Surface Engineering for Corrosion and Wear Resistance Application
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Lecture - 33
Thick Coating by Cladding

Welcome to the 33rd lecture of a Surface Engineering. You have already heard discussions on various kinds of a depositions and coatings some of which are based on solid solution strengthening like carburizing either in gaseous state or vapor state or solid state.

Similarly, we discussed coatings which where the strengthening usually comes from various kinds of reactions for example, nitriding when nitrogen forms various kinds of metal nitrites, We also discussed diffusion coating where actually not interstitial atoms, but substitutional atoms bigger ones like aluminium or chromium or silicon or any of these elements. Actually could enter into the surfaces of the metallic substrate and then create solid solution at the same time certain inter metallic phases and in the process they offer resistance to high temperature oxidation particularly and also other kinds of surface degradations.

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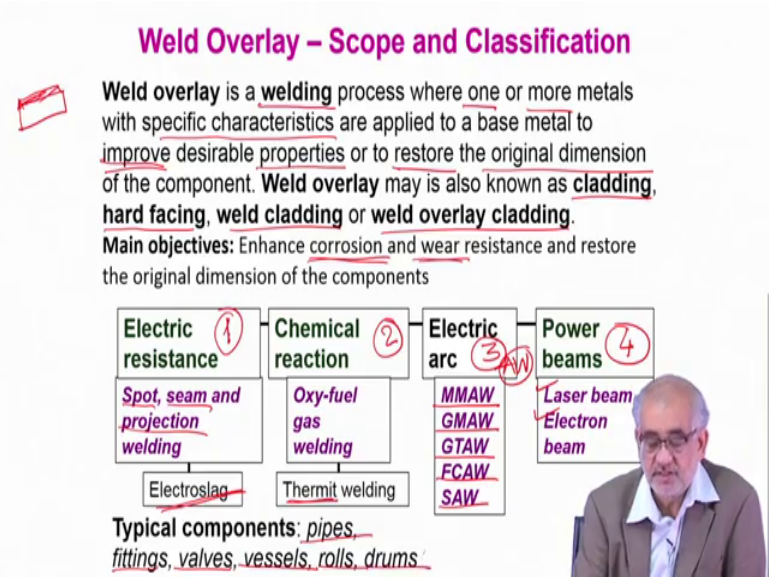

Now, we are going to discuss weld overlay which is a essentially an add on process. The word overlay clearly mentions that you actually are having an existing substrate and then you actually are adding a new layer on top of this. So, this new layer certainly increases the dimension of the substrate not substantially, but reasonably. But the most important thing is that by this method you actually can bring in a completely different composition material on top of an existing substrate.

So, we are not dependent on solid solubility not the diffusion coefficient so, the thermodynamic or kinetic barriers do not play much of a role here. What is very important is that we should have a reasonable amount of interfacial bonding adherence there should not be any big mismatch or spoliation. And the coating also can be fairly thick in fact, in some of the cases actually you can use this very approach which in today’s world is known as additive manufacturing. The basis of additive factory manufacturing actually came from this kind of an overlay based processes.

We will discuss the additive manufacturing some other time, but the for the time being let me just tell you that this whole process is as I said is based on fusion welding processes. So, you actually fuse like you in case of welding you mean two different solids you want to join together at the interface either by butter by lap mechanism. But in this case you are welding essentially creates an over layer onto the surface of the existing component.

So, here we can use one or multiple metals or solids take them into the fuel state and then deposit. So, we actually inherit specific characteristics that we add on to the base metal so, the intention is to improve desirable properties. Now these desirable properties could be typically the surface dependent properties like resistance to corrosion, resistance to wear, the hardness increase, there is also another very important utility of overlay process which is restoration or reclamation.

So, for example, a worn part of a tool or maybe a cutting tool maybe a shaping tool or a roll or any other nozzle or sprocket any component which actually for whatever reason might have lost a portion of its surface. You can overlay the material either with the same composition or different composition and restored the original dimension so; that means, you do not have to throw away you can reuse that component. So, this process is also known by several other names for example, the more commonly used word is cladding and also hard facing weld cladding, weld overlay cladding and various kinds of overlaying terms.

So, we are adding on, we are creating a new layer on top of an existing component; solid component the composition can be very different, we are not constrained by kinetics or thermodynamic constraints and intention is to improve the surface dependent properties like corrosion, wear. And in addition we can also do restoration job, we can restore the original dimension of the components.

We can do such processes by let us say the fusion process we can achieve through the electric resistance base heating; so, i square r t kind of heating process. So, so, typical methods would actually involve a spot or a seam or a projection welding. So, the electric resistance leads to fusion of maybe powder maybe a seam or maybe a wire, but basically they are projected onto an existing substrate and then they create an over layer.

So, typical such process in industry which is routinely used is called electro slag process. The electro slag process essentially will have a; so, you use an electrical current to melt an overlay and cover it up with a slag to protect it from oxidation and in the process, you get a very nice weld overlay and you call it electro slag overlay.

We can do; we can make use of a chemical reaction now in electric resistance you actually do not have to necessarily undergo any reaction at the surface; whereas, in oxy fuel gas welding the combination of oxygen and fuel may be hydrocarbon. They actually undergo a temporary, undergo an combustion process and create fairly high temperature at the nozzle and that melts.

And in addition to that there could be precursors in the in the mixture that is going to be overlaid which actually can cause chemical reaction and release exothermic heat of reaction. So, that is called thermite process. Say for example, in in railways this is very routinely used when you want to join two long strips of rails, you actually use a mixture of a aluminium and iron oxide. And then you heat using the oxy fuel torch and aluminium reacts with iron oxide, substitutes F e from F e 2 O 3 and in turn creates alumina which is a slag phase.

But molten iron actually seeps in inside the crack or the gap and welds the two pieces of iron the rail and that is how you can join; so, that is a typical thermite process. But the important distinction here is that you actually not only heat through the gas torch, but you also make use of the exothermic heat of reaction which is liberated during the heating process.

A more popular and very widely used technique is the electric arc based techniques. For example, manual metal arc welding, gas metal arc welding gas, tungsten arc welding, fuse cored arc welding or sub-merged arc welding. So, in all these cases, what is common is the arc welding. The arc welding essentially requires that you actually create an arc between the two electrodes by application of very high electric potential difference. And the arc creates such a high temperature that the filler metal or something around actually melts and fuses and then fills up.

We can also use certain directed energy beams like laser beam or electron beam and in these cases the react there is no chemical reaction, there is only direct heating and very high temperature generated at the point of contact actually can lead to very high rate of deposition. So, the cladding layer actually it can be extremely precise it can be thicker or it can be much thinner what is generally possible with any of these chemical reactions based electric arc or electric resistance based techniques.

We will discuss that later on, but the typical components that you actually can create an overlay on would be a pipe both outer and inner surfaces, various fittings, the valves, vessels, rolls, drums sprockets nozzles various kinds of components.

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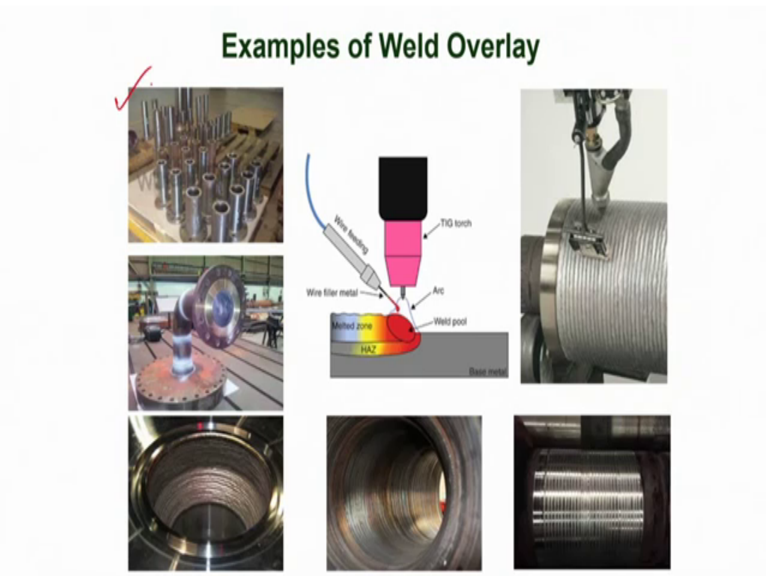

Now, these are certain examples; for example, various pipes and nozzles this is very very common because when they conduct fluid carrying slurry or certain other kinds of solid particles, having very high hardness. They can cause damage inside or at the tip and they need to be restored otherwise there will be a mismatch or leakage and so on.

Particularly, in a situation where you have such a bent tube carrying say, petroleum or slurry or say coal in coal washery or in other places. The inside the tube gets very immensely damaged and you need to restore them by using certain process by which you actually can create a beam which illustrates over the entire diameter; inside diameter and every time you finish one circle, you move up or move down by a certain amount.

Now, usually in a situation like this let us say if this is the surface that you are; if this is the surface you are actually trying to coat the layer the first layer that you apply maybe is this is the layer. If the second layer starts from where you ended, then there will be a region across the thickness which will have differences in thickness and composition.

So, you would rather do it such a way that if this is the first layer, the second layer will have a certain amount of overlap, or in the cross section it would look if this is the first layer the second layer will start here; so, there will be a certain amount of overlap. But in the process you actually get a fairly good uniform thickness and uniformity in composition.

So, we can do it vertically or horizontally within inside the diameter or outside the diameter and in some cases or in many cases. Actually the component could be much bigger the total surface area could be much bigger than that than the arc that you generate. So, in such a situation there has to be a mechanism of rotation and at the same time translation. So, for a circular section if it is a square or a flat surface then you simply need an x and y rest restoring mechanism so, that you can cover a large surface area.

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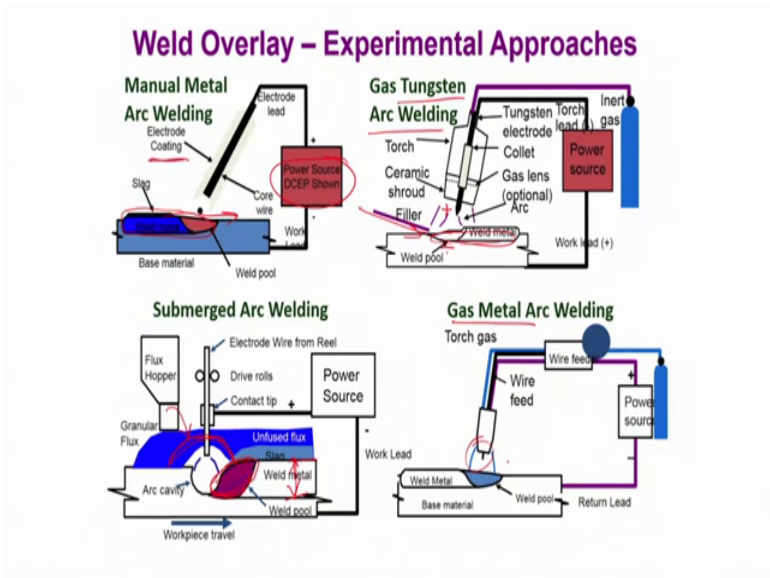

Now, typical processes particularly on the arc based process, which are very popular because of productivity, because of versatility and also because of the ease with which one can actually use for various kinds of materials. So, one of the most common and conventional method is called manual metal arc welding. So, manual essentially means that actually you have an operator who actually holds the torch which actually the electrode one of the electrodes.

Say for example, you have a power source and this is usually a DC power source. So, you have the electrode which actually is supplying the current to it. So, this is one of the electrodes and you have a coating on top of the electrode and this coating actually is the clad material that you want to overlay.

So, and this is the base metal, this is the component that you are trying to either create a coating on top of that or maybe a certain amount of thickness restoration or some such objective. So, typically this is the you create you actually bring you apply very high voltage difference between these two ends and as these electrode is brought very close to the negative electrode there will be a arc formed. And this arc is temporary, but depending upon the voltage applied there will be certain stability of the arc and during the arcing process very high current flows in and immediately melts the metal.

So, this coating metals actually get molten and the droplet is deposited onto the surface. So, this is how you form then weld overlay so, this is the weld overlay that you form.

And as you move you actually can cover much wider surface area. So, instead of a metal which actually; so, here what we have is the electrode also gets consumed in the process to some extent.

On the other hand if you use a tungsten arc welding process that tungsten wire is a non consumable electrode. So, essentially the same process the same kind of a configuration the difference here is that you create a very high much higher energy arc the temperature here could be even wider or a higher, but you feed in a filler wire here.

So, unlike in this case where the material to be deposited was part of the electrode by way of concentric coating or a sheath, but here this electrode is only an electrode is not directly getting consumed or participating in the welding process. This electrode is only to create the arc between the positive and the negative side and then this arc creates a very high temperature here and the filler material wire any alloy or any metal or any compound that you want to can be fed into this hot zone and that is how you create this weld pool and this weld pool is covering.

In case of now in all these cases these are usually done in air so; obviously, there is a chance of direct oxidation because you are dealing with very high temperature. You can also have a situation where actually you can have the entire arc submerged so, this is a solid filler; solid flux material powders or some kind of thin layer and then you have a also the composition of this flux is such that, it reacts with the metal and then creates a slag phase. An oxide phase which is not going to be part of, not going to dissolve, not going to be part of the a weld zone, but this region is the material that you have fused or welded.

So, this welded part now actually is a part of the substrate, now you fuse as well and becomes a part of the substrate. So, this is the region in which you have created this overlay a by way of using an electrode which is used to create a very high arcing. And along with that you have also a mechanism of feeding the flux which covers the entire; so, the entire arcing and the entire fusion zone is in a submerged condition.

So, this slag phase is molten, but you also have solid crust on top of that so; that means, it is completely covering and protecting from external oxidation possibilities of external oxidation, and the weld pool actually is can be fairly deep, but most importantly it does not come in direct contact with air. So, you have much cleaner weld overlay with very little scope of trapping any bubble or porosity or even slag particles.

We also can have a gas metal arc welding process, the relatively simpler process you feed a wire here and this is a consumable wire feed and so, this is the coil through which you feed the wire and this is how you actually. So, this region is the electrode; one of the electrode and this electrode tip creates an arc with the base metal here. And so, this high temperature zone here allows these wire to be molten. So, unlike here when the when the lead was coated with metal to be overlaid, here you are actually feeding the metal in the form of a wire which is molten because of this large arc or very high temperature are created here.

So, these are possibilities of some of the possibilities so, we could actually use gas or chemical reaction based, heating based, resistance heating based or electric arc based. So, this is what we discuss.

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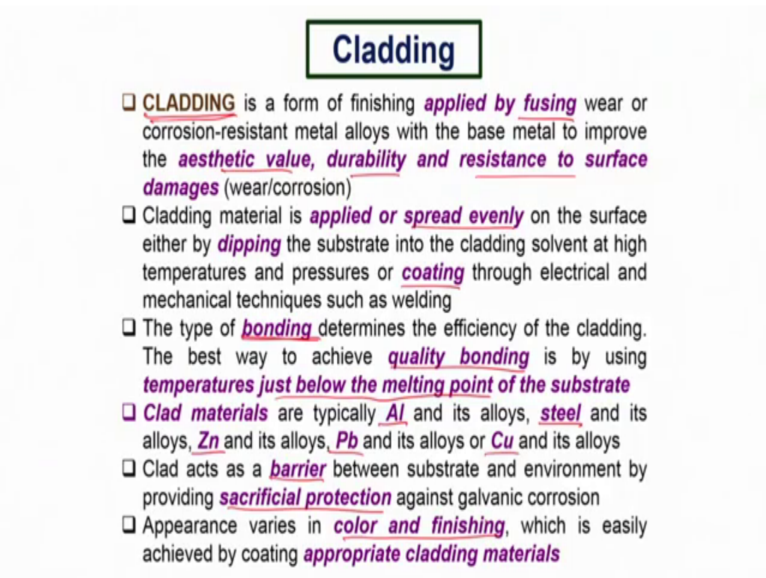

So, as I said overlay is very popularly called cladding because you actually are creating a new layer on top of that. And this is created by fusing wear or corrosion resistant metals or alloys with the base metal, and we can improve the aesthetics of the substrate, the durability the resistance to surface dependent damages like wear or corrosion and so on.

The metal that is molten actually usually should have very high weight ability. So, it spreads very easily and evenly onto the surface. So, either you actually can dip and then allow it to spread easily or you simply coat through electrical or mechanical techniques as we do in case of welding.

What is very important is since the material that we are going to overlay is may have a different composition. So, the adherence the bonding between the substrate and the coating is very important and this is ensured by a by raising the temperature of the substrate not above of, but close to or just below the melting temperature. Then the diffusion coefficient will be very high and the fusion bonding can be formed very easily.

So, you this is how you can actually clad aluminum or steel even various kinds of special steels, alloy steels, zinc, lead, copper various kinds of metals is possible and combinations of them. So, the clad acts as a barrier between the substrate and the environment and that is how it protects so, it can provide either a sacrificial protection like galvanic action, galvanic protection mechanism or it can simply be providing you a very hard and wear resistant layer prevent any further damage against mechanical interaction.

In the process if it is thin and if it is very uniform, you can change the color and finishing; so, it can be anything from aesthetics to functional and also mechanical or structural protection of the substrate. So, we can do such when we actually talk of now all these processes of so far whatever we have discussed; all these processes of cladding, they were re discussed in the form of applying heat through arcing through resistance heating or by chemical reaction.

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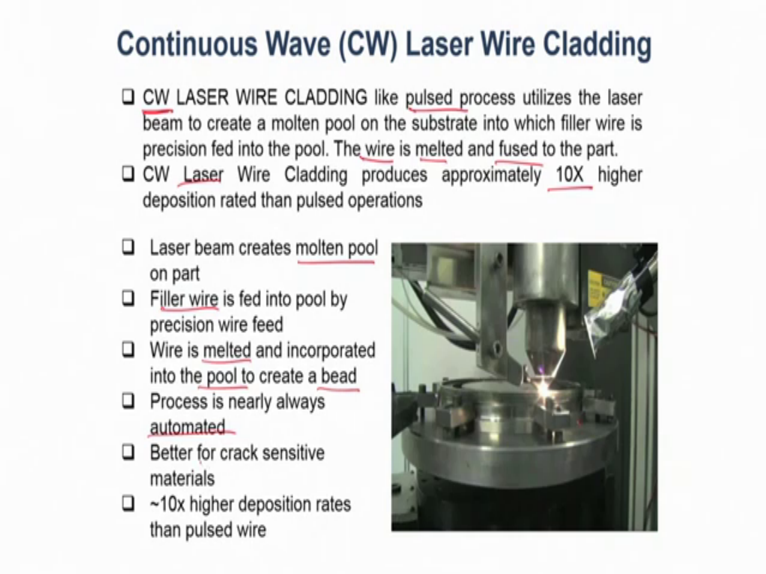

That 4th category if you recall I said was based on direct energy beams which could be a electron beam which could be laser beam. And in case of laser beam usually a continuous wave laser is preferred instead of instead of pulsed laser beam. The reason being that you actually are you need a continuity so, whatever you melt and overlay it can if its pulsed more then you create a splat. Melt for a transient period a momentarily melted pool and when it starts solidifying it creates a solid crust on top of that.

Now, the next pool comes; the next splat comes in a molten form has to first weld with this same solid form so, that actually unnecessary wastes some amount of energy and moreover creates certain non-uniformity which we do not want. So, what we want is that we use a continuous wave laser where the certain level of power density is applied onto the surface and the beam either moves or the substrate moves away from the beam. And in the process there will be a relative motion between the two, and the application of energy through this kind of continuous wave or pulse mode of laser is very precise.

So, we know exactly what thickness of material we are able to deposit because we know two important parameters the power density and the interaction time. So, usually we feed in the form of wire it can be even powdered in into the laser beam and which in instantly gets melted and then fuses to the part. Now, this actually allows this kind of a cladding process based on laser allows 10 times higher deposition rate than fusion operations.

Now, this is not just the rate which is important what is even more important is that you actually can build a much thicker, layer and you actually can build a full component layer by layer. So, this is exactly the mechanism which is adopted in additive manufacturing process.

So, what laser beam does is to create a molten pool on the part, the filler wire is fed and at a very fixed rate the wire melts and then spreads, and wets to the surface creates a bead, and the process the entire process can be totally automated, and by controlling the cooling rates and other process parameters. You actually can also make sure that there is no crack or in other words you can avoid possibilities of crack formation.

And you actually can have a very high depositing rates particularly much higher than what is possible through any pulse mechanism.

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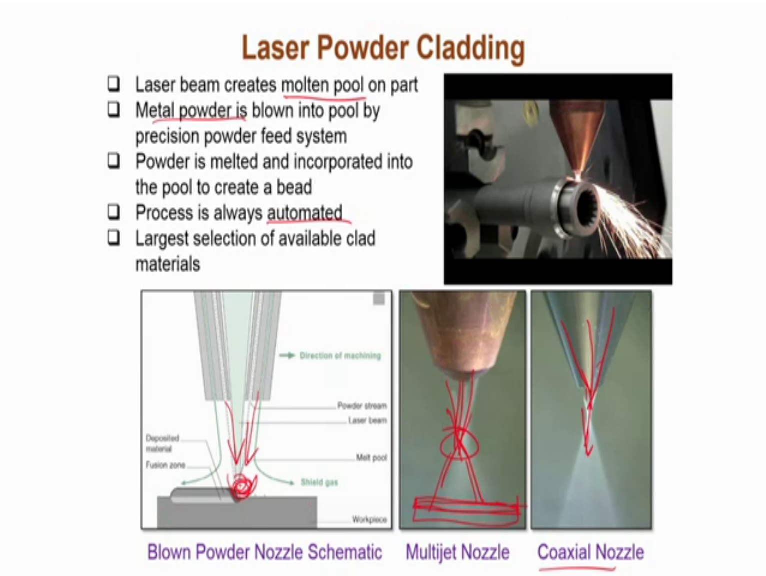

So, as I just now said that you create a molten pool, you can blow powder into the molten pool or a feed a wire into the powder pool powder pool and melt pool, and the whole process can be automated and you actually can have a very large selection of materials varieties of materials.

So, typically when you are blowing powder into so, here is a molten pool that you create and as you feed powder into it, then this powder immediately mixes here and then forms a clad layer. So, you can have multi jet nozzle so, I can have 1, 2, 3, 4 multi jet nozzles.

So, actually I can have multiple powders maybe a carbide, maybe a nickel, maybe cobalt, or maybe some alloy various powders can be fed into and this is the crossover position. So, this is the position where you have the focus and the maximum power so, they already are molten and by the time when they are molten, then by the time they reach the substrate, then they actually make a very uniform coating on top of their substrate.

You can also have a coaxial nozzle where basically if this is how the laser beam is fed at fed then this is how the powder can be fed through a coaxial mechanism. So, now, in both the cases I can have multi-jet or a coaxial single jet in the both in all the processes. I can apply this on a flat piece on a rectangular or square piece or on a circular section through some amount of rotation and translation both. So, I can actually treat the outer surface or through some reflective mechanisms, I can treat even the inner surface. So, all these possibilities exist.

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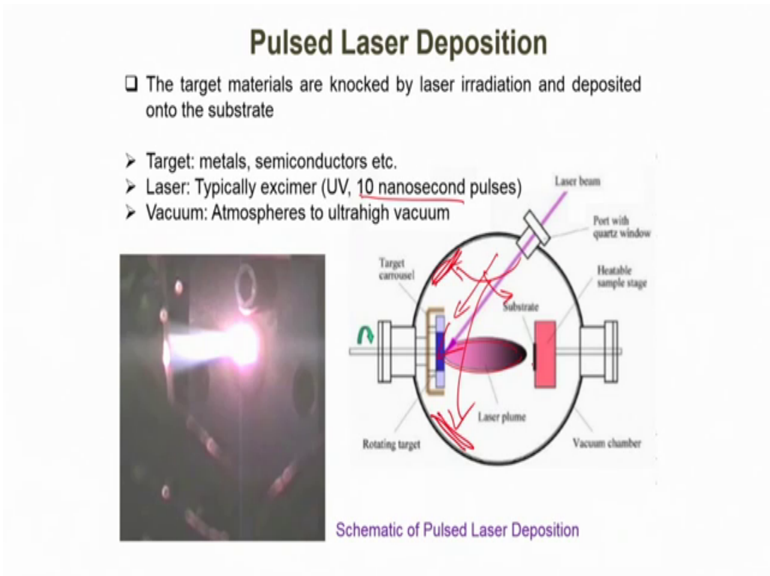

Laser also allows you to make very thin films; I mean that is the beauty of laser that you actually instead of feeding powder or wire you can have a target. And you can use a laser beam which will simply the high intensity beam will instantly create a small pool of vapor here, and that vapor creates a plume and that plume gradually comes to a colder region where you have a substrate and in which you can form a layer. And the layer thickness can be extremely small; small in the sense a few nanometers, few tens of nanometers even smaller and you can precisely actually vary that.

So, in the process you actually can create a single layer coating you can have multi-layer coating, you can have multiple components, multiple composition materials fed into such thin films; so, you have a very wide variety of processes. So, the pulse is now this is typically possible through pulsed mode, because the pulses are of very short duration and you can have multiple targets. So, I all I need to do is to change the direction in the way I am feeding the laser.

So, I can have actually a target here I can have a target here and in the process I can change the laser; so, I can make the laser heat here or make the laser heat here or here. And in the process I can create a plume here, and I can then allow this cold substrate to collect vaporized substances and form a film, and that film can be sequential and hence it can be a multi layer film. So, there is a lot of application for this particularly in functional applications on various for various semiconductor device fabrication or sensors and so on.

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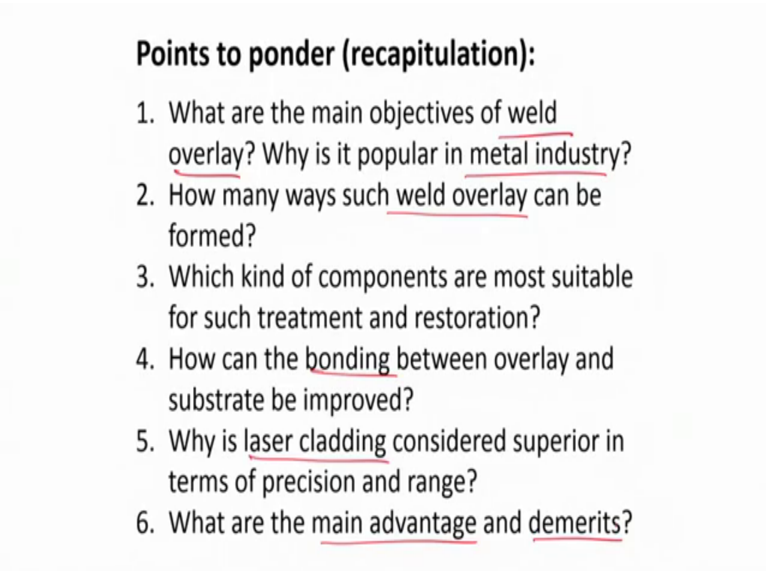

So, what did we discuss, we actually first have to understand that by weld overlay we are talking about a thick coating, these are not thin layers thin they are not thin films these are thick coatings. And this is hugely popular in metal industry because of two reasons. One is I can create wear resistant, corrosion resistant, oxidation resistant or various kinds of create mechanisms of resistance against a degradation, and I can also do restoration job reclamation job.

So, and its widely applicable in metal the advantage of dealing with metallic system is that when in the more fusion few state molten state they have infinite mostly they have infinite solubility so, they mix well so, they wet well. So, when you deposit something in the few state and you have the substrate heated up to near fusion temperature. So, they immediately can diffuse into each other and form a metallic bonding very good metallic bonding.

So, we can we saw that we can actually have multiple ways of creating such weld overlays using arcing, using resistance heating, using some oxy fuel torch or using the power beams like laser or electron and so on. Various kinds of components can be treated from anything from a tube to a nozzle to us to even at the flat, region or a disc or some bearing races or inside a tube, large tube and so on. We actually can also cover much wider surface area. So, first thing we can make thicker coating, we can cover wider area and so, this is very very useful for various manufacturing components machines and so on.

The bonding is usually very good because of the fusion the presence of fusion, and because of the possibility of metal metal bond creation at the molten state. We actually can improve the bonding further when we can; when we try to make a graded graded coating graded overlay; that means, if you are if you see that a and b are likely to form certain inter metallic phases or brittle phases. Then you may actually create situation whereby the overlay starts with a very dilute and eventually at the top can be fairly concentrated. So, because of this compositional gradation the amount of brittle phases that you form would be reduced and hence as a result you actually can have a better bonding between the coating and the substrate overlay and the substrate.

So, laser cladding is one technique out of all these that we discuss is it is extremely precise and useful and can actually take care of almost all kinds of solids for creation of overlay. So, the main advantages is as I said the very beginning thick coating, wide range of materials both protection as well as restoration kind of purposes are fulfilled, and can be done on to anything from very low to very high temperatures and so on.

But there are there are also difficulties for example, usually it is a fusion based process. So, you are heating the material. So, substrate which actually is averse to heating or is likely to get damaged by exposing to high temperature is not very suitable for such kind of overlay type of processes.

And also if there are there is a possibility of reaction and formation of brittle layers then one has to be careful because for example, if you want to overlay aluminum on iron, then you cannot do it or you rather not do it directly because then these overlay will have lot of inter metallic aluminite phases which is going to make the overlay extremely brittle. So, you have to select the right kind of materials and make sure that they mix well and they bond well.

Of course, one has to take care of the typical process parameters like speed, arcing um, current that you produce the voltage that you apply or the resistance heating the current that you pass or in case of laser or power beam, the power density that you apply. Then the speed at which you actually move the material the substrate, and you also have to make sure that the since the bead size is much smaller compared to the total surface area.

So, there has to be a surface integration and there also has to be certain overlap between one layer to the next layer. So, that there is uniformity in thickness composition and properties. So, this is a very very useful industrial practice for surface engineering purpose and wide ranging applications for a various kinds of industries from automobile to petrochemical to manufacturing precision manufacturing and so on and so forth.

So, with this we come to the end of the surface engineering techniques based on coatings, we will now go into another regime where the thickness of the coating will be substantially lower and applications will not necessarily be only structural, but also functional. So, we look forward to our next round of discussions then.

Thank you very much.