Finite Element Modeling of Welding Processes
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Module - 09
FE model of wire-additive manufacturing processes
Lecture - 38
Fundamentals of wire arc additive manufacturing processes - I

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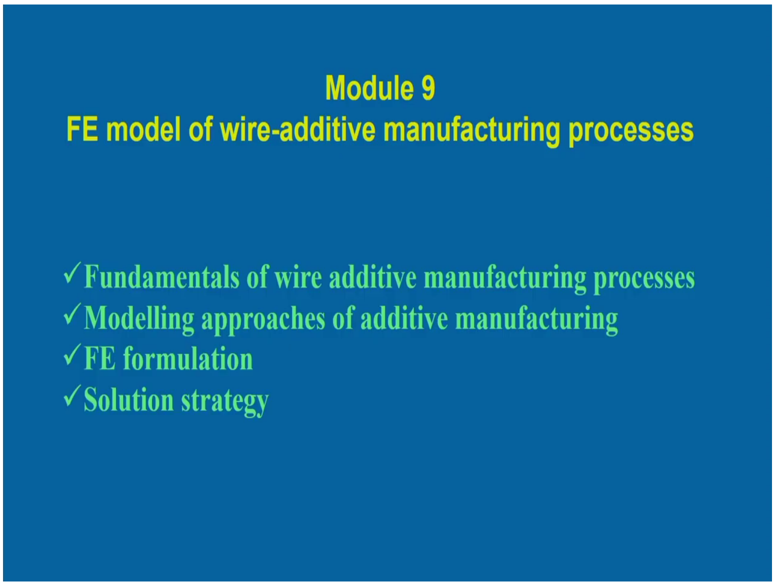

Hello everybody today we will be discussing about the finite element modeling of the wire arc additive manufacturing processes and I think this is the last module for this particular course. But in this particular module we will try to focus on the first the fundamentals of additive manufacturing at it is a very little extent.

And after that we will be discussing the finite element formulation actually this wire arc additive manufacturing processes mainly associated with most closely to the welding process or we can say that it is a organized approach, for the welding processes to take the advantage of the material deposition.

So, therefore, the modeling approach is everything more or less it will be the similar kind of things the elemental heat transfer analysis, material flow analysis or stress analysis. So, it will confined into this particular basic analysis apart from this thing only difference is that, what way we can take all these phenomena happening together in case of additive manufacturing process that we have to look.

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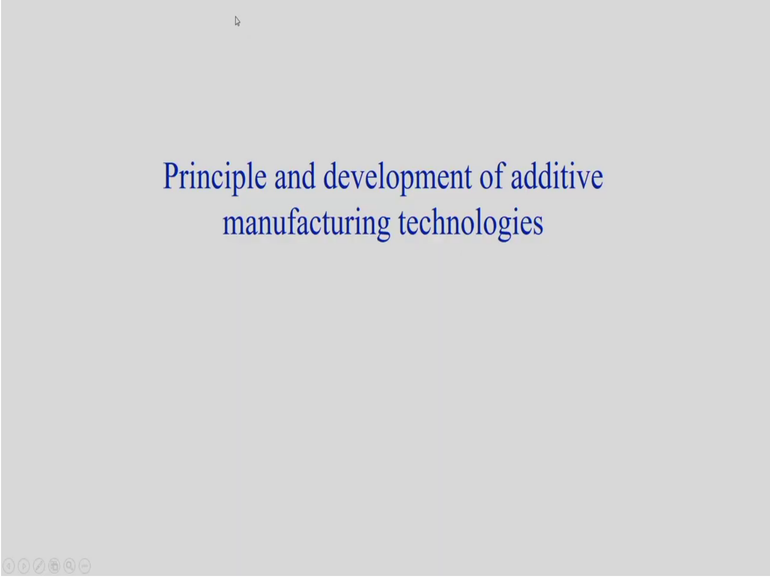

So, anyway first look into the principle and development of the additive manufacturing technologies to gain some idea about this particular technology. So, simply additive manufacturing or sometimes we call as a 3D printing process also, it is a kind of layer by layer deposition process.

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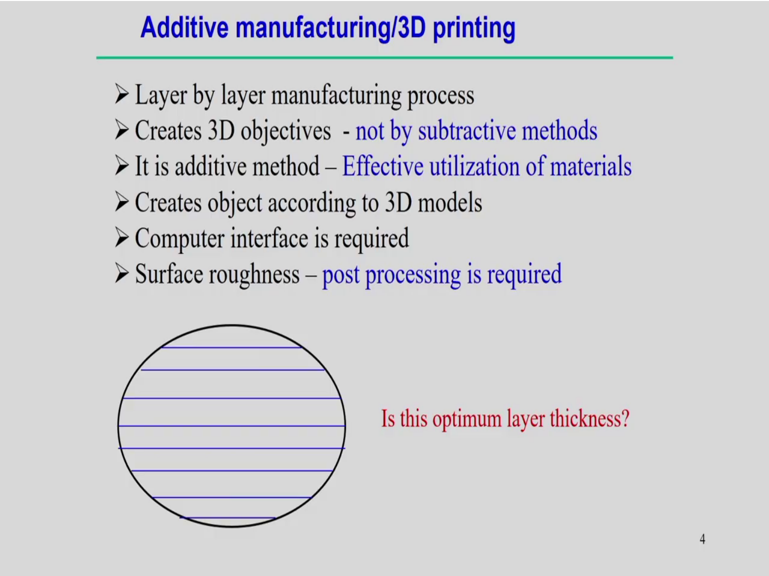

But of course, it is associated with some sort of the material transfer during one deposition. But what is the first step for this particular stage is that first there is a necessary to create three dimensional object and the three dimensional object with the help of a some CAD software. We normally first we create the object according to the desired shape we want to manufacture within this thing.

Then once it is called it is called the additive method in the sense that effective utilization of the materials in the sense that. In this it is different from the subtractive material what we follow in case of that additional manufacturing processes or may be other way we can say that if this particular process can eliminates lots of traditional manufacturing processes.

For example traditional manufacturing processes we want to make a some kind of the desired products. So, normally steps can be like that we can start from this thing is a casting process to make the billet in particular shape. Now, this billet we want to may get the desired shape, then we do some kind of machining operations such that we can remove the material.

After that may be sometimes it is necessary to do some to bend particular component then in that cases we normally follow the metal forming process. And then of course, this casting solidification one part then subtractive manufacturing means that machining of the another part then we try to follow some kind of the metal forming processes. Then we give the desired even after the machining processes sometimes we can do kind of post processing also need to follow.

For example heat treatment process some sort of surface finished process we normally follow to get the desired product. So, these are the steps, but additive manufacturing can eliminates all these conventional manufacturing processes it is a simply taking the first taking the desired shape of the particular object.

Then by following this particular object then it basically divide this object in the in physically the there is a different layer, then layer by layer deposition of the material to get the exact product. Or definitely there kind of some sort of the post processing is also involved in this particular process, but post processing is mainly done for the management of the residual stress and distortion and some sort of surface finish operation is also required.

Now, creates objects according to the 3D model. So, whatever models is there three dimensional model which is very simple model or it can be very complex geometry also. So, it follow this particular model in the layer by layer deposition process. So, definitely once we control layer by layer deposition process or lots of controlling parameters is involved or sometimes, we want to get some kind of accurate component.

Then machine interface is always required or as well as the computer interface. So, basically we other way we can say is kind of digital manufacturing process, such that the computer is to control of the movement of the wire arc according to particular weld pre defined path.

So, that is why computer interface is always associated with this kind of process and once we get the desire object that layer by layer deposition process. Then after that to achieve the desired surface finish and post processing mostly the finishing operation is required.

So, maybe you can look into this particular figure also here we can see we want to there is a particular oval shaped product and first we have to make the CAD geometry of three dimensional CAD geometry of this particular shape.

Then there is a slicing options are there, so we divide this particular object it is a small small layer now we give the instruction to the machine the deposition of the first layer may be this thickness and the width or length can be different. Then once the first layer depositions start then we go for the second layer deposition what way we can divide the slicing in this particular object.

So, this definitely some kind of computer interface always there, so to make the slicing process and then slicing process then after that what are the path has to be followed through which the deposition can happen.

So, all these kind of strategy has to be decided by using the computer interface and then finally, we can get the desired object, but of course, there is a some limitation in the roughness to achieve with the depending upon the thickness of the layer. Even we can see it is not possible in the one particular layer deposition to achieve the very smooth surface appearance what we exactly looking in the three dimensional object.

So, to some extent as close as to the near shape of this particular object we normally produce after that, we follow some kind of the post processing or may be finishing operation to get the actual product. So, these are the in general we can understand that additive manufacturing process or other we can also called 3D manufacturing processes.

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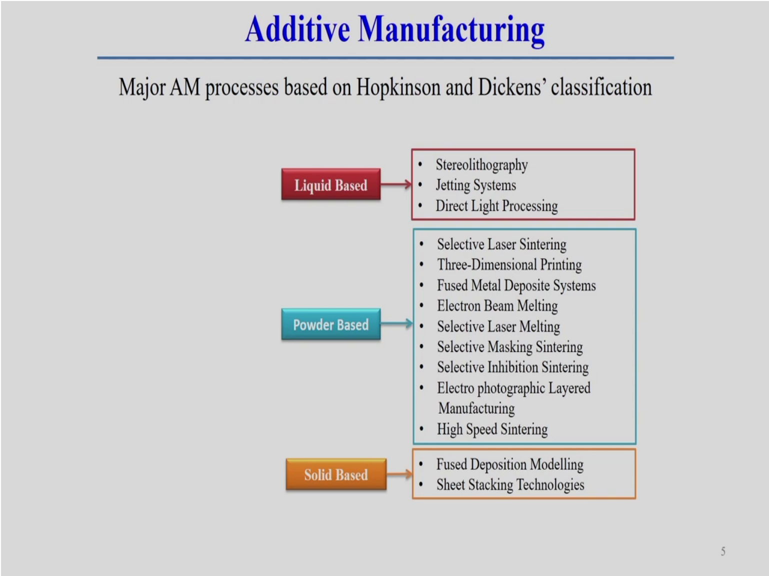

So, there are different ways to classify the different types of the additive manufacturing processes. In general I am talking about not only the additive manufacturing can be used for in the polymeric material also and can be used in metallic material both.

But based on that there are three different types of the process is there additive manufacture one is the liquid based. So, raw material is available in the form of a liquid powder based, so raw material available in the form of a powder and raw material can be available in the form of the solid based or solid stock it can be in the form of a sheet, in the form of a wire this it available.

Now, liquid based additive manufacturing the one of the process is the stereo lithography this is a very old process and then jetting system also. So, all these direct light processing all these kind of process is the liquid based, but in principle liquid based strategy follow something like that we use the liquid raw material then focus on the some laser light on this particular raw material.

So, in that particular when we control way we can focus the laser light on this liquid raw material. Then is fused in this particular position and the get the desired shape and remaining part remains as a liquid.

So, these are the principle of the liquid based additive manufacturing process then apart from this in powder based also that are different way what way the heat source can be applied and may be that whether it is melting or whether it is sintering we are following based on that powder based technology has been developed different way.

So, selective laser sintering three dimensional printing different names are there fused deposition modeling say it is electron beam melting, so laser also; so selective laser melting. So, there are different depending upon mainly the what are the heat source we are using whether you are using laser or whether we are using electron beam as a heat source.

And apart from this thing whether we are selectively putting focusing on the laser light and we are allowing some sort of whether complete melting or we are allowing only sintering. So, normally sintering happens below the melting point temperature and that is the case in case of the you know the powder metallurgy taking the same principle can also followed also.

So, that way that are differences different variant of the powder based technology additive manufacturing technology has been developed. In solid based we normally do in the different way also the fused deposition modelling. Another is the sheet stacking technology in general fused deposition modelling means direct energy fused modelling means we the we can use the raw material in the form of a wire for example.

And other cases we can use the raw material in the form of a sheet. Simply stacking the sheet in the particular to achieve the slice thickness then we cut using some kind of the cutter we cut the component and then we just bind this particular sheet. So, this is the principle of the solid based or may be sheet stacking technology.

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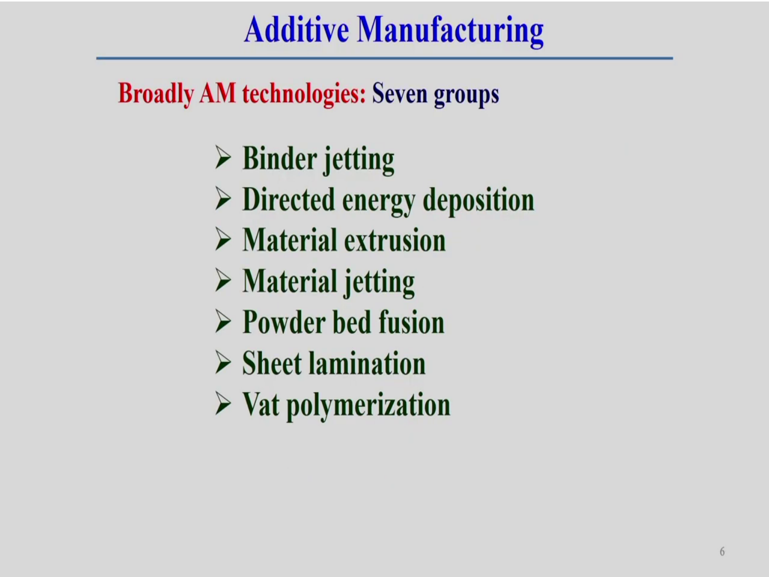

Now, we will details overview we will try to get some overview of the additive manufacturing processes. Broadly additive manufacturing there are seven groups are there one is the binder jetting, that we already explained the binder jetting means simply in this cases we can use as a liquid binder binding elements we can use.

Directed energy deposition, so directed energy deposition it means that focusing on the laser light the energy supplied. At the same time we can use the feedstock material at the same time and it when the feedstock material directly fused by the application of the laser light.

So, then in that way that is called the directed energy deposition and other cases material extrusion is there, material jetting is there, powder bed fusion is also there and the sheet lamination vat polymerization. These are the basic seven groups we will discuss later on that what are the different process in principle what are the way of working in this particular additive manufacturing technology.

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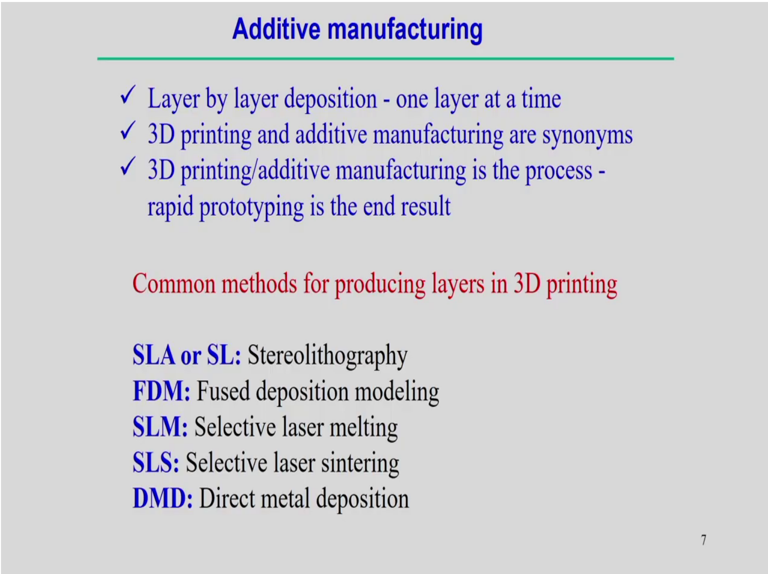

So, additive manufacturing generally we say the layer by layer deposition. So, basically one layer at particular time, so one layer is there then only we go for the next layer. 3D printing and additive manufacturing a synonym basically are in these cases 3D printing and additive manufacturing is the process 3D printing is the process and rapid prototyping is the end result.

So, actually the 3D additive manufacturing printing or additive manufacturing process it is comes into the picture, it is a basically faster. There are some rapid prototyping from the concept of the rapid prototyping there is a gradual development of the additive manufacturing process actually comes out.

So, in that case we can say additive manufacturing is the process and result as a rapid prototyping. But common methods for producing the layers in the 3D printing we can see the we can use this particular common methods that which is sometimes called SLA or SL. SL stands for the stereolithography this is very old process.

Then FDM fused deposition modeling, SLM selective laser melting, SLS selective laser sintering and DMD direct metal deposition. So, most of the additive manufacturing technologies is development normally happens around in this particular technology. But of course, there are so many variants of the additive manufacturing's are also available.

But normally we focus on this particular technology and mostly all these particular technologies either it can be used for polymeric material or it can be used for the metal metallic material.

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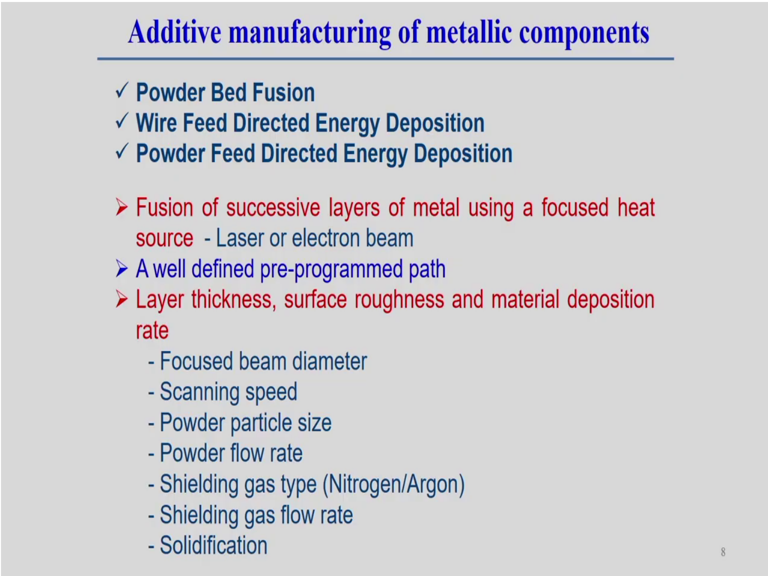

Now, additive manufacturing metallic components we can say that powder bed fusion there is a two one is the powder bed fusion, that we can look into this additive manufacturing till one different angle that one another is the wire feed directed energy deposition.

So, directed energy deposition where the wire can be used as a feedstock material or raw material and the powder feed directed energy deposition. This is also directed energy deposition, but raw material can be used as in the form of a powder, but how these two are different powder bed fusion and the directed energy deposition.

It simple way it is different in that way that powder bed fusion means suppose one particular chamber filled with the powder and that then we take the desired thickness that we are supposed to melt or sinter one particular path.

So, then according to the slice thickness we can fill the complete bed, then we follow the path planning. That means, particular path we can move the laser light such that laser will either sinter or fuse in this particular position on.

So, therefore, laser will fused in this particular position and then remaining as remains as a support structure and in the form of a powder. So, once one layer is done in this way then we go for the next layer.

So, similar strategy we can go for the next layer there again we have to fill the complete bed with using the powder and selective position. We can put the laser light according to the size of the object or may be according to the thickness of the slicing of the particular development of this particular object, so that is called the powder bed fusion.

So, definitely at any point of time this bed should be filled with the powder in case of powder bed fusion, but if you look into the directed energy deposition either in the form of a powder or solid stoke you can use the raw material in the in that case.

What happens in that case laser light is focusing at the same time powder also can focus on this particular position and the powder can be passes through some kind of the nozzle with the applications of some applied desired pressure. Then powder can be mixed with the shielding gas and it is projected in a particular position.

At the same time laser is also projected, so together laser will melt the powder as well as the depositing in the desired position. So, in these cases it is not necessary to pre fill the powder bed is required in this particular, so that is the principle of the directed energy deposition.

So, in this case either powder can be focused or directly we can use the wire feed, wire feed means in this case wire is feeding and simply what way we can do the deposition in the arc welding process, for example gas metal arc welding process. So, there is a wire is feeding and the wire is depositing on the particular substrate material.

So, in same principle we can follow also that is called the wire feed directed energy deposition. So, these are the basic two difference between the powder bed based and directed energy deposition now fusion of the successive layers of metal is using as a focused heat source.

So, there is a need focused heat source and very precisely controlled heat source and the very small zone heats will be focused because the surface roughness accuracy level depends on the what is the focus diameter of the laser that is interacting on the substrate material.

So, this heat source laser can also be used as well as the electron beam can also be used, but laser and electron beam mostly focused on this to handle the powdered material. Now while define pre programming path is also required definitely if you want to achieve particular desired product. So, pre programming path that mean which part laser has to be scanned according to the geometric shape we want to produce.

Then apart from these thing the layer thickness what should be the layer thickness that decide the surface roughness and what should be the material deposition rate all are kind of the parameters associated with the additive manufacturing process.

But if you look into that in additive manufacture there are so many parameters needs to control. So, because of that if since it is involved so many parameters, so actual the feasible domain to get the desired product also is can be very narrow. So, I am talking about the physical domain of the parameters.

Such that writers of the parameter cannot vary over a wide range may be this parameter can vary over a short range because so many parameter has to be controlled and a and in a particular positions. So, it is very important, so identification of the parameter in additive manufacturing process is one of the very important task.

In this case the fused beam diameter is the one parameter then what is the scanning speed what way it can moves? What are the powder particle size? Whether it is a very fine powder particle or very core structure is there? What is the powder flow rate? Accordingly deposition rate can vary also, then what kind of the shielding gas is used? Because different material the interaction with the shielding gas can be different also.

And what is the shielding gas flow rate? So, if shielding gas flow rate is to too high then powder can be bound it can be retracted back to disperse different area. So, that is the gas flow rate the shielding gas pressure also important and apart from this thing. What are the solidification? What solidification behavior of this particular powder? Is very important and that maybe we can say that, What is the solidification time such that? After solidification we can deposit the next layer on this particular position.

So, that is the solidification time can be decide the strategy the deposition of the next layer. So, all this parameter has to be look when you try to develop some kind of the additive manufacturing technology, even we have a very good additive manufacturing machines also.

If you do not know the parameter range of the parameter thing it is very difficult to develop this process or to finding out the set of the parameters. Because it is a it is needs a lots of trials to finding out the optimum set of the parameters associated with any kind of the additive manufacturing process.

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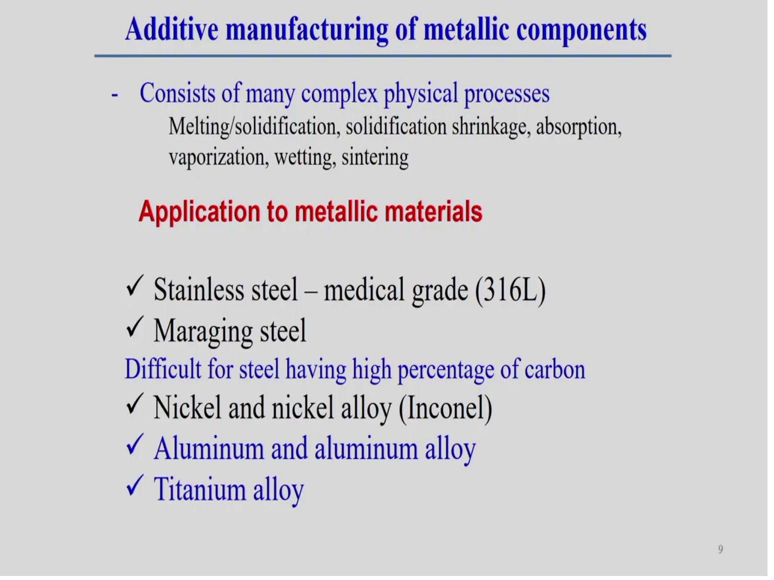

Apart from this thing this consist of the in principle consist of the many complex physical processes for example, melting solidification is there, definitely here at this one's here there it is possibility of the solidification shrinkage, we have to take into account the solidification when designing the process.

What is the absorption may be of the laser may be it is a simply these thing the absorption of a laser, over the powder and absorption of a laser over a solid metal stoke. So, in that cases the absorptivity can be different, so that is very important parameter.

Apart from this thing vaporization of the component may be if laser light is intensity is too high then vaporization may also happen, so all this kind parameter has to be there. And weighting weightability; weightability of this particular particle this if it is melting that is fine, but when you look into the sintering then how it is interacting one particle to another particle.

So, weightability property and sintering properties all actually important parameters associated with this particular process. Now, this additive manufacturing for metallic component the application for the metallic material not only additive manufacture is not only developed in case of the polymeric material also.

Because polymeric material some development happens to some extent, but in metallic material it is a exploring in this particular or direction specifically for the different kind of the metallic component. So, that is why if you look into this thing the specific application of the metallic material the development normally happens with this particular metal.

For example, stainless steel medical grade, maraging steel and if you look into this thing stainless steel and maraging steel in this cases the carbon percentage is very low. So, therefore, to handle the metallic component in case of additive manufacturing the particular material, where the carbon percentage is very low it is relatively easy to handle this particular because when the carbon percentage is very high.

So, some sort of metallurgical issue will be there associated with a additive manufacturing, that is why it is a sometimes is very difficult for the steel for the development of the additive manufacturing technology specifically having high percentage of the carbon. That is why the development normally happens with a low carbon steel as well as the alloy steel.

Apart from this thing nickel and nickel based alloy has been developed this thing I mean aluminum aluminum alloy titanium alloy of course, aluminum aluminum alloy and titanium alloy, there may be some issue associated with the formation of the porosity. Because alloy we know the aluminum and titanium when we handle we melt this aluminum or title there is a good affinitive or to form some kind of the oxides as compared to the other steel also.

So, that is why to handle this aluminum aluminum alloy titanium alloy some specific team may be required or maybe we can say that shielding should be very proper way has to be decide such that kind of defects porosity defects can be avoided in case of the aluminum alloy and titanium alloy.

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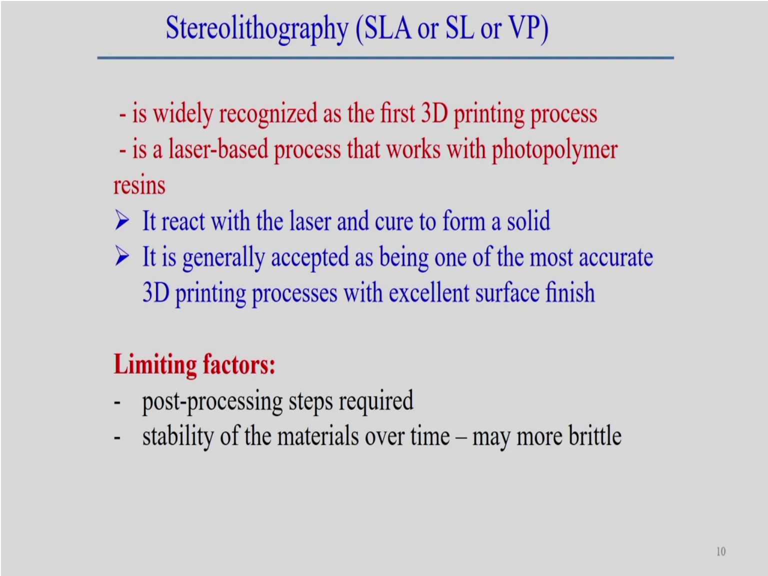

Now, it look into the what are the in overall idea overall understanding of the basic processes the additive manufacturing process. First one is the stereolithography that is called the SLA or sometimes it is called SL or sometimes it is called vat polymerization.

So, this is stereolithography process is basically wide you recognize it is a 3D printing process, but it is a laser based process that works with the photopolymer resins. So, that photopolymer resins means it is a it should be sensitive to the laser light it is simply that the laser light is focused on the liquid resin in that cases the this liquid resin will try to solidify and make the structure

So, from that principle this technology has been developed now it react with a laser and cure. Basically polymeric material, so some sort of curing term is comes into this picture. So, that is not exactly called the solidification we can say the curing and curing to form cure to form a solid.

So, this stereolithography is accepted is one of the most accurate process 3D printing process and we can achieve very excellent surface finish using this particular process. But limiting factor is the post processing steps are required, because in this case from the liquid base there is a we focus on the laser light.

And that focusing on the laser light only that part will cure to solidify remaining as in the form of a liquid. So, therefore, post processing steps are associated in this particular process even to get the desired shape apart from this thing stability of the structure with respect to time. Because when the cure metal when the interacting cure metal to solidify liquid resin in that cases over that time with the metal can becomes more brittle. So, that can be one of the limiting factor associated with this process.

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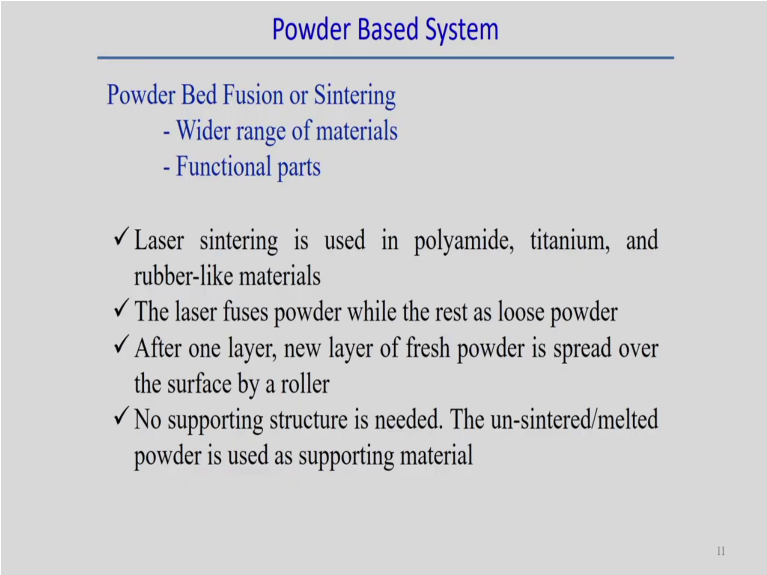

Now, powder bed fusion or sintering process, so it is a wide range of materials is possible and because functional parts can also be developed powder bed fusion or in case of the powder sintering process also.

And most of the laser sintering is associated with the polyamide titanium and the rubber like material. So, in this particular material we can handle the that is the laser sintering based process. Apart from this thing the laser fuses powder well the rest as a lose powder.

So, basically a powder bed if this is powder bed fusion means the laser fuses the powder where which part the laser is focused. But remaining as a remains as a loose powder and acts a support structure. So, therefore, one layer is one layer is deposited then the fresh powder is again the spread over the bed and by a particular roller.

So, over the bed particular roller and that then we decide the what is thickness of this thing, but the what is thick according to the slicing technology slicing process the thickness has to be decided what is the in this particular position. Now, no support structure is needed because in this particular case already extra powder they can act as a support structure in this particular process.

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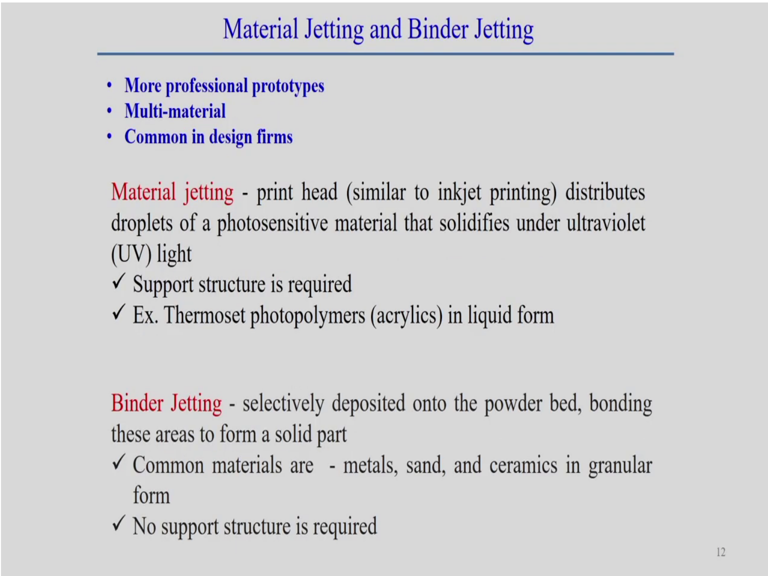

Now, material jetting and the binder jetting process this is the it is a kind of more professional prototype can be developed using this material jetting and binder jetting processes and it is possible to handle the multi material.

So, different multi material multi color material can also be handled, but this is material jetting and binding jetting is associated with a polymeric material. But common in the design form it is a common this thing, let us see the material jetting how it is in this cases the material jetting it is a kind of print head we know, similar kind of the inkjet printer.

In this case distributes the droplets of a photosensitive material that solidifies under the ultraviolet ray. So, therefore, in this cases the distribute first is the droplet to the photosensitive materials, so droplet distribution is there. And then it is the sensitive to the ultra violet ray and such that it can solidify.

In this case support structure is required, so support structure is required to build the process because when we push the droplet then after that it is secure with the application of the ultra violet ray. So, that is why some sort of support structure is required.

Thermoset polymers acrylics in the liquid form is normally used in this particular process that is called the material jetting process, but binder jetting process in this cases we use some kind of the binding element. Selectively deposited onto a powder the binding element.

So, in this case suppose powder bed is there instead of laser we can use the inject the binding element in the selective position, such that the powder can be binded using the binder in this particular position. So, bonding this areas to form a particular solid common metals are metals can be done and these thing binding elements by using.

And basically sand molding can be prepared using this particular cases and even ceramics in the granular form can also be used. So, using the some binding agent we can handle the ceramic powder also to make the particular component. In this case no support structure is required in case of the binder jetting, so this is the principle of the binder jetting process.

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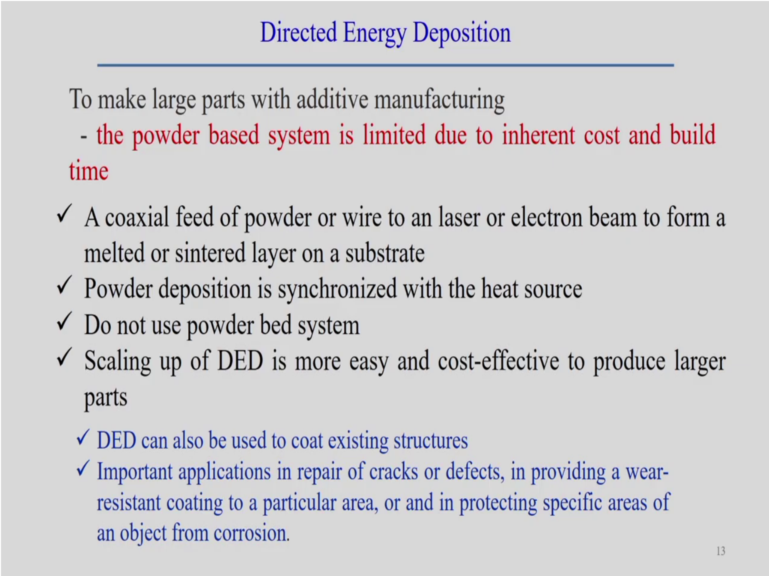

Now directed energy deposition is the another process to make large parts to make without with in additive manufacturing process. If there is a requirement of the making very big structure with a additive manufacturing process, then we can use the directed energy deposition.

Because most of the powder bed system there is a limitation because if the limitation to the small kind of the object, because it depends on the what is the size of the chamber. So, product size depends on the size of the chamber, but directed energy deposition it is opened.

So, once the this thing the one particular platform we can build up to the any direction. So, in that cases there is no limit such kind of the limitation is required in case of the directed energy deposition. Because in this case powder based system is limited due to the inherent cost and the build time.

So, in this case the parameter and maybe it is a more complicated or this process as compared to the powder bed based technology. So, how it works the directed energy deposition in this case coaxial feed of the powder or in the form of a wire, is required to an laser or any kind of the heat source to an laser an electron beam or sometimes we can use directly the any arc welding process also. To form the melting or sintering process layer on a particular substrate, so in this case.

Now, powder deposition is synchronized with the heat source. So, that is why when the powder is depositing at the same time synchronized with the heat source such that it is melt and the at the same time it deposit the particular layer and then it can build up.

So, do not use the powder bed system in this case not necessary to use you cannot follow the powder bed system and, but scaling up the direct energy deposition is more easy. Direct energy deposition is more easy and it is also cost effective to produce the large parts that is the one particular advantage is there, but the to getting the designing of this particular process.

And it is a very tight control of the parameters even you require as compared to the powder system, at the same time this holding the powder may be there may be some catchment efficiency can be low in this particular process or may be other we can say then when powder is deposited then there is loss of material also can be much more as compared to the fusion powder bed based fusion.

So, from that point of view may be it is disadvantageous. So, direct energy deposition can also be used to for the coat for the existing structure also. So, that is also true the simply put the coating of an existing structure using the direct energy deposition is possible. Important application for the repair work crack defects and may be if you want to make some wear resistant coating is required, in that cases we can use this particular area.

So, for example, very big structure and a particular position then we can use this direct energy deposition. Because that big structure it is not possible to put under the powder bed system because that powder bed system chamber is very small in most of the cases.

So, therefore, in that cases these for the repairing work for a large structure this or to apply some kind of the coating technology for a big structure in this case the directed energy deposition is more useful.

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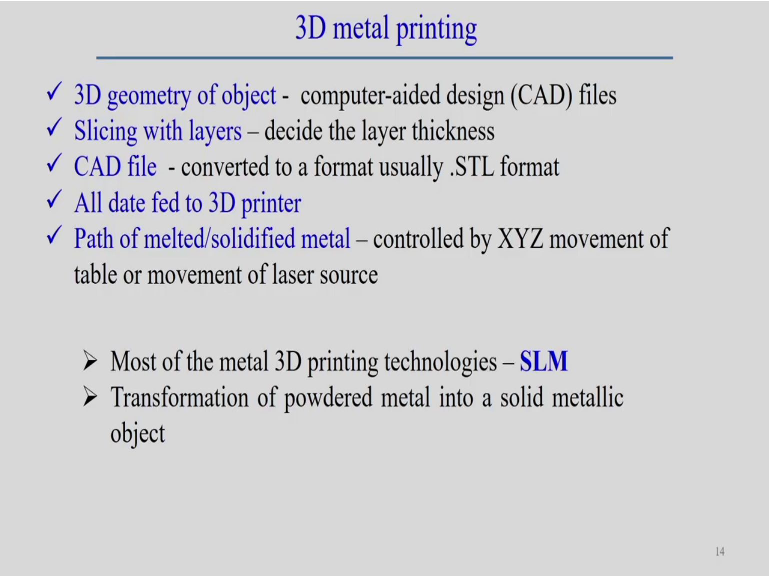

Now, in general we can say the 3D metal printing is basically associated with the 3D geometry of the object, we know this 3D geometric object. But we want to create the 3D geometry of the object we need the knowledge some computer aided design file. So, there we have to create this thing.

After that slicing with layers basically decide the what should be the layer thickness. So, accordingly we can run the process the first we have to decide what is the layer thickness is required particular component. Then CAD file has to be normally converted on the format usually dot STL file. And then all the data is actually fed to the once we create the geometry and create the dot STL file according to the path planning and layer thickness all this information is normally faced to the this thing, to the fed to the 3D printers.

Now, 3D printer is move according to the instruction basically according to the path. And then this path movement is normally controlled or melted or solidified metal is normally controlled by using the XYZ table XYZ movement of the table or movement of the laser source.

It is a kind of approach can be there for example, so some degrees of freedom can be given to the base plate for example, CNC machine may be XY plane degree of movement. And may be another degree of movement can be given on the Z movement can be given on the using some kind of the robotic hand; so that given to the laser source.

So, this way can be done or all can be given all XYZ movement can be given only on the base. So, it is depending upon the development it is part of the development product development, we can take the decision accordingly what kind of the motion can be given to whether to the laser source or whether to the base plate.

Now, most of the metal 3D printing is base technology is basically, so for develop is the selective laser melting. So, it is now more or less almost in the mature state in this thing for the selective laser melting 3D printing technology if we look into this thing. And in this case transformation of the powder metal into the solid metallic object that we have observed in this particular case.

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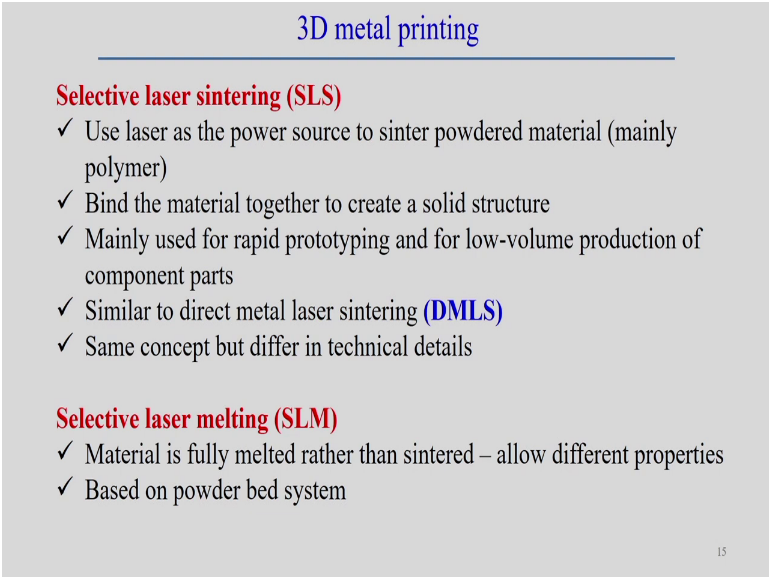

But selective laser sintering few important points is that, use laser as a power source to sinter powder material mainly the polymer normally user for sintering purpose. So, in this cases we are not allowing to melting, may be sintering we can allow; that is why it is called the selective laser sintering process.

And bind the material together and to create a solid structure, so that is the that is the principle of the laser sintering process. So, mainly used for the rapid prototyping and for the low volume production of the component parts when there is a component parts require very few numbers of component parts is necessary to requiring that cases we can use.

Apart from this thing similar to the direct metal laser sintering also. So, direct metal laser sintering and selective laser, because selective laser sintering is associated with the powdered bed system. And directed metal laser sintering is associated with some directed energy deposition in that format, we normally consider this thing.

So, same concept, but differ in the mechanical details technical details, technical details is means that one is the powder bed based system another is the directed energy based system now selective laser melting in this case instead of sintering we can follow the melting process. So, that is material is fully melted rather than the sintering is allowed.

So, in this cases allow different properties. So, different kind with the properties can be achieved depending upon the solidification behavior of these particular material. And normally selective laser melting is based on the powder bed system.

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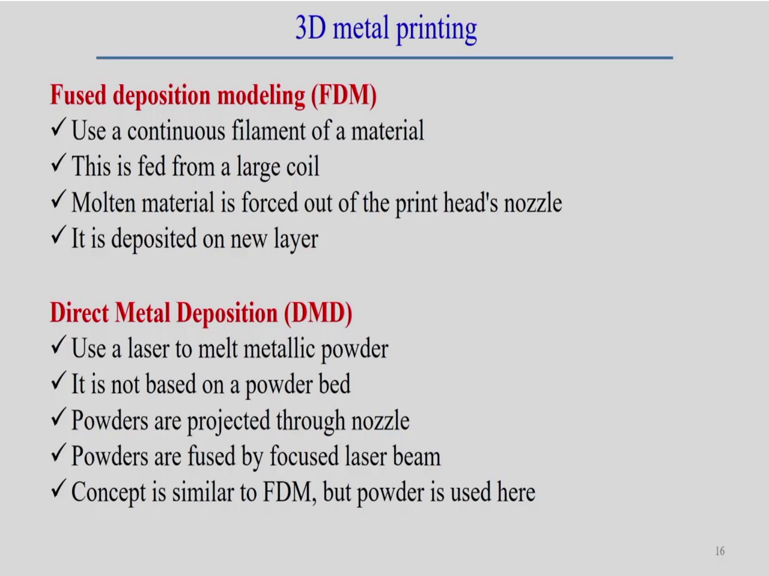

Apart from this thing the fused deposition modeling is also there, in this case it is also is a continuous filament of a particular material and this is this material can be fed from the large coil. And then material then is forced out of the print head nozzle.

So, basically print head the temperature is controlled the from the head this thing and the sorry temperature is controlled the nozzle. And this it is passes through the print head nozzle and then the temperature is there allowing to melt this thing and then it deposited layer by layer by the movement of this head.

Now, apart from these thing direct metal deposition is there is basically use a laser to melt the metallic powder normally and it is not a based on the powder bed based, it is seem and powders is basically projected through the nozzle. At the same time powder is fused through the fused focused laser beam in this particular position.

The concept is similar to fused deposition modeling, but in this cases powder is used in this particular cases instead of the solid wear that is called the direct in metal deposition.

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Now, some overall this thing different processes that SLS or direct metal lasers sintering is selective laser melting process. So SLS selective laser sintering is normally referred to the process applied to the variety different kind of the materials for example, plastic glass ceramics.

So, normally assess the all the technology has been developed in case of the selective laser sintering is that plastic glass and ceramics in this case. Because which is having a difficulty to join, so many other difficulties if you allow melting process. DMLS refer to the process applied to the metallic alloy direct metal laser sintering is basically normally associated with the normally associated with the metallic components.

And sintering process we know they do not fully melt the powder, but heat it on to the point the powder can fuse together in case of we know the powder can fuse together, but not completely powder can be melt on a molecular level in this case.

But with sintering the porosity of the material can be controlled also that is possible also with the if you allow the sintering process procedure can be controlled. But SLM selective laser melting in this case using the laser to achieve the full melt in this cases we can allow the melting process and powder is actually melted and when this melted it becomes a homogenous part of a component.

Working with an alloy use normally sintering process or direct metal laser DMLS or SLS. So, when you try to handle the alloy in principle it is better to use using the sintering process, but working with the pure titanium in that cases we can use the selective laser melting process. So, SLM is stronger because fewer or the no voice will help to prevent the part failure.

So, selective laser melting is the becomes very stronger because we are allowing the melting this thing and then part failure this porosity may not be can be avoided kind of this thing, but only feasible when the using with a single metal powder.

So, selective laser melting to order to avoid this this thing we have already seen that when we try to handle we use the sintering process or when you try to handle the pure metal then we can follow the melting process. Because there may be some sort of the metallurgical issues associated with the sintering process or the melting process.

So, because in alloy so many components are there and their melting temperature different in this particular alloy system. So, in these cases it is better to allow to follow some kind of the sintering process.

So, that we can avoid some sort of the formation of the kind of the defects, but pure metal there is the only single point a melting point is there. So, therefore, in those cases we can allow the melting in this particular case.

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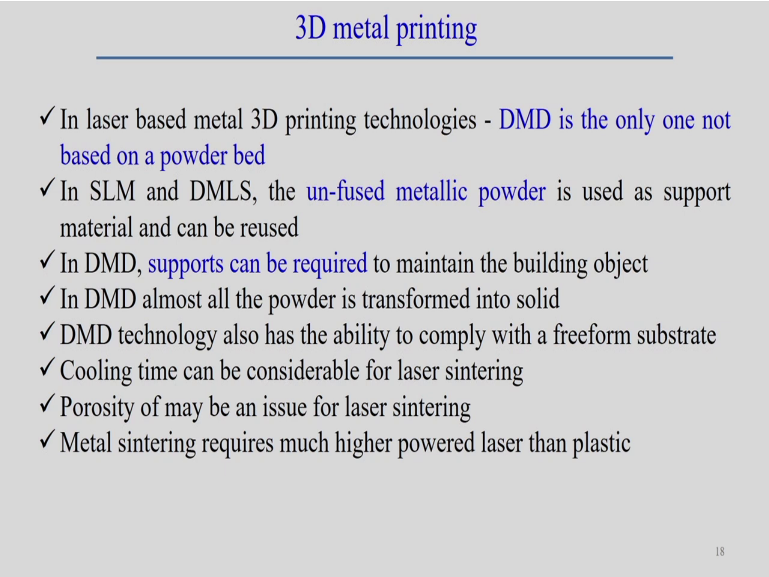

So in general the in laser based metal 3D printing technologies DMD is the only one not based upon the powder bed. We if we summary this thing what in the about the metal printing process.

So, in this case we can say the DMD direct metal deposition is the only which are not on the powder based because direct metal deposition is normally the feedstock in the form of a wire can be used.

In SLM or DMLS the unfused metallic powder is used as a support material and can be reused. So, definitely if you look into the powder based system also the unfused material can be used reused also. In DMD supports can be required to maintain the building object may be sometimes direct metal deposition, in this cases support structure may be required sometimes.

In this case and DMD almost all the powder is into the transformed into the solid. So, DMD we can see the almost all powder is transformed into the solid, but in DMD technology also has the ability to comply with the feed freeform substrate.

So, we can see that DMD technology also ability to comply with the freeform structure. So, freeform any kind of the form can also be developed in case of the DMD technology. Cooling time can be considered, considerable for the laser sintering, so definitely it is very important that to control the cooling time in case of the laser sintering process.

And porosity can be an issue in case of the laser sintering process, but it can be controlled. Metal sintering requires much higher power laser then plastic. So, definitely if we handle the metallic component and the plastic component high power laser is required to handle the metallic component as compared to the plastic component.

So, these are the key points associated with the 3D metal printing process. Now, if we look into this thing that this is the that was the overall overview of the different kind of the additive manufacturing or different kind of the printing processes.

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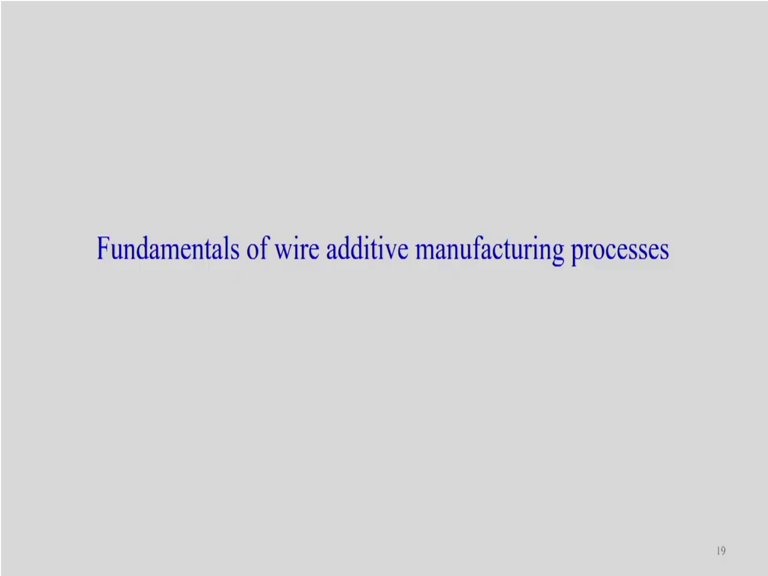

Now, we will try to look focus on the fundamentals of the wire additive manufacturing processes. We know that wire arc additive manufacturing process in this case we can simply use the welding process the non welding process that is converted to the additive manufacture or the printing process.

So, most of the cases we use the in general we gas metal arc welding process because gas metal arc welding process is suitable in this case, because in this case there is a continuous supply of the wire in gas metal arc welding process.

But control of the metal transfer is not up to that extent, so therefore development in the wire arc additive manufacturing process is happened. So, on the ground of the what way more precisely we can control the metal transfer, because that is the main part which technology based on which different kind of the technology has been developed which is called wire arc additive manufacturing processes.

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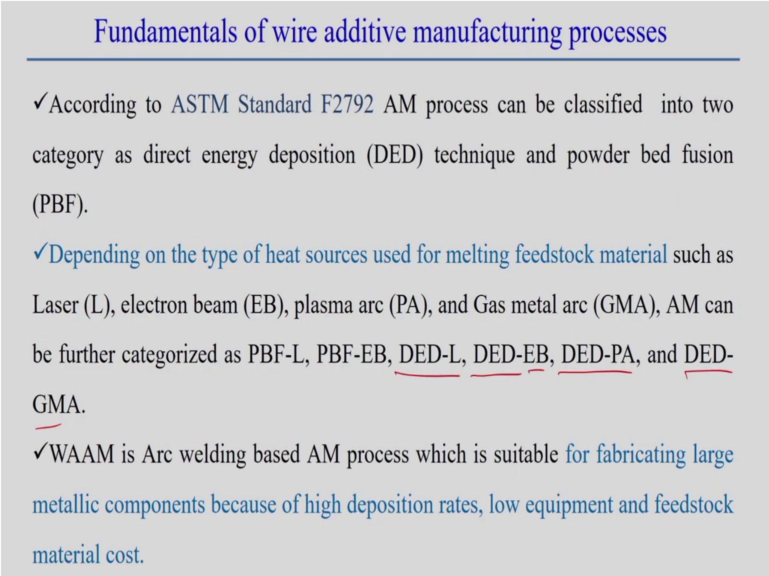

So, according to the ASTM standard we can see the additive manufacturing processes broadly classified into two category; one is the direct energy deposition, another is the powder bed fusion. Normally, these two category we normally divide and an in additive manufacturing process.

But depending on the type of the heat sources and the melting feedstock material. So, what form of the feedstock material we can use either powder form or we can use in the wire form. They are depending upon there are so many different category of the wire arc additive manufacturing process has been developed; one is the.

Now what are the different sources can be used in this case laser can be used electron beam can be used plasma arc can be used also and gas metal arc welding. So, this thing if you use this different kind of the heat sources.

In this case then additive manufacturing can be categorized as the, for example, PBF powder bed fusion, L hyphen L it is means the powder bed fusion laser based. Then powder based fusion electron beam based and then direct energy deposition DED you can see the DED also. Direct energy deposition, but it is the laser based direct energy deposition is the electron beam based, direct energy deposition is the plasma arc and direct energy deposition GMA gas metal arc.

So, definitely we can see that we can use this different kind of the additive manufacturing technology wire arc additive manufacturing has been developed, but if you look into this thing if the laser and the electron beam. In these cases there is a need when we talking about the deposition, so external material has to be feed here.

And then in the form of a either in the form of a powder or in the form of a wire then in that cases the deposition can be controlled depending externally controlled with the application of the laser.

But if you look into the gas metal arc welding process the metal deposition itself is a intricate part of the system. So, in this case the whatever is process has to be controlled if you want to control the material deposition process. So, that is the different between the gas metal arc welding base or the remaining in which cases the metal deposition is normally done the externally.

Now, wire arc additive manufacturing is basically arc welding based additive manufacturing processes which is suitable for the fabricating very large structure. So, if you cannot expect very good surface finish in wire arc additive manufacturing process if you want to get the desired surface finish, then in that cases the powder bed system or may be is more suitable.

But if we rewind there is a need to develop very large structure then in that cases that wire arc additive manufacturing becomes more suitable. And at the same times the metal deposition is much more about as compared to the powder bed based system. And low equipment cost as well as the feedstock material cost is also known.

If you compare the raw material in the form of a wire in the form of a powder. So, definitely there is a huge difference, so powder will be more costlier as compared to the wire. So, in that sense the equipment cost on the raw material cost are different in case of the powder based system as is the arc based system.

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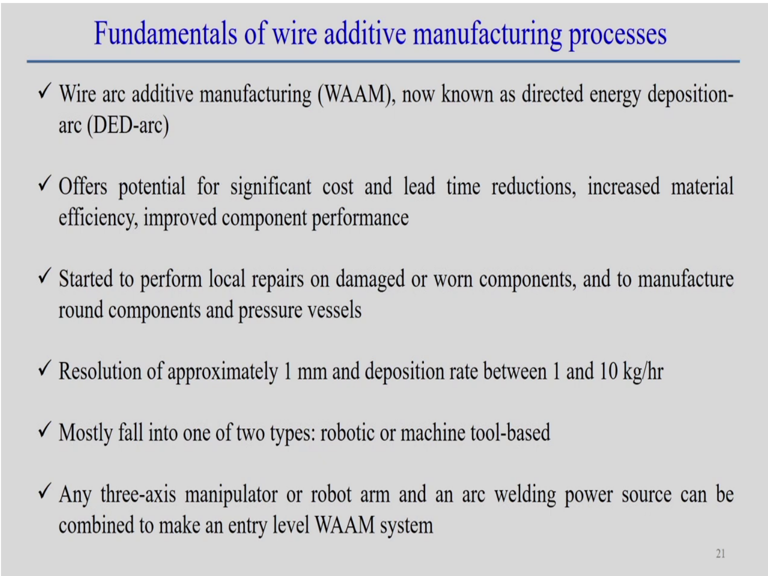

Now, wire arc additive manufacturing which is also known as the directed energy deposition DED arc. Because in this case the metal deposition is there and the symptoms it is open it is not a closed chamber kind of things has been developed. So, that is why it is called the directed energy deposition, the arc and the metal deposition happens together.

So, therefore, in this case we can say the DED arc also known as this thing. It is actually offers potential for significant cost and the lead time reduction, so cost reduction is also there. So, if you look into the one laser based system laser powder based system and repeatedly to develop in particular larger size component is very costlier if you use the laser based system.

But in that cases if you know simply using some welding machine gas metal arc welding machine. So, that cost is very lower gas metal arc welding process only thing is that we have to develop the XYZ moment table. So, in that way we can integrate the XYZ moment table and the any gas metal arc welding machine, then we can develop some kind of the printer also.

But there may be several scope to improve the metal transfer in case of in this particular process. Now, apart from this thing increased material efficiency improved component performance is also associated with the wire arc additive manufacturing process, but actually the wire arc additive manufacturing process normally started from the repair based work. So, own component damage component repair and after that this came into the mainstream metal printing process or additive manufacturing processes.

Resolution of approximately one millimeter is possible to achieve using the wire arc additive manufacturing process and even deposition can vary from 1 k g to 10 k g per hour, depending upon the requirement or depending upon the process heat source what kind of the diameter or of the wire we are using.

Mostly fall in to the one of the two types either robotic or machine tool based. It means that we can use the robotic control of the movement of the wire arc or other way that we can use the some kind of the CNC machine. So, numerically control machine we can use for movement of the XYZ movement of this particular table.

So, both a if they normally the development happens with respect to this two particular types now all three axis manipulator or robotic arm, can be used and the arc welding power source, can be used combining this two can have a entry level wire arc additive manufacturing system.

In which the one welding machine and another that XYZ movement table or kind of the robotic arm, combining these two can be the preliminary stage of a wire arc additive manufacturing system.

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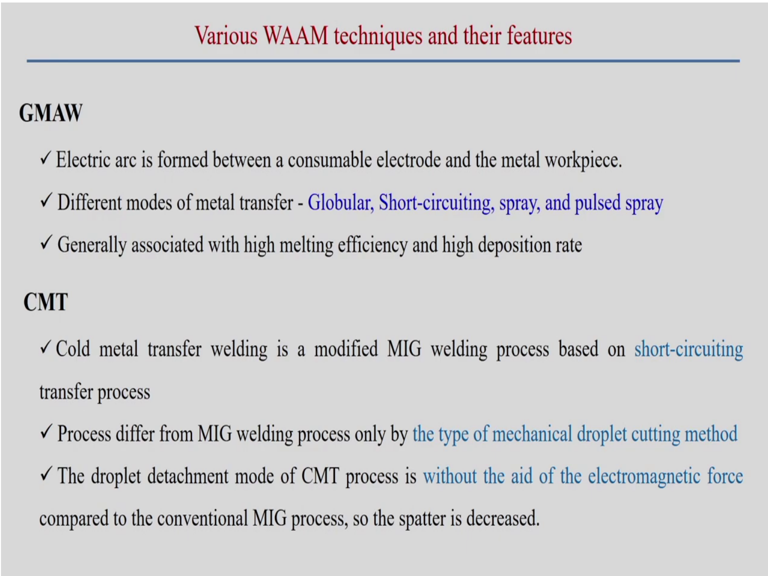

Now, various additive wire arc additive manufacturing techniques and their features if you look into this thing gas metal arc welding process we know. The gas metal arc welding process the electric arc is formed between the consumable electrode and the workpiece material.

So, that with there and there is a different types of the metal transfer we have already discussed the different type of the metal transfer and their characteristic in the previous module. So, normally associated with the metal transfer globular transfer short circuit transfer spray and pulse spray kind of metal transfer is associated with the gas metal arc welding process.

But of course, all kind of metal transfer may not suitable in the metal printing technology development. So, we have to look into in details what are the metal transfer mechanism is available or may be what kind if you want to promote one particular type of the metal transfer in this GMAW process and that then only we can make this a suitable for the additive manufacturing technology or metal printing technology.

Or normally associated with the very high melting efficiency and the high deposition rate is associated with the gas metal arc welding process, so that take the advantage to develop a large structure. Now, we know that we have already discussed there is a one methodology that is called the CMT cold metal transfer also this is a one of the advance level of the gas metal arc welding process. But in this case the metal transfer is normally happens cold metal in the short circuit mode.

So, in that case we can say that short circuit very controlled way the short circuit metal transfers is most suitable, for the development of the wire arc additive manufacturing process. But of course, it process differ from the MIG welding process in case of the CMT cold metal transfer process by the type of the mechanical cutting method of the droplets.

So, there is a interference of the mechanical system for the detachment of the droplet or maybe we can say the transfer of the droplet to the workpiece material. So, from that point of view this CMT process is different from the conventional gas metal arc welding process.

So, GMAW process gas we do not use any kind of the mechanical method to accelerate the metal transfer to the workpiece, because it is a continuous process and the it is integral part of the system of the gas metal arc welding process.

But CMT process it is a well controlled metal transfer is there, but with a intervention of the kind of the mechanical system. But one thing is that the droplet determinant of the CMT process is different from the GMT in gas metal arc welding process is that, that it is the without the aid of the electromagnetic force.

So, without the aid of the electromagnetic force the metal transfer is possible in case of the CMT process. So, compared to the conventional MIG welding process such that without the aid of the electromagnetic force it is if it is possible to transfer the metal in case of the CMT process, this actually reduces the spatter formation during this particular process.

So, that advantage we can gain. So, that is why when there is a no spatter formation there is smooth surface finish, smooth transfer of the metal is possible to the work piece. So, that is way the if we say we can say that CMT process is more suitable for the development of the metallic printer as compared to the gas metal arc welding process.

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STEPS IN CMT

✓ During the arcing period, the filler metal is moved towards the weld-pool.

✓ When the filler metal dips into the weld-pool, the arc is extinguished. The welding current is lowered.

✓ The rearward movement of the wire assists droplet detachment during the short circuit.

✓ The short-circuit current is kept small.

✓ The wire motion is reversed and the process begins all over again.

❑ **Different Variation of CMT process**

✓ CMT PULSE
✓ CMT ADVANCED
✓ CMT ADVANCED PULSE
✓ CMT DYNAMIC

Now, what are the steps in CMT process we can see the during the arcing period; that means, we know the say short circuit metal transfer we have already discussed there. But in this cases when the arc is creating in this case is the filler metal is moved towards the weld pool.

Now, arc is created filler metal is moved towards the weld pool, but when there is a molten droplet will be created and then this molten droplet may touch to the workpiece then when it is touch to the workpiece then it clear the short circuit.

And the ones it is creates the short circuit then we apply some site of the retract back the wire such that metal can be transferred to the workpiece. So, once there is a retract back the wire there is a gap is created once the gap is created then again we there is a creation of the arc. And then this metal transfer is normally happens at the very low current.

So, that is why it is called the cold metal transfer process ok. So, once we repeat this particular process in the CMT process. But there is so many variants of the CMT processes one is the CMT pulse, CMT advanced, CMT advanced pulse, CMT dynamic.

All this difference in the particular processes depends on what control way the metal transfer is normally happened, by using the different kind of the power source in case of the CMT process. So, that is the beyond of the scope for this this particular discussion.

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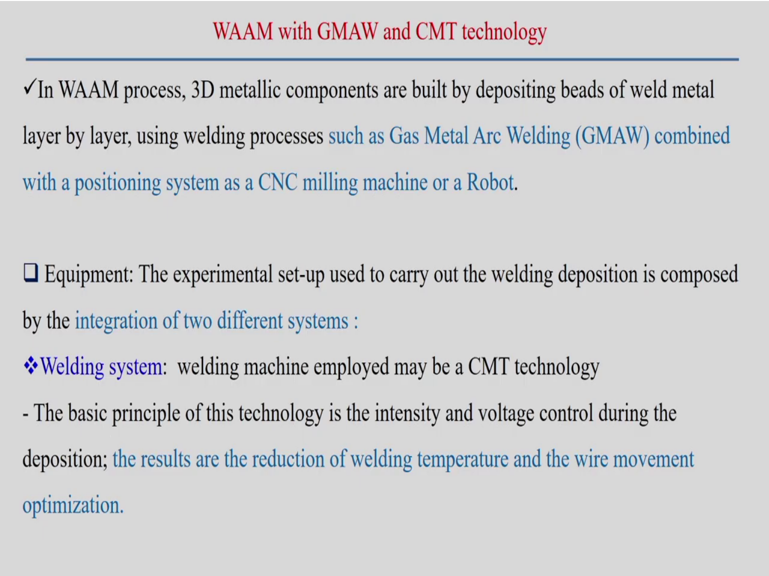

Now, in wire arc additive manufacturing process, the 3D metallic components basically build deposited all the particular beads forms the beads of the weld metal. It is a layer by layer wave and any kind of the gas arc welding process one can be the gas one is the gas metal arc welding process or using the some kind of the positioning system.

For example simple CNC milling machine can be used with the wire arc additive gas metal arc welding process, then one 3d printer can also be possible to develop. Then if we look into the equipment one in case of the wire arc additive manufacturing process the it is a basically experimental set up to carry out the welding deposition.

Is composed by the integration of the two different system, see basically welding deposition composed of the two different system already one is the welding system another is the positioning system. In welding system we need to employ some kind of the welding machines, so, may be in this cases CMT is the better way to use the CMT technology.

The basic principle of this particular technology is the basically intensity and the voltage control during the deposition process. So, that is why the results are the reduction of the welding temperature and the wire movement optimization can be done.

So, in principle the CMT technology is basically that is a reduction of the welding temperature. So, that metal transfer happens at the very low temperature and the wire movement optimization actually the when we try to control the wire movement optimization or may be the gap wire movement.

In that cases, it is necessary to control the voltage because in the arc welding process the arc gap is more sensitive to the change in the voltage. So, therefore, if you want to control the metal transfer and the maintain the arc gap or in this case or creation of the arc between these two gap or in that cases, it is necessary to control more on the voltage.

So, that kind of technology is available in case of the cold metal CMT process. So, we take the advantage of this thing and the control such that it can as the control metal transfer is possible in case of the using the CMT technology.

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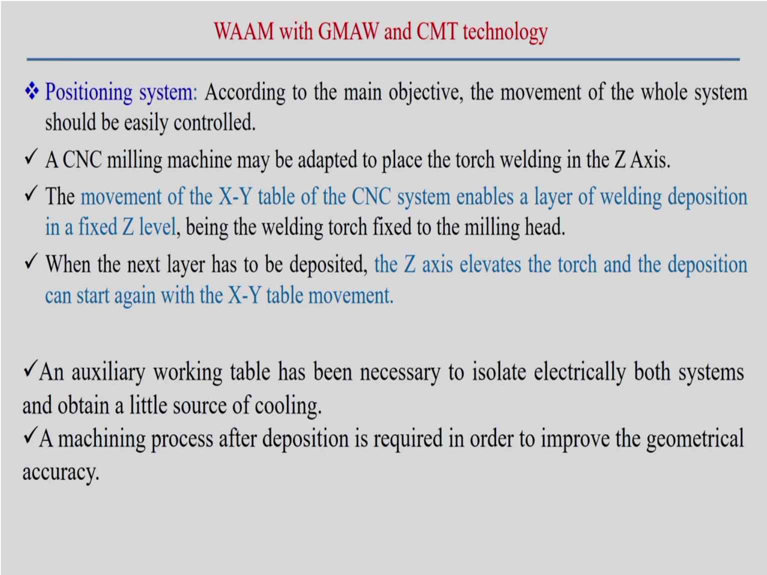

Now, positioning system according to the main objective the movement of the whole system should be controlled. So, one is the metal deposition is there, but at the same time the if you want to they build direction or may be path planning which path has to be move.

So, that is better required to some positioning system is also required. So, most commonly use we can CNC milling machine can be used for positioning of the this thing placement of the welding torch CNC milling to place the torch welding in the in the Z axis.

So, in these cases XY movement can be given by the CNC machine and the tool tooling position torch can be given to the another motion, the Z motion can also be done. So, in that way we can control the on the bed and the XY control why the tool is attached in that way we can control the Z axis.

So, this way welding machine give the deposition of this process. So, combining these two can be possible to develop one complete on the additive manufacturing or may printing process technology. But auxiliary working table has been necessary to isolate the electrically both system and obtain a little source of the cooling also.

So, some sort of the external arrangement may be required in this particular process and development. So, some sort of a cooling arrangement can also be done on this cases. So, that we can control the cooling rate also in the deposition process. So, once it is done after mess once the complete build up of the particular component is done then we can follow some kind of the machining process, after deposition which is required to improve the geometrical accuracy of this particular process.