Surface Engineering for Corrosion and Wear Resistance Application
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Lecture - 52
Electron Beam Surface engineering

Welcome to the 52nd lecture of Surface engineering. In the previous lecture we discussed application of Electron Beam primarily for welding purposes and we realized that electron beam offers one of the biggest advantage possible by way of deep penetration welding which is not possible with other kinds of be directed energy or conventional tools. But then EB is not necessarily only mean for welding, EB also has a large number of applications particularly a very specialized application for surface engineering and that is what we need to discuss now today.

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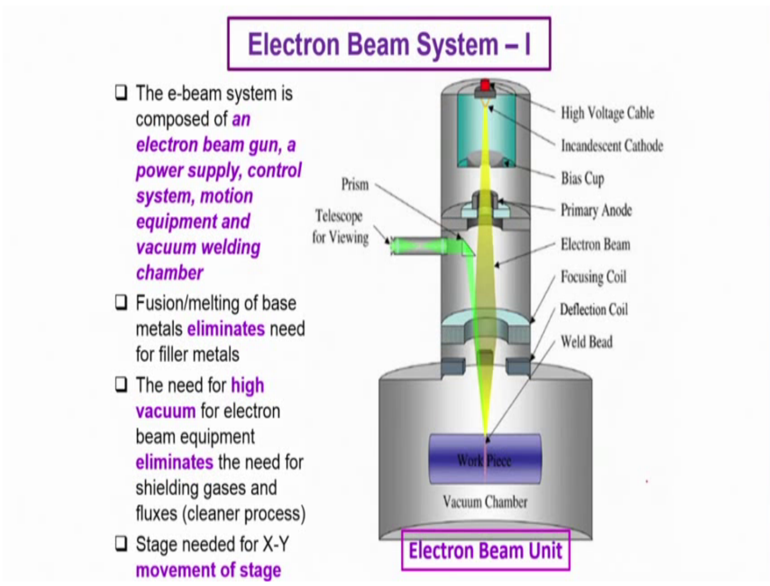

So, let us go straight away into the configuration you have seen this view graph in the previous lecture. So, essentially we have these are the constructional features we have an electron beam gun, we have a power supply which applies very high negative potential difference to give you a kinetic energy to the electrons, we need a control system, we need an sample manipulation stage and of course, very high vacuum chamber.

So, this is the overall setup and this is the high voltage cable and tungsten cathode which emits electrons, the bioscope which actually deflects and makes a beam. The primary anode which a certain central hole the electron beam this is the electron beam and this is how we actually focus. And for focusing as I mentioned please recall that we need both electromagnetic lenses for focusing as well as deflection or deflecting. So, that we actually are able to irradiate exactly the desired spot and not elsewhere; maybe this is the desired spot, but if you want to move from this spot to this then we need to move the stage along this direction or the other direction.

So, there could be a relative motion between the beam and the work piece and this is where we get the either call it a weld beads or may be the surface melt zone. So, this is the overall setup; we must quickly recall that we require very high vacuum and since there is no extraneous material present in the form of shielding gas or flux or anything. So, it is a very clean process and we need certain stage manipulation.

If we want welding of course, then we do not need a filler, but if we want surface, modification surface, cladding or surface, allowing and so on, then we actually can have a pre deposited layer or sort of a already unavailable coating and then we melt the coating along with part of the substrate and create in a large zone. But we can also feed in material inside the chamber so, we will come to that in a minute.

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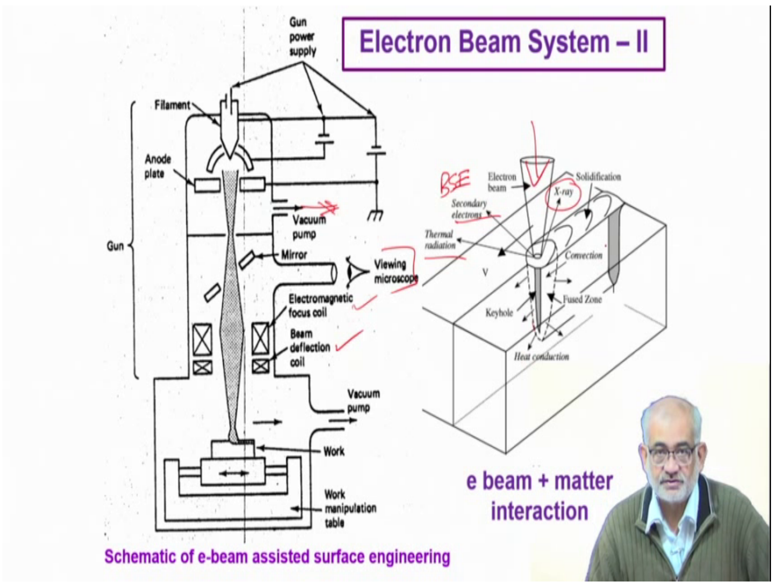

So, this is the overall setup this again is repeated from the previous lecture just to bring home the point that the same configuration and we require the similar mechanisms for focusing for deflection, also we need a viewing port and we need to maintain very high vacuum before we start the electron flow. And eventually, once the erudition occurs then this is how the surface of the solid gets I mean undergoes melting process.

But this also is important to recall that when the electron when the incoming electron beam interacts with the solid. It actually creates a heat affected zone or hot zone below and in the process because of this high stream of particles carry charged particles carrying very high kinetic energy when they resistant on to the surface and when they interact with the solid. They can emit secondary electrons, they can certainly create heat radiation out of the surface, they can also create not only secondary electrons, but also backscattered electrons.

Then it can also emit certain amount of X-rays because you are rapid; you are rapidly decelerating the incoming stream of electrons and that rapid deceleration can actually lead to emission of X-ray. So, you need a good protection around. But the most important thing is in no time the incident beam will interact with the solid matter, rays the electrons to higher energy state and allow the electrons to come back to the ground state. And in the process, it will allow the heat to be absorbed by the solid and this will be converted into lattice heat. And then heat flows, heat flows vertically downwards and also laterally to some extreme depending on the relative size or the diameter of the beam with respect to the substrate thickness.

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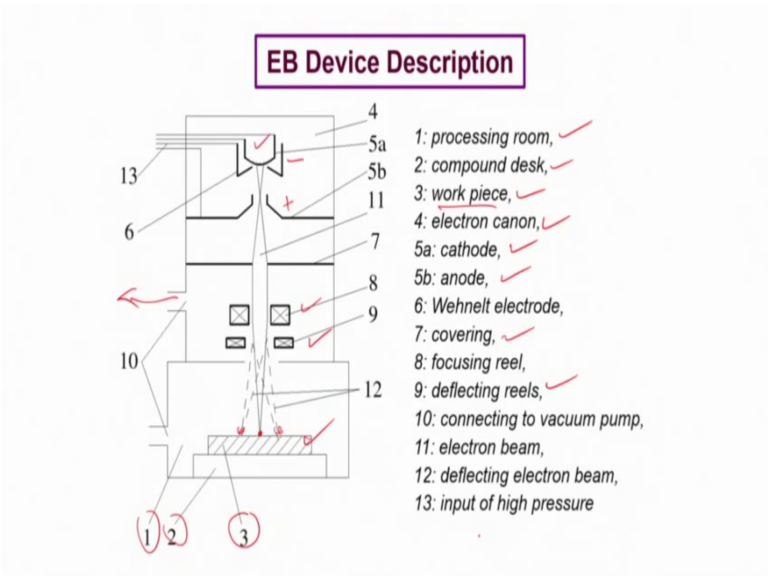

So, this is the processing zone the so called processing room, you also need a compound desk on which the substrate which may be a small light one or may be a very large thick one and you also need to be clamped well. So, that it does not deflect during their processing period.

Then you need this; so, this is your work piece which is placed here you need the electron gun here; so, this is the electron gun which actually emits electrons you need a cathode. So, this is the cathode through which the electrons are emitted from which the electrons are emitted and towards the anode. So, from this side you actually will have it the emission will take place towards the cathodes or the electrons will flow towards the cathode.

Then through this opening central opening the electrons will flow, but you also need some kind of a covering to cut out the stray radiations and then this the configuration actually this entire electron this is the electron gun part. So, in the electron gun part this you have the filament, the cathode, anode and this whole thing together is called a Wehnelt electrode.

Then you have the focusing lens here, you have the deflection lens here and so you actually can at the moment let us say the point of contact is here irradiation is here, but you can also deflect to this point or this point. So, this deflection or rastering is possible by manipulating through this deflection coil or the reel. Then you need to evacuate maintain very high vacuum; so, this is how you in very high vacuum and this is how the beam interacts and then converts the kinetic energy of the electrons into the lattice heat of the solid substrate.

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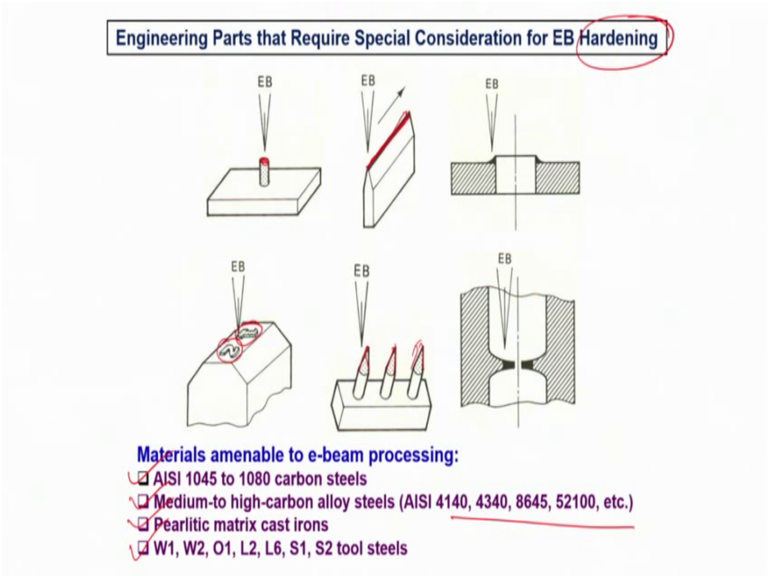

So, we can have; we can for example build components like this vertically, we can build a component like this or we can irradiate only this part only this part and not elsewhere. Similarly, we can irradiate or heat up only this part or build a material at this sharp part of the shear blade and not the rest of it.

So, we can create additional layer and for example, the way they have written one and two likewise, you can build certain structures you can even irradiate only these portions; the conical portions the sharp tip of the conical portions leaving the base regions completely unaffected.

So, material wise all kinds of steel may be low carbons, plain carbon, steel or medium or high alloy steels all these various series, then pearlitic matrix cast irons, various tool steels work hardenable, oil harden able or an hot working tool steels and so on. So, various types of ferrous materials are ideal to be treated. But you can also do for titanium alloys magnesium alloys or any other reactive materials zinc alloy, for example is a standard material for all nuclear power reactors.

And electron beam facility is ideally suited for such highly reactive materials like zircon alloy, which is zirconium containing alloy. Similarly, niobium alloys or which requires very high melting temperature or even the similar cases when you would like to create a clad on zircon alloy with another composition; so, electron beam would be ideal for that.

So, the term hardening here does not necessarily mean only phase transition, what we generally are used to of austenite converted to martensite. This means also creation of hardened layer onto the surface including by way of cladding.

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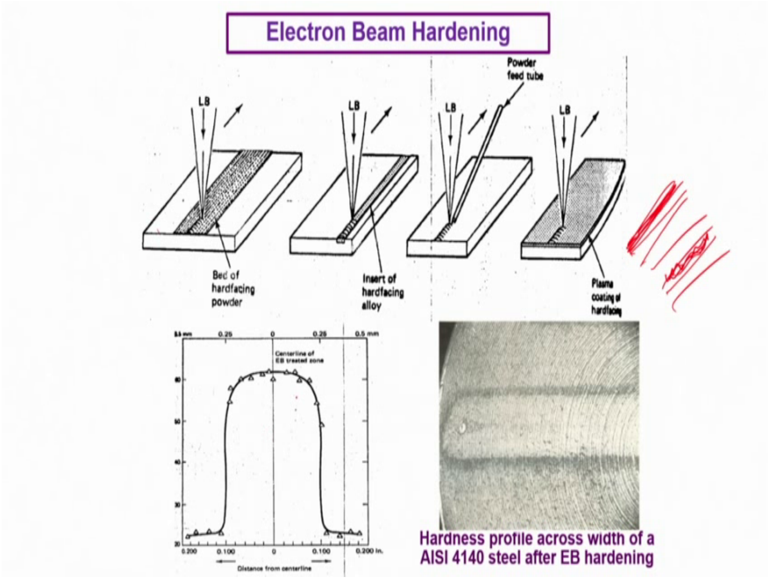

So, these are the processes so; obviously, if you want to harden the entire surface or with a create a coat then you start with a certain layer and then you go layer by layer and then make it wider. And when you have done the whole surface then you will definitely see certain level of overlap. So, if this is a particular layer, the next layer will not begin exactly at this surface at this interface will begin somewhat here.

So, one layer created like this, the next layer will actually start somewhat in between. So, there will be a certain overlap here, and that is what you see, but very nice geometric and precise bead sizes. So, typically across the bead you will see that the hardness wise actually, there could be variations and that is purely because of the treatment or the composition that you actually are treating.

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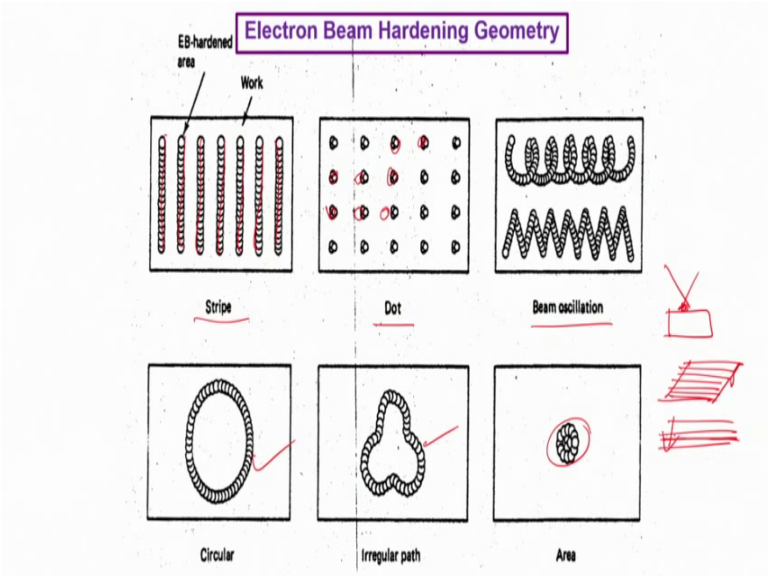

The various geometries are possible, you actually can make stripes or make dots or circular dots or you can create oscillation of the beams and create certain complicated shapes. So, the point is that on a flat surface for whatever reasons if you would like to treat these kind of stripes or create these kind of stripes and leave the portion in between unaffected or you create certain patterns like this, which are may be circular or some geometric shapes.

But leave the rest of the surface unaffected or on the surface you actually would like to create such special shapes or contours that is also quite possible with electron beam. So, anything like irregular path or a circular or a certain area coverage and so on; so, all these are possible.

So, essentially we have to ensure that if this is a substrate and this is the beam then we need either of these to move to create surface integration; so, if this is the surface we are talking about. So, we need one beam to cover like that, another like that and likewise this is how we can cover the entire surface. And when we do that then as I already mentioned that there will be a certain overlap, the next beam we will not start where we ended, but we will actually start somewhat you know already covered area. So, that there is uniformity in the microstructure across.

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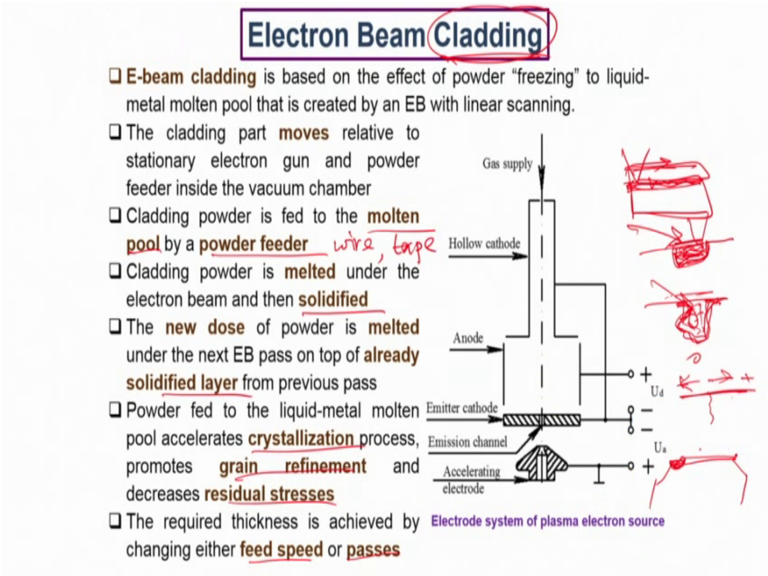

The one of the biggest application in terms of surface engineering using electron beam is related to cladding. And this means that for example, the one parts of a very expensive tool or shaping tools may be cutting tool or may be a nozzle or maybe even a gear or something if it does not make sense to throw away or replace with a new one because the component is a very expensive one. Then one can actually try and clad the same alloy composition or a different alloy composition by using electron beam as a source of heating and melting.

So, either you have pre placed powder which is which with certain binder you actually can create. So, if this is a component surface on the cross section, you can create a top layer and then use a electron beam to raster over the surface. So, that not only the top layer melts, but the molten layer also dissolves a part of the underlying substrate.

So, that you form a nice bond here and in the process you actually develop a much harder layer on top. It is not only about hardening the layer, it is about also restoration of the or basically if a particular component has developed some crack or some dent like this here, you actually can refurbish or reclaim this by way of putting material here.

And this precise filling up of the crack or the gap is possible by way of either feeding through a filler wire or fill the gap with certain powder and then use electron beam to cover this area. And when it melts if the composition is the same as the substrate in this interface are practically in invisible, they actually integrate very well with the components.

So, cladding is a very important application; in fact on components which is for example, modeling steel or high alloy tool, steels or even circular or titanium alloys and so on so, this kind of possibility is certainly very useful. So, we can feed by into the molten pool by way of powder it can be instead of powder it can be wire , it can be a tape, it can be other forms in whichever way you actually can create. So, the molten layer will solidified and create a good metallurgical bond and this is done in vacuum and if it very high precision.

So obviously, there is no in most of the cases there will be very little requirement of subsequent processing or machining and so on. The liquid metal pool which actually solidifies within this gap say for example, if this is was the gap and you have filled it up with the powder and then you are melting or you are feeding filler metal and just allowing the liquid to flow in and cover.

In such situations when the melt pool solidifies you actually cannot make out any difference after this and there is no need of any surface machining or any other post requirement post treatment requirement, there is no further annealing or anything required because this volume is very small this is the same composition as here and there is very good wetting here inside the cavity. In the process you also see lot of grain refinement and creation of certain residual stresses.

Now, this is something which one needs to be worried about because in any fusion process we all are aware that generally the residual stress is tensile in nature. So, on the surface a beam welding or surface engineering if you generate residual compressive stress then this is not so good news, because if you form a cracks by some means there will be an easy chance of opening up the crack and failure and leading to failure. So, one needs to find out as to how you can reduce the relative degree of residual tensile, stress on the surface or if possible bring in residual compressive stress on the surface by way of some special treatment.

So, the thickness that you require will depend upon of course, the parameters the current and the energy or the potential difference that you are also the relative position of the weld of the electron beam focus. But also the feed rate or the speed at which you feed material in at the melt pool will determine what will be the relative thickness of the clad or the refurbished layer.

I mean, clad essentially would mean as if you are cladding the whole surface then you call it cladding, but when you are repairing only a small part of a let us say a particular shear plane. So, you so this is the shear blade which actually got worn out; so, you are treating only this part. So, this is refurbishment this is reclamation whereas, if you want to put our hardened layer on throughout the surface you call it a cladding process.

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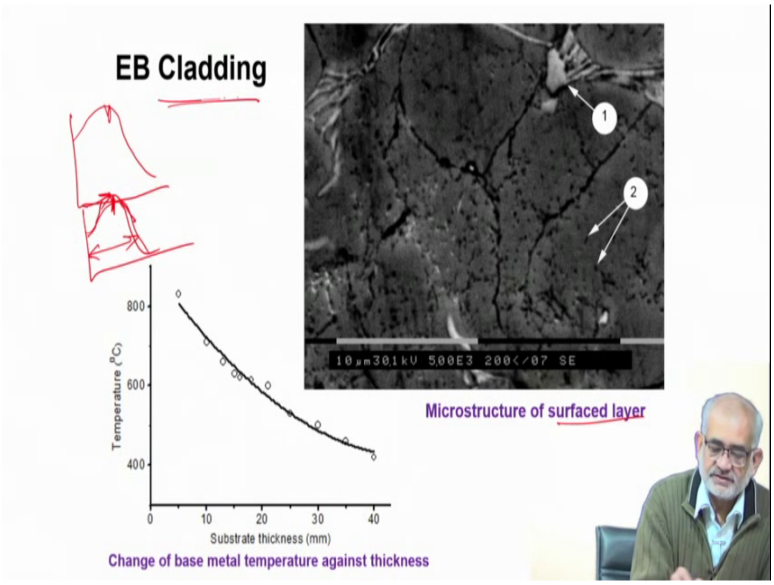

So, this is a typical microstructure done on a tool steel. The temperature that the metal seize will decrease from the surface to the core and yesterday we did discuss about the way the ion beam interacts with metal. And there if you recall while discussing ion beam we did not say that the deposition profile is Gaussian and the peak is below the surface. The same deposition profile or the feature applies to electron beam as well.

Though the penetration depth is I mean one can vary or is controllable, but what is not controllable is that the peak temperature is not at the surface, but below the surface. And hence because of this reason EB is more suited to deep penetration welding than a shallow welding or for that matter surface engineering applications. But nevertheless this peak is not too far below the surface. So, if you are doing a cladding operation then EB can be ideal and it is also very ideal because if you are dealing with components which are very reactive. For example, titanium or magnesium which easily would like to would always react with the oxygen present and then create a oxidation.

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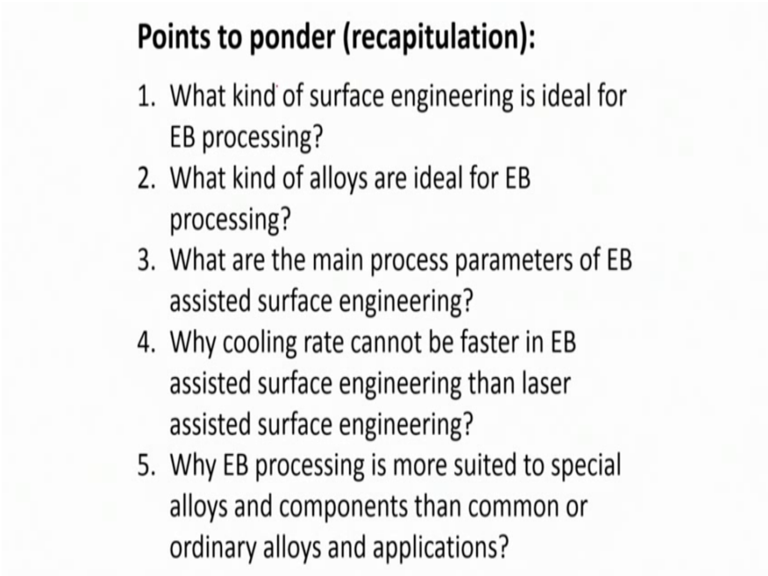

So, what all we discussed in this surfacing application of electron beam, for reactive metals, for sophisticated or expensive components, we can use EB also not for joining alone, but also for surface engineering. And the biggest possible surfacing application could be; for example cladding or simply surface melting under, because melting and rapid solidification because of the rapid heat extraction during the solidification process.

Allows a very small grain size or nucleation high nucleation rate, low growth rate as a process in the process, we actually end up getting very small tiny little crystallites throughout the surface and they do not grow much so, we get large grain refinement affect. The process parameter is just like welding here also the beam current applied voltage between the node and cathode then degree of vacuum, the degree of overlap the relative position of the focus with respect to the substrate surface all these are very standard process parameters.

Since, the whole process is done at very high vacuum it is quite possible that the cooling rate that we effectively get in case of welding or surfacing using electron beam is not as high as one can get in for example, laser processing. So, that is a limitation, but it is also at the same time should be argued that laser or other many other processes actually had done in air on.

So, if you are dealing with zirc alloy or zirconium or titanium which is very high magnesium, very highly reactive ones, then EB is better suited than other processes. But EB is not an ideal tool necessary not necessarily an ideal tool for surfacing. Why this is still used for surfacing engineering? Because if you want to clad or harden or deposit or simply surface melt are very sophisticated and a very reactive metallic component, then the high vacuum that you have in case of electron beam is very very helpful.

And of course, another very big advantage is that it probably can melt anything, if you apply good combination of time and power density. You actually can melt almost all possible solids, unless they decompose even before melting like diamond. You would rather use sophisticated expensive complex shape and other major specialized requirements by EB as a straight welding or surface engineering and not necessarily those things which are done routinely outside can be done routinely; outside using even just an art torch or art melting unit or (Refer Time: 22:14) unit and so on.

Just because this unit itself carries a large capital cost, now you have to have the whole chamber kept under very high vacuum, you also require the electron beam, you need a gun and the gun should be able to provide you stable substrate a stable electron beam to be to hit the substrate surface and melt or do other things. So, then you have to need a protectant chamber so, that emitted electron secondary backscattered or X-rays do not actually go and create problems for the operator or anybody outside in the room same room.

So, after this we will move into the third possible direct energy beam called laser and you will realize that laser actually could be a much more versatile tool for surfacing engineering to an electron beam. But we must realize that there are niche applications where you would rather use electron beam and not laser depending on the scopes of that oxidation or reaction with atmospheric air or other gases present or may be some other specific reasons.

But if you are dealing with components of sophisticated components which are expensive, the material is very expensive, and at the same time very reactive and you are willing to you are not willing to take any chance then of course, electron beam facility will be most handy either for welding or for surface engineering.

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References

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So, thank you very much.