**Rapid Manufacturing**
**Prof. J. Ramkumar**
**Dr. Amandeep Singh Oberoi**
**Department of Mechanical Engineering & Design Program**
**Department of Mechanical Engineering**
**Indian Institute of Technology, Kanpur**

**Lecture – 30**
**Beam Deposition Processes**

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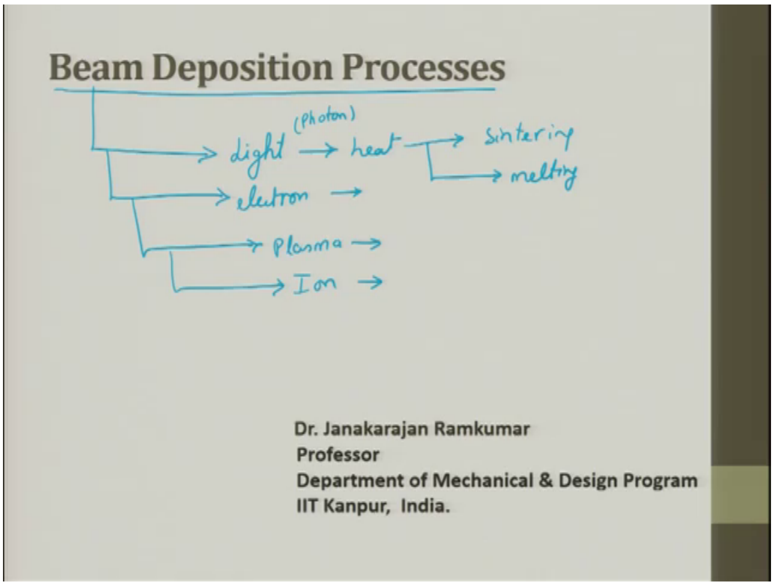


So, the next lecture of discussion in this course of Rapid Manufacturing, we will see the topic on Beam Deposition Processes. So, as it is very clearly says there is a beam. So, this beam can be made of light which can convert into heat, we can use it or we can use electron as a beam and we can do it we can use a plasma as a beam and then we can do it. So, it is nothing, but a source which can be lights, which can be electron source, it can be a plasma source.

So, we use these sources where and which we have your focused thing called as beam. So, this beam is allowed to help in depositing on the surface through which we try to make a prototype or we try to make a rapid manufacturing part. So, the beam can be light; light if you want I can change it, I will put it us photon; you can use photon as a source, you can use electron as a source, you can use plasma as a source why not use ion also can be used.

So, you can use any of these sources and all these sources when it strikes the material or matter, it tries to interact and when it interacts it tries to generate heat. We choose in such a way that it generates heat it rather than transmitting. So, it generates heat this heat will be used for sintering or melting and you try to get the required output. So, this is what will be in a nutshell covered in this lecture.

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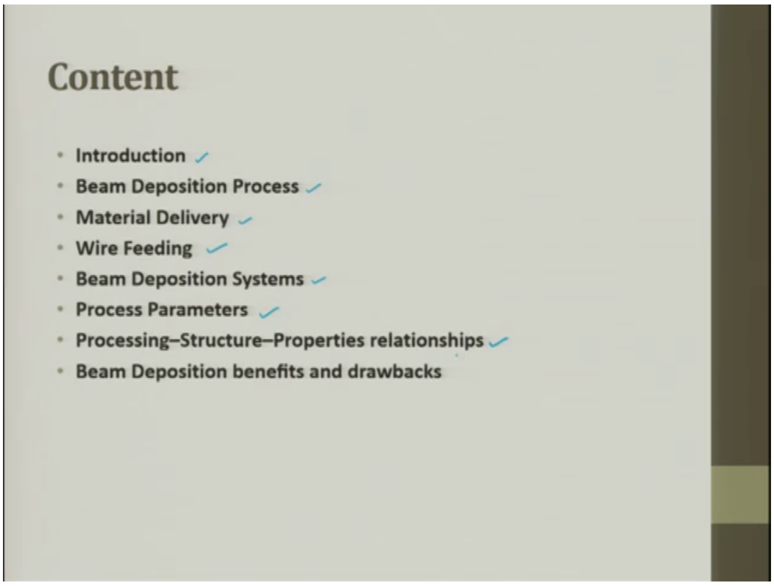


So, the content of this lecture, we will have a small introduction followed by it beam deposition process we will see, material delivery system, wire feeding, we will see beam deposition system and then we will try to see the process parameters, then process structure and property relationship and finally, we will see beam deposition benefits and it's drawback.

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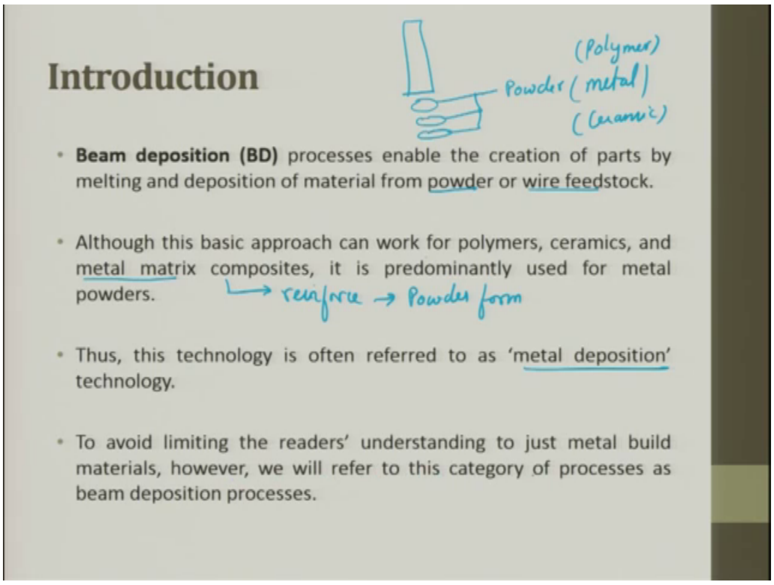


Beam deposition process enables the creation of part by melting and deposition of material from powder or wire feedstock. So, you can make a powder or you can make a wire feedstock. In a crude sense; if you see you have a wire when you heat the wire is changes into small small droplets, so these droplets are nothing, but for analogy sake you can call it as powder. The wire when you apply heats it melts, so when it melts it finds into small small droplets.

So, these droplets whatever we see are nothing, but powders you can either call wire converted into powder or we can directly take powder, this powder can be metal the powder can be ceramic ok. The power can also be polymer why not. Although this basic approach can work for polymer, ceramic and metal matrix composites, it is predominantly used for metal powder, when I say metal matrix composite.

So, metal is a matrix and you composite you will have a reinforcement and this reinforcement also will be basically in powder form ok. Thus this technology is often referred to as metal deposition technology. To avoid limiting the readers understanding to just metal building materials; however, we will refer to this category of the process as beam deposition processes.

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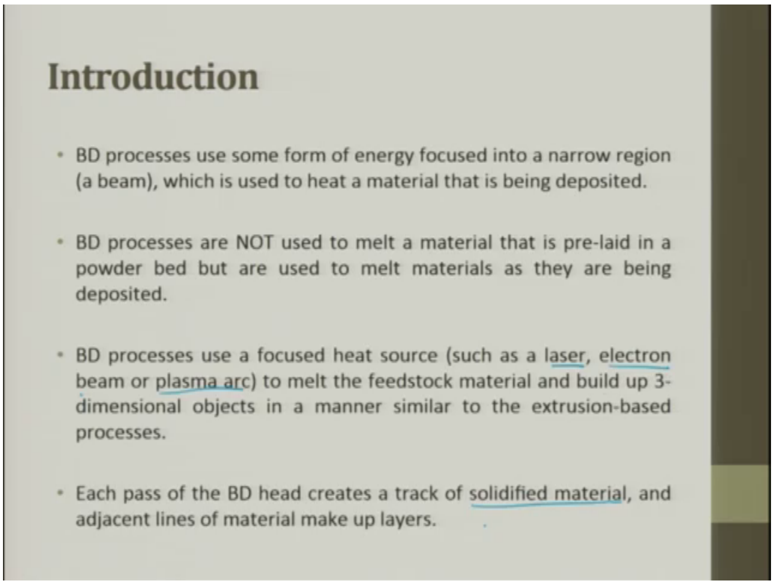


Beam deposition processes use some form of energy focused into a narrow region a beam, which is used to heat a material that is being deposited this is what I discussed in the introduction. Beam delivery process are not used to melt a material, that is pre laid in a powder bed, but are used to melt material as they are being deposited.

Beam delivery system processes uses a focused heat source such as, laser, electron plasma arc to melt the feedstock material ;feedstock material is a wire here material and build up your 3 dimensional object in a manner similar to the extrusion based processes. Each pass of the beam delivery head creates a track of solidified material and adjacent line of material makes up the layer.

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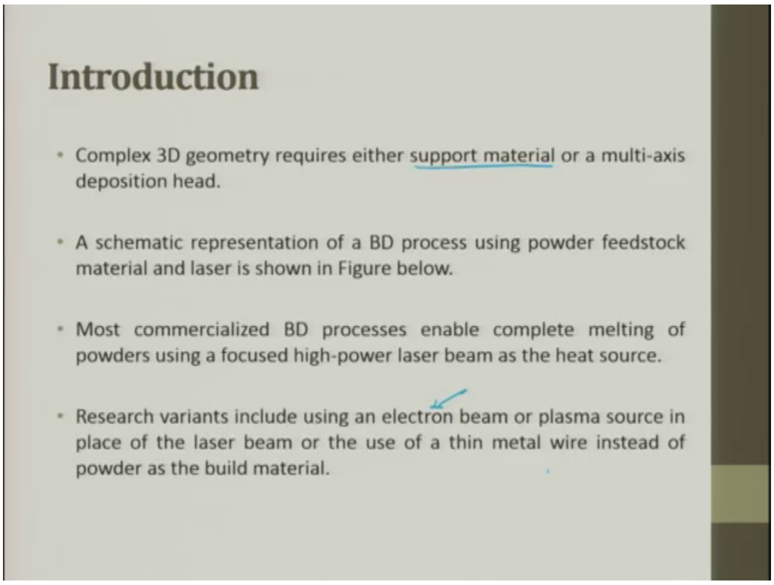


A complex 3D geometry requires either support material or a multi axis deposition head, supporting material is very important if you have free form or free hanging structures. A schematic representation of a beam delivery process using powder feedstock material and laser is shown in the next slide. Most commercial beam delivery processes enable complete melting of the powder using a focused high power laser beam as a heat source.

Research variants include using an electron beam or plasma source in the place of laser beam or use a thin metal wire instead of powder as a building material. See the advantage of electron beam is more focused, but the disadvantages it needs vacuum. Today, we talk about a low pressure or low vacuum systems for developing and today electron beam is competing with laser beam in this beam delivery system in the rapid manufacturing way.

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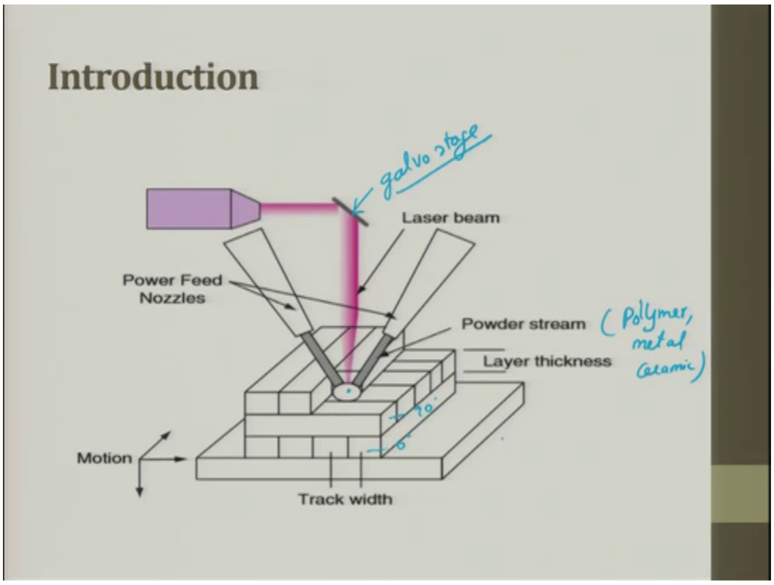


If you look at it, this is a powder feed nozzle. We have to powder feed nozzles, so and then you have a lunch with comes. Suppose you try to take a powder as you can take a polymer powder, you can take a metal powder, you can take a ceramic powder and generally ceramic needs a very high power. So, what will do is we try to have this ceramics which will not melt, but it will the metal will melt and the ceramic gets embedded into the liquid metal and then it forms a composite.

So, it is very clear; you can see here you can have multiple nozzles and feeding the powder and then you have a laser which is in the center, which exactly focus is it and then melts it. So, you will have an optics system in between the schematic diagram, we do not show, then this is called as a galvo stage, which swings and sweeps to get the x y plane data.

And here you can see these are the track widths the track width it is pretty interesting you can see the direction of the track width also changes. So, it is 0 orientation, this is 90 orientation maybe, you can have 45 orientation whatever it is and we can start building up the product. And here since it is made out of metal, it is directly it can be used for as a real time usage or this part which comes out is an example for rapid manufacturing.

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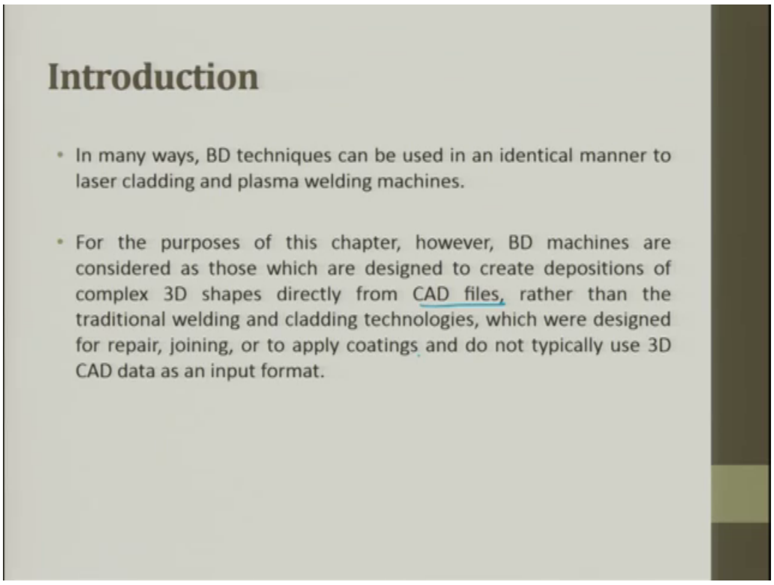


In many ways BD techniques can be used as an identical manner to laser cladding and plasma welding machines. For the purpose of this discussion on a chapter; however BD machines are considered as those which are designed to create depositions of complex 3D directly from CAD files, rather than traditional welding or cladding techniques, which were designed for repairing, joining or applying coatings and do not typically used 3D data as an input format.

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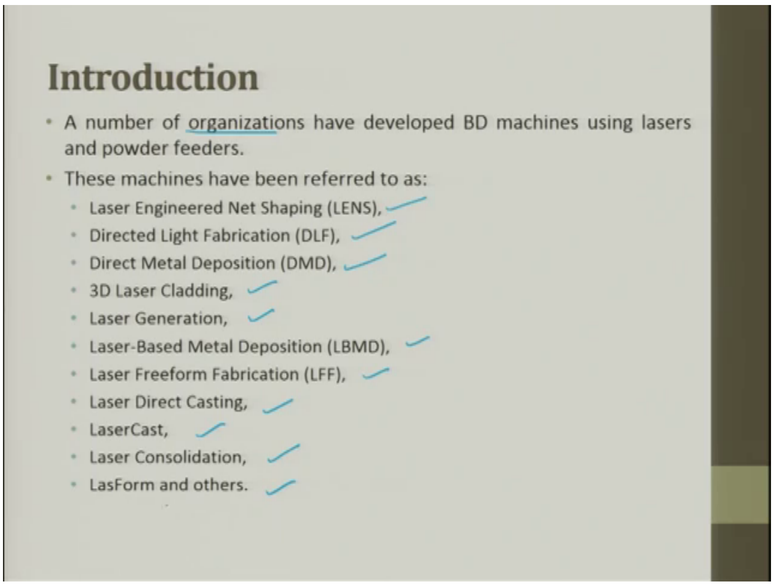

The number of organizations that develop BD machines using laser and powder feeder are there are number of organizations. So, the machines can be referred as LENSE, direct light fabrication, direct metal deposition, 3D cladding, laser generation, laser based metal deposition, laser freeform fabrication, laser direct casting, laser cast, laser consolidation laser less form and others. So, these are some of the machines and the techniques which are available today in under the category of beam delivery system.

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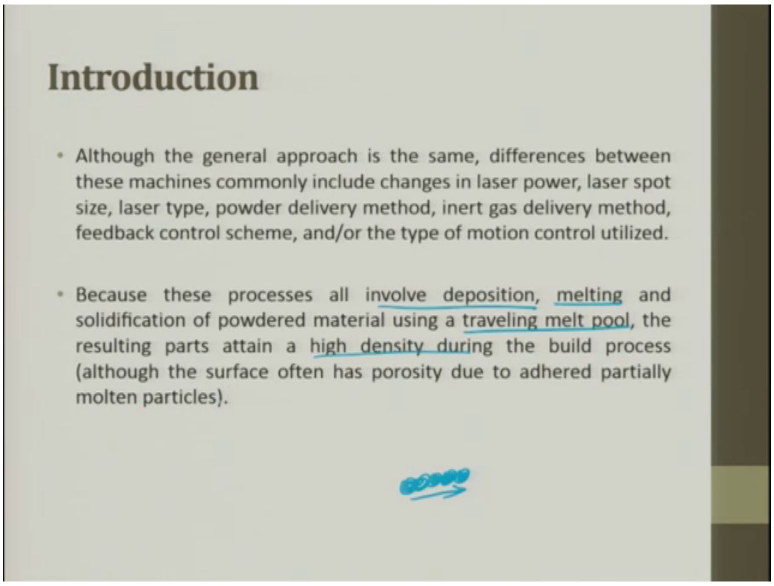


Although the general approach is the same differences between these machines commonly include changes in the laser power, laser spot size, laser type, powder delivery, method inert gas delivery method, feed feedback control scheme and or type of motion control utilized. Motion control is a belt drive lead screw whatever it is.

Because these processes all involve deposition, melting and solidification of powder material using a travelling melt pool, deposition melting travelling melt pool; that means, to say it's not a pool at one point the pool keeps travelling; that means, to say as and when the laser keeps moving it is trying to melt powder and it is going to take it along. Travelling the melt pool the resulting path attain a high density because all the metal powders are now melt. So, it will have been a pool form, so it will have high density during the building process and porosity will be reduced.

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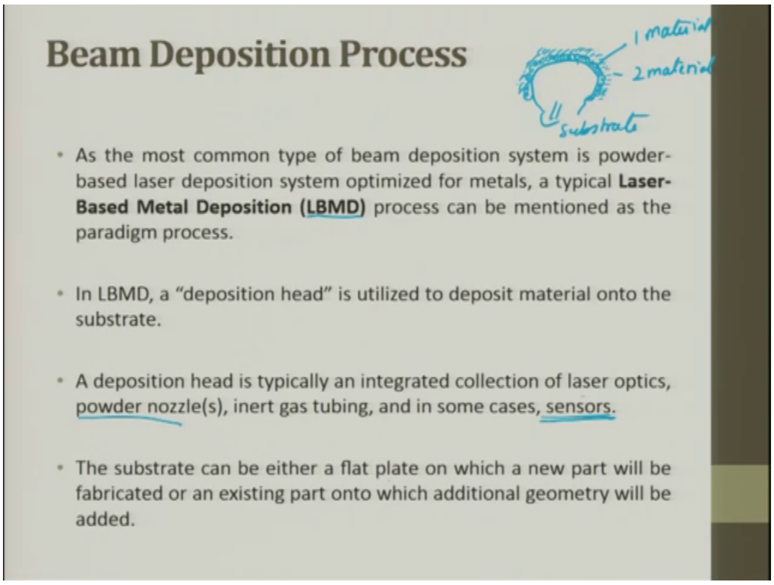


As the most common type of beam deposition system is powder based laser deposition system optimized for metal, a typical Laser Based melting Melts Deposition; LBMD process can be mentioned as the paradigm process. In LBMD, a deposition head is utilized to deposit material on to the substrate. So, here it is interesting you have your substrate you can allow metal to be deposited, it is like laser rework you can say or laser deposition you can say and what you have done is you can have functionally graded materials on top.

So, you can have multiple materials and this is the substrate ok. So, in LBMD, a deposit a deposition head is utilized to deposit material on to the substrate a deposition head is typically an integrated collection of laser optics, powder nozzle, inert gas tubing and in some cases sensors. The laser optics is very important because the laser optics is not the ordinary optics you have to do a coating, this coating should withstand the laser power and the laser passes the laser light passes through this optics and then it tries to heat at the substrate.

Powder nozzle is also a challenge, feeding the powder feeding powder at their at the exact space at the required pressure is also a huge challenge and when you try to flow powder, there is always a problem of agglomeration or clanging of the nozzle, then it leads to defects. In order to overcome this we always try to use a inert gas tubing, this inert gas tubing helps in pressurizing as well as forming a jacket on top of it such that the oxidation does not happen and in some cases, it is also used as sensing.

The substrates can either be flat plates or with a new part will be fabricated or an existing part on which the additional geometry will be added. So, this is what I said here. So, you can see here 1 material, you can see the 2nd material; you can see 2 different materials. So, you can have functionally graded materials there, so it is used for laser cladding or laser deposition.

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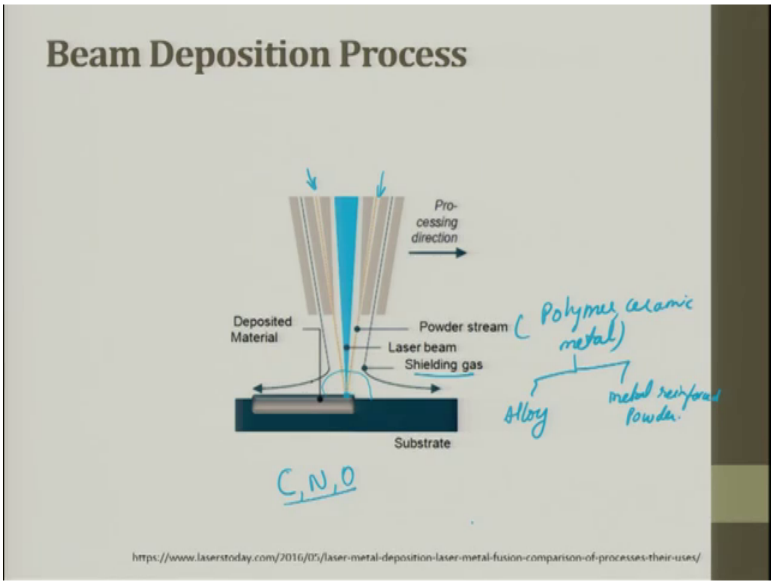


So, the figure clearly says this is a substrate here, it is flat and then you have a deposited material see these deposited materials flow through this these 2 orifices. So, it come at a pressure, so when the particle comes it comes in along the axis it tries to meet and it tries melting at this point, when it starts melting at this point it slowly gets deposited. So, you can have the powder coming from this powders can be polymer again, it can be ceramic, it can be metal.

And when we talk about metal, it can be alloyed metal or it can be also a metal reinforced powder. So, this can come through and it can heat at the laser tape and it can start melting. So, a powder which comes and when this powder melts, it is definitely it will when it reacts with the atmosphere it is going to form compounds. Say for example, you have carbon riched, you have nitrogen riched, you have oxygen riched atmosphere around. So, the powder whatever is there in the melts molten condition where the diffusion can happen very fast. So, it can form carbides or it can form a ceramic material on top of it which might functionally degrade or which might deteriorate the usage of this part in real time.

So, whatever gets generated from here it is directly used as a final product for usage. So, here this air which comes here shielding gas, this gas is basically purchase or it tries to create an atmosphere around. This atmosphere tries to protect the liquid pool from getting reacted with the atmosphere and form these compounds are ceramic materials. So, it is very interesting today, we can make aircraft parts by this process, we can make lot of biomedical parts through this process; we can make lot of automotive parts through this process.

So, you divide decide what is the substrate, you decide the laser power and you decide the powder which is to be deposited. Today we have a huge application using this process ok, so this process is called as laser based metal deposition process. And this is also interesting if you want to do die correction; if you want to do a die correction if there is a brownout die, you want to add material, do some correction and then you want to do some gouging process to remove the excess material; you can use this process and get it done.

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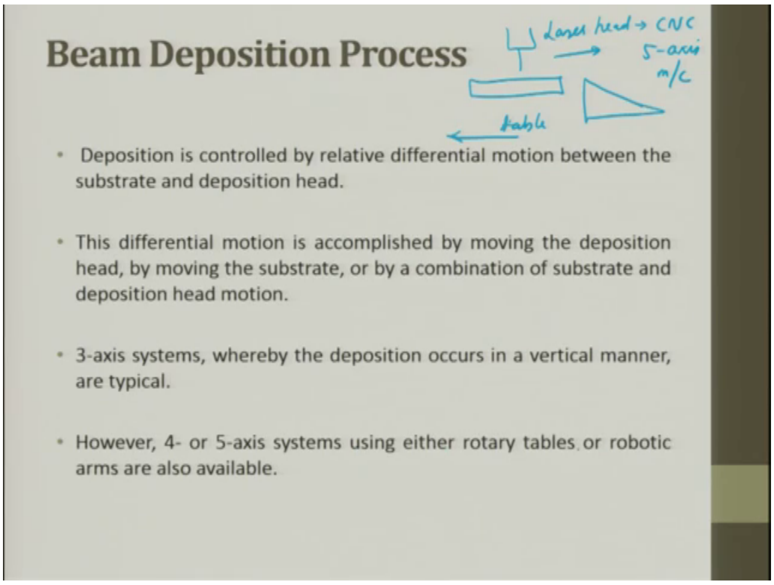


The deposition is controlled by relative differential motion between the substrate and the deposition head. This differential motion is accomplished by moving the deposition head by moving the substrate or by combining the substrate and the deposition head. See it is interesting, if you want you can try, if you want a flat surface you can either move the laser or you can the laser can be moved or the table can be moved, the laser can be moved or the table can be moved.

But if you move both; if you move both what you get easier taper you can. So, what I am trying to says you can also try to have multiple shapes freeform shapes by beside in the movement alone and today the technology has gone so high the laser head is attached with a CNC 5 axis machine. So, it can create any free form surfaces and it can deposit.

This differential motion is accomplished by moving the deposition head, by moving the substrate or by combination of substrate and the deposition head motion. A 3 axis systems, whereby the deposition occurs in a vertical manner are typical. However, 4 or 5 axis system uses either rotary table or robotic arm are also can available today.

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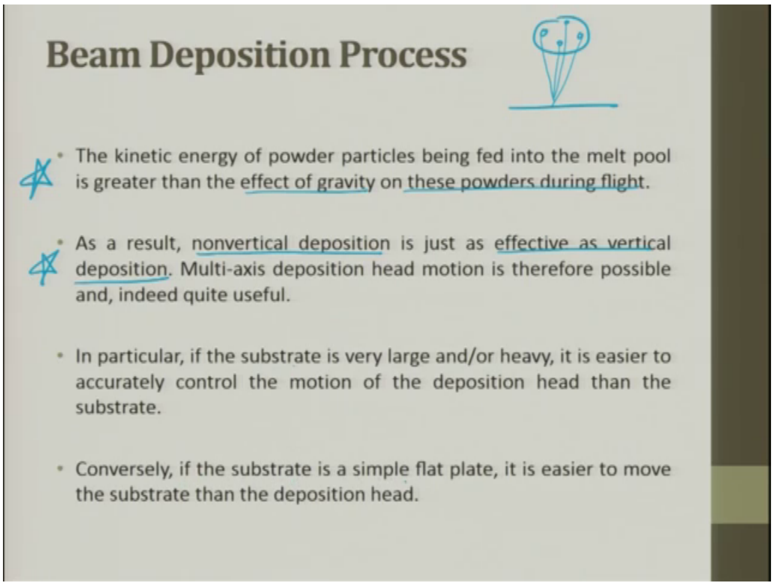


The kinetic energy of the powder particle being fed into the melt pool is greater than the effect of gravity on this powder during flight, understand this point. This is very important. The kinetic energy of the powder particle being fed into the metal pool is greater than the effect of gravity on these powder during flight ok. So, this make sure that it does not there us is a buoyancy which comes because of this buoyancy in the melt pool there is a buoyancy, there is a density difference.

So, the material can be moved at, but on top of it the kinetic energy of the part of particles just goes hits it and then starts moving it. As a result non vertical deposition is just as effective as vertical deposition, very important point. Multi axis deposition head motion is therefore, possible as indeed quiet useful. So, that means, to say if you see a nozzle you will have holes. So, in the there are 4 holes here; so from each of the holes you can start feeding different different powders and this can hit at the surface.

So, this is one way or the other way round is you can have multiple access multiple access deposition heads are this is. In particular, if the substrate is very large and are very heavy, it is easier to accurately control the motion of the deposition head than the substrate. Conversely, if the substrate is a simple flat plate it is easier to move the substrate than the deposition head.

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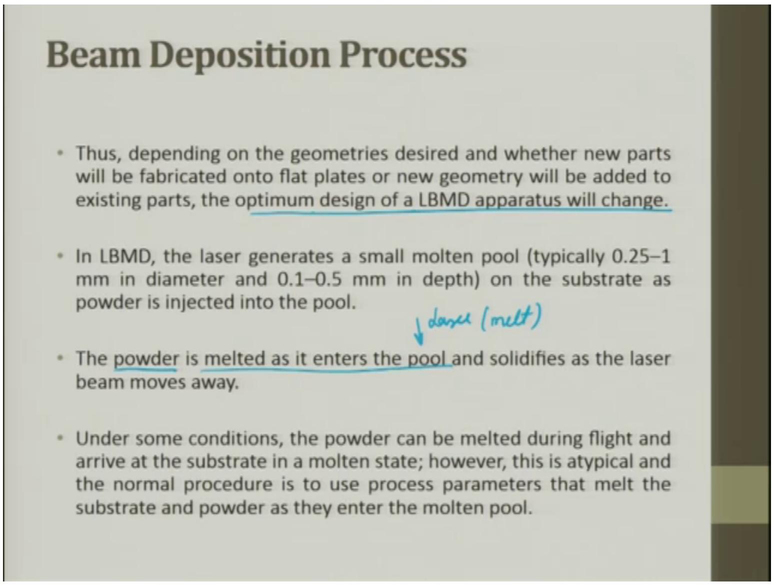


Thus, depending on the geometries desired and whether new parts will be fabricated on to the flat plate or new geometries will be added to the existing part, the optimum design of LBMD apparatus will change, design of the machine will change. The LBMD the laser generates a small molten pool on the substrate as powder is injected into the pool. The powder is melted as it enters the pool, the powder enters the pool is what are the pool you will have a laser which is getting focused, what is pool? Pool is a melts whatever it is and solidifies as the laser beam moves away instantaneously.

Under such conditions the powder can be melted during flights that means, to say before dropping during the flight itself the powder can melt, why does the powder melt? Because a surface area is large the volume is to less, so it can easily melts ok. So, during flight and arrives at the substrate in the molten state; however, this is typically and a normal procedure is to use process parameters that melt the substrate and powder as they enter into the melt pool.

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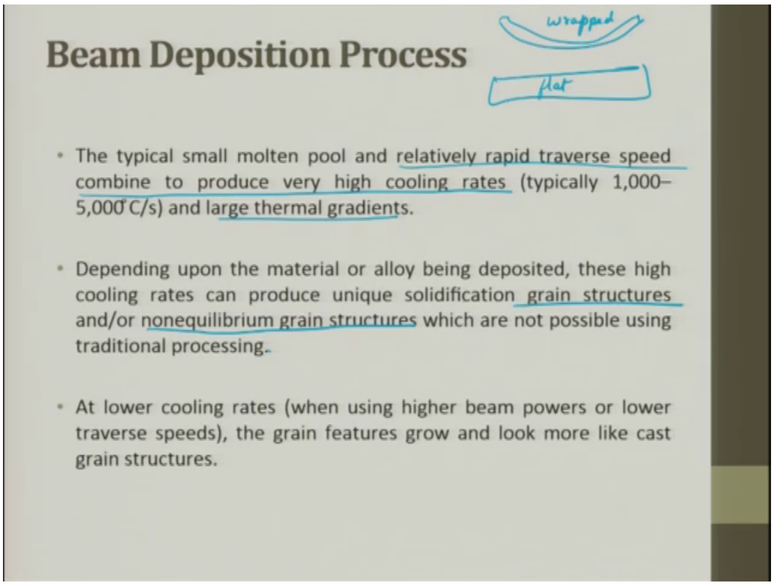


A typical small molten pool and relatively rapid traverse speed combine to produce very high cooling rates and large thermal gradients, rapid traverse speed combine to produce very high cooling rates. So, gradients are created, these gradients are disaster you should try to avoid having large thermal gradients.

Because if you have large thermal gradients, it is going to wrap the surface; you are going to get instead of flat plate you will get something like a wrapped plate ok, this is flat and this is warp, instead of this you will get a wrapped plate. So, large thermal gradient should be avoided. So, for this what we do is we try to do the entire exercise or the plot development in an ambience where the temperature is maintained at a certain level, so that the thermal gradient is avoided.

Depending upon the material or the alloy being deposited, these high cooling rates can produce unique solidification grain structure and or non equilibrium grain structure which are not possible using the traditional process. So, we know by extracting the heat you can try to dictate the grain structure, if you extracted in if you extracted in different different directions or if you if you can a control the extraction of heat.

You are controlling the grain structure, you can create columella grains, you can create; you can create small axial grains uniaxial grains are equiaxial grains you can try to create and this dictates the final property. So by doing this, we can also try to create unique solidification grains structures or non equilibrium grain structures the structure grains structures which you could never ever think about in the normal convention process you can do. Why are these grains structures very important? They play a very important role in creating toughness property; in creating hardness property are your trade off. At lower cooling rates the grains features grow and look like a cast grain structure.

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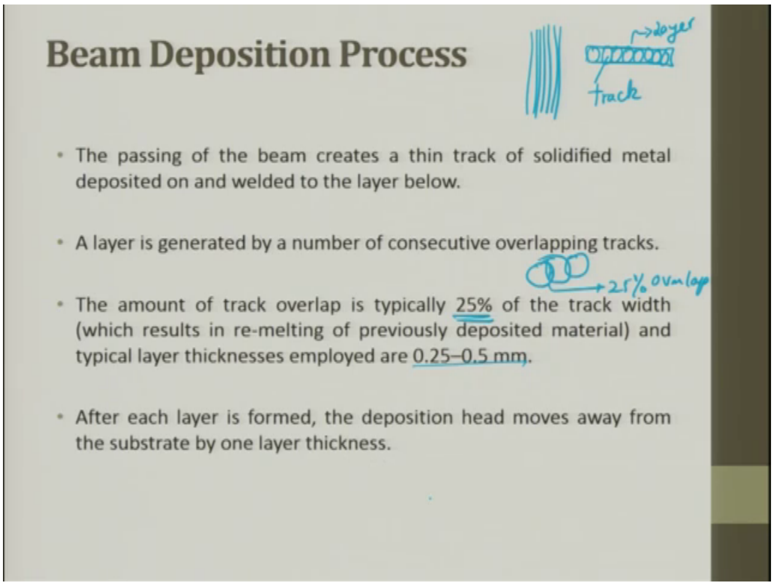


The passing of the beam creates a thin track of solidified metal deposited on and welded to the layer below. A layer is generated by a number of consecutive overlapping tracks ok. So, what your talking about these are the tracks several of these tracks forms a layer, these are the tracks and these are the layers these are tracks and the entire thing is a layer. The amount of track overlap is typically 25 percent, so what are we talking about? One track is typically 25 percent.

So, this helps you to stretch in the track, so this is 25 percent overlap of the track width and typically typical layer thickness employed are 0.25 to 0.5 millimeter. After each layer is formed the deposition head moves away from the substrate by one layer thickness.

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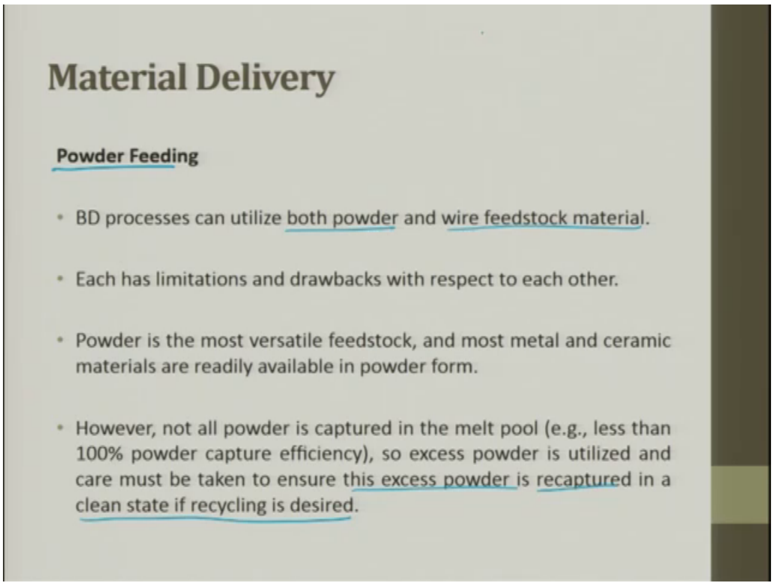


Powder feeding is a very very challenging task, powder feeding because the powder are smaller in size, so they can easily fly off they can easily get agglomerated when agglomerates it clocks. So, powder feeding is a huge challenge and if you have multiple different different varieties of powders falling, the flow rate between them has to be controlled. The beam delivery processes can utilize both powder and wire stock feeding like FDM process wire stock feeding.

Each has a limitation and drawback with respect to each other. The powder is the most versatile feed stock and most metal and ceramic materials are readily available in powder form because you do atomization metal; metal you melts you melt and atomize like how do you spray the injection nozzle in your cylinder. So, like that you can also try to atomize and get metal powders.

However, not all powders is captured in the melt pool, so excess powder is utilized and care must be taken to ensure that the excess powder is recaptured and clean state if recycle is required. So, that means, to say all these if you dump lot of powder it need not at all of them will be more melt in. So, you will try to you will have only at track along the track it melts and rest of the powder should be ex removed, so that it can be used to for a melting.

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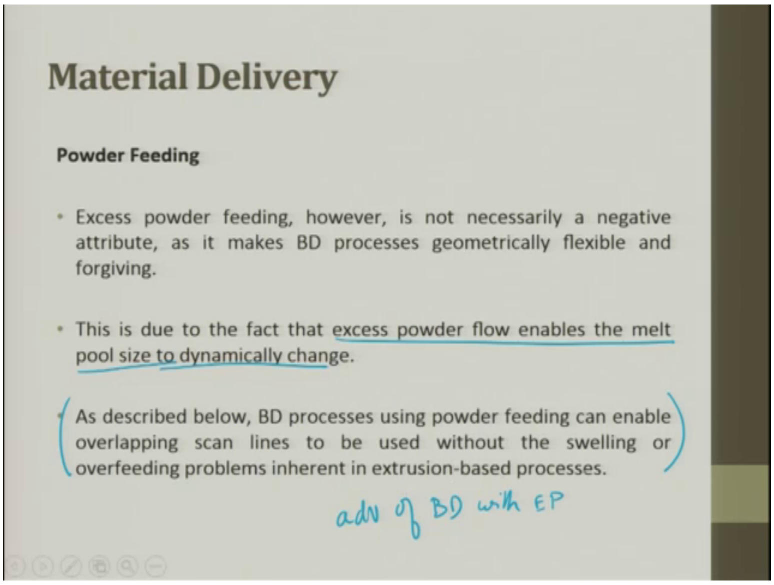


Excess powder feeding; however, is not necessarily a negative attribute, as it makes beam delivery process geometrically flexible and for giving. This is due to the fact that excess powder flow enables the melt pool size to dynamically change. So, excess powder flow dynamically changes the melt pool, when you dynamically change the melt pool you do not know whether you get a larger track or a smaller track.

As described below, beam delivery process using powder feeding can enable overlapping scan lines to be used without the swelling or overfeeding problem inherent in the extrusion based processes. This is the advantage of BD system with EP system, EP is Extrusion based Processes.

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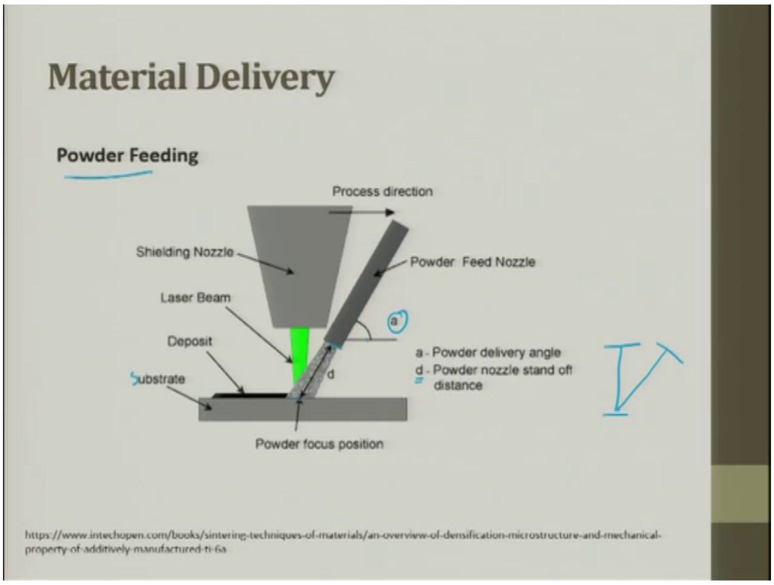


So, powder feeding, so if you see that so this is the shielding nozzle, this is the laser beam and when the laser beam you are feeding the powder from here, so powder melts and it gets deposited. So, this is a substrate and powder feeding position you can see this is at an angle a; a is the powder delivery angle this is 1 and d is the powder nozzle standoff distance. This is the standoff distance, interestingly standoff distance generally when you speak it is vertical, but here you will have at an angle. So, this is d and the nozzle delivery angle is a.

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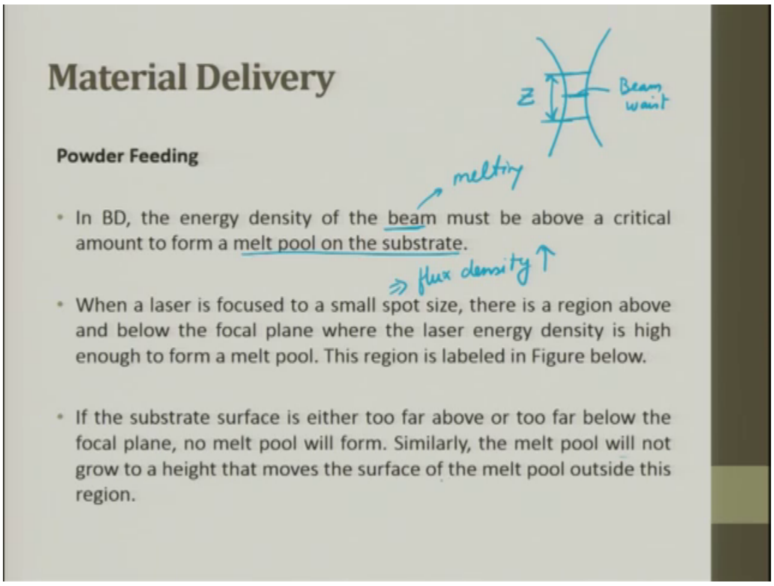

In BD the energy density of the beam must be above a critical amount to form a melt pool on the surface. So, it depends on the laser beam power laser beam because melting, it has to help in melting. When the laser is focused on a small laser spot flux density increases, there is a region above and below the focal plane where the laser energy density is high enough to form a melts pool. This region is labeled in the figure we will see the figure.

So, what are we talking about this is the laser beam and in the laser beam this is the waist, this is a beam waist and this is what above and below the focal plane we have a small area, but this z will be too small will be in few millimeters ok. So, here the reason above and below the focal plane where the laser energy is high enough to melt the, melt pool this ok.

If the substrate surface is either too far above or too far below the focal plane no, melting will happen, so if it is above this or below this no melting will happen. Similarly, if the melts pool will not grow to a height, that moves the surface of the melting pool outside the region.

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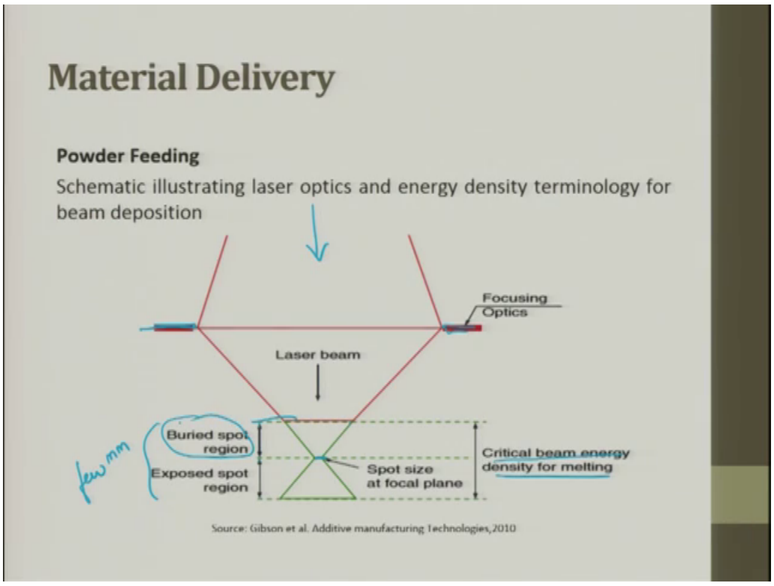


So, this is what we were trying to talk about. So, here as focus optics, so the laser beam comes from here. So, you put an optics; you put an optics, so the optics will they converts. So, here is the, this is the buried spot region, this is the exposed spot region, this is the spot. So, from here to here this is a critical beam energy density for melting this and this is as I told you this will be few millimeters ok, so you can move up and down.

Suppose, you move less than this or above this you will have always have a defocusing, this defocusing will not help you to melts the material. It will just try to allow you to heat, if you are smart we can use this for heating down the layer such that the temperature gradient is not created much and you can start joining with the previous layer. So, here it is very clear it is left to you to play with optics and the focal plane distance to get a proper melt.

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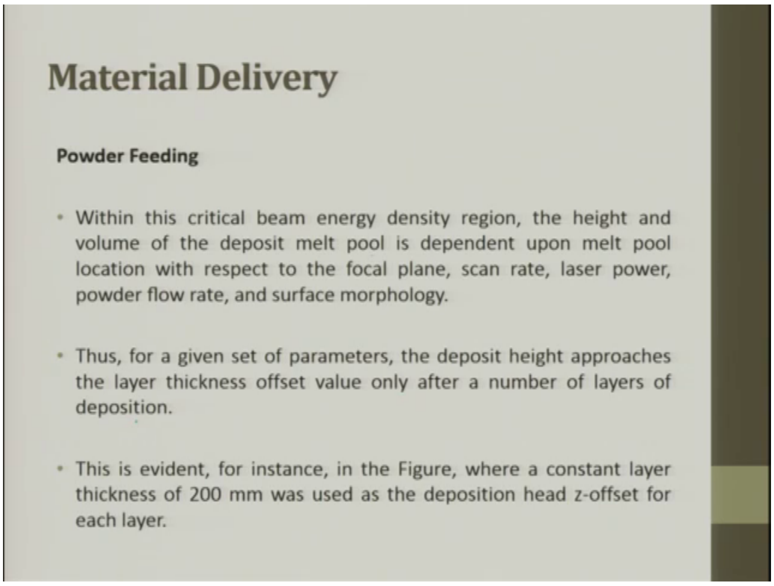


Within this critical beam energy density region the height and the volume of the deposited melt pool is dependent upon melt pool location with respect to the focal plane, scanning rate, laser power, powder laser flow rate and surface morphology. Thus for a given set of parameters, the deposit height approaches the layer thickness offset value only after a number of layer deposition. It is evident for instance in the figure where a constant layer thickness of 200 millimeters was used as a deposition head z-offset for each layer.

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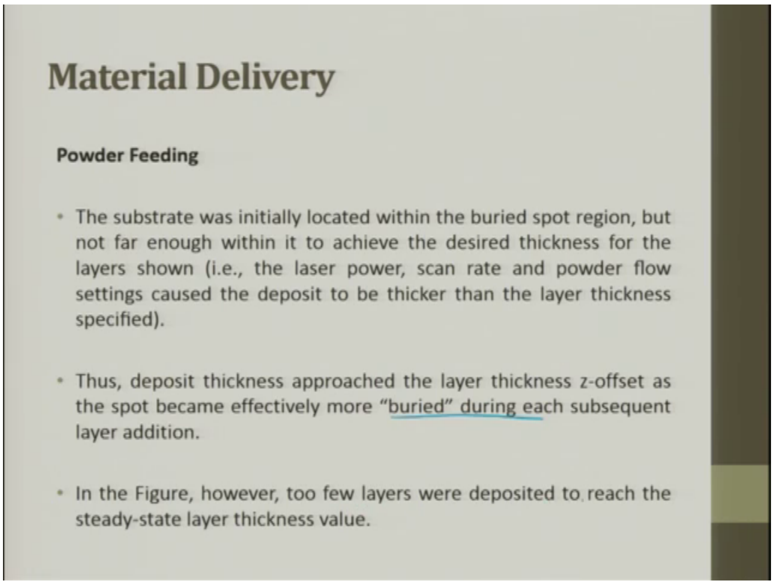


The substrate was initially located within the buried spot region. So, let us go back and see the buried spot region, but no for enough within it to achieve the desired thickness for the layer show as a layer shown. Thus depositing thickness approach the layer thickness z offset as the spot becomes effectively more buried during each subsequent layer addition; however, too few layers were deposited to reach the steady state layer thickness value.

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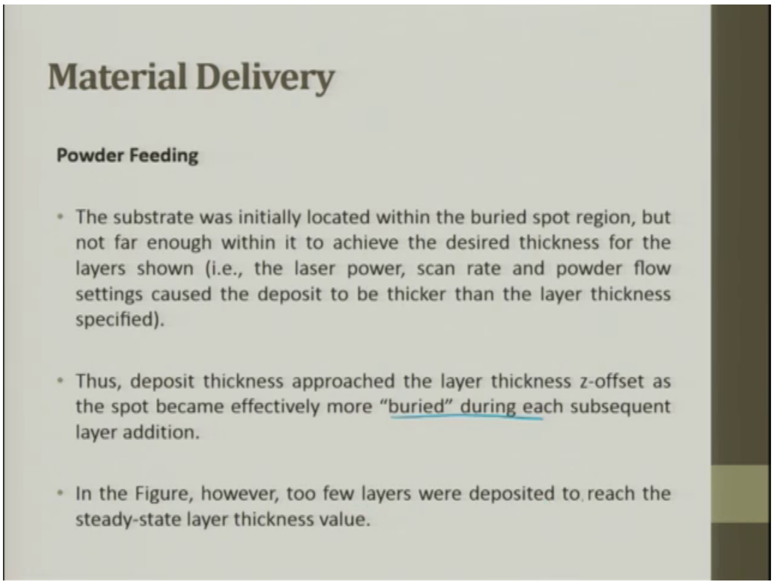

If the laser and the scanning parameter setting used are inherently incapable of producing a deposit thickness at least as thick as the layer thickness of is z offset value, subsequent layer will become thinner and thinner to be noted. If the laser and the scanning parameter setting used are inherently in capable of producing a deposit thickness at least as thick as the layer thickness z offset value, subsequent layer will become thinner and thinner.

Eventually, no deposit will occur when scanning for the next layer starts outside the critical energy density region. In practice, when the first layer is formed on the substrate, the laser focal plane is typically buried below the surface of the substrate approximately 1 millimeter buried below. So, we are just trying to play with the height, make sure between 2 layer there is proper enough of gradient, melt pool happens on the top and heating happens on the bottom and when the next layer comes there is a shift in the layer.

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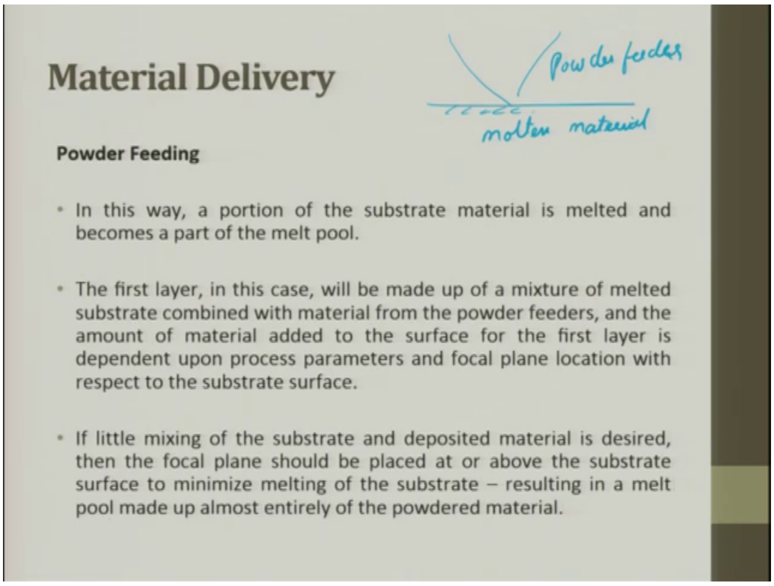


In this way a portion of the substrate material is melted and becomes a part of the melt pool. The first layer, in this case will be made up to the mixture of melted substrate combined with the material from the powder feeder. So, one place it is all molten, now a new powder is sitting, so with the material from the powder feeder this is powder feeder; powder feeder, this is molten material powder feeder and the amount of material added to the surface for the first layer is dependent upon process parameters and focal plane location with respect to the substrate surface.

If little mixing of the substrate and deposited material is desired, then the focal plane should be placed at or above the substrate surface to minimize melting of the substrate resulting in the melting pool made up almost entirely of the powder material. So, it is just playing with a focal plane and depositing layer. So, what happens when the laser hits the powder? It creates a melt pool.

So, now there is a liquid metal, so in this liquid metal when you try to add material that is what is you are talking about. If little mixing of the substrate and the deposited material is desired like in laser cladding, then the focal plane should be placed at or above the substrate surface to minimize melting of the substrate, resulting in a melt pool made up of almost entirely with the powder material.

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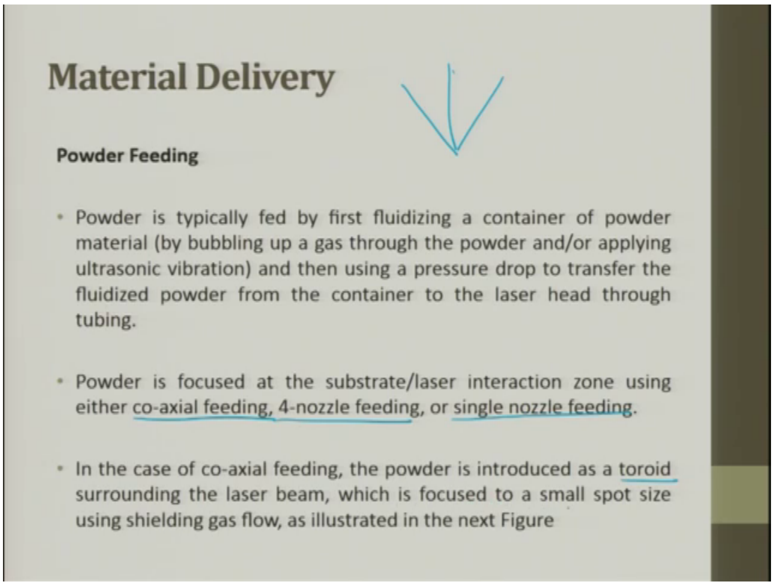


The powder is typically fed by first fluidized fed by first fluidizing a container of powder material and then using a pressure drop to transfer the fluidized powder from the container to the laser head through the tubing. So, when you start flowing the powder it is not necessary the powder should keep flowing because of gravity. So, here you have to create a pressure drop, so that the powder flows properly and it hits at the liquid metal.

The powder is focused at the substrate laser interaction zone using a co axial feeding, 4 nozzle feeding or a single nozzle feeding coaxial means it has multiple access around the axis. There are multiple feeding points co axial feeding and 4-nozzle feeding or a single nozzle feeding. In the case of coaxial feeding, the powder is introduced as a toroid surrounding the laser beam, which is focus to a small laser spot using shielding gas flow as illustrated in the next figure, so this is what it is.

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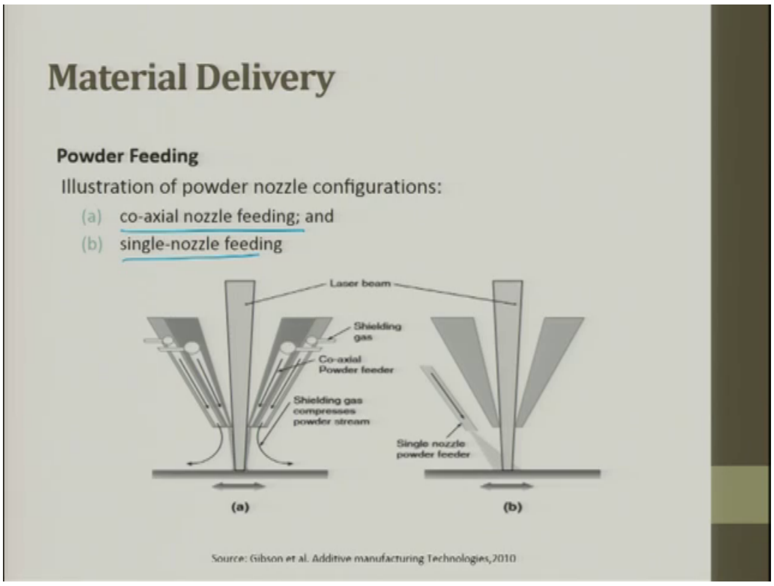


So, you can see a coaxial feed, this is co axial and b is single nozzle, so this is single nozzle. So, you can see here this or shielding gases switch come and here are powders which come powders can be same powder, powders can be alloy powder, so whatever it is you can do is it no issues. So, this is a diagram is talks about coaxial feeding, this is talking about a single axial nozzle feeding.

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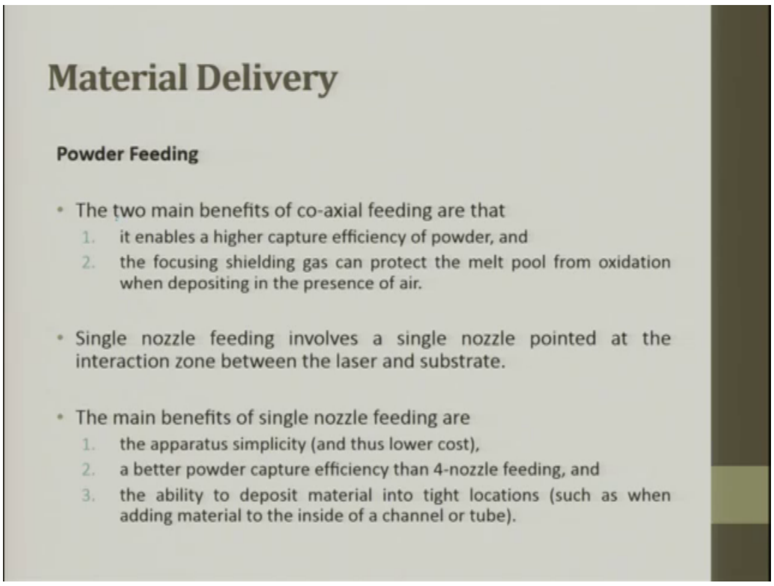

The powder feeding the two main benefits of coaxial feeding are that, it enables a higher capture efficiency of the powder, the focusing shielding gas can protect the melt pool form oxidation when deposit in the presence of air. The single nozzle feeding involves a single nozzle point at the interaction zone between the laser and the substrate. The main benefit of a single nozzle feeding are the apparatus simplicity, a better powder capture efficiency than four nozzle feeding, the ability to deposit material into tight locations. So, these are some of the advantages of single nozzle feeding and as compared to that of coaxial feeding.

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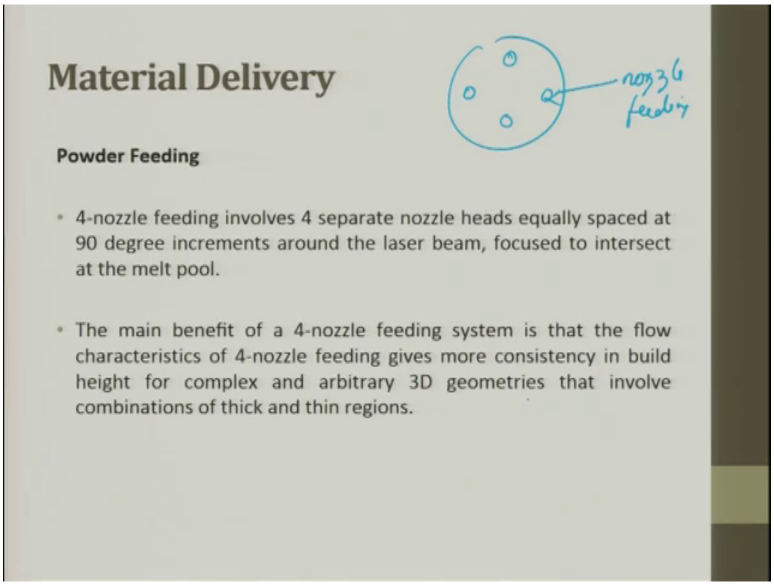


4 nozzle feed involves 4 separate nozzle heads equally spaced at 90 degrees increment around the laser beam, so it is something like this. Focus to interest intersect at the melt pool, these are all nozzle feeding. The main benefit of 4 nozzle feeding system is that the flow characteristics of 4 nozzle feed use more consistency in building height of complex and arbitrary 3D geometries that involve a combination of thick and thin layers.

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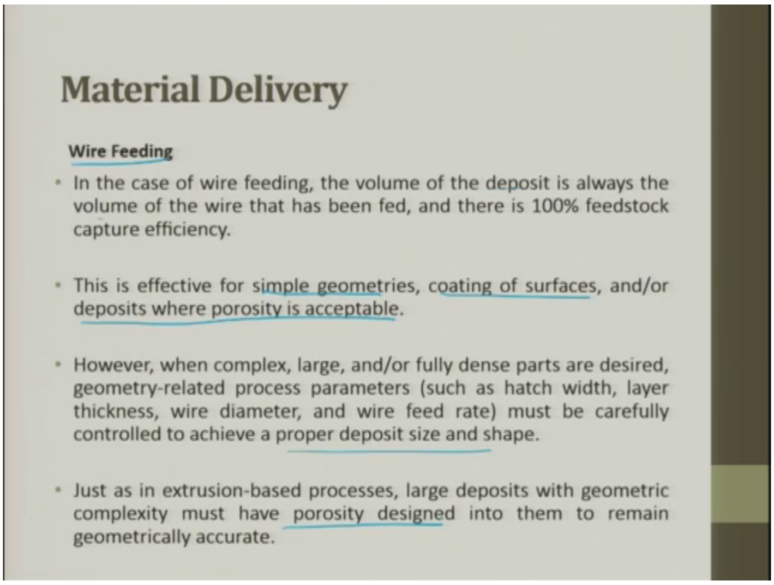


So, and if you see interestingly all the product which are produced out of this process is directly used for application. When we use metals it directly gets for example, people make crown which is put on top of a teeth directly through this process, the people make implants through this process, people directly make dye repair through this process, people make small micro channels for micro fluidic applications or for heat exchangers through this process, people make medical devices through this process, so lot of interesting things are coming out.

In the case of wire feeding, the volume of the deposit is always the volume of the wire that has been fed and here is 100 percent feedstock capture efficiency which is not there in the powder form. This is effective for simple geometries, coating of surfaces and or deposits where porosity is acceptable; simple geometry coating of surfaces and or deposits where porosity is acceptable.

However, when complex large and fully dense parts are desired geometry related process parameters must be carefully control to achieve a proper deposit size and shape. Just in extrusion based process large deposits with geometric complexity must have porosity designed into them to remind geometrically accurate.

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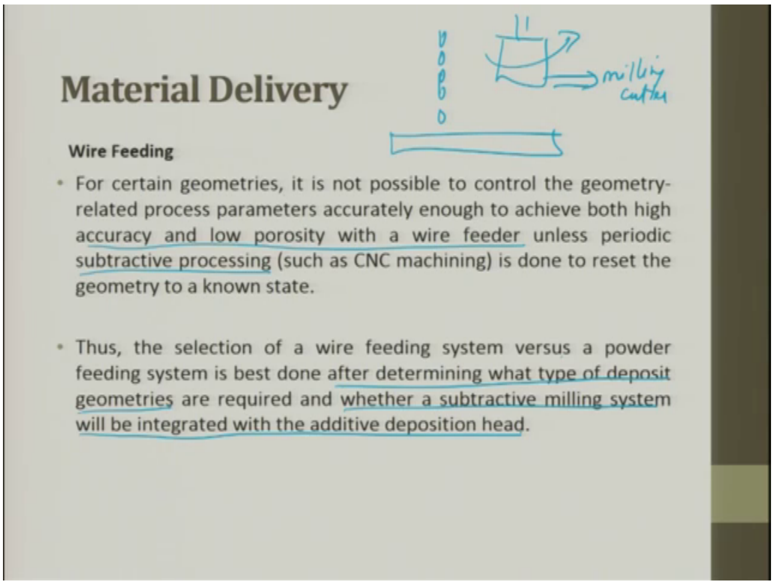


For certain geometries, it is not possible to control the geometric related process parameters accurately enough to achieve both high accuracy and low porosity with wire feeding unless periodic subtractive processes is done so; that means, to say you deposit and then you have a milling cutter which rotates and cuts. So, you have deposited on top of a surface this is a milling cutter. So, this cutter after deposition comes here, machine set reverse the undulation on the surface and allow the next wrap to come in, so is done to reset the geometry in the state.

Thus the selection of wire feeding system versus powder feeding system is best done after determining what type of deposit geometries are required, whether you a subtractive milling system will be integrated with the additive process head. This is if cannot be done should go for powder, if milling along with the wire feed if you can integrate a milling cutter then look for such systems.

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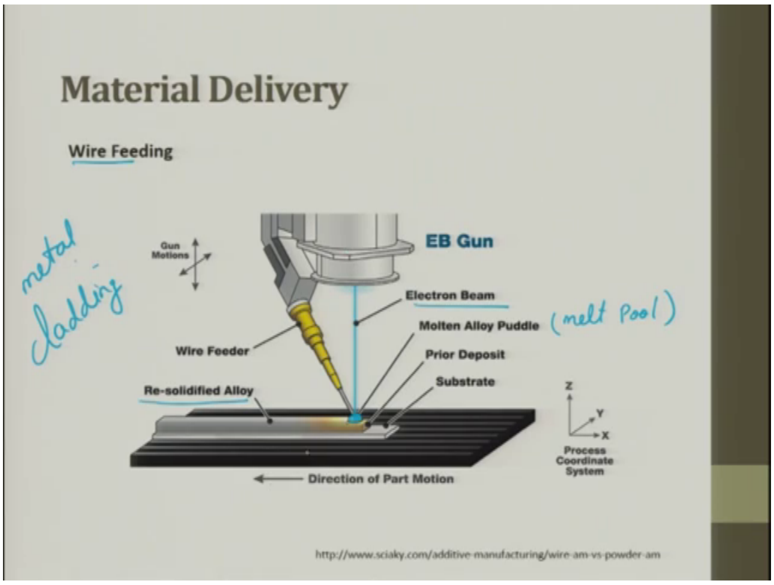


So, wire feed, so this is the wire which is getting fed it looks like your make system and take system. So, this is a wire feeding coming up here is a laser, so this laser or the electron beam, so it comes and hits at the pool and here it melts the here is a melt pool we talk about. So, this is the molten they call it as puddle we will call it as melts pool. So, this is this is the wire coming here electron beam; electron beam can be replaced by laser.

So, this is done prior; that means, to say before it is now it is moving side is deposited prior and here is a substrate. If you want to have cladding metal cladding, then this process can be effectively used for doing it, so here is resolidified alloy. So, this is at the bottom, so you can get it done. So, here is electron beam for you which can do the process. This is the direction motion you can move the path, you can move the electron beam, you can move both also to get the required output.

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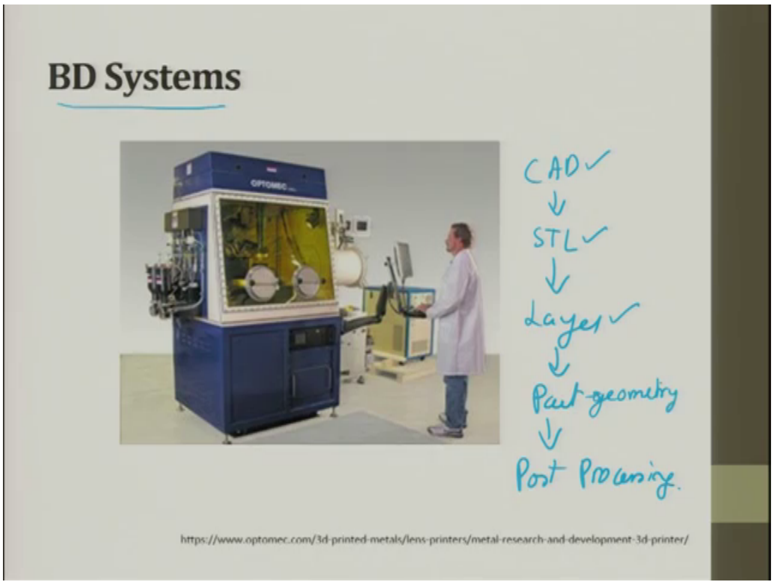


So, here is a typical BD system, so this is how the entire system looks like and you have the CAD is fed here. So, the CAD is come it so CAD, CAD to STL, STL to layer, layer to part, part to post process is done in this machine. So, CAD, STL, layer cutting is done and then it is fed to the machine the part geometry is getting developed in this machine, so where we use metal wire for or wire feeder for doing it.

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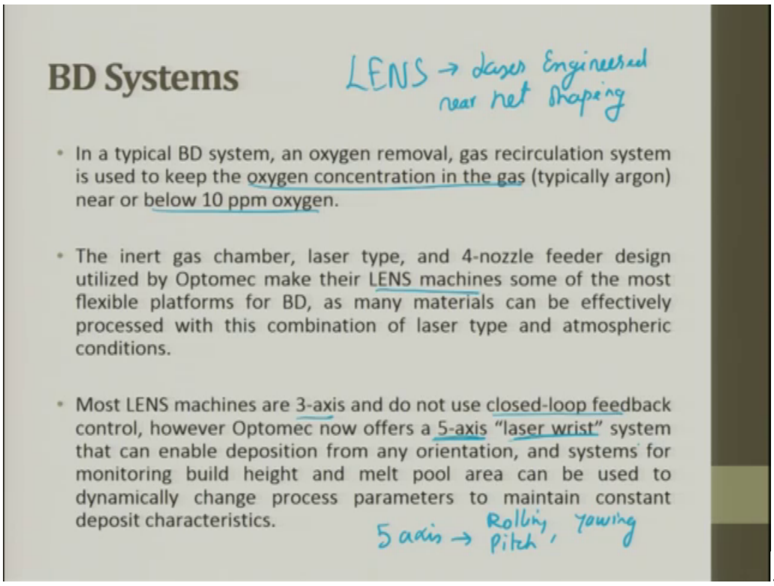


In the typical BD system, an oxygen removal or a gas recirculation system is used to keep the oxygen concentration in the gas nearly below to 10 ppm oxygen. The inert gas chamber, the laser type, 4 nozzle feeding design utilized by Optomec makes the LENS machine, LENS; LENS is expanded has Laser Engineered Net Shaping or near net shaping people also call it as near net shaping or net shaping ok, LENS machine some of the most flexible platforms for BD, as many materials can be effectively processed with this combination of laser type and atmospheric condition.

Most LENS machines are 3 axis and do not use a closed loop feedback control; however, Optomec now offers 5 axis laser wrist. So, which has all freedoms when we talk about 5 axis you have rolling motion, pitching motion and yawing motion. So, this will try to give you all possible orientation, so that you can develop the object and get it have, that can enable deposition from an orientation and systems for monitoring built height and melt pool area can be used to dynamically change process parameters to maintain constant deposition characteristics.

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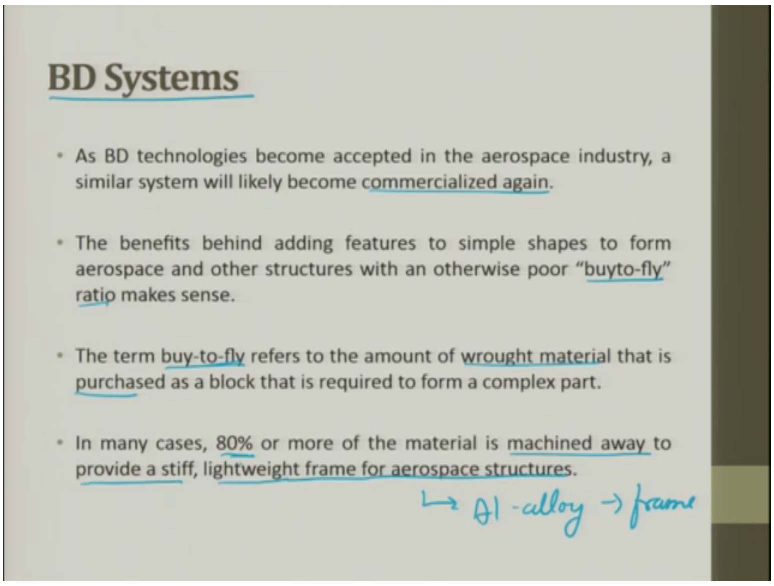


As BD technologies become accepted in the aerospace industry, a similar system will likely become commercialized again. The benefit behind adding features to simple shapes to form to form aerospace and other structures with an otherwise poor buy to fly ratio make sense. So, now, what is happening? Very complex geometry can be easily made through using this lens process or this beam delivery process direct metal.

So, now you can see GE or air bus claiming themselves they have reduce the weight of the machine by 30 percent, they have wrapped up the production rate by 30 percent because of this rapid manufacturing machines coming into existence. The term buy to fly refers to amount of wrought materials that is purchased as a block that is required to form a complex part is called as buy to fly. The amount of wrought and wrought materials that is purchased as a block then you tried to do subtract to process and then try to make a complex shape.

In many cases 80 percent or more of the material is machined away to provide a stiff, lightweight frame for the aerospace structure, this is what happens with aluminium alloys for frames. We remove 80 percent of the material, so now by using this beam delivery system direct the position we can try to make energy efficient aerospace materials.

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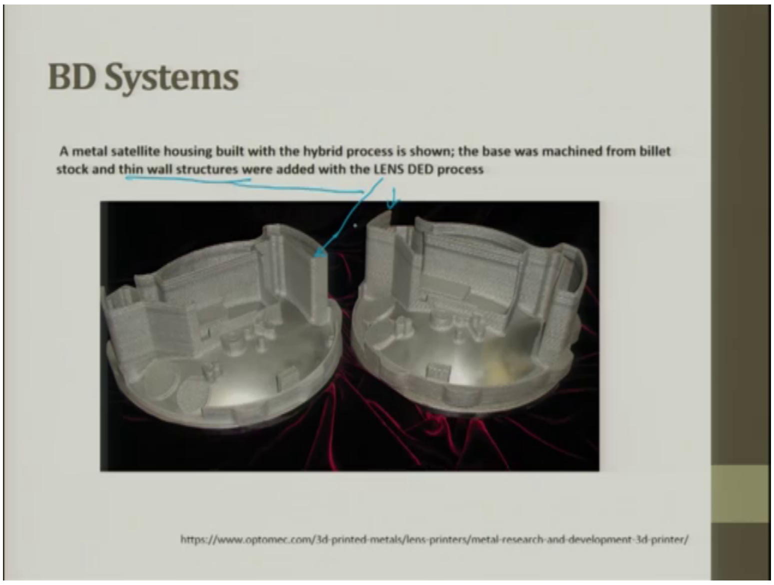


So, this is a metal satellite housing built with the hybrid process is shown, the base was machined from billet stock and the thin walls structures were added with the LENS DED process. So, thin wall structure this is all done by LENS, these are thin wall structures.

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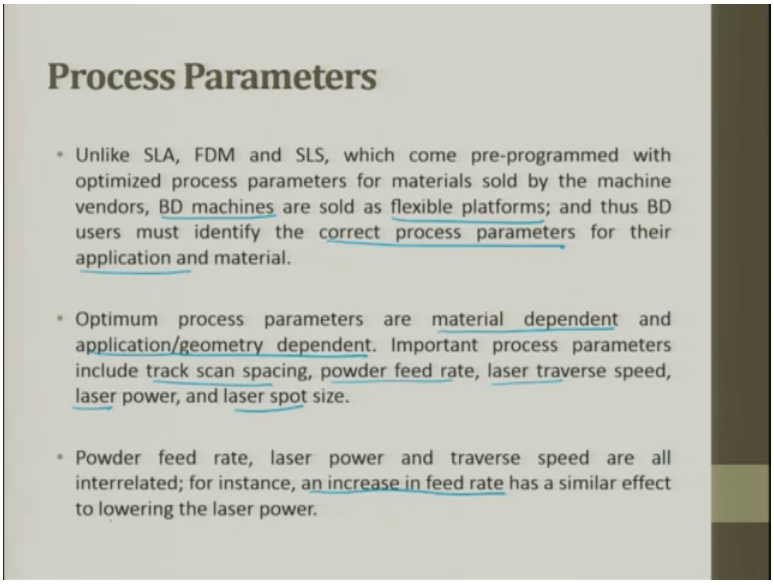


So, process parameter unlike SLA, FDM, SLS which comes pre programmed with an optimized process parameters for material sold by the machine vendor, BD process are sold as flexible platforms, thus BD users must identify the correct process parameter for their application. Optimum process parameters are material dependent application geometry dependent.

Important process parameters are tracks scan spacing, powder feed rate, laser traverse, laser power and laser spot size. The powder feed rate, laser power, traverse speed are interrelated for instance an increase in the feed rate as a similar effect to lower the laser power. So, these two are interrelated, so you should be careful.

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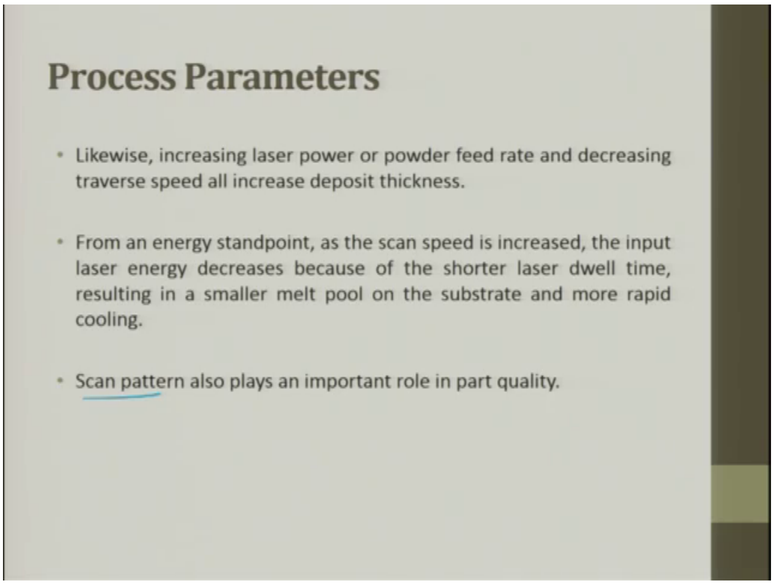


Likewise, increasing the laser power or powder feed rate and decreasing the traverse speed all increases deposition thickness, so you have to make a tradeoff between thus. From an energy standpoint of you, as the scanning speed is increased the input laser energy decreases because shorter laser dwell time resulting in a smaller melt pools of the substrate and more rapid cooling.

So, basically when you quickly scan it is going to be fast movement laser interacting with a material is less. So, low amount of energy is applied on the surface low melt pool, so this will try to give you thin layers are it may produced defects. The scanning pattern also plays a very very important role as far as a quality of the product.

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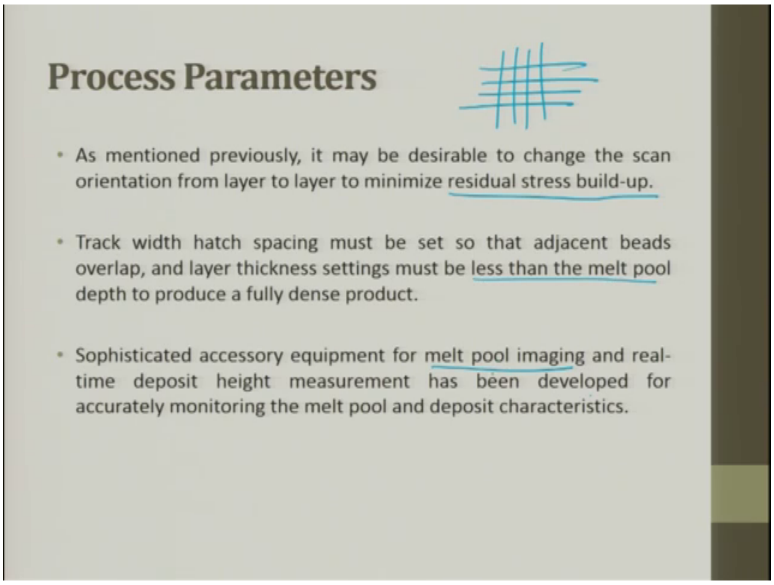


It may be desirable to change the scanning orientation from layer to layer to minimize the residual stress build up. So, that is why you see we saw earlier it's a 0 degrees, 90 degrees, 45 degrees orientation. The track width hatch spacing must be set to, so that the adjacent beading overlaps and the laser thickness setting must be less than the melt pool depth to produce a fully dense products. Sophisticated accessory equipments for melt pool imaging and real time deposition height measurement have been developed, what is the reaction or what is the temperature at the melt pool because you have there is more amount of melt pool.

So, this is going to create more amount of melting and solidification and we have to know balance set up and the other thing is all the melt whatever happens when it solidifies it does not giving uniform height thickness. So, we need to measure the melt pool temperature using imaging techniques and measure the real time height, so that we know how what is a flow of the powder to be given.

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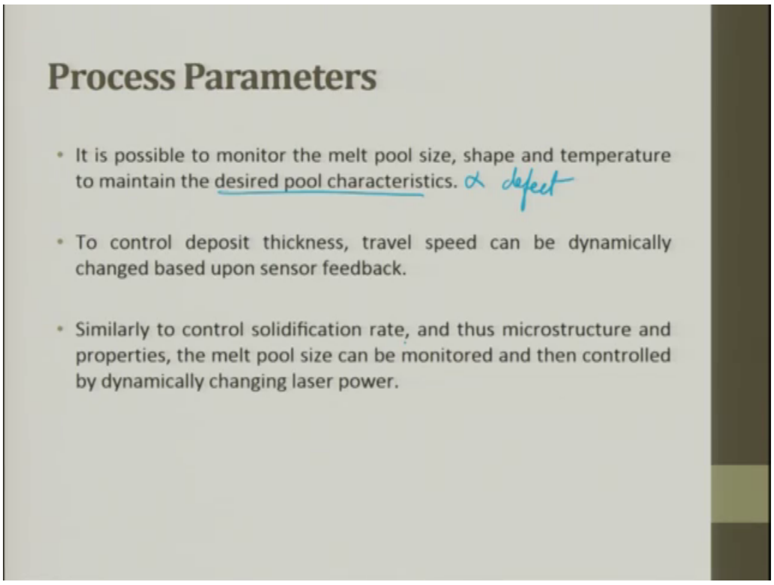


It is possible to monitor the melt pool size shape and temperature to maintain the desire pool characteristics, the pool characteristics is directly proportion to the defect. To control deposition thickness travel speed can be dynamically changed based upon the sensor feedback. Similar to the control certification rate the microstructure and the properties also changes.

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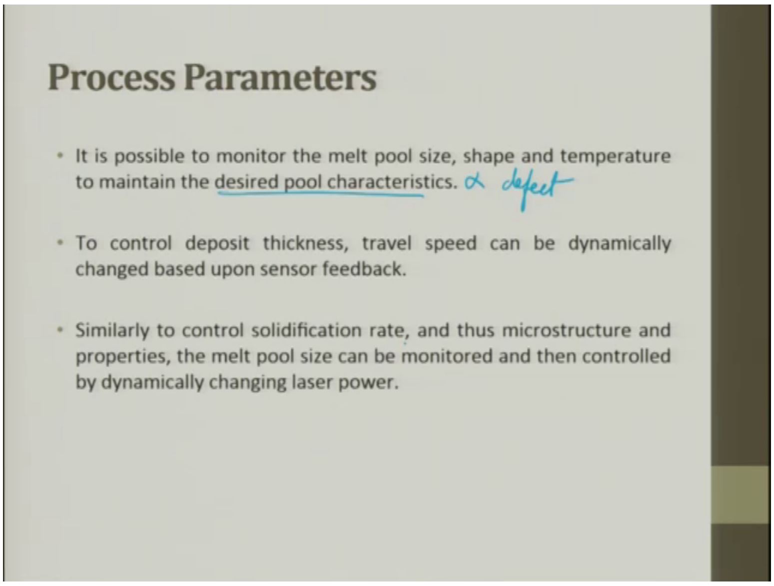


Part produced in beam deposition process exhibits exhibit cast microstructure; that means, to say columella (Refer Time: 48:55) whatever. The processing condition influence the solidification microstructure in way that can be predicted in part by rapid solidification theory. Grain engineering is a new latest topics which is in the research front, people have identified if I start doing engineering on the grain size distribution green shape I can dictate the material property.

For a specific material, solidification microstructure essentially depends on the local solidification condition especially the solidification rate and the temperature gradient at the solid liquid interface. By calculating the solidification rate and the thermal gradient we can try to play with the predict or play with the microstructure.

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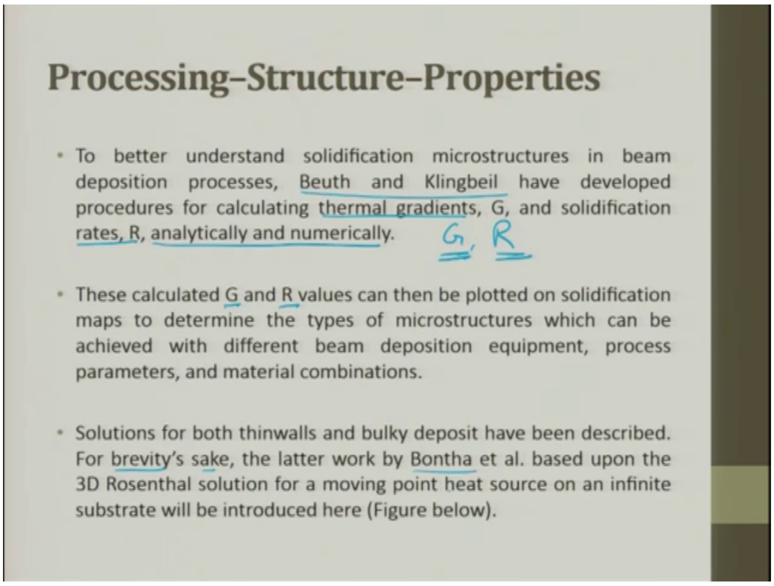


For better understanding of microstructure in beam deposition process, Beuth and Klingbeil have developed a procedure for calculating thermal gradient, G and solidification rate R analytically and numerically. So, there is a factor called as G factor and R factor, thermal gradient and solidification rate ok.

The calculated G and R values can be plotted on solidification map to determine the type of microstructure which can be achieved with different beam deposition equipments, process parameter and material composition; this dictates the quality of the product. Solution of both thin wall and bulk deposition has been described. For brevity's sake a later work of Bontha et al based upon the 3D Rosenthal solution for a moving point heat source on an infinite substrate will be introduced here, so this is what is the Rosenthal effect.

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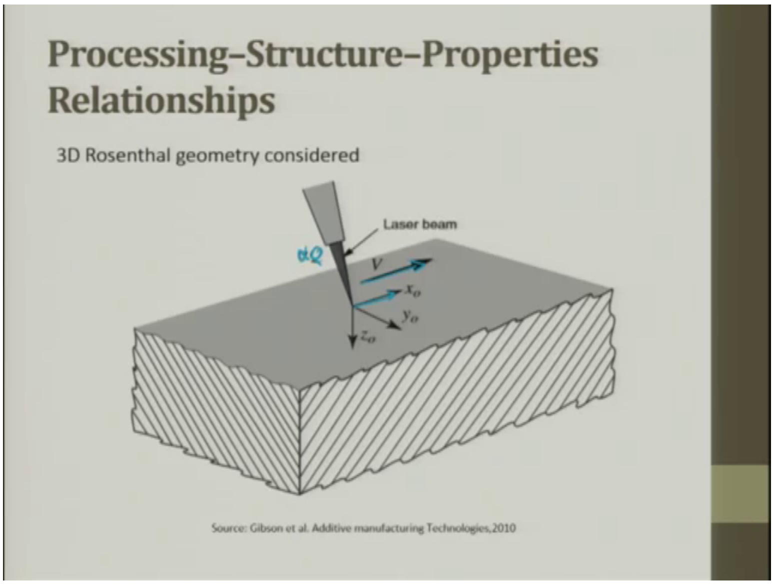


So, Rosenthal geometry is there this is a laser beam it moves at a velocity V. So, at x plane, y plane, z plane here is the alpha and Q heat and the and the thermal conductivity.

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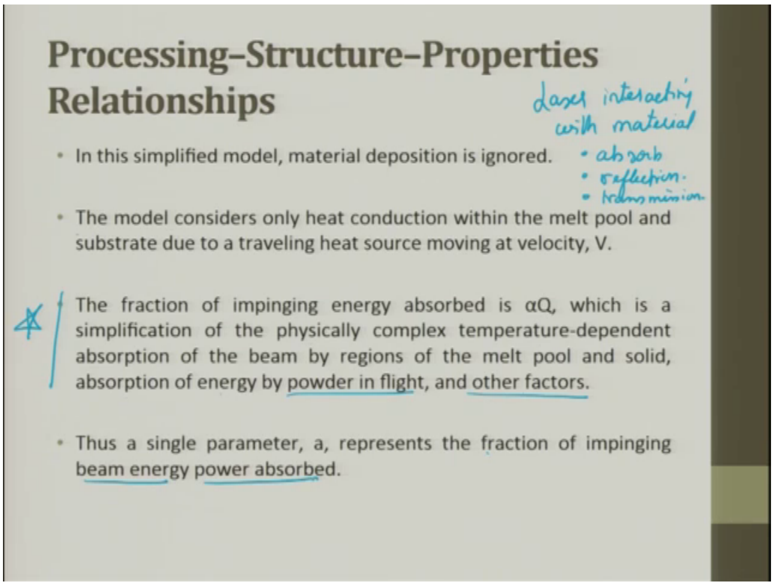


The simplest model material deposition is include ignore, the model considers only heat conduction with the melt pool there is convection and radiation, but we take only conduction and substrate due to the travel heat source moving with a velocity of V.

The fraction of the impeachment energy absorbed is alpha Q, which is a simplification of the physical complex temperature dependent absorption of the laser by region of melt pool and solidification, absorption of energy by powder in flight and other factors this is very important. See when we talk about laser interacting with material, we have absorption, then we have reflection, we have transmission. The laser when it interacts with material it can undergo anything it can absorb it can reflect or it can transmit and go.

So, we have to find out what is the ratio? And it this abortion absorptivity the light interaction absorptivity it depends from material to material it is not a constant and also it depends on the wavelength of the laser. So, thus a single parameter a represents the fraction of impinging laser beam powered absorption.

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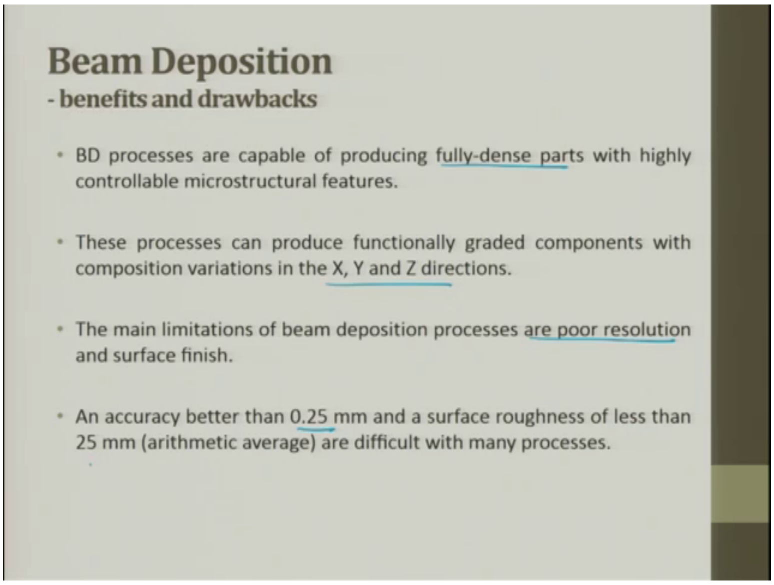


Beam delivery process are capable of producing fully dense part with highly controllable microstructure. This process can produce functionally graded components in the X and Y Z direction. The main limitation of the beam deposition process are poor resolution and surface finish. The accuracy is which we talked about it is point 0.25 millimeter surface roughness of less than 25 millimeter are difficult for this process.

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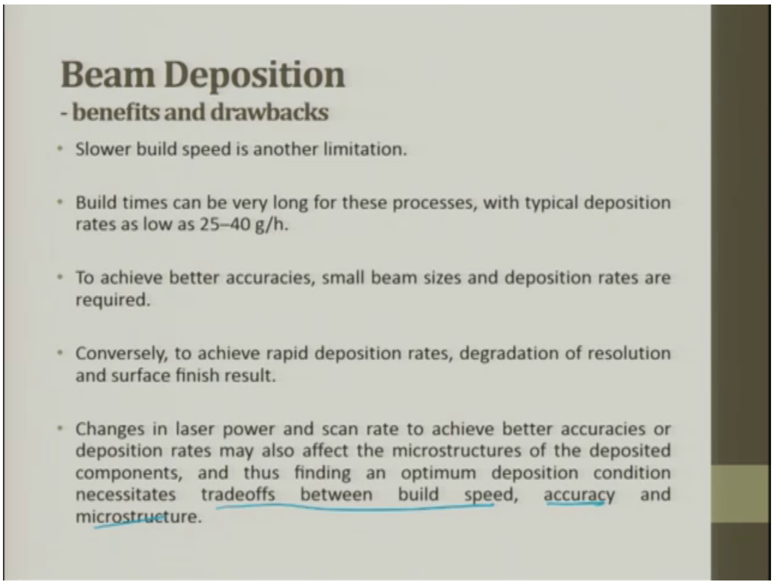


The benefits and the drawbacks, slower beam speed slower build speed is another limitation. Building time can very very long for this processes 25 to 40 grams per hour, to achieve better accuracy small beam size and deposition rates are required. Conversely to achieve rapid solidification rate degradation of the solution and the surface finish results.

Change in the laser power and scanning rates to achieve better accuracies deposition rates may also affect the microstructure of the deposited components and thus finding an optimum deposition condition necessitates tradeoff between the build speed, accuracy and the microstructure.

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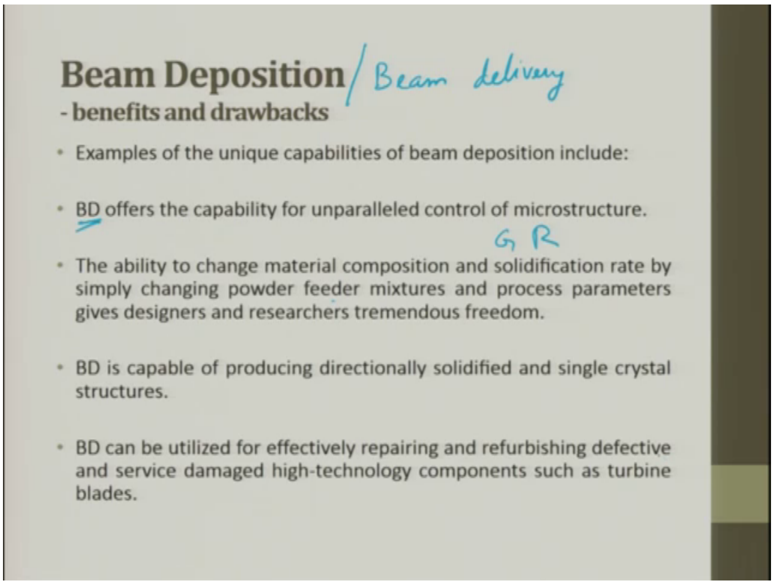


The examples of unique capabilities of beam deposition includes beam delivery deposition offers, I have been using mixer mixedly using beam deposition or beam delivery please try to have, so I have also talked about beam delivery ok. So, this is all beam deposition or beam delivery, but I would like to see cannot to the word beam deposition. Beam deposition offers the capability of unparalleled the control of microstructure.

The ability to change material composition and solidification rates by simply changing the powder feet; so, this is what is the 2 terminologist thermal gradient and are divergence in solidification rate, for process planning gives designer and research is a tremendous freedom. The BD is capable of producing directionally solidified and a single crystal structure. BD can utilize can be utilized for effectively repairing and refurbishing defective and service damaged high technology components such as turbine blades can be worked about.

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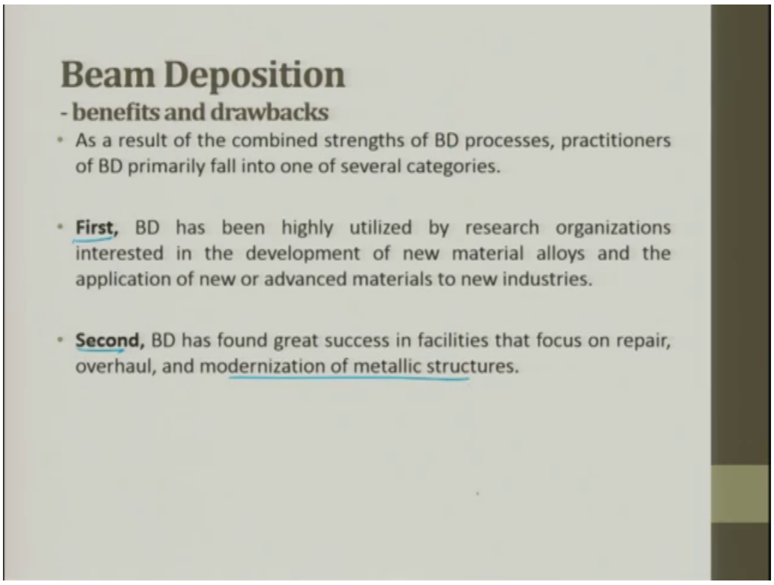


As a result of the combined strength of beam deposition process practitioners of beam deposition primarily fall into one of the several categories. The first categories they have been highly utilized by research organization interested in development of new material alloys and the application of new or advanced material to industry. They have used in second, they have found a great success in facilities that focus on repair overhauling and modernization of metals metallic structures, so the people can fall in this category.

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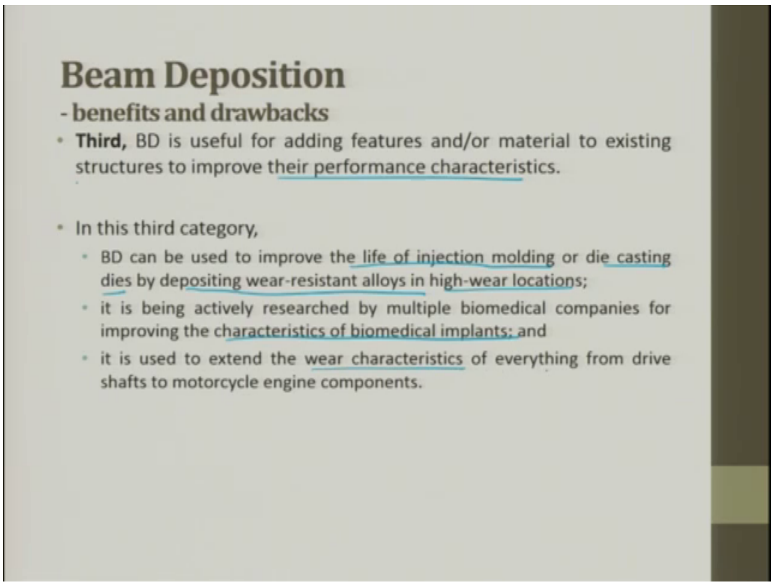

The third categories for adding features or materials to the existing structure to improve their performance and characteristics. So, these are the three places where people a fall when they wanted to use this beam deposition process, in this third category beam can be used to improve the life of the injection molding or die casting dies by depositing wear resistance alloys in high wear locations.

It is being actively researched by multiple biomedical companies for improving the characteristics of biomedical implants. It is been used to extend to wear characteristics of everything from driving shaft to motorcycle engineering components is used.

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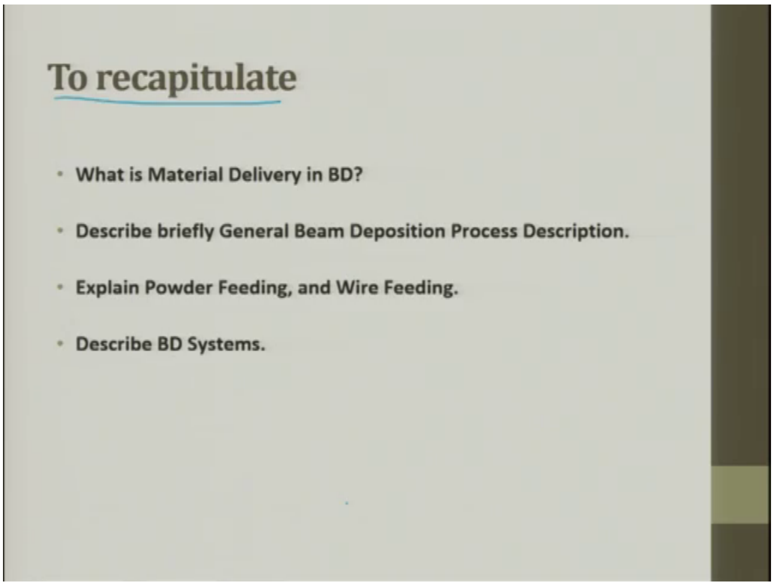


Finally to conclude to recapitulate what we have seen in this lecture, what is the material delivery in BD, describe briefly general beam deposition process description, explain powder feeding and wire feeding, describe BD systems? So, these are some of the things which we saw in this lecture.

Thank you.