Mathematical Modeling of Manufacturing Process

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Principle and Development of Additive Manufacturing Technologies

Hello everybody, now I will discuss second part of this module eight, that is principle and development of additive manufacturing technologies. Actually nowadays in manufacturing sector, that it is rapidly moving to the most attractive manufacturing processes that is called additive manufacturing processes, and of course, up to a certain extent it is already established. But still some research is also going on to establish this process for commercial application.

To produce any kind of the product, but of course.It is one of the important manufacturing processes that maybe we should know about this thing, and discuss the basic elements of these manufacturing processes at with two different perspective. So in additive manufacturing the definition itself we can see that it as simple as that. Manufacturing process that is from by layer by layer, deposition of a particular element.

So this is not limited to only the non metallic materials, of course, some metallic materials also used by this technology additive to manufacture, or sometimes. This additive manufacturing process is also called metal printing process also, or maybe simply 3D printing are very specific to the metallic material.

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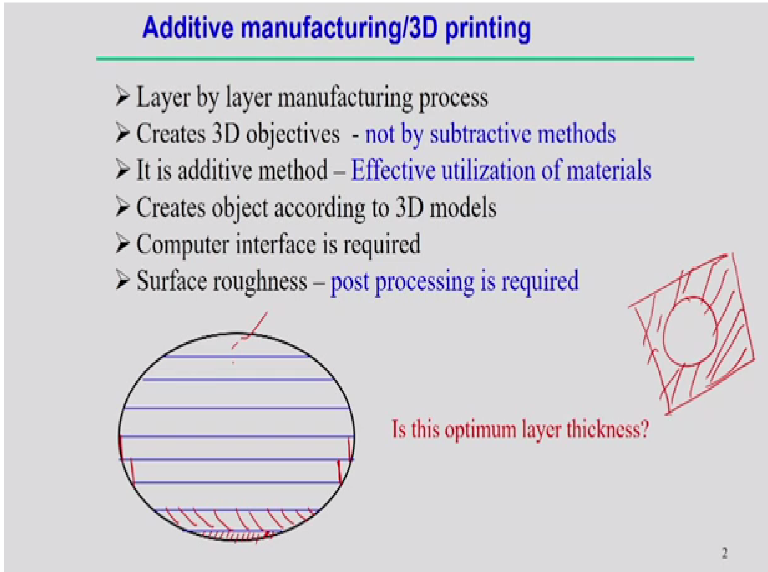

So of course, these additive manufacturing technology broadly , we can categorize into two parts first one is metallic and the other is the non metallic components what we can handle. So a simple layer by layer deposition process manufacturing process so it is not, we cannot create the object object by pulling some particular manufacturing conventional manufacturing process.

Rather we create the 3D objects, and of course, when we create the 3D objects, it is not by following the subtractive methods, subtractive methods means, for example, you want to create this kind of objects, round objects so we can start with this thing. Taking a block of middling material and we just remove the remove this material from this block and to get the desired shape, so that is simply called the subtractive process.

Or in general we consider machining process Just remove the material and we get the desired shape, but instead of that, doing in additive manufacturing what we can do here. First we deposit to one small layer, then next clear third layer fourth layer like that and that layer by layer we develop, and to create the final shape of the object. So that is called additive manufacturing. So of course, in the second method.

The machine additive manufacturing process is the effective utilization of the materials normally happen so there is no wastage of the mostly no wastage the material, because in machining process once we remove the machine by permission of the chip generation. So, that is all we can say, to get some kind of desired shape. We need to remove the material to machining process what here.

So in that cases the wastage of the material may be high, to develop a particular object or particular component but the additive manufacturing and just opposite, we can minimize the utilization of the raw materials in these cases. So of course, first we need to create the 3d objects so of course with the help of a computation computer we can create the three dimensional view of this object.

And then, of course, in this cases computer interfaces required. Once we develop the three dimensional, three dimensional object.. Then we create the layer that basically simply if we slice this three dimensional object. It will be created some some particular define thickness, and it is. This is called a slicing of the of an object. And then within this additive manufacturing processes.

We just deposit in each and every slice, we just assemble each and every slice. And we get the object. But what we can achieve these things. And of course one of the most important aspect in additive manufacturing, once you develop the product by layer by layer deposition. So surface roughness maybe one general issue for the development of this object. So, we can look into this object so we had to create this oval shape object.

Of course the oval shape object can be created by falling the machining process but we need the volume of the metal which is more than that of our shape, and then we use the access material, and then we can get the desired shape in a determined additive manufacturing process. The fourth step is to, we make it a more slicing so that is called. This is called the slicing. So small, small division layer we can create but this layer created with the computer interface.

And this creates the data will be stored in the computer. All this information, and such that when there is a deposition of the material. So in a particular layer, it will be followed by the instruction from the computer which is already from the already stored data. Now, in this case, we can say produce this first we can produce this layer. So once you develop this layer. Then next after the deposition of this year, then we can create the next layer.

So once it is done, then you could go for the next layer so that we can continue to depositing with the material, but with a layer by layer. Of course it is restricted. What is the length and other geometrical features is already restricted to the moment of this source. Such that it will be the controlled way, we can deposit, the material, up to the thickness, up to the layer thickness. Now, point is that what should be the, what's the word, Layer thickness.

So Layer thickness can be very small can be very high depending but of course it decides the roughness of this Material so of course, if we see this is the thickness of the layer. And of course this is the thickness of the layer. So in these two successive layer course in the Smooth surface may not very smooth. Some, it creates some, some roughness, actually clears it could pull the layer well into position.

But of course, the softness smoothness, we can bring the smoothness also, if it is possible to as minimum as. Thickness of the layer we can reduce it. Instead of taking very high thickness of the layer, deposition, we can pull the very small thickness of the deposition. So when you call them small layer thickness to deposition, probably, in this case, further slicing. Then in that cases we can achieve better surface finish in that case, of course, once we produce.

So many layers in these cases multiple the total time to produce a particular object will definitely increase. So it depends on that so therefore you need to know. Depending upon the capability of the machine material deposition capability and rate of the material deposition. Based on that, we can decide what may be the slice thickness in a particular layer by layer deposition process. Now, in general, additive manufacturing processes can be classified based on this three different mode.

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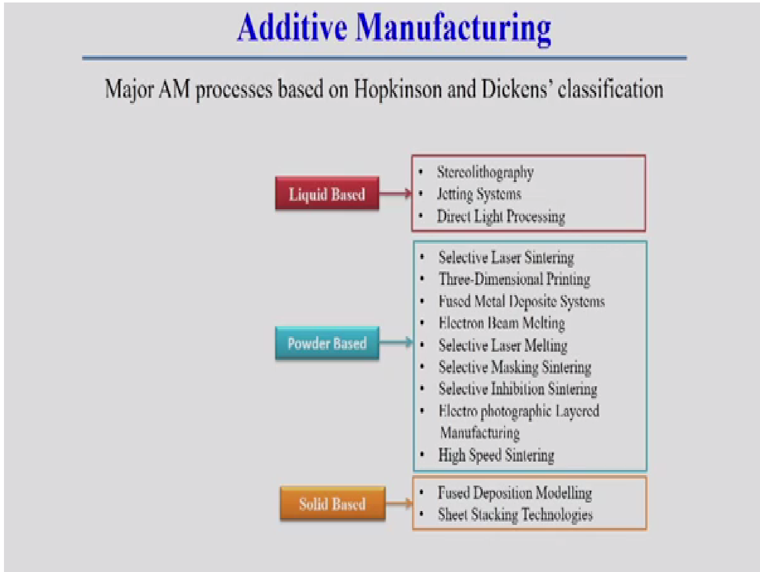

So one is the liquid based liquid based means the raw material is in the form of liquid. Powder based means we can use the material powder to produce a desired shape in additive manufacturing process. In some cases it can be solid based instead of powder. We can use the ware, or we can use a sheet stacking technologies. So, in this case, a liquid based additive manufacturing process is as the very oldest process that is stereolithography.

It can be jetting system also and direct light processing, these are the three different processes, which is based on the liquid based additive manufacturing process. So in principle, in the, we use some kind of the photo polymer which is sensitive to the laser light or may be other kind or may be sensitive to the ultraviolet rays. So, once you want to get the desired product in very deposition is required in that cases.

We just we just moved the photo polymer according to a desired path. So along this path, only that part, the polymer will be curing, and it becomes hard.And then it creates an object according to the desired shapes, but in this cases that we use some kind of the liquid based material. Similarly for jetting system also and of course direct light processing all this technology depends on this is based metal , in the form of a liquid.

Similarly powder based technologies additive manufacturing technology has also been developed. But in this cases will use raw metal in the form of a powder at once with the form powder, then this powder can be sientered or this powder can be fused together with application under some kind of heat source so it can be laser source it can be electron beam heat source also, such that if we put the selected position.

This is also only that position can be solidify or can be sientered and create the part of the object. So like that, if you follow the similar repetitive with a layer by layer, the same process, then we can get the whole product using the powder based additive manufacturing technology. There are so many processes has been developed based on powder based material. So one is the Sintering, selective laser melting, three dimensional printing.

These are different names, fused metal deposition systems. The electron beam melting, selective laser melting, we can see the selective masking sintering, inhibition sintering electro photographic layered manufacturing or high speed sintering but all these processes have been different names. There may be different types of the material, different form different principle in follow but in general, we can say the powder of the system.

We use the raw material in the form of powder. And then that powder is normally either use normally sintered or fused to get the desired size. Third is the solid base so instead of using powder. In this cases we can use the wire. And that wire actually continuously feeding of the wire, maybe, or maybe we can control the period of wire, and then where can be melted, and then it deposited and such that one particular layer can be formed.

So this is the way the solid based additive manufacturing processes has been developed. So these are the basic classifications and now we'll try to look into the basic manufacturing additive manufacturing processes will try to get some overview of all this kind of additive manufacturing technologies. So, in broadly additive manufacturing technologies having the in seven group.

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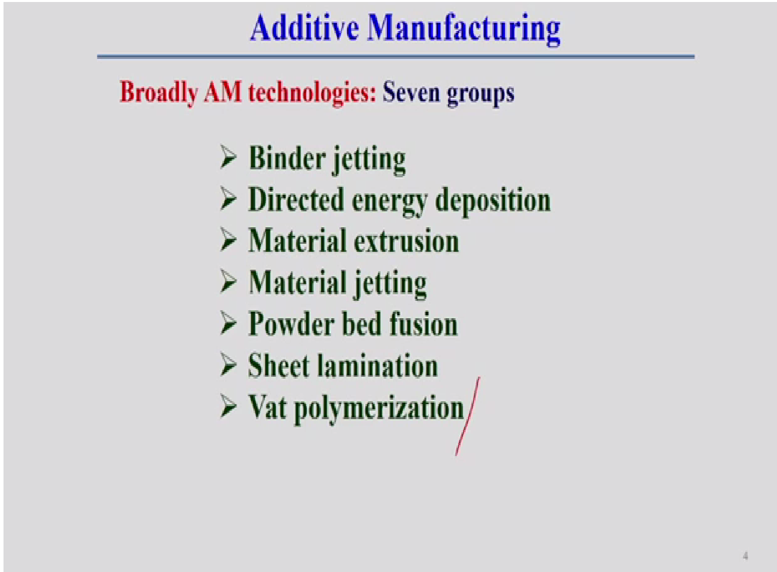

One is the binder jetting.

So it is respective that whether it is metallic material or non metallic material. So this seven groups are binder jetting, direct energy deposition, material extrusion material jetting. And powder bed fusion, sheet lamination. And of course, vat polymerization or steriolith, we can say that stereolithography .So, in this case is binder jetting means simply. In this case binder jetting or we can use in binder jetting we can use some liquid polymer more some.

Normally, that liquid polymer is physically cure or we can we can mix is at hard. By application of the some kind of the focus laser or ultraviolet rays also use in the case of binder jetting process. A direct energy deposition. In this case, we can use the powder directly throwing the powder and that same time we can sinter or fused that powder to make the desired shape.This is a metal extrusion means we can use to pass the metallic wire.

Or non metallic wire may be some polymeric material also. Once we pass the wire, and that is continuously we can feed it. And that wire, by application of the heat. This wire can be melt. And then it will deposited in the desired position. So that is called the material extrusion. Material jetting jetting means, we use the powder different form of the granular materials. Can be bind, using some kind of binding element we can bind it.

And then we can normally use the liquid binder and so that we can get the desired shape that is called material jetting. And powder bed fusion means in this cases there is a is a split of the metallic or non metallic powder. But we run the laser in such way, it can melt and the selected position that is called powder bed fusion. so once it is done the selected position we can reuse the unmelted or our unused powder also in the next for the formation of the next layer.

And sheet lamination. We have seen the different specs to follow the different stalking secret stalking of the limited sheet and then we can pass, we can heat it or we can use some kind of heat source in some selected position for that so we can put the lamination of sheet lamination cannot see. It is also on kind of additive manufacturing processes and then, bed polymer is stereolithography also we can use the photo polymer and such that you can use the photo polymer.

And we can pass the heat source in the selectivie position and selected position becomes harder. And then we can follow we can remove the remaining part, and then we can follow the similar strategy for the development of the others next layers, or subsequent layers. So in that way, that three separate most in general the seven groups of additive manufacturing processes has been developed. One by one, we can see that in general,

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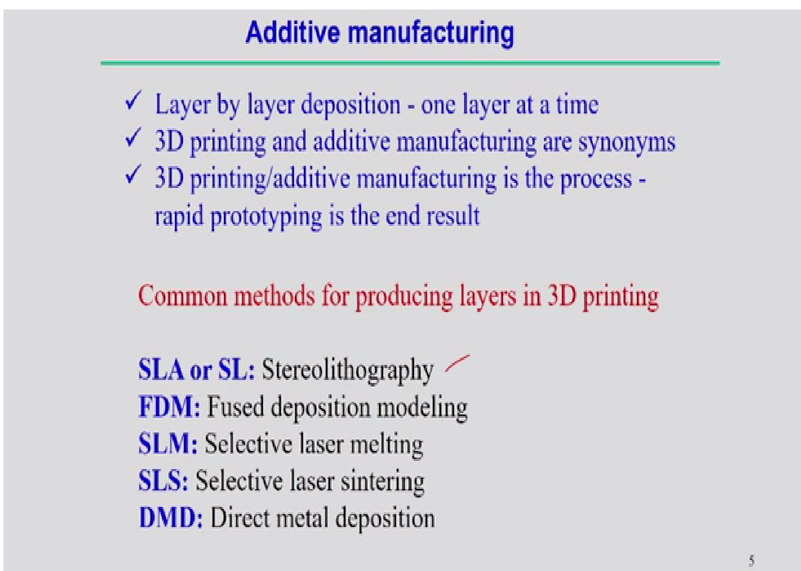

Additive manufacturing is normally used a layer by layer deposition, and of course, one layer at a time. And it is sometimes called the 3d printing process also and that is why 3D printing process and additive manufacturing processes are synonyms and 3d printing or additive manufacturing is, is the process that is the process outcome in result is the rapid prototyping, so rapid prototyping is is the output from this 3d printing or additive manufacturing processes

Common methods for producing the layer in the 3d printing process in the 3d additive manufacturing process the what are the common methods for producing the layers that processes is the stereolithography we will discuss this thing, which is called SLA or SL it or we can sometimes it is called polymerization then FDM fused deposition modeling. So in this cases mostly wire has been fused and deposited.

And of course, SLM selective laser melting. Selective the position, we can put, we can run the laser source. And of course, instead of melting. It is also possible to selective laser sintering but selective laser sintering normally pulling case of the non metallic material. And of course, then some more focused, that is the recent development additive manufacturing process or latest development is a direct metal deposition.

So we try to look into all this methodology their princple. What way they are different. And in terms of principle that will discuss in this module. now apart from this development of additive manufacturing processes by using the conventional development what what we have discussed so far. But there is a possibility of development of this additive manufacturing process from using the principle of the welding process or in the welding process.

In some welding process, we can use the material deposition, or we can directly use the heat source of the welding process, and that if we feed the extra material we can add to the welding process by putting the extra material. Then, this is also possible to convert this simple welding process to additive manufacturing process or we can say that, mostly metal printing processes. So normally welding process is an welding process, normally we use some consumable wire consumable electrode.

So that is consumable electrode, also a one, this is also in principle deposition of the material is a particular particular position and such that the two materials can be joined in case of welding but similar principle can be used for the development of the additive manufacturing technology so we can say that 3d printing metallic to develop the 3d metallic printers.

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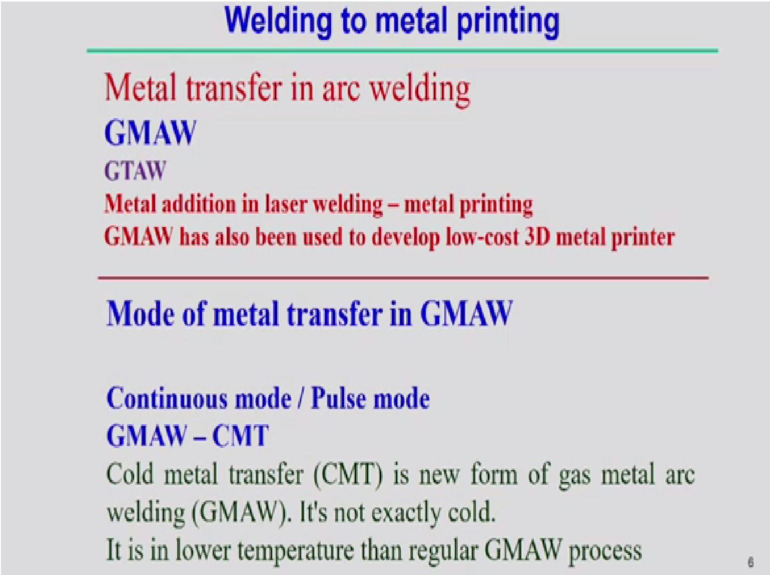

So one important part in welding process is the gas metal arc welding process. This is a very old welding process and. And in cases the gas metal arc welding process there is some, the process itself, the sustained by use of the consumable electrode and there is a pool of the wire, and this is a continuous pass of the wire for the deposition process so now this pool of the electron electrode.

And now we can if we change of the path of this electrode, depending upon a particular product or development a particular layer. And if you follow, if you. If we move that heat source metal deposition which is a predefined path, then it is possible to develop the layer wire is a particular, layer , which is the principle of the additive manufacturing technology. But of course, GTAW or other autogenous laser welding can also be used.

But in this cases, we need to develop some kind of the material feeding, the material feeding system such that we can, it is possible to develop that some certain metal printing process. Now metal addition in a laser welding process. It is also possible metal addition to laser welding process to develop the metal printer also but of out of that. GMAW gas metal arc welding process can also be used for the development of the three dimensional low cost metallic printer.

But before doing that we need to analyze the gas metal arc welding process their mode of metal transfer. So mode of metal transfer in gas metal arc welding process is the one aspect such that which more of the metal transfer may be applicable for the development of the additive manufacturing processes. So it may be continuous mode or pulse mode that uses application of the source of the heat both can be used.

The pulse mode and continuous mode of the current supply for the development of the additive manufacturing using the gas metal arc welding process for of course more development has been happened in terms of the metal transfer. That is from CMT cold metal transfer CMT is the cold metal transfer is a new form of the gas metal arc welding process. So we can say the CMT cold metal transfer is is a modification of the gas metal arc welding process or advanced level of the gas metal arc welding process.

But of course it is not exactly cold, but metal transfer normally happens relatively low heat input, that so it is called the Cold metal transfer process.

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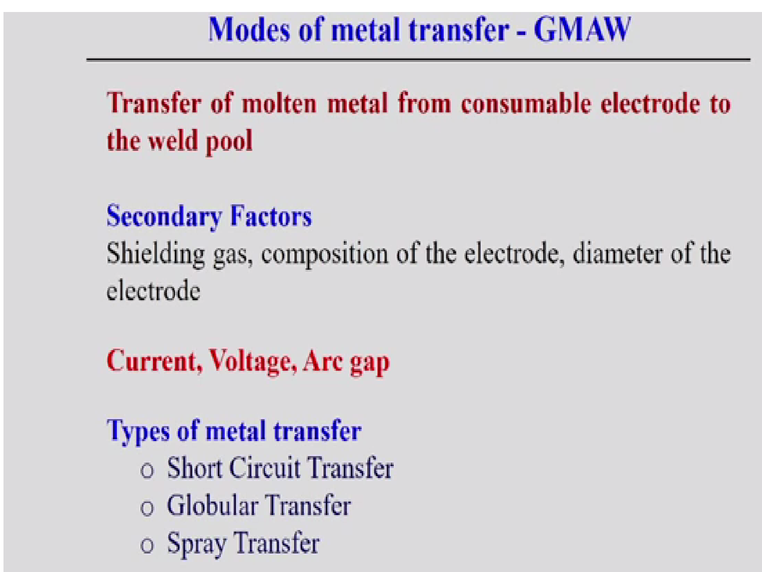

Now, in the transfer of the molten metal from the consumable electrode to the weld pool, so that we need to understand this metal transfer process so that will helpfull to analyze that which will not have metal transfer is actually feasible or suitable for the development of the metal printer. This is the first step for the development of a metal printing using the gas metal arc welding process. So of course the other part also important to consider that actually influence the metal transfer mechanism.

That is shielding gas, composition gas flow rate and the composition of the electrode and size of the electrode all and all actually influence the mode of the metal transfer. And apart from the current, voltage and arc gap, that is a main parameters for the gas metal arc welding process what are the current supply to create the arc. And what is the voltage has been used for the particular welding process and what arc gap to be maintained during this welding process.

Apart from that metal mode of the gas metal arc welding process is like the short circuit metal transfer, globular transfer and the spray transfer. This is the basic three type of metal transfer normally observed in the gas metal arc welding process. Short circuit transfer is the most suitable in metal printing process, recording these cases, it is more feasible to controller or transfer in this process with respect to the globular transfer and the spray type of the transfer,

Because spray type of transfer is sometime. Not, it is very difficult to control to focus in a particular zone particular area. And of course the similar difficulty also arises in practically it is a very difficult to achieve the globular transfer because globular transfer system normally it is the gravity of the molten material so it is a metal transfer formation,globular formation and transfer of metals takes relatively much more time as compared to the other type of the metal transfer.

So it is very difficult to control the metal transfer by using globular transfer and the spray transfer rather short circuit metal transfer is more suitable. In case of the, For the development of the additive manufacturing or metal printer, using the gas metal arc welding process apart from gas metal arc welding process, CMT also, more precisely, used for the development of that additive manufacturing technology.

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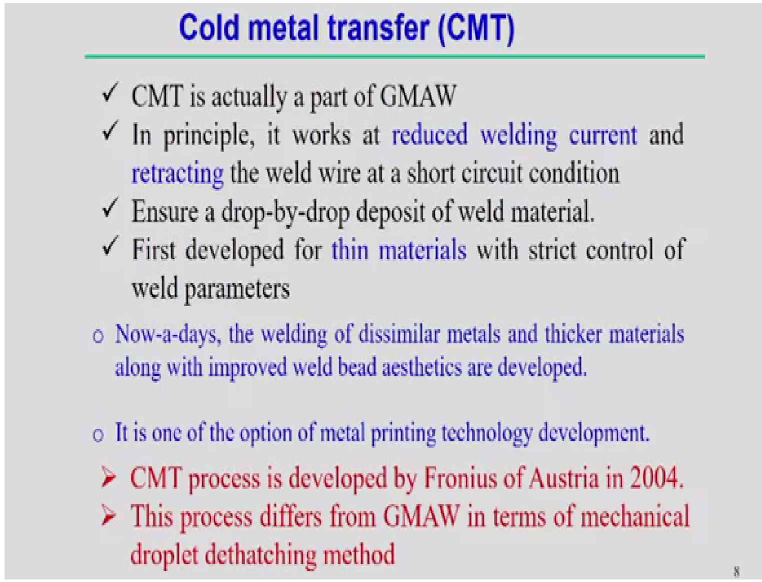

Of course I already mentioned that CMT specifically a part of the gas metal arc welding process. In principle, it actually used in the reduced welding current and retracting the welding wire at a short circuit current conditions. So, that why ensure drop by drop deposit of the weld material but it is weld controlled. Normally the CMT cold metal transfer mechanism, it has been developed initially from the thin material with the stick control of the weld parameters.

But nowadays, the welding of the dissimilar material and even higher thickness material with the improved weld build aesthetic that is surface appearance actually very good. In case of the cold metal transfer mechanism as compared to the normal conventional gas metal arc welding process,. So therefore, that is why cold metal transfer is more suitable for the development of the metal printing process as compared to the gas metal arc welding process.

So CMT actually it is a very new process has been developed 2004. But the main difference for CMT the metal transfer or CMT process, from the gas metal arc welding process is the mechanized control. So, we use of some kind of mechanical system. To create to detach the droplet and the transfer of the droplet to the desired position. So that is the difference in terms of the metal transfer process as compared to the gas metal arc welding process.

Now we can look into that. The difference between the CMT and the gas metal arc welding process is the main difference in terms of the wire feed.

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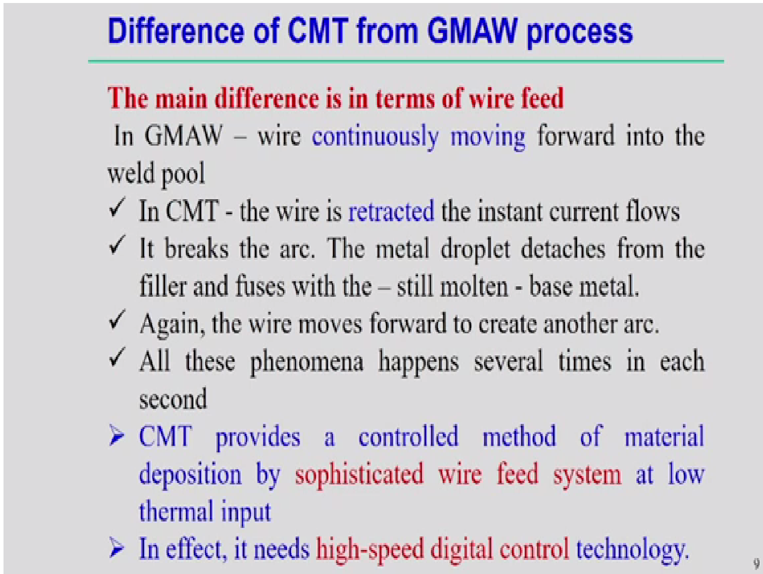

In terms of what we can wire feeding, because in gas metal arc welding process was normally continually speed to the desired positions. And that actually creates the arc and melt it at the same time, and deposit the material is a particular position. But in case of CMT to process the, wire is actually retracted to the desired to instant the current flow, and the current flow and then it wants to detected where there is a breaking of the arc.

So, Once the breaking of the arc the droplet is detached from the filler and fuses with the base material and still molten with the base material. So again, the wire moves forward to create another arc, and of course all this phenomena, actually happens, several times in a unit time.
For the unit second. Therefore, the CMT s provides a very controlled method of metal transfer or deposition. And of course by sophisticated wire feed system .

And of course, this happens, normally at low thermal input. So, all this favorable conditions, is physically attractive for the development of the metal printing technology and of course, this CMT actually needs high speed digital control technology to control its metal transfer mechanism. So that is why nowadays. This is it development of the metal printer, using the cold metal transfer mechanism.

But of course, with a look into that either CMT or GMAW based metal printing processes in these cases.

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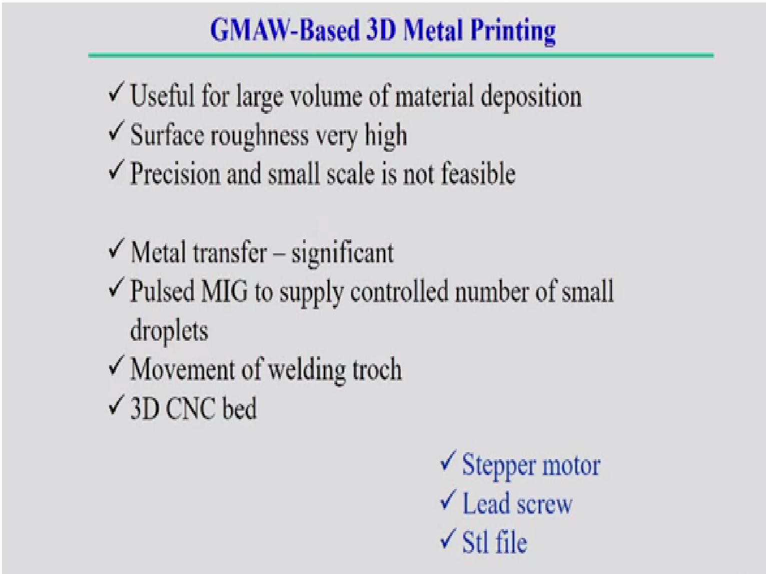

If you look into overall that actually the metal deposition in welding process. The, what we can control. It may not be comparable. In case of additive manufacturing process were, we can use some laser based system because laser can be focused into a very small area, and the focus laser can melt it is a very selective very small part with some desired accuracy is possible for that kind of accuracy not able to achieve using a simple achievement of GMAW or arc based additive manufacturing technologies.

Because if there is a need for volume of the metal deposition becomes very high. In this case, this, this arc based technology is more suitable. And of course, arc based technology the surface roughness is also not good smoothness also not good, as compared to laser based system. So thats why some meaching is required to get the desired surface finish. And of course if we want to produce very small intricate complex part in good surface aesthetic.

Then we should not prefer the gas, arc based additive manufacturing technology, but of course, we want to develop this using this additive manufacturing technology using this arc based fusion welding technology. and differently, we need to understand the metal transfer mechanism fast, and we are looking to be suitable for the development of the feeding technology, or if it is suitable then what may be the surface accuracy.

We can achieve using this thing or what other strategy, you need to follow that we can use as much as possible very good surface finish. So pulse MIG to supply the control number of small droplets so in this cases as compared to the continuous may be pulse mode, it is more easy to control the metal transfer also therefore, in that sense. Pulse mode of GMAW is Probably it is more preferable as compared to the continuous mode of the material transfer in a continuous current supply in case of the gas metal arc welding process.

So therefore moment of the welding torch is also another important parameter. So that we need to move welding torch to the desired path. So definitely we need to redefine this path. And of course, this, according to this path information, we need to move that torch so in that cases it say it is. We need need to use some kind of the CNC three dimensional CNC bed, we need to or if we do not use a three dimensional CNC bed.

So maybe we can create some kind of the setup, or we can control the XY and Z movement so we can use the simple stepper motor with the lead screw and we run the stepper motor with the desired, we screw with some linear movement in particular direction it is possible to move that. so apart from that we can use using this stepper motor, lead screw and small arrangement, we can use we can develop the XYZ table so that we can control the XYZ.

Of course, this cost is comparable as compared to the any limit available CNC machines because CNC machines also can very precisely control the movement. So therefore, the welding heat source metal transport mechanism is one important aspect, and the risk aspect is the how to move this welding torch is a desired path, of course, the path can be converted the stl file so we can use the computer interface.

And by using from the computer interface we can control the moment of this, according to the path generated and normally we export the file in a stl file on the path information. And accordingly the torch movement can be controlled. So this way we can use the literally low cost metal printing processes metal printing technology, as compared to the very high cost laser system

Now,apart from this, arc based or welding based welding technology the development of the different additive manufacturing process has been going on, but what we actually understand the additive manufacturing of the metallic components, using the most precisely or has been developed so far. That is one is that powder bed fusion technology,

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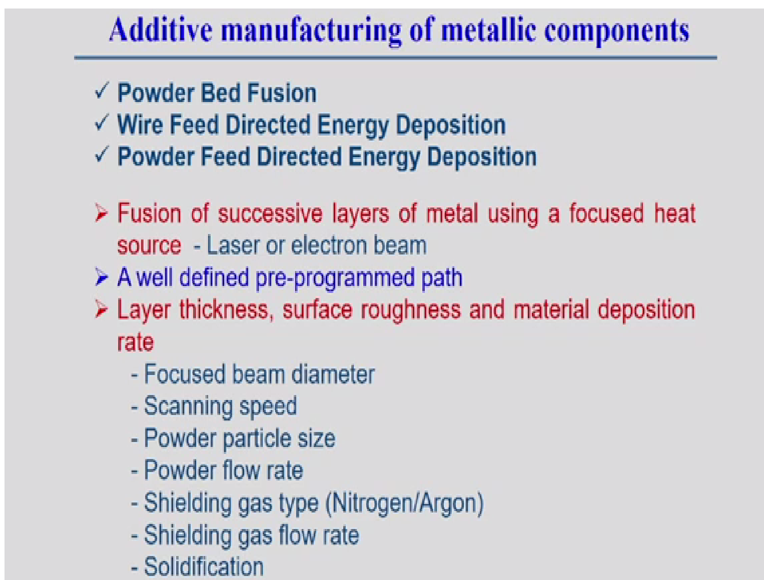

and other is that wire feed, directed energy deposition and powder feed directed energy deposition. So, powder bed fusion is,. In these cases, we create a bed of full of the powder, then we melt the selective part.

By using some kind of the Laser. So that is a principle of the powder bed fusion but when you use a directed energy deposition. We just directly at a particular subject position. We just directly transported the metal. See it can be it can comes from directly projected the powder and the desired position at the same time, we can fuse or sinter the powder, or we can directly feed the wire.

And that we melt the wire and then metal deposition happens. So it is in this cases it is different from the powder bed fusion, in the sense that we have the layer of the complete layer of the one particular layer of the powder exists. But Selective your melting part. But in the second case is not the selectively and directly, and which position and there is a need for the powder and this, where we directly protected at this particular position.

At the same time, we can melt and are fused or sintered at this particular position so that is called the directed energy deposition. So of course, in this case this initial volume of the metal may be very high. Second cases it is more economically, or more economical way we can use the material that is the basic difference between these two processes. Of course, fusion of the successive layers of the metal using the focused heat source.

We can use it in these cases but using the laser, or the heat source can be laser, mostly using the laser or electron beam because in laser and electron beam, with small diameter, even microscale that we can focus the particle, we can fuse it basically it is a well controlled way we can heat source can be very controlled. In case of using the laser or electron beam, so that is why the additive manufacturing or metallic components mostly developed using the laser source or using the electron beam source.

Of course in this cases that a well defined pre-programmed path is actually required such that we can create some complicated object. So it define that object so you create that object and that one we create the particular layer on which path. It should be melt or in the selected parth, the laser will be focused in that part only melting or sintering will happen.So of course, other part also layer thickness that means what should be the maximum thickness of the layer should we melt just, it depends on so many parameters.

What surface roughness we want to achieve, and what are the material deposition rate, all of the all important parameters, the attitude or metallic additive manufacturing process of metallic components, but it depends on the other parameters also so focused beam diameter scanning speed then powder particle size and powder flow rate and all at this parameter shielding gas what are the **e**ffects of the shielding gas, we can use nitrogen/aragon savings and impress the shielding gas flow rate And of course the solidification.

That means, going into deposition of the next layer, then we need to know whether this layer has been solidified or not so that is kind of information is required to decide the path of this thing so the getting the optimal solution using so many parameters is sometimes really very difficult, so that is why the domain feasible domain of this all parameters is actually very narrow to get a desired product and maybe if we change of the shape of the products happens.

If we use a similar kind of the technology the we use a lot of trial to develop the range of the parameters and most of the cases the range of the parameters, actually. Normally often is a very narrow range. Of course in metallic components, we can see that consist of many complex physical processes, if we look into what are the different processes actually involved in additive manufacturing process of metallic components.

It is having the melting is as to the melting solidification. And of course, if there is a solidification, solidification single unit on for that absorption,vaporisation **,**wetting sintering all this process has to be taken care of, we have to look into that. And analyzed during the development of this additive manufacturing technology So far we have seen that the application to metallic materials.

In this case is, these are the different materials, normally apply all this additive manufacturing processes, stainless steel, mostly the medical grade steel and the steel, which is having actually low carbon percent is so presence of the carbon metallurgical issue for the development of them and additive manufacture components so therefore, it is very difficult to develop for still having the very high percentage of carbon so it is trying to develop these things but of course, to getting the feasible evidence of the parameters is a difficult task in this process.

So that is why stainless steel maraging steel that process has been successfully developed even nickel nickel based alloy inconel aluminum, aluminum alloy also and titanium alloy for all this type of in general materials the additive manufacturing laser based additive manufacturing process most with a selective laser SLM selective laser melting processes has been developed so far. Now look into the different processes in principle.

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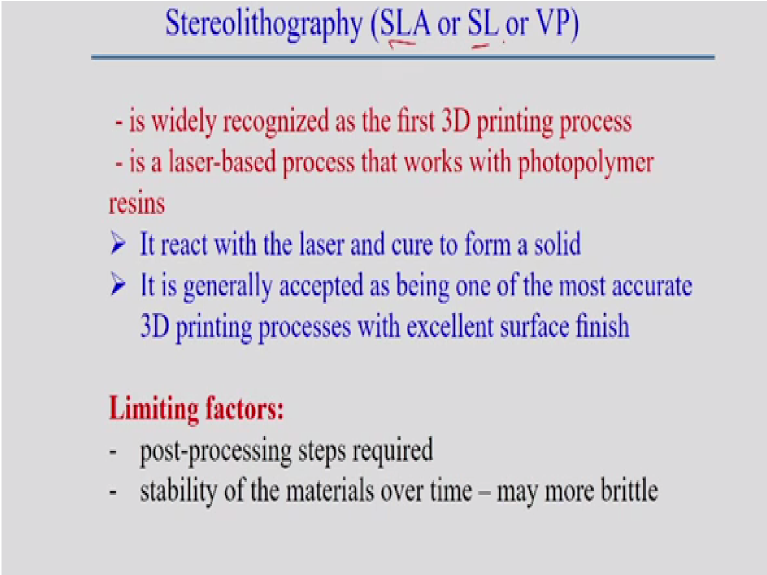

First is the stereolithography, stereolithography is the, it is called vat polymerization also it is called the SLA or SL process. It is widely used for the fast 3d printing processes. All 3d printing process. Of course it is a laser based process. And that works with a photo polymer resins, actually, when the photo and there is a laser is focused on the photo polymer resins, then the resins react with the.

laser and actually cure it and make in the form a solid. So, in a particular position if a photopolymer resin in path very precisely we can control the laser up to this part. So this path will only solidify is the only cured and mixed on the solid. So therefore, according to the path, so it generally accepted as being one of the most accurate 3d printing process with excellent surface finish.

So this excellence of this comes from the very precise control of the heat source for the laser this surface accuracy, actually, is should be a function of most of the cases is it, what is the focus diameter of the lasers. The limiting factor is the post processing is required for example we get the desired product. And then we have to remove the remaining part so that the post processing steps are required.

And of course, stability of the materials maybe another issue, because over the time or the cure part, the solid part becomes more brittle with respect to time. So that is a typical characteristic of the photopolymer resins. So that is one of the issue using this process. Otherwise, this is a very accurate and very., we can expect very good surface finish using this process.

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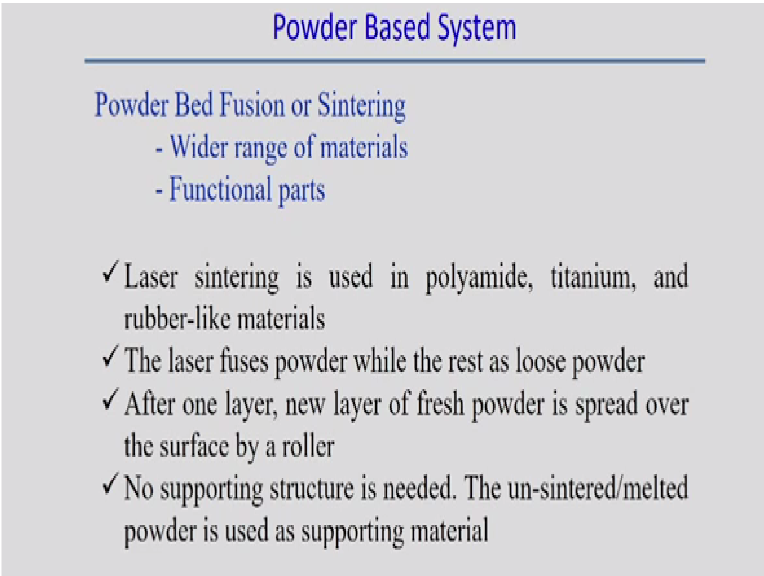

Powder based system This system or the system in this case is we can use the powder bed fusion or sintering process. Wide range materials can be used and functional scanners we produce so different parts of the produce upon the different kinds of the material, or we consider consider integrated materials can also be used.

In this case, in the powder bed fusion process or **s**intering process. Lasers sintering is used in the polyamide, titanium and the rubber Like materials. So what happens in this process. So, we create it is a powder.on bed That is peel of powder. But thickness of the powder is maintained, according to the layer thickness. Now, the laser **is** moved fuses the powder according to the path,

and laser chooses that particular material.And remaining stay as the loose powder.
So therefore once one layer is formed. Then, a new layer of the fresh powder is spread over surface by roller so roller, another sphere of the surface over these things. And then again we repeat the same process. And then, according to the path we just melt this or sinter that particular position. So then fused, and this attached to the previous layer So of course, in this case is no supporting structure is required to support the structure.

Basically the, unused powder or un sintered powder or unmelted powder is basically used as a supporting material, so there for not support all these materials so this is the principle of the powder bed fusion or sintering process.

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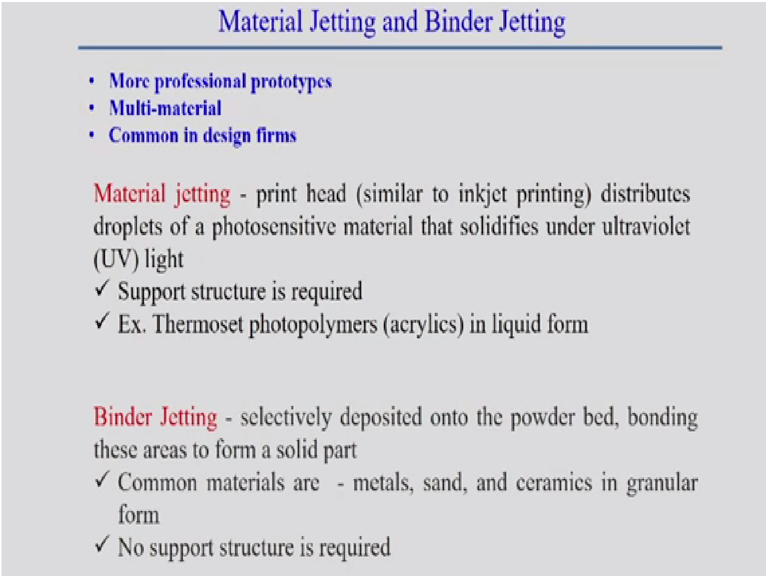

If you look into the material jetting or binder jetting system also, it is a most professional prototype multi material can also use different color can be produced using this additive manufacturing technology and of course, common in design firms but in material jetting process, the print head. So what are the principle of the inkjet printing and normally use inkjet printing in that principle.

This additive manufacring technology, actually has been developed. So, print head distributes the droplets of the photosensitive material. And, of course, this droplet of the photosensitive materials on the most and of course it is in liquid state. And it solidifies under the ultraviolet light so once the droplet forms droplet of the according to this position, and then upon the droplet, there is a ultraviolet light actually flow so that ultraviolet light is focused on the liquid droplet on the liquid material, photosensitive material then this part actually solidify or cure.

But in this cases to extend that liquid material. Then some support structure is required to support this liquid material. So, most of the example is the thermoset photopolymers ,acrylics in liquid form is used for the developing in material jetting system. Similarly binder jetting means instead of using the base metal as a liquid in this case as selectively deposited on a powder bed bonding these areas to form a solid path.

Simply there metallic powder, or or non metallic powder exists so here we just say it is possible to using some kind of the binding element on that particular path. And that path and that position is selectively put the binder element, and it binds the powder particles in that form so this is the principle of the binder jetting process so common metals metals, sand ceramics in the granular form can be used as a base material.

And along with that, we just supply the appropriate binding elements. And then, it forms a binder jetting process so therefore no support structure in this cases there is to support structure, it is just like in the powder bed system. So, they have no need of the any kind of the support structure in this particular process

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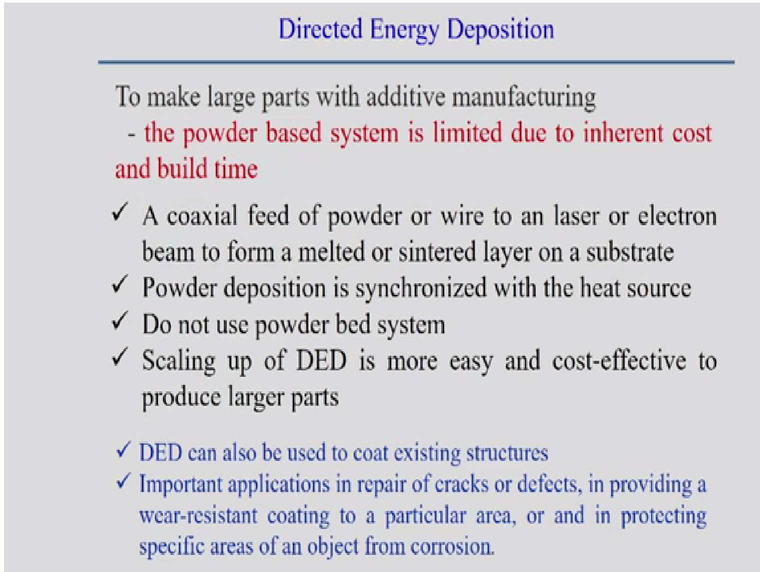

Now, directed energy to position that is a mostly developed, and now it is developing in this area directed energy deposition. So in this case is directed energy deposition is more suitable to make a large parts, with the additive manufacturing processes so the powder of the system is limited. Actually due to the inherent cost in the building time, powder based system. So, total cost of the powder because involves lots of powder during this process.

If you want to create a very small product. And of course, it takes a huge time building time is also much more, because there are so many steps and this one layer is formed. Then, we need to spread the powder for the next layer. And then, after that or need to livelized that particular thickness of a powder material. After that we can focus on the laser beam on this powder, and to create the shape of the object by following this particular path.

So thats why, it is normally time consuming and involves initially due to the inverse large amount of the raw materials in this case so therefore, it is the development of instead of using this powder bed, maybe you can use the coaxial feed of the powder at the same time, or wire to an laser or an electron beam so particular one laser beam or electron beam coaxialy focused on either powder or the wire such that it form a layer melted or sintered layer of the, of the on a substrate.

So therefore, powder deposition is synchronized with the heat source for that is also required because with that particular position powder is deposited.Accordingly we have to put the apply this laser or electron beam source at that particular position. Of course, we do not use in the powder based system in this process, and scaling up the DED direct energy to deposition is possible more easy and most cost effective way.

And when you try to produce a very huge large big product, basically in this case is more suitable. The direct energy deposition process. But of course, DED can also be used in some coating technologies that we have discussed in the first part of this module that different coating technology so therefore DED can also be used for the to coat, the existing structure in go to application of this repair of the cracks on defects in providing the wear resistant coating to a particular position area.

Or in protecting the same specific area of an object from the corrosion. So in that purpose also we can use direct energy to position. Of course.this is more or less. These are to produce process it is equivalent to the laser cladding system also. Now in general the 3d printing process, having 3d geometry of an object is created.

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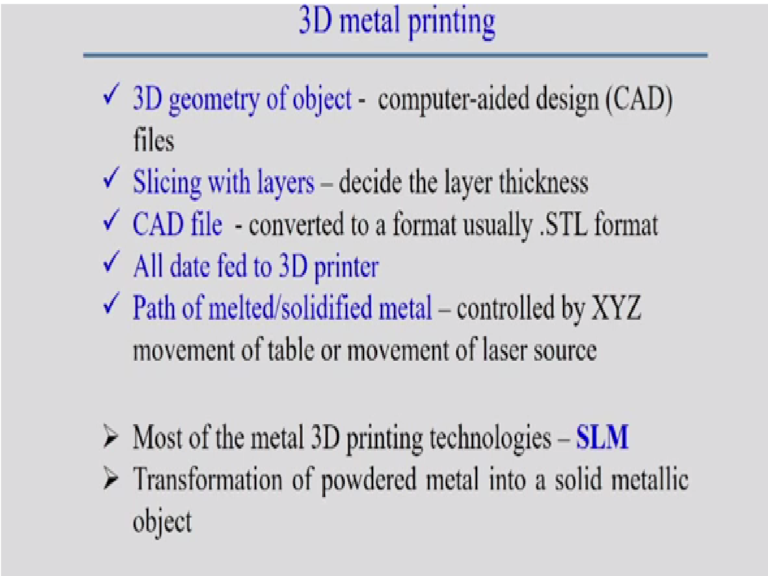

And of course, this is normally done from the computer aided design files. And once you create the CAD model of a particular geometry if you want to produce from there, using that additive manufacturing technology The next step is the slicing this CAD model. And, this slicing technology decides the what is maybe the thickness of a particular material. Of course the thickness depends on the which additive manufacturing technology you are supposed to use.

Then once it is converted to the CAD file. So converted to the CAD file is required, converted to the format usually dot stl file format. And the all data fed to the. So, the dot stl file format so all data CAD data actually is basically turn to the printer process so that, according to the skin. And then the path of the according to the CAD information the path can be generated. And then Path to the melted or solidified metal.

And of course the path is normally control, XYY moment of a table of a moment of the laser source or it is a two dimensional movement can be used from the table source and one dimensional moment can we use the heat source that is also possible. So that most of the 3d metal printing technologies has been developed using the selective laser melting process, laser melting process, basically powder based system.

So here, the transformation and the powder metal into solid metallic object that is the basic objective of a additive manufacturing process. Now try to look into the different processes. Different 3d metal printing processes. firstly the selective laser sintering so basically when the selective is a centering is the use as the powder. The powder source to sinter the powder, then follow the sintering mechanism.

So, this is mainly used in case of polymer so mainly This is sintering processes normally use the polymer actually in the sintering process, we just not cross the melting temperatures and just about to melting melting point temperature at a particular metal. And then the binding. Maybe the at molecular attraction happens between the surfaces. Without melting of this particular metal that is the sintering process happens.

And that is similar sintering process what we normally following powder and metrology techniques also. So here, bind the materials together in sintering principle to create a solid sub structure. And of course, mainly used for the rapid prototyping and fo the, low-volume production of the component parts so low volume production which is required we normally follow selective laser sintering.

Of course, the direct similar to the direct metal laser sintering process. So, this selective laser sintering can also be converted to the direct lasers, sintering process or direct direct metal laser sintering process. The same concept but different in technically they are different in discourses we have already discussed the direct mental energy to position.Selective laser sintering or melting processes.

Now, in case of selective laser melting. So melted, instead of sintering process melted materials is actually fully melted rather than the sinter. And of course, allow, different properties, of course. Only the properties can be different as compared to the sintered components. And it is based laser selective laser melting is normally based on the powder bed system. So, similarly selective lasers sintering also may be based on the power based system.

But normally selective laser melting can be based on the powder bed system. Okay, so apart from the fused deposition modeling there is another metal printing technology, in this case is instead of powder, the continuous filament of the material is normally used, and this is fed from the large coil, the material, and molten material is actually forced out of the nozzle tip, nozzle head, and then it is deposited on the, on a new layer.

So this is the principle of the fused deposition modeling so in this cases both metallic and non metallic, materials can be used, using this technology but instead of metallic powder we can use the wire based. It is actually wire based technology. Direct metal deposition. So in this cases use the lasers to melt the metallic powder. But It is not based on the powder bed rathe when we focusing the powder particular area.

So, and that area laser is actually focus such that the suppling powder same time. It can be melted, or fused together. So actually powders are projected through the nozzle and powers are fused by the focused laser beam. Concept is similar to the fused position modeling but in this case powder is used. Now if you look into the different aspects of the selective laser sintering, direct metal laser sintering or selective laser melting..

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So SLS used to refer to the process applied to a variety of the materials plastics and glass ceramics. Sintering process normally use a non metallic material. So, basically the plastic, glass and ceramics, in that process normally used DMLS direct metal laser sintering refers to the process is normally applied to the metal alloy sintering process do not fully melt the powder. But here, to the point that the powder can be fused together on a molecular level.

So in that cases but in the with sintering the difficulties that the porosity of the material can be can be in the porosity of the material can be controlled with the sintering, sintering process. Now if you use the selective laser melting process, using the laser to achieve the full melt in this cases instead of sintering the full melting is applied. powder is actually melted into a homogeneous part.

And of course it working with an alloy, we can use the liquid selective laser sintering process, in case of alloy, or direct metal laser sintering process but in case of pure metal pure titanium normally user selective laser melting process. So selective melting is definitely stronger as compared to the as compared to the sintering process but there may be another issue. For application of the melting when we mix two different metal powder.

And we can, we can maybe we take the handle the alloy system.So therefore, melting is, advantages in the selective laser melting advantages in the sense that it does notit conform to the melting of the material, so it can this no voids in this cases to prevent no vois which helps to prevent the failure part. But in case of the centering process one way with the difficulty specifically in the metallic material, is the formation of the voids.

But of course sintering deposition is more feasible. using the single metallic powder, and combined metallic powder then sintering is the most feasible there. So in laser based metal 3d printing technologies

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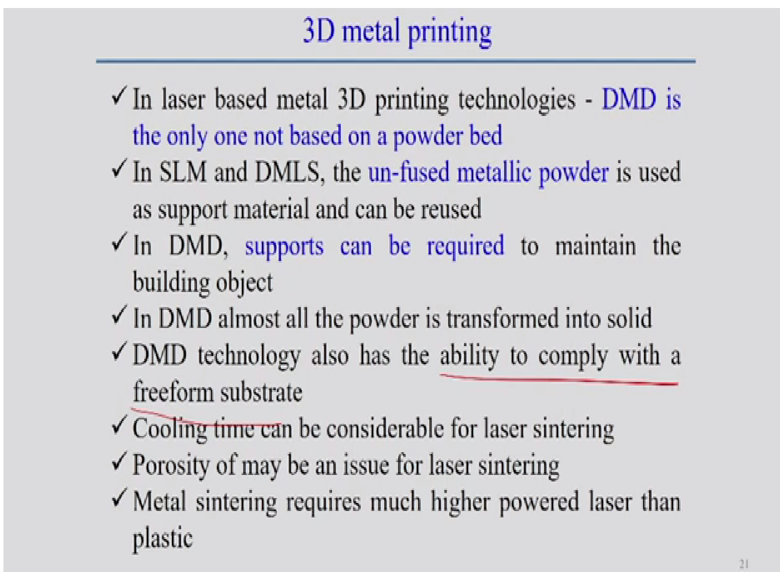

DMD direct metal deposition is the only is the only one not based on the powder powder bed, so this is just kind of summary from this different kind of the printing processes in selective laser melting and direct metal laser sintering both the cases the unused metallic powder is used as a support material and can be reused also.

But in case of the DMD supports can be required to start to the developing the layer to maintain the building object. But in DMD almost all powder is actually transferred into the, into the solid. So, because in DMD processes we normally follow the synchronized the application of the powder. And this projected area. We focus the laser as well also. So therefore, DMD technology, also has the ability to comply with the freeform structure.

So freeform structure can form in case of the direct metal deposition structure. But cooling time can be considerable for the laser sintering process so that is most important in case of sintering process or porosity of the one of the issue, In case of the lasers sintering process another metal sintering metal metal requires. Of course much higher or, as compared to the plastic similarly, the melting also require much more power, as compared to the plastic.

But definitely when we try to process the plastic components in additive manufacturing normally we normally follow the sintering process as compared to the pure melting of the polymeric material.

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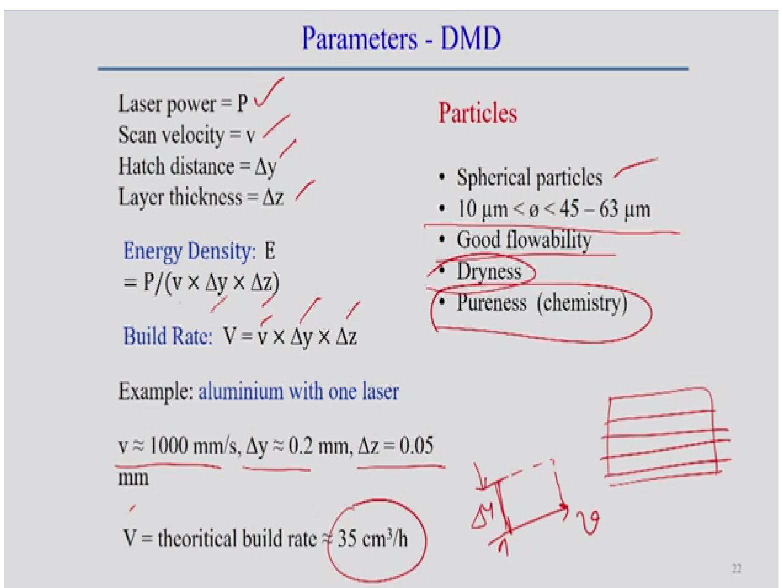

Now, if you look into the different parameters associated with the direct metal deposition processes here we can see that we can cure, we can create the layer by layer Division Two, three dimensional object. So, laser power, if we see the laser power use as a power P. Now, scan velocity, that means moving of the laser power because particular path moves with certain velocity that is called a scanning velocity of the laser.

Hatch distance delta Y, and the layer thickness, in Y direction, what will be the width of a when we try to produce on particular layer, it is limited to the certain amount of the width. In the cases that width delta Y, and the layer thickness is actually delta Z. So therefore, energy density can also be estimated by this equal to PY this P into delta Y into delta Z. So that is that, that is a measure of the energy density build rate of this additive manufacturing technology that cannot switch to mention the velocity.

Delta Y, Delta Z. So, this way we can create the build rate so actually the velocity is moving, and the particular direction, and the Delta Y and velocity, if this is the delta Y velocity is moving perpendicular to that. And this is delta Y. And delta Z in the thickness direction this is it in the settings and so the link is the bit late is basically how long for it.How long built it and during this process.

We can take one example of aluminum with one one laser source, we can see that Willis typical velocity is normally 1000 millimeter per second, delta is in that order around point two millimeter delta is it in the order of point. 05 millimeter, and these are theoretical build rate. Can we switch it around 35 centimeter per hour meter cube per hour, therefore, we can see in additive manufacturing technology normally it is very slow process.

We can get the only 35 centimeter cube metal deposition or, if we consider all these parameters. So, another important aspect parameter in direct metal deposition or week in general additive manufacturing to produce the particle size. So particle shape and size particles normally spherical particles. Of course, it is the range of this particle is like that 10 micrometer to the diameter the single 45 to 63 micrometer is the diameter of a particular in that range.

So of course, if you try to create that size, uniform size of the particles. Then, cost becomes very high to create that kind of to create the metallic powder also so in that sense metallic powder becomes more costly, as compared to the raw solid metal. Good probability is also required for this powder dryness need to maintain the dryness of the powder. And so, product quality difference on that. And of course, maintain the pureness without any additive on this thing.

That is also another aspect for producing the usability of the powder in additive manufacturing technology so that is why we look at look into the quality of the powder. So cost of powder becomes very high, so that is one issue in case of the development of the additive manufacturing processes or economical situation to produce a particular object using additive manufacturing technology metallic powder. Thank you very much for your attention.