Surface Engineering for Corrosion and Wear Resistance Application
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Lecture -58
Laser Surface Cladding

Welcome to the 58 lecture of Surface Engineering. We are now discussing in the last few lectures about how to utilize laser for surface modification, initially we talked about only micro structural changes namely its a hardening or surface melting and so on. And then we also picked up examples of cases where we modified the composition as well.

So, one of the example was called surface alloying, where we use incident laser beam as a cleans, non contact source of heating and by way of either feeding alloying elements or pre placing certain layers of allowing elements we could modify the microstructure and composition both. And we did see that certain improvements, in terms of surface dependent properties are possible by this approach.

So, in case of laser surface alloying, the change in composition is graded. The top surface probably will have the highest concentration of alloying elements and near the solid substrate. The coating substrate interface the concentration of the allowing elements usually is the minimum. So, you see a maximum concentration minimum concentration across the alloyed zone, in case of certain applications where we want a very different composition to be overlaid just like we do weld overlay.

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So, we are now going to discuss a process called laser surface cladding which is nothing, but another approach of laser assisted surface engineering or laser surface engineering.

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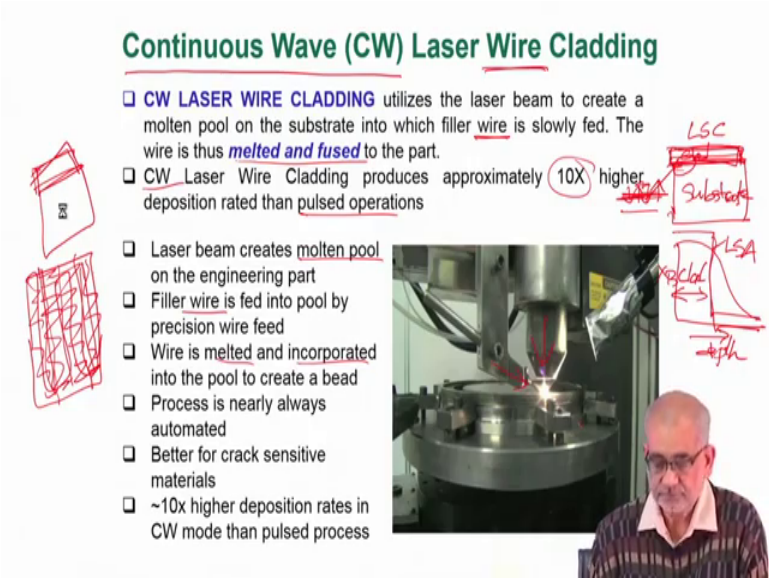

And in this we actually will be change, we will actually discuss the process which will make us allow us to change the both the composition and the microstructure so this is Laser Surface Cladding. Now we can do in either of the two possibilities just like any other laser processing, we can use pulses of laser in quick bursts of certain frequency with a certain pulse rate.

So, that is one way of doing that, but that is also very useful in certain applications, but generally the more common and the more popular method is continuous wave. And when the laser is actually irradiated in a continuous wave and the alloying elements are so, to say the clad elements are clad mixture is fed in the form of a wire.

So, you actually have to prepare a powder feed and then compact that and extrude that in the form of a wire or a rod and then you feed into the system. So, for example, as you are seeing here from the top you are feeding the laser beam and side wise laterally you are feeding a wire or a rod which actually has a completion very different than the substrate. So, the very basic or the fundamentals of the approach wise if this is the substrate.

Now, in case of alloying, we actually had a pre placed layer or a simultaneously fade layer and then we allowed the laser beam to raster over scan over and then create an alloyed zone. In case of cladding, what we create is possibly a thicker layer, but the most important part is this clad well have a composition very different than the substrate. So, in terms of composition profile let us say we are talking in terms of a particular element B and in terms of the depth as a function of depth into the substrate. So, in case of alloying we expect a profile which is diffused like that.

So, this is in case of laser surface alloying, in case of cladding we may have a composition profile which will be very drastically very different. So, we will have a rather sharp interface and this would mean that this region the so called clad region will have a completely different alloy altogether.

So; obviously, the interface being sharped immediate concern could be about the integration or adherence to the underlying substrate, but the advantage in case of laser cladding in case of laser surface cladding is that we when we overlay this molten layer, the molten layer because it is in the molten state is at a much higher temperature. So, invariably in contact with the substrate it will dissolve or melt a portion of the substrate and the interface that we are talking about so this interface is not entirely devoid of intermixing.

So, the clad will have certain amount of inter mixing with the underlying substrate and as a result the interface though is fairly sharp, but will have good metallurgical bonding. In other words the adherence is not a major concern in surface cladding. So, what we do is we can feed in the form of a wire or rod or some other form and we expect that feed to be melted and fused to the underlying substrate. And since this is a continuous wave process here we can expect a much thicker and a much faster process of cladding than, what is possible in case of pulsed deposition. So, continuous wave cladding actually kinetically is faster and also is more convenient to make a thicker coating.

So, as I said we actually we will create a molten pool and the molten pool and in that will feed the filler wire and the where wire is melted and incorporated and we have very nice bonding metallurgical bonding and the whole process can be completely automated. So, essentially for a certain surface area coverage, if this is the area that we want to cover. So, well have said this is depending on the size of the melt pool and the beam size, if this is the first clad layer then the next layer will be here with a certain amount of overlap just like in case of any other laser process.

So, this is how we will actually create overlapping layers and then eventually we will cover the whole surface. The whole process can be automated with a motion like this and in the process we will cover the whole surface. So, this is the top view, but in terms of front view when we create this thick layer, this layer can be fairly thick compared to alloyed zone.

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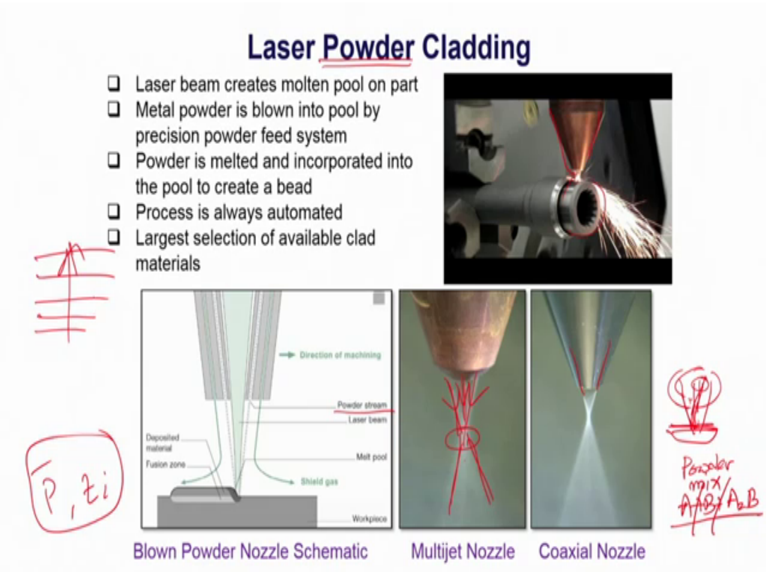

We can actually think of creating a similar clad by feeding powder. So, we can have a situation where this is the way we are feeding the beam, this is the beam which is actually creating an overlay on top of the circular section the tube. And we can have multiple nozzles and this is the way the laser beam is irradiating, but we can have multiple nozzles which can feed powder into the zone. And so, this is the zone in which the powder is flowing and so, these nozzles could be actually could be subtending a certain angles.

So, that the feed creates a bigger or the focus plume here. But we can also have a crossover earlier in case we are feeding through coaxial nozzle; that means, this is the or this is opening for the laser to pass, laser to fall to irradiate. And we can have a concentric hole which is just surrounding the laser beam and through this we can feed the powder. So, by the time that the beam hits the substrate here, the powder also will be molten in contact with the laser beam and create a clad on top of this.

So, what is important is we have to control the beam fluence of course, the power density and the point of focus and so on. Then also the interaction time by way of controlling the speed relative speed between the two then we also take care of the powder stream and the biggest advantage in case of cladding is we can actually feed a powder mix which this mix actually may have not just A it can A B or may be certain compounds like A to B and so on. So; that means, it is up to us what kind of applications we have in mind and we mix the powder and then, either feed the powder mix directly or we can have multiple hoppers and we can feed these powders as different through different nozzles.

So, both are possible the best option to make very uniform clad is to mix them and then fuse them in the form of a wire or of other kind of feed and then, directly feed along with the laser beam. The relative movement of the work piece with respect to the laser either the beam is moving or the work piece or the stage is moving either way we create a relative motion and that will actually be that will determine what is the interaction? Time and this interaction time apart from the power density are the two process parameters just like any other laser material processing.

The thickness that we built can be built to a higher degree to the height of the clad zone or the bead, that we create may be controlled and may be built to much higher vertical height by way of making multiple layers. So, we actually can create multiple layers and then make up vertically a layer thickness we can increase the layer thickness to a reasonably high level.

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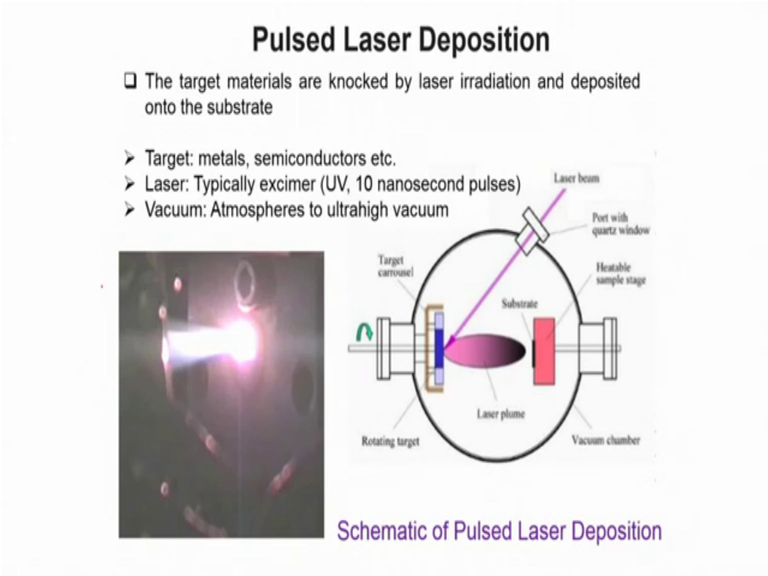

This was about thick coating. We can also create similar clad layers by way of pulse deposition. So, here the delivery mode is the laser irradiation mode is pulsed. So, here we will have a particular substrate. So, this is the substrate and this is the target which can be a target of desired composition. So, we can premix powders or other feed and then create an alloy here which can be very different than conventional alloy.

So, in other words the composition of these target can be completely tailored the way we want and we use a laser beam, which will hit this target and immediately vaporize a part of it and those vapor will travel through this particular distance and by the time, it reaches the substrate it actually undergoes a change of state and then either condensed directly from the vapor or condensed in the form of semi molten splats. Now this is how we actually can also create a clad layer, but that thickness of that clad layer will be fairly small.

So, here we may use this either for semiconductor applications various device applications where we need a very thin layer. Or even in metallurgical applications we can use this as a final layer which can close the pores and other defects onto the surface, and create a thin layer of a very different and a matching composition.

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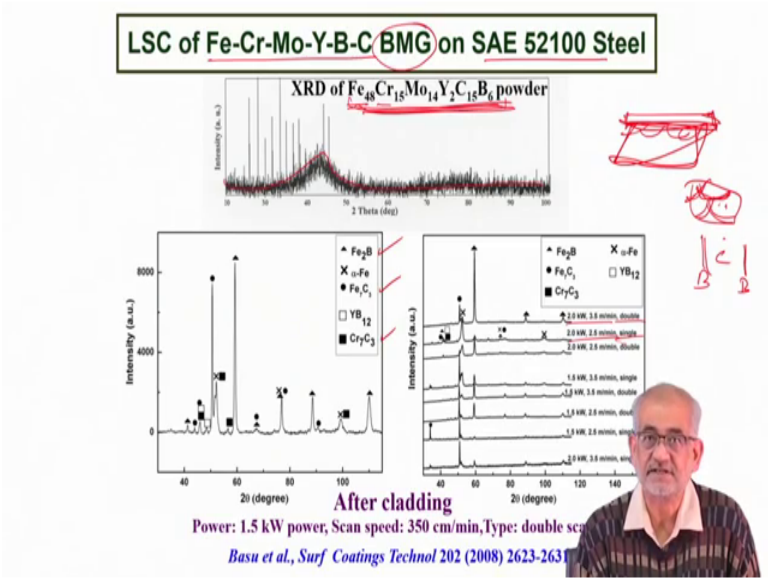

Now, just like the previous few examples I am now going to take up a few examples from the published results from our own group at IIT Kharagpur. The first example is about trying to clad bulk metallic glass. Now we all are aware that metallic elements when we routinely use them in any form at room temperature we expect 99.9 percent of them to manifest in the crystalline form.

So, in general metals are crystalline and metallic alloys also are almost every time is a crystalline metal, but then, under certain non equilibrium processing conditions like rapid solidification or high energy milling or high angular actions pressing and so on. We can actually destroy the usual or equilibrium structure the crystallinity and then retain a liquid like structure, which we call amorphous and a subset of that could be a glassy material.

So, bulk metallic glass is specially made alloy, which when cooled not necessarily under very rapid cooling condition like not unlike splat cooling where the solidification velocity could be 10 raised to 4 to 5 Kelvin per second, even with a few hundred degrees per second cooling rate. So, typically what you experience when you cast a metal onto a metal mold. So, a molten metal cast in your metal mode easily will undergo few hundred degrees per second of sorry few tens of degrees per second up to about few hundred degrees per second of the quenching rate.

Even in that we are able to if we are able to retain a liquid like structure which is amorphous then we call it a bulk metallic glass. So, essentially the critical cooling rate that we need to employ for this set of alloys is relatively slow and yet we are able to retain the amorphous structure just like in the molten state. So, these bulk metallic glass one particular composition with certain metalloids like boron and carbon along with a (Refer Time: 14:29) yttrium and then iron chromium molybdenum.

So, mixture of these is known to be a good glass forming composition. So, this is the signature that at room temperature when you cast this alloy this typical composition and an atomized them in the form of this powder; the powder shows completely hallow and its completely devoid of any crystalline peak. So, this is completely amorphous.

So, the idea was that if you have a steel substrate and if this steel substrate is coated with such bulk metallic glass then you are completely covering up the poly crystalline aggregate with an amorphous layer. Now we are aware that in any microstructure when you have such polycrystalline aggregate, usually the boundaries contain more defects and act as an od compared to the core of the grain.

So, we always we will have typically this is the boundary and this is the core we always we will see a galvanic cell created between the center of the crystal to the surface of the crystal. And this is the reason why steel for example or for that matter most of the polycrystalline metals are prone to corrosion attack at room temperature.

Now, if you can cover this up with a layer which is completely devoid of these boundaries; that means, when you have a bulk metallic glass then; obviously, you are talking only compositional variation or domains, but there is no crystallinity there is no grain and grain boundary structure. So, in such a situation you are likely to see a complete I mean you may expect that there will be no corrosion at all.

So, with this idea we actually overlaid this kind of a bulk metal glass, using laser beam and created a clad surface on top of a bearing steel. And to our surprise what we found that no matter how we change the process parameters either single or double seam or various form various combinations of power and scan speed.

But every time we end up getting certain crystalline peaks in other words, that we were unable to retain a complete metallic glass or amorphous structure after laser cladding and the reason is very simple that when you have elements in on one hand like iron, chromium, molybdenum and on the other hand you have metalloids like carbon and boron.

So, they have very different melting temperatures very different densities very different specific heats and most importantly they have very different tendencies of formation of clusters. So, under forced cooling, we were able to retain this entire composition as a single phase, but when we clad whatever little time we allow for the melt to experience or allow solute partitioning within those few tens of milliseconds or microseconds it was enough for the elements like boron carbon to segregate away from iron chromium and so on.

And in the process easily they could form these borides or carbides or carbides or various forms of inter interstitial compounds. And as a result once you allow this valued segregation then those phases emerge from the liquid and once the composition is violated from this uniform composition then; obviously, the glass transition temperature or the glass forming ability decreases. And by the time the liquid solidifies you no longer have a composition which can stabilize the amorphous structure of the liquid, but instead it allows multiple crystallization of these phases and the remnant liquid also crystallizes in the form of a matrix solid.

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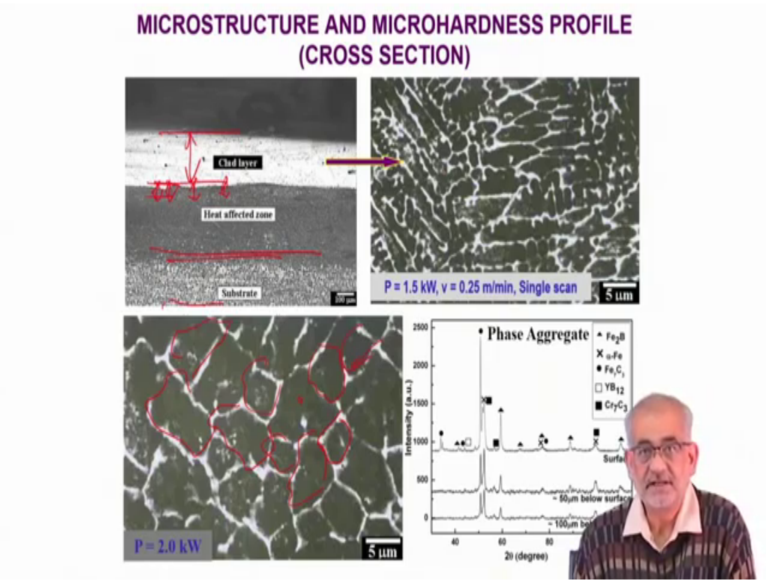

So, we are enabled but so typically this is on the cross section, this is a kind of a clad layer thickness that you develop on top of that there will be a heat affected zone, but in this heat affected zone; obviously, there will be some amount of intermixing. So, this is the substrate this is the heat affected zone and there is a clad layer and a very little area where you will have some intermixing in the semi molten state.

So, if you look at this micro microstructure of this clad zone you see these kind of dendritic pattern of solidification which simply shows that there must have been solid segregation. And because of which you actually form these primary phases and in inter dendritic spaces you have multiple compounds like, those borides and carbides precipitating out.

So, on the top few this is the kind of views you have. So, these bright regions white regions are typically the intimate interstitial or interest interstitial compounds there that are formed and they have decorated these boundaries in between. So, this is the primary solid when it grows so there are multiple such primary solid nucleating and growing together and steadied competition.

And during such growth the in the spaces in between such columnar grains or the dendritic arms you have the remnant liquids eventually solidifying in the form of multiple mixtures. In fact, it can be a eutectic, it can be just several, compounds a prospect out of the liquid. So, this is also borne out by this kind of a phase diagram.

So, the take home message is that you do create a very you can create a very thick layer a clad layer, very well integrated with the substrate, but there is no necessity that even with the cooling rate that you can employ with the laser surface cladding process easily 10 raised to 3 Kelvin per second or higher even then you are not able to retain the entire glassy matrix or the amorphous matrix.

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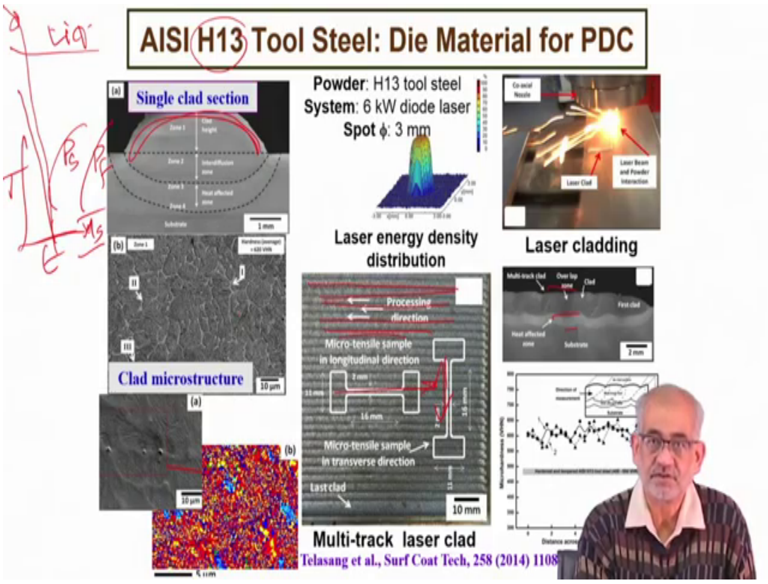

Now, this kind of an approach can be more useful. So, that was an exploratory approach where we wanted to retain amorphous structure of the liquid state into the solid, but that was not possible, but nevertheless I did not present the remaining part of the results which shows very significant improvement in hardness and variance of that layer. But here we are talking about a different example where for example, imagine a particular tool may be a roll or a shear blade or some other manufacturing device because of certain working conditions undergoes heavy amount of wear.

So, if the whole component is very expensive then you do not feel like throwing it away and then replacing overnight. The manufacturer always would like to retain and reuse it as far as possible. So, that is when you go for reclamation or repair job and we did discuss in the earlier sections something called weld overlay. So, where you actually use a welding torch and a filler metal to create an overlay on top of the tool or the solid substrate and then try to restore the dimensional whatever dimension you had before.

So, but in order to restore the dimension we used a material usually in the form of filler rod which is very different in composition than the base substrate. But laser surface cladding allows you to actually create an overlay for dimensional restoration or repair or refurbishment with the same composition; that means, they will be hardly any sharp interface created at all and there will be no question in terms of extra stresses created at the interface.

So, here is a cross section of such a clad the compositionally both the substrate and the clad has the same composition h thirteen tool steel and this tool steel we were able to actually create a clad for example, these are seams which are parallel ones very neatly done parallel seams.

So, if you create such clad beads, along a certain direction with certain level of overlap then you act what actually was done in this case was not only to look at the cross section and so on. So, very nice bonding with the base substrate, but from this top layer we were also able to extract samples for tensile testing which is along the clad direction or across the clad direction; that means, in the longitudinal and transverse direction both. Because this clad thickness was sufficient for machining out these small specimens.

Now what is really significant in this whole case is that we had very good mechanical properties and so on. But what is very interesting is that the microstructure that you develop in the clad zone also is martensitic in nature. Now normally in case of plain carbon steel or normal alloy steel you when you melt and solidify you do not necessarily get martensite because you go through the liquid to solid transition and that is when austenite forms and most of the cases austenite is retain during a fast cooling process until room temperature.

You may form certain other phases, but in order to get martensite we are aware that we must avoid occurrence of any diffusional transformation. So, if you just quickly recall if this is the temperature and this is the time axis.

So, we are referring to a continuous cooling curve like this and our cooling rate all the way must be very fast and be able to we should be able to avoid intersecting any of these power light start or power light finish curves. Now usually this is a solid state process, but when you start cooling all the way from liquid state. So, here is your liquidus line so you start all the way from liquid state to be able to avoid altogether and then reached room temperature after crossing the martensite start this is not very common place.

But in this case in this kind of a situation because the bulk of the substrate acts as a heat sink and extracts heat very fast. So, the cooling all the way from the liquid state to room temperature in this particular case allowed formation of not only the solid, but solid in the form of shear transformation product or martensite.

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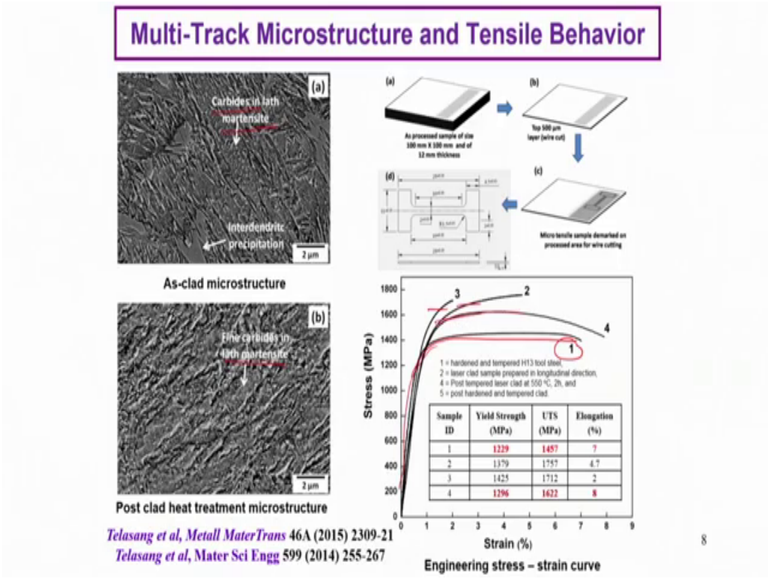

So, when we carried out these mechanical tests and by the by along with martensite there were also plenty of carbides form during this cooling process. So, very fine carbides in between the laths martensitic lath created a very good mechanical property.

And as I said we actually extracted machined out micro tensile specimens both along longitudinal and transverse directions. And when we carried out the tensile tests to our surprise what we found that if one is the situation of mechanical testing result in case of hardened and tempered condition in case after laser clad we were able to reach much higher strength much higher real strength.

And after not only clad, but cladding plus some tempering or annealing treatment we were able to get fairly higher still higher strength, but a much higher range of ductility much higher deformability. So, you are able to actually combine both higher strength and toughness in a material which is overlaid or clad.

So, laser surface cladding then gives me a possibility where actually, one is able to reach very high strength very high yield strength and UTS both and also retain 7 or 8 percent of ductility which is a very good news. In fact, in a way this layer could be better in terms of mechanical integrity and property than the original cast product.

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So, similar approaches can be obtained say for creating certain graded composites onto the surface. So, here is an example these are automobile components which can be eventually made out of magnesium not even certainly not steel not titanium not even aluminum we are talked on magnesium.

So; obviously, density wise much lower and then the overall weight reduction will be significant, but magnesium is very prone to oxidation corrosion and also carries fairly low strength and poor wear resistance. So, in order to introduce a good amount of wear resistance, so what is possible is by your laser cladding you actually create a composite surface.

So, you clad a powder which is a mixture of matrix phase which could be magnesium or magnesium aluminum mixture along with that certain carbides in this case silicon carbide. So, you can select the required type of carbides mix them and then when you clad, you actually if this is the substrate; if this is the substrate the 1st layer, the 2nd layer, the 3rd layer.

So, you create different layers and as you go on top you can change the amount of these carbides gradually. So, at the bottom layer you can have low volume fraction of carbides and higher amount of matrix metallic phases. So, that the bonding here is better more metallic bonding metallic bonding metallurgical bonding.

But then on top layer you can have a higher volume fraction of these carbides. So, on the cross section you see very nice wetting and a composite layer created on top. So, on a metallic substrate and alloy I can create a composite layer and that too with graded composition by way of laser cladding.

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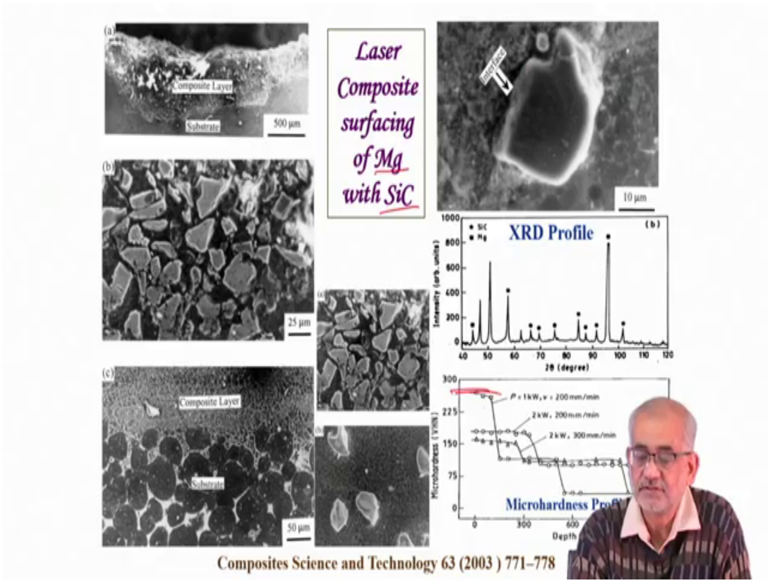

So, this was possible with earlier one was with a particular magnesium alloy and this is pure magnesium with silicon carbide similar composition layer, composite layer, created with certain amount of good wetting and so on. And as a result one can create a very high hardness level, almost twice or three times then the hardness level. And see a very well wetting of the carbides forming certain reaction layers or around them.

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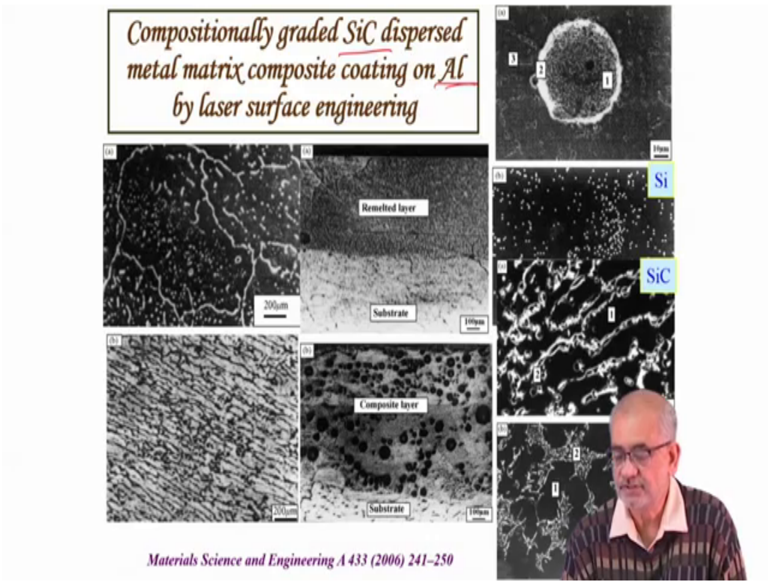

One can do a similar thing with aluminum here the composite layer is the matrix is aluminum and the dispersed oil are the silicon carbides. And you create such micro structures which is very well practically defect free and can be fairly thick which is not possible in case of other materials. And another good thing is that you when you create such a layer you actually have very nice there will be certain eutectic formation in the inter dendritic spaces, but these are the regions which is very good in terms of offering high wear resistance and hardness.

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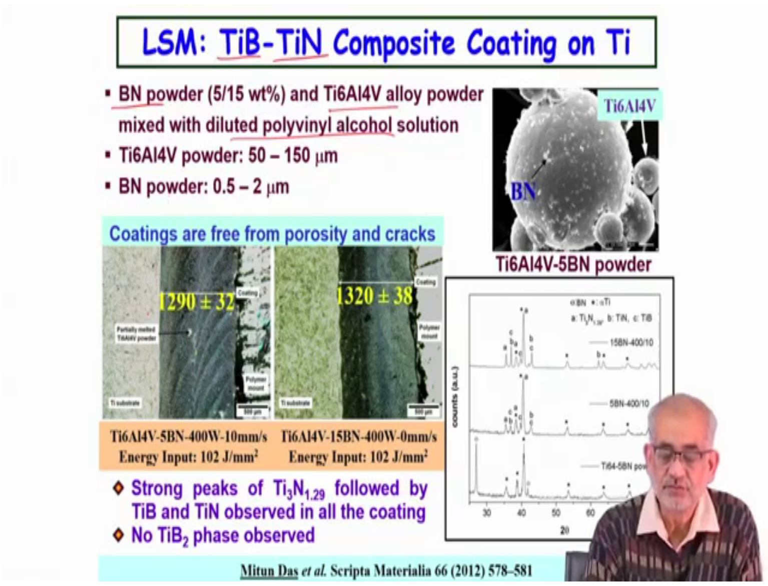

Now, laser also allows you to create a very exotic combination of phases, a boride and a nitride on the same created on the same surface by the same operation. So, you start with a certain boron nitride powder mix with titanium alloy powder and then, spread it with some binder like PVC, PVA and then you create a thick layer pre press layer and then use a laser beam to scan over it.

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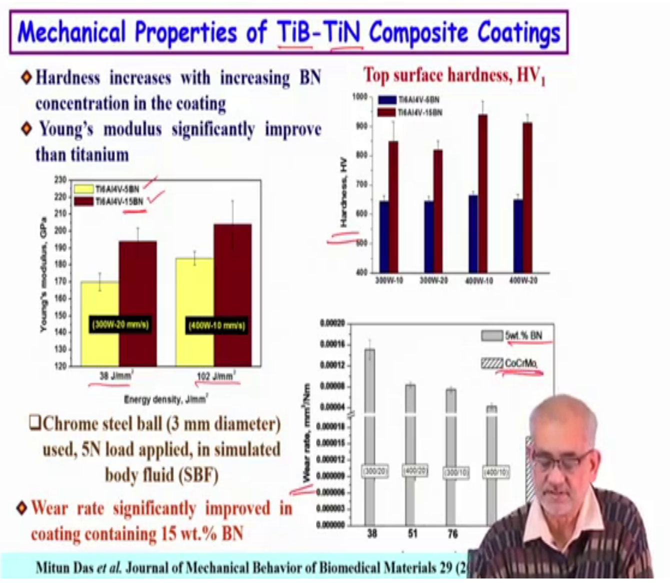

And in the process you do see certain reactions which allows you to form both boride and nitride a composite layer comprising both boron boride and nitride of titanium by the same operation. And in fact, you can use different energy densities and as a result you can see so, this is with 5 boron nitride and this is made 15 weight percent boron nitride edition.

And as a result of course, the Young's modulus would be higher in one of these two cases where you have higher amount of boron nitride. You can also see variation in hardness variation in wear rate and you can easily figure out that with the 5 weight percent of boron nitride, you actually can create a wear resistance level which is fairly comparable to substrate which is much harder.

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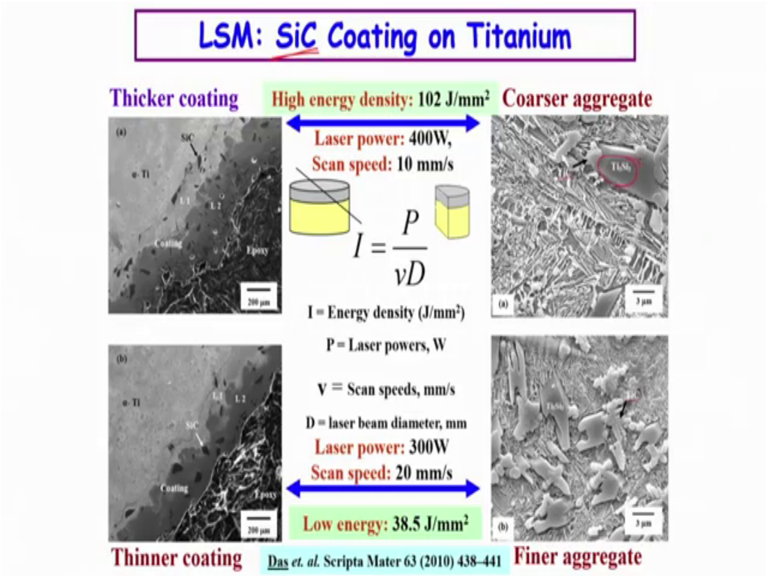

So, one can also alloy silicon carbide on titanium. So, I showed you examples of magnesium, magnesium alloy, aluminum and now silicon carbide on titanium pure titanium. So, here again you create an exotic microstructure where you have these silicide layers formed, along with a eutectic of finely dispersed phases. So, this kind of a microstructure actually can make you can give you much better mechanical properties and the fineness of the microstructure of the clad zone can be easily controlled by controlling these typical laser parameters as power and the scan speed and depending on the.

So, at depending on the level of or the combination of these two major process parameters you can vary the microstructure. And even composite composition to a significant level.

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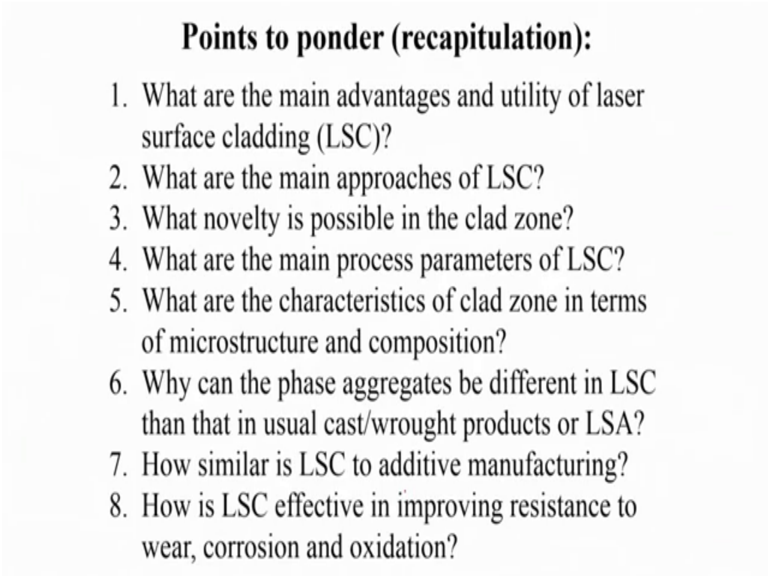

So, we have now completed the discussion in terms of changing the composition by way of alloying and now cladding. So, cladding gives us an advantage that in case we need to build a layer which should be compositionally very different than the base substrate we can do it. Or in other words on the other extreme if you want the same alloy to be overlaid on top of an existing substrate for a repair job for reclamation or dimensional restoration we can even do that.

So, laser irrespective of what we are feeding can melt and create an overlay which could be fairly thick. And in fact, it could be much thicker than what is normally possible in case of surface allowing or other approaches. So, we can either feed powder we can feed wire, we can feed a tape, but the difference is in case of allowing will melt the substrate first and then feed the powder or wire into it so, that we form an alloy zone.

In case of cladding, we will melt the clad feed before hand and allow the molten layer to be incident onto the substrate and in the process we create a layer which is compositionally very different. But the advantage is because we are overlaying a liquid pool the liquid actually intermix as well with the substrate and then creates a good bonding with the substrate.

So, compositionally the novelty lies in the fact that we actually can create multiple layers with very different compositions and micro structural relations, which is not necessarily possible in other methods. Process parameter wise we are talking about the same the feed rate apart from the two normal ones which is the laser power density and the interaction time. Here the composition of the feed and the feed rate also will determine what we create at the finally, at that clad zone that clad zone actually can create a microstructure and phase aggregate which is very different than the normal equilibrium phase aggregate.

And this could be to our advantage, but the beauty is that we create a cast layer unlike a typical big cast product on a rod product the microstructure and the phase aggregates could be very different. So, there lies the novelty. And in fact, this is also different than what you can create in terms of laser surface alloy which I already explained. Laser at surface cladding actually is a precursor to the additive manufacturing process. So, you can actually build layer by layer and then create a complete structure a complete component gradually.

The advantage here is that the fusion zone integrates well so, we actually mechanical properties or addition properties are much better. So, because of the layer that we create which could be much harder or much more corrosion resistant we certainly can make a very significant improvement in terms of resistance to wear corrosion or any other surface dependent properties.

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So, with this we actually come to the end of the laser assisted surface engineering processes. And in fact also discussion on all kinds of laser all kinds of surface engineering techniques; so, we covered a wide range of techniques. And in the remaining couple of lectures we will discuss a little bit about the various real time situations of components undergoing heavy degradation and discuss as to what kind of surfacing technique would be useful for them.

So, thank you very much.