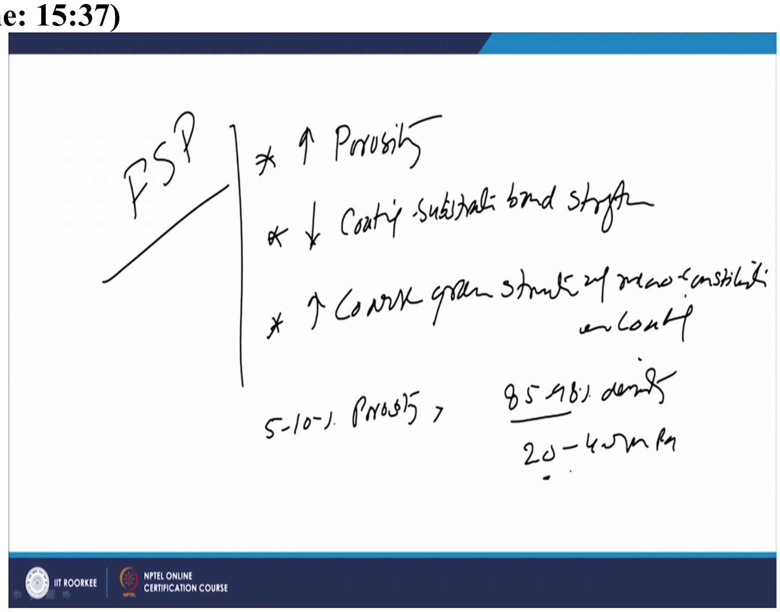

So, as far as the flame spray process is concerned there are two; there are few issues which are like higher porosity due to the limited particle velocity at the time of impingement and reduced coating substrate bond strength and third one is the very coarse grain structure of micro constituents in coatings. So, these are the three issues and it is required because even for the same feedstock material flame spread coatings will be offering the poor and mechanical properties and that is why it is required to improve the performance for improving the performance of the flame spread coatings.

It is required that some additional approaches are used for enhancing the performance of the flame spread coatings. As far as the properties of a flame spread coating is concerned there can be 5 to 10% of the porosity and the density is about 85 to 98% because of the porosity inclusions this is one respect and the bonding is also very limited like 20 to 40 MPA bond strength which is achieved in this case apart from these issues there are some commercial aspects.

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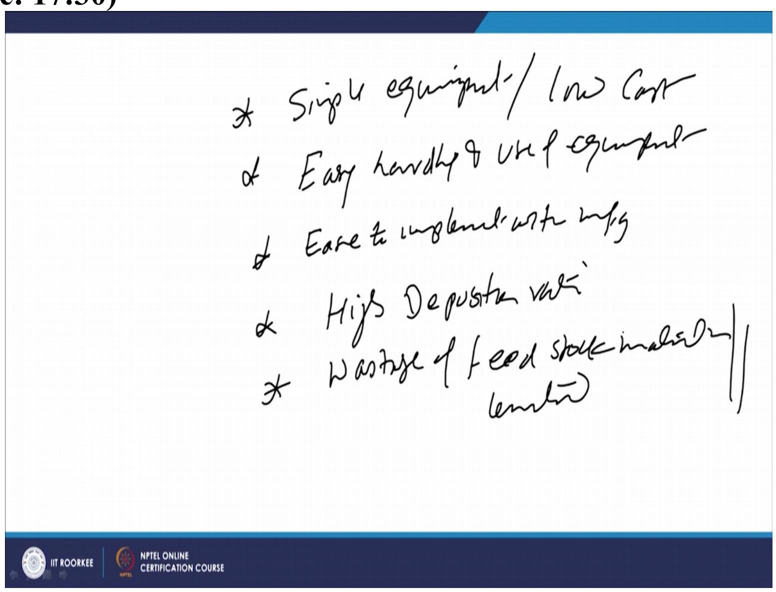

Which are associated with this process process like since the equipment used for flame is spraying is very simple. So, simple equipment flame spray torch and that is why it is a very low cost and the simple equipment leads to the easy handling and use of equipment. And since the equipment simple it is easy to implement and apply and synchronise this process with the manufacturing system.

So, easy to implement with the help manufacturing system of the process, the process of course quit high deposition rate which is a good side will be able to cover the larger surface area for surface modification and the wastage feed stock material is limited. So, this is another good side there are few processes where particle velocity is very high after the impeachment particle tends to a scatter here and there in that will be increasing the wastage of the material.

So, here the wastage of the feedstock associated with this process is flame spray process is very limited these are the some of the good sight as far as the flame spray process is concerned.

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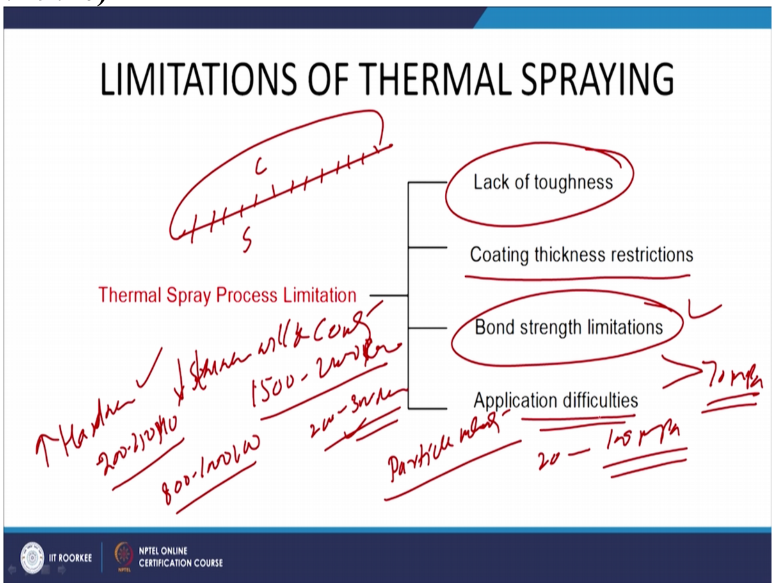

Now we will see some additional aspects related with this process. Whenever we develop any flame spread coating in general we encounter some of the issues with the flame spray coatings like this. Since the coatings are developed by splat bonding or bonding of the splats with the substrate and this in turn leads to the limited the toughness of the coatings. In some of the materials where is a restriction on the thickness of the coatings which can be produced.

In general greater is the hardness of the material smaller or thinner will be the coatings that can be developed. For example the materials of a like 200 or 200 HV hardness can be developed to the; like coatings can be developed of 1500 to 2000 micrometre easily means 1 to 2 mm thickness coatings can be easily develop. But if the hardness is too high like 800 to 1000 HV then this is limited to like say 200 to 300 micro metres.

So, there coating thickness restrictions harder is the material lower will be the thickness which can be deposited. As that the delimination and removal of the coatings will start. So, higher is the hardness lower layer thickness and lower is the hardness greater will be the thickness of the coatings which can be made by the thermal spray process. Now there are bond strength and limitations as well like as per the particle velocity.

The coating bond strength like this is the coatings and this is the substrate. So, that coatings do not bond very effectively with the substrate because most of the time it is mechanical bonding I did you to mechanical bonding in form of mechanical interlocking as well as little bit metallurgical bonding also change place but that is limited that is why they are bond strength limitations.

And as per the particle velocity the bond strength like say from 20 to 100 MPA it is always desired that the bond strength for most of the engineering applications is greater than 70 MPA as minimum acceptable bond strength. But since the bond strength is influenced by the number of factors such as the surface of the substrate, cleanliness of the substrate, particle velocity of the substrate, rise in temperature of the state factors influencing the bond strength of the coatings.

There are limitations associated with for example of flame spread coatings of a very limited bond strength and exposure of the substrate material to the flame and this in turn this factors influence the bond strength. And their application difficulties I like the processes to be applied in the in the shop and in all those difficult to access locations cannot be subjected to the coating using the flame spray process. So, there are few application related difficulties as well as thermal spraying is concerned.

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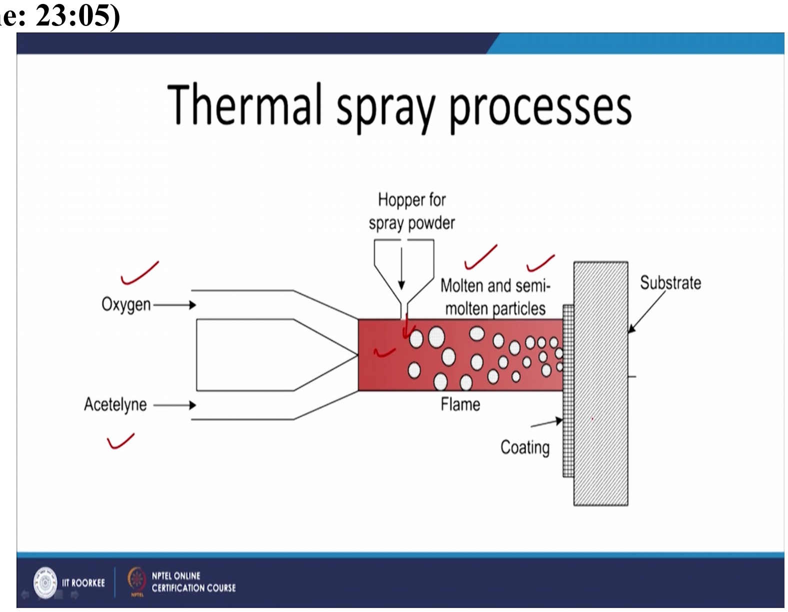

Now this is the schematic of the flame spray process where in we use oxygen and acetylene separately both are fed in the chamber where this flame is produced and in the flame before getting outside the nozzle we feed the spray powder or feed stock material in form of powder to the hopper. So, that this material whenever it is fed it will be heated in the flame and then it will be accelerated towards the surface of the substrate.

So, heating may will be leading to the complete melting or the same molten state of these particles and one these attain the velocity as per the as per the flame velocity as well as they stand off distance between the nozzle and the substrate surface. The particles will be impinging the surface of the substrate and they will be getting deposited in form of the splats.

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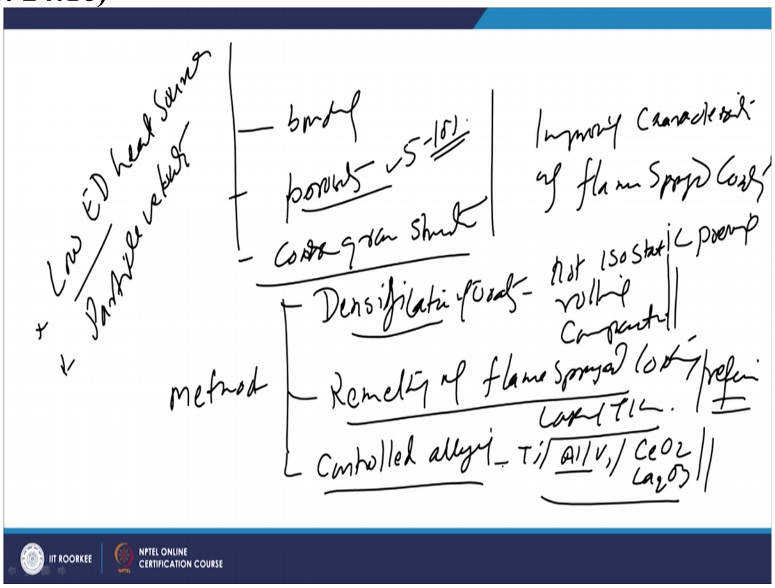

So, as I have said this the flame spreader coating process uses the completely low energy density heat source and the particle velocity which is achieved in case of the flame spraying is very limited and which in turn leads to the issues related to the poor bonding, porosity and coarse grain structure course brain structures. So, to overcome these issues are some of the methods have been developed for improving the characteristics of flame spread coatings.

And there are few categories of these methods and like methods for improving the characteristics of the flame spread coating so one is like densification of coatings this may involve use of hot isostatic pressing, rolling or compaction during the flame spraying itself. The another method is the remelting of the flame spread coating. So, remelting is facilitated using the laser or the tig arc.

So, whenever the coating is remelted the heat source is of the higher energy density for this intern facilitates the control melting as well as the rapid cooling which in turn refines grain structure. While densification will be reducing the porosity and improving bond strength. Similarly there is another improving the properties know as control alloying. Now as per the material system we can use suitable alloying element like for aluminium alloys it may be titanium for steels it may aluminium or vanadium.

And similarly the rare earth elements are also used in form of Cedia or the Lanthanum oxide La2 O3. So, these are the elements will be helping us to refine the micro constituents present in the flame spread coatings for improving the performance. Since the flame spread coatings offers course grain structure and the porosity or higher porosity ranging from like say 5 to 10% and the bonding is poor. So, sometimes remelting helps in increasing the bonding as well as refining the grain structure densification helps in reducing the porosity.

As well as and the control alloying helps in finding the grain structure. So, that there are different approaches for taking care of the various issues related to the flame spread coating so, that their performance can be enhanced. Now I will summarise this presentation, in this presentation I basically talked about the way by which we should look into the micro structural aspects of flame spread coatings and thermal spread coatings because these structures are completely different from the conventional structure of the feed stock material.

As well as at the same time I also talked about the various aspects related to flame spread coatings and the kind of quality which is achieved in the flame spread coatings and we have also seen that there are some issues related with flame spread coatings like poor coating substrate bond strength and high porosity, coarse grain structure. So, there are certain method used for improve the performance of the flame spread coatings.

I probably elaborate these methods for improving the performance flame spread coatings in the subsequent presentations. Thank you for your attention.