Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-52
Surface Modification Techniques: HVOF and Detonation Spraying

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and you know in the previous presentations we have talked about the other thermal spray processors and more specifically the flame spray process the flame process is known as high temperature low velocity process under which suffers from the various undesirable features like coarse grain structure, porosity inclusions and limited bond strength.

So, we have also talked about the few methods which can be used to enhance the performance of the flame spray coatings. In this presentation will be talking about the three processes, these are the high velocity oxy fuel spray process, detonation gun spray process and the cold spray process. All these three processes are the combustion based process where as fuel oxygen gas mixture is burnt to generate the heat.

And then after accelerating the particles to sufficiently high velocity are the impeachment of the coating material with substrate takes place for the development of the coatings. So, this process these three processes primarily defer with the velocity which is attained and the temperature up to which material is heated during the spray process. So, I will be talking about each of these processes one by one.

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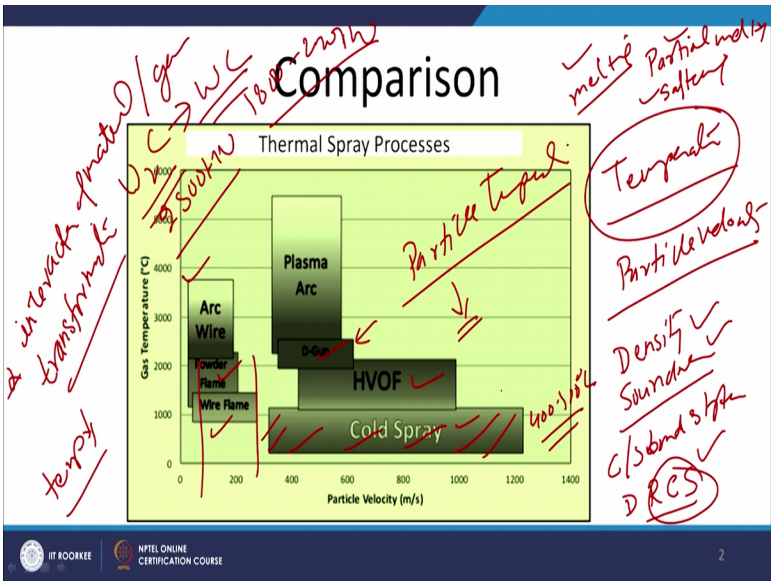

Like say if the comparative plot of the various process then the particle velocity and the gas temperature these are the two very crucial parameters that temperature which is generated during the thermal spray and the particle velocity which is attained during the thermal spray. So, particle velocity decides the density or the soundness of the coating as well as coating substrate bond strength and the kind of splat bonding is also influenced by the particle velocity.

On the other hand the temperature of the heat source or the gas temperature of whatever is generated during the thermal spray process that may cause complete melting of the particles which is being is sprayed or it can cause the partial melting or it can cause the thermal softening of the material. So, in case of the cold spray process the temperature the gas temperature is limited and the particle temperature is also 400 to 500 degree centigrade.

So, there is no melting as such primarily thermal softening of the material takes place. While in other processes the temperature rises more like if you see the arc wire spray process the temperature is in the range of 2000 to 4000 degree centigrade. While in case of the plasma arc is process temperature can be even greater than the 5000 degree centigrade. For detonation gun temperature is low like 2000 to 2500 degree centigrade same is true for the high velocity oxy fuel process.

But it is higher than cold is process like 1000 to 2000-2200 degree centigrade. But these are the flame temperature, the particle temperature will in all these cases will be lesser. And since higher the flame temperature greater will be the particle temperature and which will be leading to the either melting or partial melting softening tendencies. But apart from these there will also be

tendency for the interactions of the material which is being is sprayed with gases which are present.

So, this will be affecting the soundness especially with regard to the inclusion formation and the second one kind of the metallurgical transformations sometimes undesirable transformation degrade the quality of the coating material which is being sprayed. Especially like W2C like tungsten carbide can transform to the WC. So these of the higher hardness of 25 HV while these is of 1800 to 2000 HV.

So, this kind of thermal degradation can occur if the coating material is exposed to the higher temperature for longer time. So, if we consider these two aspects then will notice that those processes where temperature is limited they will be favourable with regard to the inclusions formation are the undesirable mythological transformation point of view.

While the higher particle velocity will be leading to the more dense less pores and the good coating substrate bond strength and apart from that when the particle velocity is too high then it will be leading to the development of the residual compressive stresses. And this is found to be favourable under the wear conditions as well as this can also be helpful in enhancing the mechanical performance of the component.

So, if we see the more thermal damage will be occurring in case of the arc wire spray and the plasma arc is process. But the wire flame and the powder flame processes these are very low velocity processes. While in case of the detonation gun high velocity and cold spray process these are the high velocity processes. And so they will be leading to the much better much better coating substrate bond strength and development of the residual compressive stresses as well as reduced porosity in the coatings.

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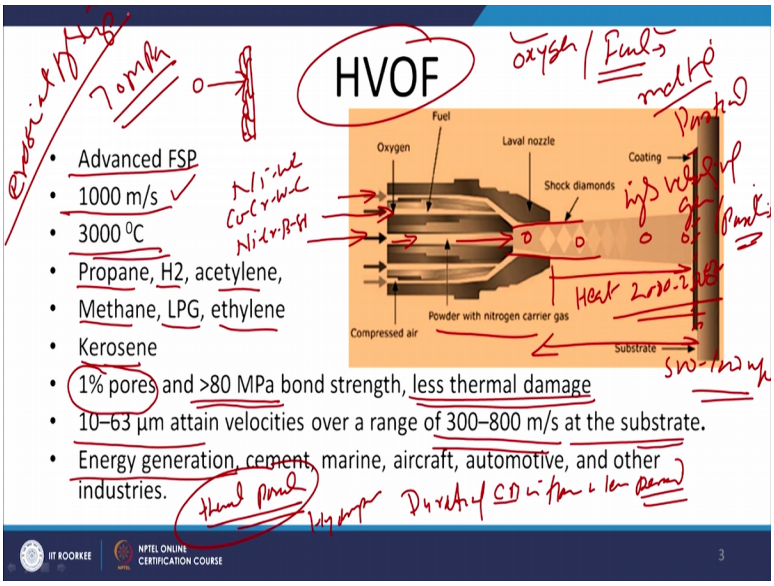

Now we will see the particular process in detail the high velocity oxy fuel process. So, here oxygen and fuel gas can use number of fuel gases it may be in form of like says the propane hydrogen, acetylene, liquid petroleum gas, ethylene, kerosene, methane etcetera. And all these know we can select one of these fuel gases mixed with the oxygen and then it is fed in the torch. So, that the flame can be produced so we can see the oxygen is fed and then we will see also that the fuel gas is also supplied.

So, oxygen and both fuel gases are supplied so that after forming a mixture they can; and combustion that can take place and sufficient heat is aerated and the temperature rise takes place like 2000 to 2500 degree centigrade and this one is needed for either melting or partial melting of the material which is being which is to be coated. And the material which is to be coated is fed with the help of suitable career gas which may in form of like say nitrogen.

So, material in form of the powder may be like say Nickel, Chromium, Boron, Silicon or the Cobalt Chromium Tungsten carbon or the Nickel Tungsten Carbide powder mixture. So, as per need suitable hot air is selected and it is fed up with the help of the nitrogen as a career gas. When it passes through this one very high velocity is attend due to the heat generation as well as the compressed air is also used.

Combination of these things will be leading to the generation of the very high velocity of the gases as well as the particles which are there. It will be say like 500 to 1000 meters per second velocity. In this case if you see oxygen and the fuel gas mixture is being burnt and at the same time as we are also using the compressed gas and powder is fed with nitrogen as a career. Earlier

we have just used the oxygen and fuel gas mixture and in that one, we had fed the powder mixture.

Because of the additional role of compressed air along with oxygen and fuel gas mixture and the feeding of the powder with the help of the nitrogen as a career gas all these things will you facilitating the supply of the coating material in the flame which will be heated to the surface at high temperature then it will be accelerated and when it is accelerated to high velocity, the impeachment of this material with substrate leading to the development of the coatings.

So, we can say this is an advanced version of the fuel flame spray process and very high velocity of 1000 meters per second can be attained by the powder particles which are being sprayed on to the surface of the substrate. And the temperature is also high enough to cause either melting or the partial melting. Since the velocity which is attained in this process is quite high and that is why the impingement of the power of particles with a substrate will be occurring at very high velocity with high kinetic energy.

So, it will be getting flattend and very formally and that is why the pores which are left out between the coating and substrate or other between the various splats these are very less and that is why we find very limited pores. So, the porosity in these coatings in HVOF coating is less than 1% and high velocity impeachment with the surface of substrate or already deposited material will be leading to the very good coating substrate bond strength greater than 80 MPA.

We know that minimum acceptable coating substrate bond strength is 70 MPA but when this process is effectively applied we get much higher coating bond strength. Since the particle velocity and through the flame is extremely high so the material; spray of the material during the flight from the torch to the substrate is very less. Duration especially the duration of the coating material in the flame is for very less period.

And therefore the kind of thermal damage in terms of the undesirable metallurgical transformations or the interaction of the coating material or material to be coated with the gases which are present all that is very less. So, what is important the duration of the stay of the material we coated at high temperature is less in HVOF process because of the high velocity and that is why thermal damage in terms of the undesirable metallurgical transformations or interaction of these materials with the gases is very less.

And that is why we get extremely reduced damage to the material which is being coated on to the surface of the substrate. And like say particle velocity particles of size that to 63 micrometer can attend the velocity in the range of like 300 to 800 meter per second especially at the time of impact the kinetic energy of the powder particles at the time of impingement is more crucial. So, that in turn also will be affected by the stand of distance which is between the nozzles to the substrate.

So, it has to be optimised are so that the particle attain the maximum velocity and at the time of impingement the particles are having the enough velocity. And this kind of the process can be effectively used for coating wide range of the materials which can be used for enhancing the abrasion resistance, corrosion resistance and since the deposition rate offered by this process very high.

So, it can be effectively observed for at the industrial level for surface modification so that the resistance to the wear under that different condition can be enhanced. And considering the application the HVOF is effectively used in the energy generation sector like say in thermal power plants or in hydro power plants like hydro turbine blades subject to the sturdy aerosol coated using suitable materials then there will be able to effectively reduce erosion.

Similarly high temperature resistance is needed in case of thermal power plant. So, erosion resistant at high temperature is important for thermal power plants and for that purpose like thermal barrier coating resistance will be used which will not only be reducing the temperature of the main component but will also be increasing erosion resistance. These are also use like in cement industry for resistance as well as erosion and automotive industry and many other industries for enhanced wear resistance of the component.

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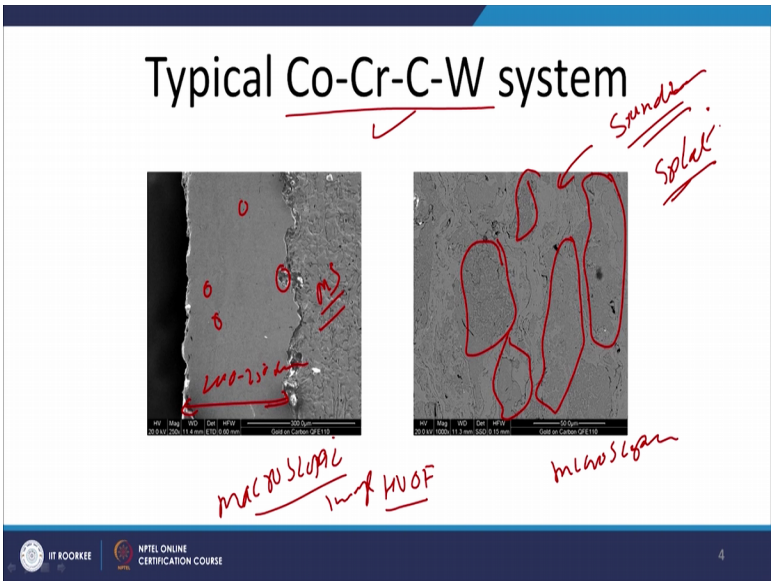

In the next slide always showing typical HVOF coatings of the Cobalt Chromium Carbon Tungsten system and if we see this is the macroscopic image of HVOF coatings of this material, this is the Cobalt based material which of these very good abrasion resistance as well as corrosion resistance. And we can see here this coating thickness is about the 200 to 250 micrometre. And this is a coating is developed on the surface of the mild steel to investigate what kind of the wear resistance.

If we see hardly we have a very hardly there are measured discontinued is very fine pores are there here and there and other quantify this pores is very fine and these are very less in terms of the percentage. And further closer look if you see for microscopic observation then we can see there a lot of splats in the form of these are we can see these are the flattend particles which have been deposited over the surface of the substrates.

So, these micro structural features are completely different than what we normally observe in case of the conventional crystalline systems and here primarily we can see if there is there are discontinued, so indicating soundness or what kind of the is splat are being formed and what kind of the bonding is there between them. And these are the kind of the micro structural features which we can observe.

And these features are completely different as compared to that what we get in case of the conventional spray process or conventional material where the fusion followed by the solidification.

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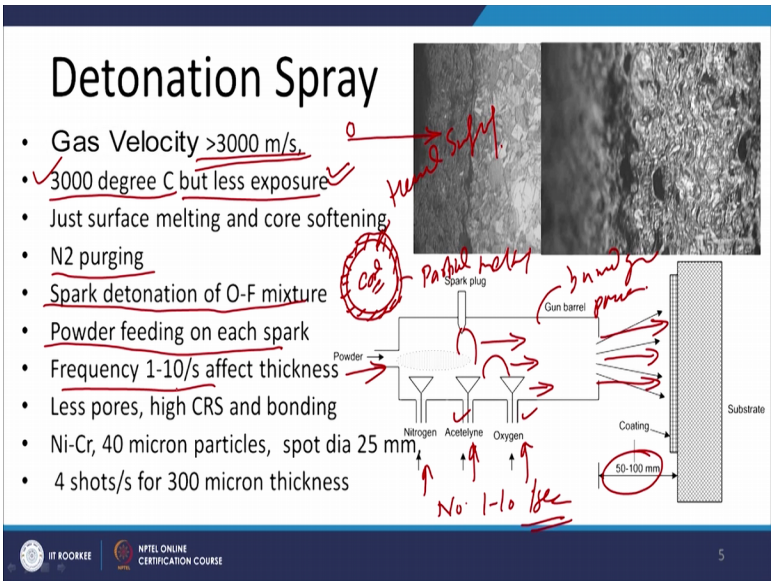

Now we will see the second process this is called detonation spray process in this; this another high velocity is spray process where in the velocity of the gas is too high like 3000 meter per second the temperature is 3000 degree centigrade. But since the velocity is very high and that is why we exposure of the material coated is for very less time and since the time is less at high temperature time of exposure at high temperature is less.

And therefore the associated the thermal damage to the material be coated is also less that is why despite of high temperature since the velocities high the exposure is for the less period and in this case only the; if the material is being sprayed by the detonation spray the high velocity leading to the limited transfer of heat to the powder particle. So, only the surface layer will be brought to the molten state while core remains in the solid state.

So, only this is the situation of the partial melting and in this case core is thermally softened which is a favourable especially with regard to the development of the residual compressive stresses. So, how does it work in case of the detonation spray we have to feed, I just say this is another combustion process we have to feed oxygen we have to feed acetylene and this mixture is burnt or detonated by giving the spark through the spark plug in very controlled way.

So, like say mixture is fed through this controlled like oxygen and acetylene is fed through these control valves and then this mixture is detonated with the help of the spark plug and as soon as detonation takes place powder is fed and this barrel and so whenever this detonation happens the high velocity gases will be moving towards the exit along with the powder particles. And these

powder particles during their travel through this barrel will be heated to this partial melting or thermal softening conditions.

And once this come out they will be directed towards the surface of the substrate where these are to be coated and these distance is of like say 50 to 100 mm so the barrel to the substrate distance is about 50 to 100 mm and after each like say after each detonation like for its each detonation we feed the oxygen and acetylene spark plug is detonating will and then powder is fed the matter and all the material the gases as well as powder mixture will be directed towards the surface of the substrate.

And once this cycle is completed the purging net purging is performed of this gun barrels with the help of Nitrogen. So, all those burnt gases and the powder which has been fed can be cleared from the gun and the next round of the detonation is carried out. So, this process of the detonation is repeated number of times. So, number of detonations in this case may vary like say 1 to 10 number of the detonation per second.

And this will be determining the rate at which the coating thickness will be increased. Obviously greater is that number of detonation per second higher is the rate at which the coating thickness will be increased. So, that is what has been explained in these points like that the mixture is fed spark plug will be detonating it powder is fed and once the; and then the things are accelerated towards the substrate and then particle is deposited on to the surface of the substrate.

And then just to clean up the things that nitrogen purging is performed spark plug performs detonation of the oxygen and fuel mixture powder feeder is used to supply the powder in very controlled way the gas gun barrel so that we can deposit the material at the required rate detonation can happen at a particular frequency of 1 to 10 and number of detonation per second which internal view affecting the thickness the rate at which thickness being increased.

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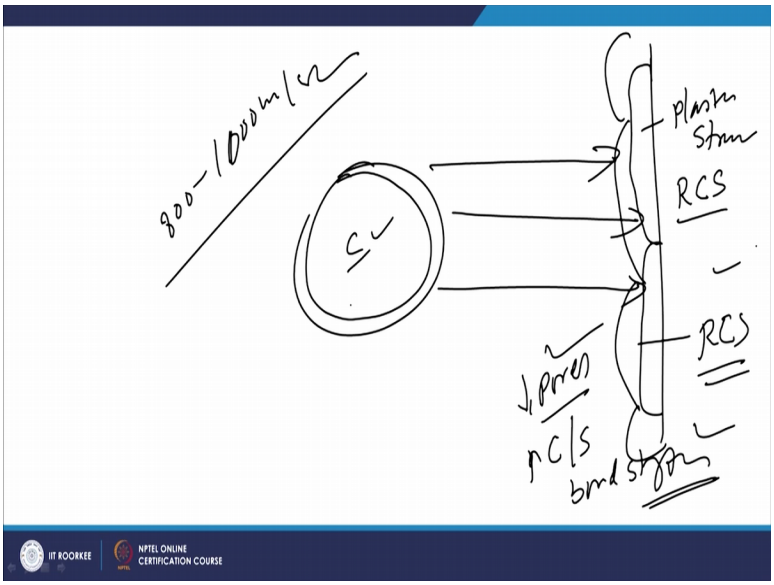

And then since the velocity of the powder particles which is a attended during the spray process is very high and that is why is this powder particles where just the surface has been brought to the molten state and the core has been soften and when the impingement of these particles happened at very high velocity then it will be leading to the flattening with the very of firmness and with very soundness and it will be leading to the reduced pores.

And very increased coating substrate bond strength so this is the good side associated with this process that high powder particle velocity of 800 to 1000 meter per second leading to the very sound coating substrate bond strength reduce the porosity. And at the same time since the shooting material is getting flattend in the solid state itself that is why it will be under the plastic strain conditions. So, when the material is flattened under the plastic strain conditions it develops the residual compressive stress.

So, whatever coating is developed through this process if the coating at the surface has the residual compressive stress, so, because of high velocity and limited heating or on the surface layer melting facilitates the reduced porosity good bond strength and residual compressive stresses and this now the typical result for the detonation spray spread material.

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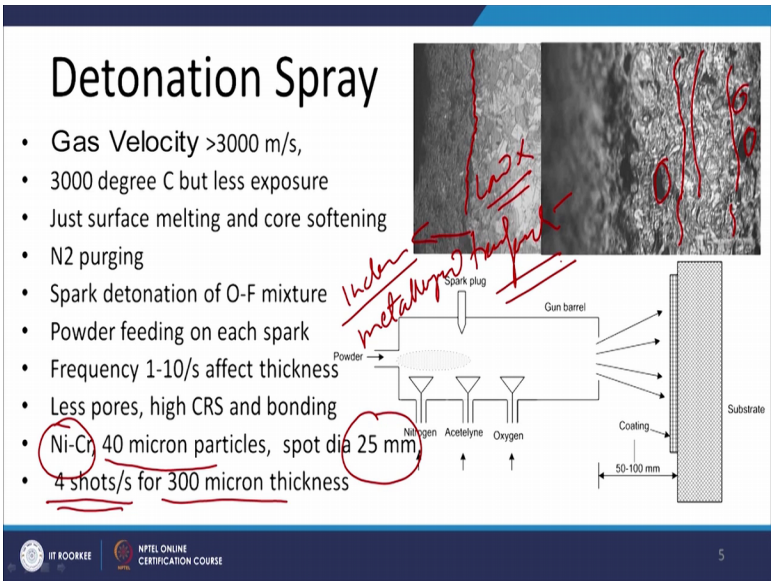

Here in these are the two micrographs which show that the Nickel chromium material of the powder particle size 40 micrometre is spread over the surface of the substrate having spot diameter of the 25 mm and detonation is praying was carried out at the rate of 4 shots per second for developing the coating of the 300 micrometre then we get the coating structure of described. And here this is the low magnification structure of the coating which shows that coating is by large sound and free from the defects.

However some of the limited bonding at the interface can be seen. But this is primarily because there is no fusion of the interface effusion of the substrate and the coating only the surface layer of the coating material powder is brought to the molten state. But if we see the closer look of the coating that these is splats can be clearly seen which is been deposited over one over other and still some of them micro porous can also be seen here.

And there since this process there is no compete fusion of the powder particles and primarily high velocity on a surface layer melting of the powder particles leading to the very sound coatings with very good bond strength and that is why are this process does not suffer any kind of the thermal damage and thermal degradation, especially with regard to the formation of the inclusion or formation of the undesirable metallurgical transformation.

So, this is how we can say this detonation spray process can effectively be used for depositing the variety of materials without any thermal damage while developing the sound coatings which are with very limited pores with very good coating substrate bond strength. Now I will summarise, in this presentation. In this presentation which will have talked about the processes

one was the high velocity oxy fuel spray process which leads to the higher temperature as well as the high velocity.

In case of detonation spray process also the velocity is very high and the temperature rise of the coating material is very limited. Thank for your attention.