**Technology of Surface Coating**
**Professor A.K Chattopadhyay**
**Department of Mechanical Engineering**
**Indian Institute of Technology Kharagpur**
**Lecture 27**
**Combustion Spray Process**

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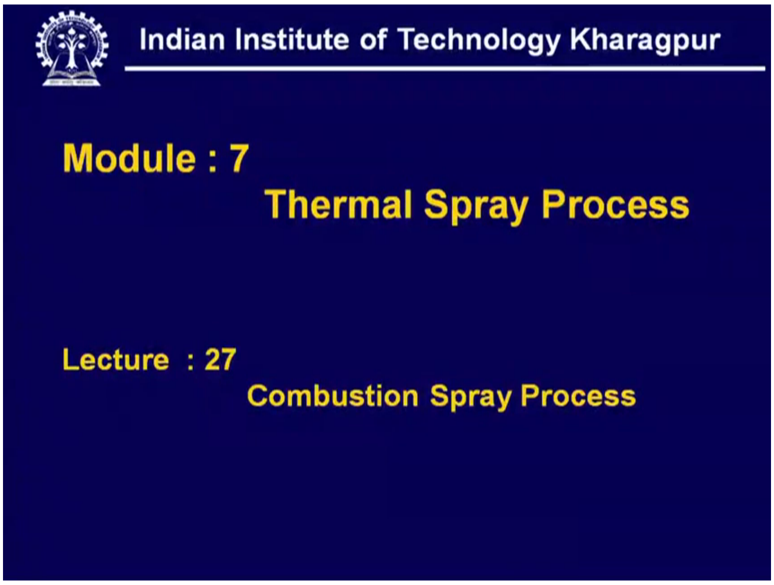


Today we shall discuss this topic of thermal spray process and it includes both combustion spray process and plasma spray process.

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In fact this combustion spray process also we can call it flame spray process that uses that energy of this combustion which occurs during reaction between acetylene that means the fuel gas and Oxygen and this energy is utilized in melting and then finally having a deposition on a particular substrate of choice. Now both the processes are actually particulate deposition process.

That means here the material which is going to be deposited that is not exactly synthesise because of a reaction on the substrate surface but this material is already available in the form of powder or in the form of a wear or a rod. So material is already preformed, now here the problem is limited to that that this material which is available in the form of powder or grain that has to be transported and during this flight it will have a liquid phase, so it will be like a liquid drop and then this property will arrive on the substrate surface, it gets deformed and then get condensed and solidified and this drop by drop arrival and then that series of drops which are arriving on this substrate surface that will build up a layer of this particular coating.

Now in this particular flame spray process or combustion spray process we can call it an extension of that conventional Oxy-fuel welding or Oxy acetylene welding that means the same hose same cylinder all the setup which are already available for any Oxy acetylene welding that can be readily used only with one modification that is on in the welding torch. So with such modification it is possible to use this flame spray process or Oxy fuel process.

Now the question is where we can use this process or the technology and what are those materials which can be used as the coating material performing this layer? Now what we see? Normally we need a coating which is mechanically functional at least there are 2 aspects, one is wear resistance another is also corrosion resistance. Now for normal application it is also our experience that Nickel and Nickel Chromium or Chromium that can be also used for protecting some ferrous material low Carbon steel, medium Carbon Steel which can be readily corroded.

And prevent it from rusting, normally it is a routine practice to put a layer of Nickel or to increase its wear resistance or to have a metallic lustre we also put a bleeding of Chromium. Now these are all electrodeposited process. Now electrodeposited process we don’t have always the same level of same quality of adhesion and in many unfortunate eventuality it may so happen that the coating as a whole gets flicked off because of the poor adhesion at the interface that means there is no metallurgical bonding and the material is poorly added on the surface.

Now in comparison to this if we can apply same Nickel or Nickel Chromium by this process then at least we can have a better adherence and better density of the coating and that possibly can give us a better service life in terms of resistance to corrosion resistance to wear. So those are the application area where of course the temperature of the substrate that is one important issue but as such flame spray doesn't require very high temperature of the substrate until we want a very intimate contact or an interface which is a metallurgical interface between the substrate and the deposited coating.

Then a low-temperature should be sufficient to carry forward this process. However this temperature requirement just cannot be compared with that very low temperature which is useful or necessary for any electroplating process. So the advantage here is not exactly the temperature but the coating it's adhesion and its bonding with that of the substrate. Now this is just an application area what we have mentioned?

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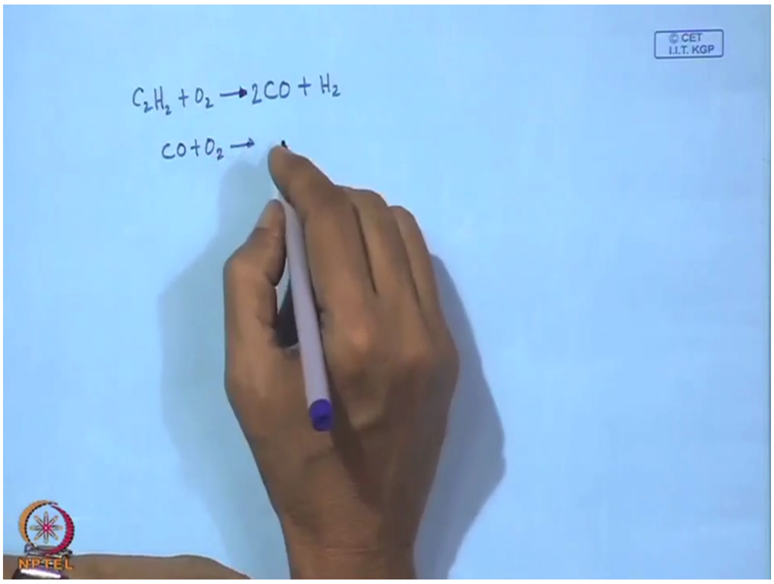

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And now we can see what is the principle of working of this process? So here what happens? We want combustion, so that means energy will be available through this combustion. So here it is C2H2 plus O2 that gives us CO with proper balancing and H2. So from this, this is actually the first stage of the reaction and then we know that this also have external source that is Oxygen from there it gets CO2.

Similarly H2 plus O2 and with proper balancing we get H2. So this is the first stage and these are the second stage of the reaction and through this reaction huge amount of heat is available which is one exothermic reaction and available temperature can go as high as 3000 degrees and that should be sufficient for this material which are basically Nickel-based alloy or Nickel Chromium alloy, there are also alloys which are available containing Molybdenum, Vanadium or even Tungsten Carbide.

But mostly it is Nickel and Nickel Chromium base alloy which some additives which we also discussed their role so these are the materials which are available in the form of the pre-alloyed powder is this is also an element in the form of powder and these are put in those alloys here we can also have Cobalt, so the whole idea here is to have a corrosion resistance and wear resistance on a substrate which is rather cheap and also having a low Carbon which the Steel which is commonly available in the market and for common use.

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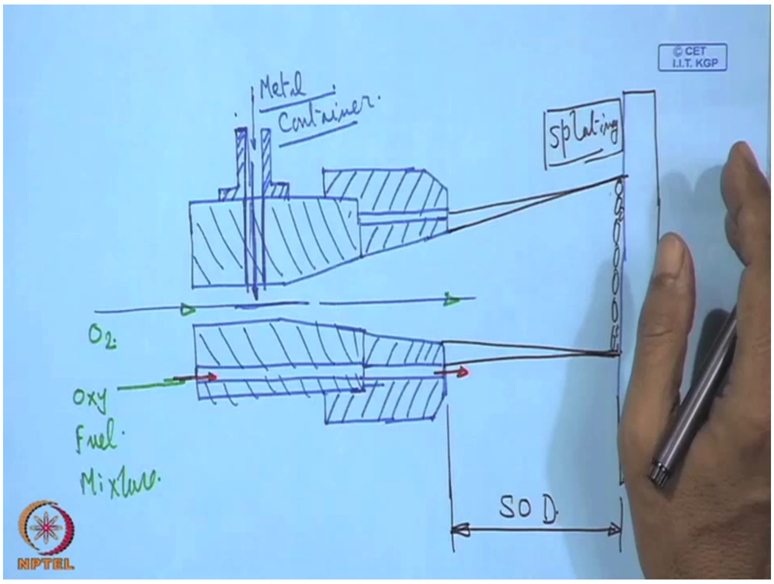


So here let us just have a look how this modification of Oxy-fuel welding torch takes place? Letters have quick look, so we can say it is just like if we can have a sketch. So this is just a central hole in that nozzle and then over this, what we can add? That is the front portion of this nozzle, okay. So, so these are the 2 parts of the nozzle, now what we have? We have a small slit here that means through this from this front nipple we have a slit, cut through this.

So this will be symmetrical, so we have to have this one to here, okay. Now on this, so let us put this hatch mark here. So that is the construction of the nozzle. So here we have a direct flow passage. So this is just like a flow passage to this point and then what we have on this side? On this side, here we have done the modification and this modification is like this that means here we have the metal container that means we have connectivity between these 2, so this is something like a connector which fits well with this and here on the top of this we have the metal container which will be put upside down.

So from this, this side it goes to the metal container or the powder container, so we can now complete this drawing, okay. So we have now 2 passages, one is just on one side which we have marked with this Red Line and another central one which they are marking with this green line. So through this we have flow of Oxygen and through this we have both Oxy fuel mixtures.

So this is Oxy fuel mixture, so through this it is actually the Oxy fuel mixture and here now this O2 which is passing through this central passage that is call actually the aspirator gas and here we have to have this opening right up to this point. So it will flow here up to this point, so this is actually the hole and over that we have this connector and on the top of that we can put this metal container.

So this is actually an opening, so what happens? The moment Oxygen is passed through this, so with a high velocity there will be an aspiration effect, since the velocity is high pressure will fall and because of that fall of pressure there will be a drag it will like to suck this metal powder through this and it will be directed. So this Oxygen will direct this metal powder and this Oxy fuel mixture that is actually going to reach this point and here we have the flame front.

So if we have a substrate somewhere here, this is the substrate so what we can show? Right from this point, here also we can show this thing. So this is actually the area where this whole combustion will take place and then this substrate is placed just before this and this is called the stand-off distance, this one is SOD stand-off distance. So now this Oxy fuel mixture which will have burning and the heat will be generated and with this jet velocity of Oxygen this will be thrown inside and then it will be melted here and just like a droplet it will deposit on this surface.

So it is just like dropping over the surface, so this is the way it is working that means combustion of this Oxy fuel mixture that generates heat and then this centrally flowing through this central passage this Oxygen which is flowing through this that takes this powder to this zone and it gets melted, Molten or semi-molten and with that stream of this velocity it is thrown and it is going to strike this surface and there it is become almost deformed in it is called splatting. So it is just splat formation, splatting. So splat formation that takes place and gradually one splat and on that another will grow over passage of time and this is in principle the basic process of flame spray of powder.

Now material of spraying, as we have said it is mostly the Nickel or Nickel Chromium like material which are very popular and commonly used the whole idea here is to augment the property of the material say corrosion resistance and wear resistance of these 2 properties and this is going to be a substitute for electroplating process. So these are the 2 materials apart from that material like Cobalt, Molybdenum, Vanadium, Tungsten and sometimes Carbide of Tungsten, Carbide of Chromium those can be also brought in to enhance further wear resistance.

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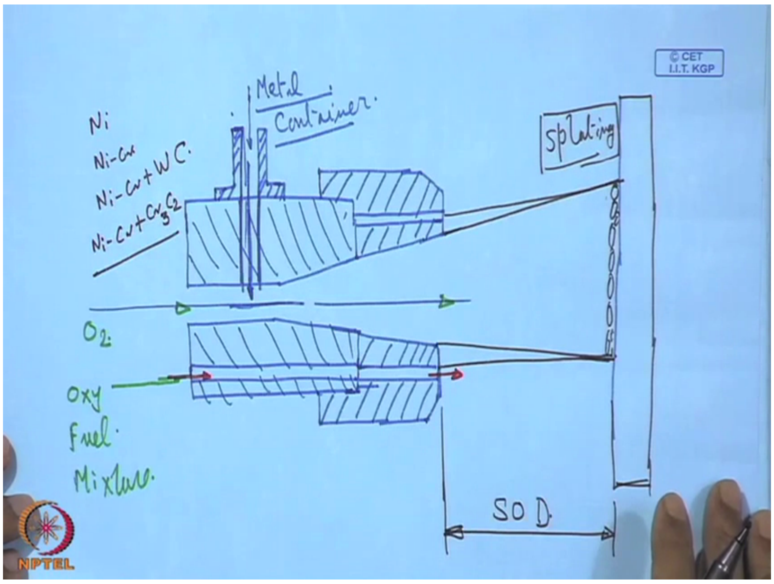


So spraying composite, spraying composite means in this case instead of just Nickel or Nickel Chromium we have Nickel Chromium plus Tungsten Carbide or Nickel Chromium plus Cr2, Cr3C2 Chromium Carbide that is also one of the good candidate for augmenting the resistance to wear of this particular material of the substrate.

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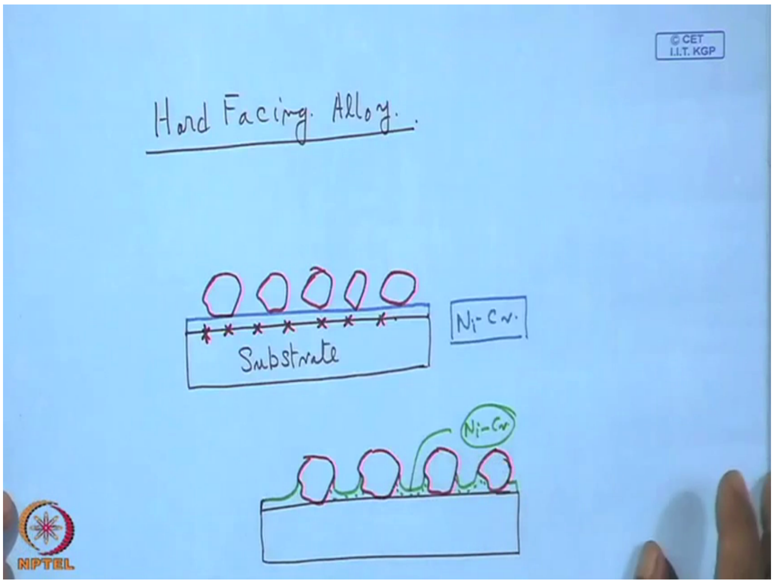


Now here what we can see? Use of spray process for bonding of diamond grit this is one of the very important and interesting applications of this hard facing alloy. So this is just one hard facing alloy to increase the hardness of the substrate, hard facing alloy and that can be used in many implements or surface to have a court of diamond particle. So it becomes like a abrasive surface.

The way it is done say this is a substrate and over that what can be done? We can put this flame spread material which will be Nickel Chromium-based at least it should have some Chromium and then over that what we can have? We can place some diamond crystal of a required size which is suitable for a particular application and then the whole thing can be heated in a furnace and in a controlled atmosphere mostly high purity Argon or hydrogen atmosphere or even vacuum.

So what is going to happen at that point of time? This material will melt and this will have a bond formation very good metallurgical bond with the substrate here but most important thing what is our expectation? If we just redraw this sketch that after melting what is going to happen? So in that case what we find? So these are the diamond crystals and this material Nickel Chromium will melt and this will make a, it will climb up the diamond surface like this.

So it is just by wetting action we can get a good holding of this diamond and this can be used as an abrading surface in many application and this one this layer which we have shown by just this green line this is actually this Nickel Chromium bond and this is quite hard and wear resistance and that can combat the abrasive action over this alloy. So this way it can be also conveniently used for bonding diamond crystal for many abrading action.

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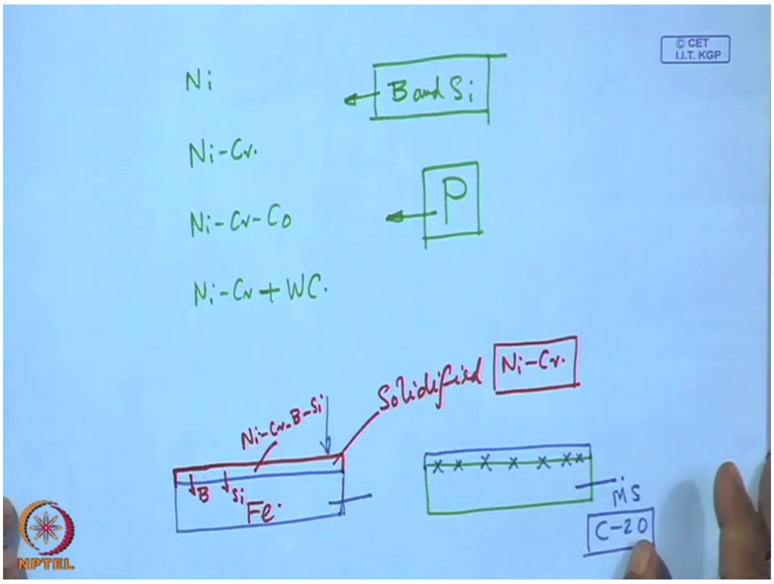


Now comes the role of Boron, Silicon and Phosphorus what we are looking at? In principle this Nickel alloy or Nickel Chromium or Nickel Chromium little bit of Cobalt. It can be also Nickel Chromium plus Tungsten Carbide these materials are not just present what has been added in addition to this material? We can have one combination may be Boron and Silicon that is one combination or it can be even just Phosphorus that is another additive. So one additive may be Boron and Silicon another additive is Phosphorus.

Now what is there exact rule that is very important to know? Because this Nickel Chromium or say melting point of Nickel or Nickel-Chromium-Cobalt that is quite high and to attain that temperature it is not a very easy way or may not be of that practical interest what we want? We want the whole processing can be done say around 1000 degrees or even little below that but if we like to melt this material to have a metallurgical bond with the substrate. So that this adhesion problem can be totally eliminated, in that case what is important?

That melting after the position that means here we deposit by this spray process we deposit the material but it is not exactly the chemical or metallurgical bond formation takes place then and there, no it is not the case, it is just added to that and it may be little bit of metallurgically bonded but mostly it is mechanically interlocked which we are going to discuss.

So this is just the formation and then if we like to have a metallurgical bond we must melt it. So this is a low Carbon Steel or say mild steel, low Carbon steel, say C20 Steel which is commonly used and here if we don’t like to increase the temperature say above 1000, most likely below 1000 that is always preferable. Now how to do this thing? To give this answer actually the find that this very role of Boron, Silicon or Phosphorus.

What is the role? Number 1, they are actually depressant they depress the melting point or another depresses the liquidus and solidus point. So if it has a liquidus point that will be depressed by Boron, Silicon or by Phosphorus, this can be added here also. We know that Nickel Phosphorus with 10 percent Phosphorus it forms a eutectic and that melting point is around 890 degree centigrade. So that is quite low and it is of immediate interest for application.

So the basic role of Boron and Silicon is to depress the melting point or liquidus point, so this is number 1 and number 2 is that during deposition at the point of deposition that nozzle comes and it is going to heat the substrate. So there is little bit heating and immediately it starts playing the material, so during this though temperature is not very high but one thing we have to make a note of this that this process is conducted in open atmosphere that means it can be carried out in a welding shop.

So it is even in a fabrication shop in open atmosphere it can be conducted. So it is not at all a protective atmosphere but when we use this Oxy fuel torch though it is a neutral flame but the Oxygen present in that zone, environment that can cause oxidation of this material but this should not be a big problem for us because then comes the second very important role of Boron and silicon.

Now this Boron and Silicon being with this it can also little bit get into this Iron or Iron Oxide and this Boron will be transformed into Boron Oxide or this is also Silicon Oxide. So Iron will be again reduced to metallic Iron and those can escape just like a volatile Oxide. So this is just one, second important role of this one for protecting or for removing the Oxide from this low Carbon Steel substrate.

And then what is going to happen? Part of this Boron and Silicon can also get diffused into this. So when we are going to really melt this, so this is now a melted and solidified. So in that after this what happens? Here this Silicon from this side it has gone into Iron.

So this is basically Iron and this side we have Nickel Chromium and say Boron and Silicon but now this material it has less of Boron and Silicon and more of Nickel and Chromium because most of the Boron-Silicon that was engaged in preventing the Iron from oxidation and also its diffusion tendency because Boron and Silicon as a very good affinity for Iron.

So this side we have migration of Boron and silicon. So when ultimately we get a solidified, solidified layer which is melted and solidified, what we get at this point? The top layer is not at all Nickel-Chromium-Boron-Silicon it is just Nickel and Chromium. So what does that mean? It means simply now it’s melting point or solidus point it is not the same as that of the starting material.

That means if it was the case is that with this combination with particular combination of Nickel-Chromium-Boron and Silicon say melting point or the liquidus point would have was at say 1000 but after this melting and solidification this Nickel-Chromium without this Boron and Silicon it cannot be liquefied at 1000.

Now the point is this, liquidus point is raised, so the conclusion which we can draw here that means this material now cannot be melted and it has some high-temperature operation capability because of the migration of Boron and Silicon from the basic parent material. So these materials are sometimes also used for step bonding or step brazing process. So once that is melted, its melting point or liquidus point is automatically raised.

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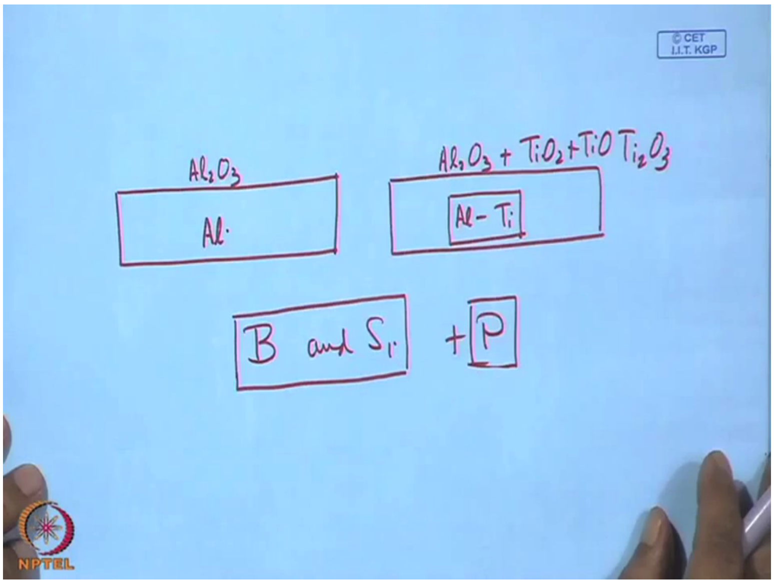


So selection of the substrate material. Now selection of the substrate material this is also one thing here also we must pay attention, what are those material? Obviously those materials which are available easily and which are not very expensive to protect it against possible corrosion or wear that would be. However here in essence the role of Boron, Silicon or Phosphorus that should be also considered. So what we do? In open atmosphere when the process is carried out the top surface will be oxidised but this oxidation may affect this metallurgical bond because oxidised surface is nonwetting compared to a pure metallic substrate.

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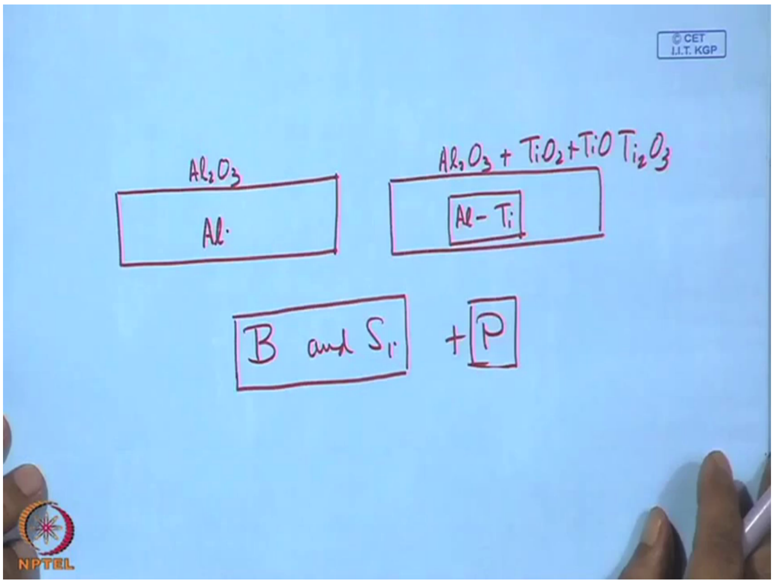


But what happens? When we have a material like say for example one alloy, let us take this example when alloy having Aluminium as one of the component or one another alloy having Aluminium and Titanium in addition to other material but Aluminium Titanium these are some important ingredients, Aluminium containing or Aluminium Titanium containing. Now here one should take a notice of this that this Oxygen can readily oxidised Aluminium or here both Aluminium and titanium's those will be oxidised.

As the consequence of that weekend expects formation of Al2O3 and here Al2O3 and some Oxide of Titanium it can be TiO2, TiO or even Ti2O3. Now chemistry suggests that it may not be possible for this Boron and Silicon to reduce this Aluminium Oxide to metal Aluminium or Titanium Oxide to metallic titanium. So is the case with Phosphorus also.

So this Boron, Silicon or Phosphorus which were quite active, quite effective and protecting the substrate material  even in open atmosphere deposition but unfortunately for those substrate material containing Aluminium or Aluminium Titanium unfortunately it cannot reduce. So we have to look in to those elements whose Oxides are more stable than that of Silicon or Boron or Phosphorus.

So there we have to put one restriction on use of those because the purpose is not to have a deposition on an Oxide surface but on a metal surface. So the elements like Aluminium, Titanium and similar materials who's Oxides are very stable and that mostly comes from the transitional elements of group 4, 5 and 6. We have to really look in which are those materials or elements cannot be used because of the incapability of Boron, Silicon and Phosphorus to reduce those Oxides.

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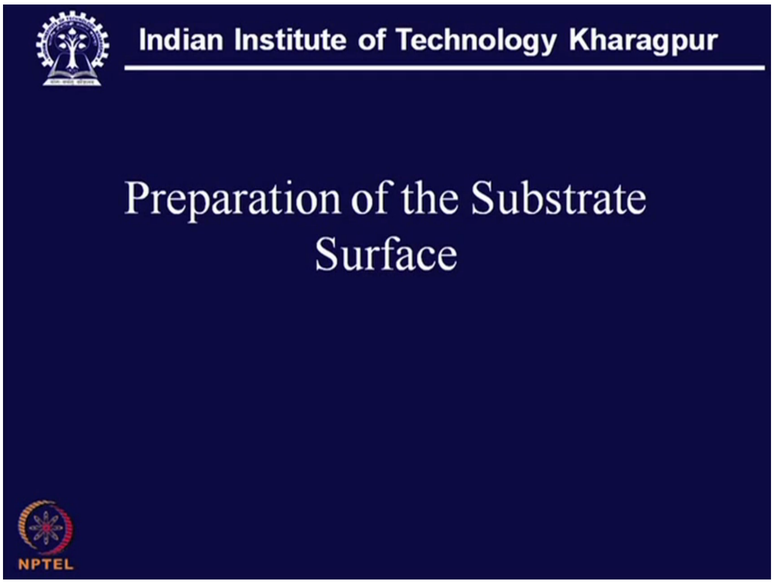


Now comes preparation of the substrate surface. Now preparation of the substrate surface means here obviously for all surfaces we want to have deposition it starts with decreasing that mean ultrasonic cleaning in any alkaline bath followed by pickling bath that means acid bath to remove the Oxide. So decreasing an Oxide removal these are the 2 very important preliminary steps followed by what is important here to have roughening of the surface?

So here is the smooth surface cannot be a good receptor of this particle which are going to impinge over the surface and here as a receptor surface more important will be mechanical interlocking and for that cavity, presence of those cavity irregularities on the surface is essential.

So that's why it is also important to have sandblasting like process where the said particles will hit or strike those surfaces and have erosion in a very non-uniform manner causing some pitting, cavity formation and this will depend on size of the grit material and also the angle of incidence at the point of striking, stand-off distance and also the flow rate therefore velocity.

So these are the things to be optimised and then the roughness value has to be (()) (36:28) to have a standardization of this roughness value. So that we can have a good  we can prepare a good receptor surface but some machining or grinding marks can be also created particularly by machining by milling or by shaping or even by knurling, some roughening of the surface can be also done. So that surface can be also become a good receptor surface.

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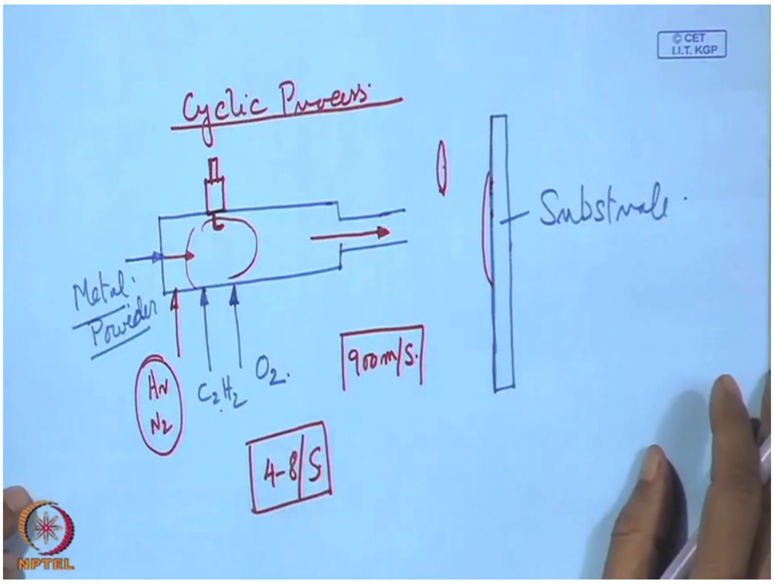


Now this is actually a combustion spraying with detonation gun. Now here also we use this principal of combustion but it is a not continuous process but this is a cyclic process. So basic thing is that, we use the same principle of combustion within a chamber that means say this is a chamber and this just one at that on this end and this is just the only exit and at the exit the very presence of the substrate can be seen.

This is the substrate, so here we have powder, metal powder entry point and there can be some carrier gas. Now on this side, what we have? We have one port to have entry of C2H2, another port to have entry of Oxygen. Now there will be valve which will be operated in particular sequence following one particular cycle and the process will be obviously automated and here what we have?

We can show it schematically it is just one spark plug to generate to create one spark. So what happens? Material is faded here and then  this Oxygen and acetylene that is also fade here and immediately a spark is generated by that spark and there this whole gas in this area is ignited and this will result, so that is exactly called the ignition of this gas by this spark generation and that is exactly called detonation and that will lead to almost like an explosion but since we have one exit at this point, so the metal powder which is already in this zone that will be thrown with a very high velocity and that will be thrown on this surface.

So during this flight we have generation of heat that means this C2 plus H2 plus O2 that will be having some kind of chemical reaction which has been mentioned and with that this material will generate heat and at the same time material powder that will be thrown on this side with a high velocity and that velocity range can go up to 900 meter per second. So with that velocity what is the advantage here? That means this substrate needs not to be heated.

So substrate distortion and other possible damage that can be protected but this is just making the liquid of this metal powder and this liquid drop will heat and it will impinge with a very high velocity and we get here what we call splatting that means it becomes almost like a flat when it strikes this surface and then this splat will one will follow the other and one will build up with over the other but since the velocity is very high, striking velocity. We can expect a better densification of the coating and better intimate contact with the substrate which is already rough and.

So we expect a much better intimate contact because of the plastic deformation of this fluid which is already deformed and having a better contact with this surface. So basically it is a combustion process but it is a cyclic process but the result of this combustion by this generation of spark is a high energy release and that is actually utilized in getting a high impingement velocity and that is utilized in getting a dense coating with a better bonding better adhesion even with a lower substrate temperature.

And one thing also after followed by one particular cycle the whole process before going to the next cycle the whole area is flushed with argon or nitrogen, so it is just rinsing or cleaning of the whole detonation chamber and then again it can go to the next cycle of this detonation. Now as for the industrial practice it is a proprietary process we can have 4 to 8 detonation per second and that is quite a productive process from industry point of view.

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Wire Flame spray. Now wire Flame spray, it is also a combustion process but instead of this powder here we use one wire, the idea is that if we make availability of the wire then that can be also made a continuous process because the whole wire can be (()) (43:18-43:20) and that can be very conveniently released from that spool.

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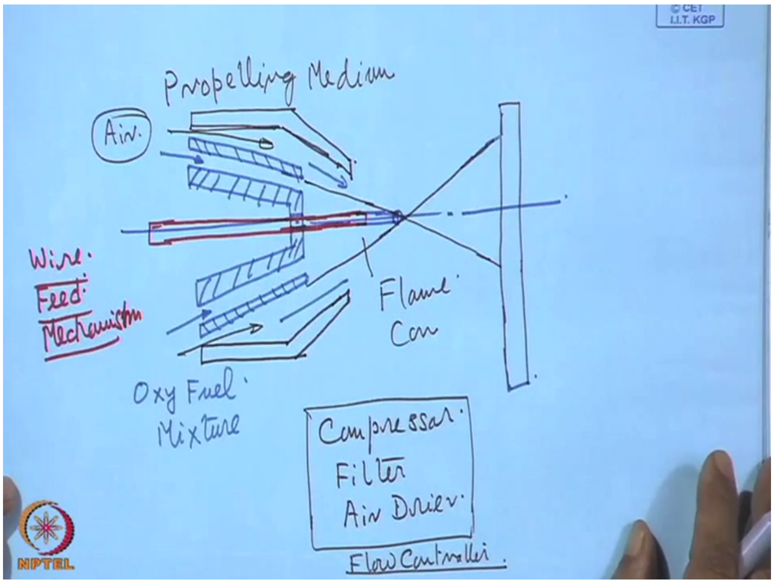


So the principle the process we can have a quick look to this, so this is the schematically we are trying to show this. So that is the central area of the nozzle and here we have 2 annular passages, this is one so through this actually we have the wire feeding. So this is going to be the wire, so this side we have the wire feeding, wire feeding mechanism, wire feed mechanism.

Now this is one annular area and what we can show quickly? So this is one annular passage, this is annular passage like a ring through which Oxy fuel that means Oxy fuel mixture that is passed that means Oxygen and acetylene that mixture is passed and we have another annular passage, so these are all concentric, so this we can show this way here, this is another annular passage which is also here.

So through this we allow air that is actually we call the propelling medium. Obviously on the upstream side, what we need? We need one compressor, we need one filter these are the peripheral unit it is a must for any supply of quality and then we have series of filter and finally what we need? The air dryer, so these are the units and then also there is one flow controller that means the amount of air which is passing here.

So that is the flow controller, so that is the airflow controller that should be also there. Similarly for Oxy fuel also on the upstream side we have 2 cylinders then we have the pressure regulator and also the flow meter which continuously metres the amount of Oxygen and Acetylene in that particular mixture. So these are all the peripheral units on the up strip side.

Now what is going to happen? In this case, now this Flame, so this is actually the Flame cone here. So that is the Flame cone which is formed and it will be like this. So it will now spread out and then we can put the substrate, this is going to be the substrate what we can show here? That this air, now this air will be admitted at a high-speed and that will be like a propelling medium and this droplet it will finally itemise this droplet and this atomise particle will be thrown towards this substrate surface.

So here the role of air is to carry to atomise and it is just by this propelling action, finely divided particle of this Molten metal that will be thrown towards the substrate and a rod is fade and that is in the Flame cone which actually gets melted at this tip and that is thrown in the form of liquid by this air which is flown through the outer annular space. So this is known as wire flame spray process.

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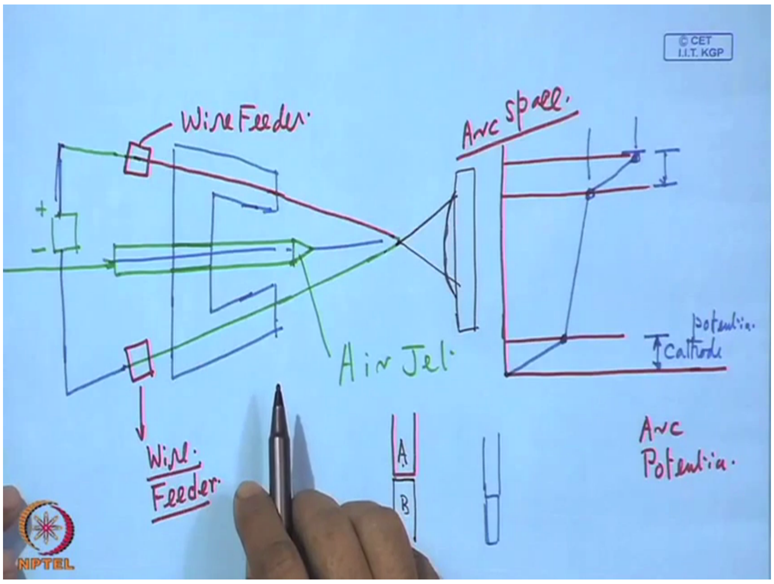


Now this is actually Electric Arc Spray. So here it is not exactly a combustion process however here we can use, make use of 2 wears of the material to be deposited. So in this case what we see? And just like one holder for feeding the wire, so we have here 2 wires, this is one and then we have another wire which is coming from this side, so these are the 2 wires and through this centrally we have one arrangement to have, a air jet. So this will be the air jet which will be available and which will be readily available.

So this is going to be the air jet. Now these 2 wires will be polarised that means we have power supply then this is going to be, this is connected to this, positive polarity and this is going to be the negative polarity. So this is going to be the negative polarity of this wire and this is going to be the positive polarity of this wire and here what we have? Wire feeding arrangement.

So here we have the wire feeder, so this is actually the wire feeder. So what we see now? That it is almost going to be like one Electric arc that means if we have say arc space, this is arc space and this is arc potential then it will be like this. So here we have a drop that is in the cathode space this is the cathode potential, now there we have very little drop and then this is drop in front of anode potential.

So this is the cathode potential and this is the anode potential in this space, in this is the anodic space in this area very close to that and this arc is struck and to have this striking of the arc, what happens? That when we bring them in contact there is a short-circuit between these 2 but what happens as we have say these are the 2 wire from 2 sides, let us show it here.

So this is say A and this is B, so when we try to separate them at that point an arc is struck between A and B.

So when they are in intimate contact there is no arcing but when we try to separate them the reason is as follows. When you try to separate them, the number of contact points that gets reduced and as a result current density in those high points of asperities that will be more and that will cause localised generation of heat and temperature that means when we try to separate them by loosening the contact there will be generation and that may lead to Thermoionic emission of electron and this electron actually causes ionisation of that gap region.

So it is finally Thermoionic emission of electron this electron generates because of the rise of temperature because of the simple reason fact that the points of contacts are less. So current density is high, so once that arc is struck there is high rise of temperature and with high rise of temperature these 2 materials are melted and this air jet from this side that will throw the material on this side and if we have the substrate somewhere here that will be covered by this material. So this is also another way of handling this thing. So in this case it is just not one wire but 2 wires are used and between these 2 an electric arc is struck.

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So with that we can make a summary of the whole discussion that we have seen that this is a flame spray process, basically it is a combustion process using the energy released because of the combustion between Oxygen and it is mostly Acetylene and the metal to be deposited or the alloy to be deposited that can be converted into semi-molten or molten stage and that is just by that jet velocity of the gas that is going to arrive on the substrate and this substrate will have impingement by these droplets  which will be there deformed and condensed solidified.

And in the process we can use powder or we can use wire and at the same time this wire can also be used using electric arc process but what we have seen? Quite interesting that the use of Silicon, Boron and Phosphorus in the alloys particularly in the flame spray process, they are useful because they are material melting point depressant but once they get diffused into the substrate then the melting point of the parent alloy raised and this coated layer can be used for high-temperature operation and these materials are found to be well adherent and dense in comparison to that electro plated electrodeposition Nickel or Chromium.